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Road Map for a European Innovative Sodium-cooled Fast Reactor

(EISOFAR)

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- Électricité de France, France
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- AREVA NP, France
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REPORT SUMMARY

This report summarises the different stages and the characteristics of the EISOFAR project. It clarifies the high-level objectives (requirements) assigned to the future European sodium fast reactor (ESFR) and identifies the associated technological viability and performance issues. Proposals are listed for a research and development plan that is necessary to solve these issues.

The identified programme has to allow selecting promising options by the end of 2009, then to choose among them, by 2012, those susceptible to optimise the meeting of the objectives. As many as possible of these options will be represented in a prototype which could be deployed from 2020.

The vision presented in the document aims to be exhaustive. In a second time it is foreseen that a critical analysis of what is realised at the international level will be achieved to identify the possible complementarities with the current programmes (e.g. generation-IV SFR; national programmes) and to select the actions that can represent an original European contribution, while avoiding duplications.

In what follows, and in the light of the contributions from the EISOFAR work packages (WP), it is suggested to tentatively resume and structure the whole activity into four big domains:

– Core, fuels, fuel elements and fuel cycles,

– Safety, including consideration of severe accidents,

– Energy conversion systems and materials,

– Simplification and optimisation of the reactor, systems and plant operation.

A preliminary indication of the needs, in terms of experimental support, is proposed coherently with the technical programme.

The estimation of the average human effort has to be the object of a detailed analysis which will integrate in particular the degree of complementarity which it will be possible to implement at the international level.

PROJECT SUMMARY

Fast reactors have a unique capability as sustainable energy source in terms of both utilisation of fissile material for energy production and minimisation 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.

It is interesting to note that the increased awareness about the above concerns is modifying the current international context. Beyond the very important efforts by Japan and Russia there are now three new major inputs from the international nuclear community:

– the extremely ambitious sodium-cooled fast reactor programme planned in India and China (hundreds of units by 2050)

– the US Global Nuclear Energy Partnership (GNEP), which plan the deployment of critical fast reactors for the waste management with two main stages: the implementation of an experimental sodium-cooled reactor by 2014 (advanced-burner test reactor, ABTR) and a prototype (advanced-burner reactor, ABR) by 2025

– the French President announcement of a generation-IV prototype by 2020, to be built in France within a European collaboration framework, prototype for which sodium technology is the reference, with the gas fast technology as a back-up solution.

The Specific Support Action (SSA) named “Road Map for a European Innovative Sodium-cooled Fast Reactor (EISOFAR)” aimed enabling the European Community to define its specific R&D strategic objectives on European sodium-cooled fast reactors. For this, the proposal established a road map for a European R&D programme for a fourth-generation European sodium-cooled fast reactor (ESFR).

These activities were fully embedded in the discussions performed within the Coordination Action on the Sustainable Nuclear Fission Technology Platform (SNF-TP) and the Sustainable Nuclear Energy Technology Platform (SNE-TP).

The road map has the ambition to be a key component of the European strategic research agenda addressing research and development as well as technology demonstration (at the pre-competitive stage).

To achieve these top-tier goals and to be coherent with the generic Sixth Framework Programme (FP6) SSA goal for the development of research or innovation strategies, the EISOFAR SSA pursued several technical objectives:

– 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); implicitly, under this item the action also aims at identifying the hard points for the stakeholders acceptance (especially by the public) and at opening the tracks of reflection to bring the answers. The guidelines for the definition of such innovative requirements will be the generation-IV goals. Insights on user requirements and methodologies for assessment came from the work of GIF expert groups, where available, and from the results of the IAEA/INPRO project. Meanwhile European specificities were the reference for the work with due consideration/integration of the available European expertise on sodium technology

– the preliminary definition of new opportunities of viability domains where the solutions can 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, if decided, for specific Euratom R&D studies

– the preparation of a preliminary self-standing road map for the ESFR.

Knowledge capture, skills retention, training the next generation, and maintaining a leading position for Europe are among the complementary objectives.

Coherently with the generic FP6 SSA purposes[1], the results contribute actively to the implementation of activities of the framework programme, the analysis and dissemination of results or the preparation of future activities, with a view to enabling the Community to achieve or define its RTD strategic objectives.

During its one-year period (2006-2007) several parallel activities have been implemented to achieve the EISOFAR's objectives. The main goal being both the innovative requirements definition and the rough identification of feasibility domains and innovative technology options, the EISOFAR SSA adopted a structure which is analogous to the one of the generation-IV sodium fast reactor (SFR) project and was organised into three main technical work packages (WPs):

– System integration, design and assessment;

– Fuel with minor actinides;

– Component design and balance of plant.

Each WP was asked to provide insights for the main themes: requirements, feasibility domains, innovative options and corresponding R&D. A coordination WP assured the whole coherency of the action, provided the assessment vis-à-vis the generation-IV goals, and started managing the preparation of future activities. A specific open information meeting was devoted to disseminating the results to other EC partners.

It is expected that the road map will contribute mainly to the following items:

– strategies and requirements on: sustainability, safety, and ways for possible improvements; safeguards for proliferation resistance & physical protection (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

– specific R&D needs, the objectives and content of future activities, and the plausible schedule for ESFR deployment.

The project was not formally linked to the generation-IV SFR project. Meanwhile, as indicated above, the EISOFAR SSA, in close relationship with the CA SNF-TP and the SNE-TP activities, contributed to providing a European perspective in identifying, suggesting and motivating requirements and innovation domains that can help meeting the generation-IV SFR goals.

For FP7, Euratom could – if this is considered interesting/strategic – bring the EISOFAR road-map results to GIF (exchange, communicate, keep informed).

[1] Cf. Provisions for Implementing Specific Support Actions; FP6 Instruments Task Force – European Commission, 25 June 2003.

I. INTRODUCTION

The EISOFAR project followed three main stages:

– The elaboration of coherent set of requirements for future sodium-cooled reactors;

– The identification of the domains which it is important to investigate to look for the solutions which can bring answers to requirements;

– The identification of the needed R&D to study, within the feasibility domains, the solutions which seem promising.

The corresponding work was driven with a structure in three work packages:

– *System integration, design and assessment;*

– *Fuel with minor actinides;*

– *Component design and balance of plant.*

The activity, although focused on the short to middle term, is structured with a hypothesis for a timing compatible with the industrial deployment of ESFR reactors by 2040 with, very likely, the deployment of a prototype by 2020.

With regard to the identified requirements two intermediate milestones are proposed:

– by 2009/2010: **consolidation of the orientations**, that is to decide keeping or not, until 2012/2013, promising options related to the considered technological issue, and to deepen their analysis before 2012/2013

– by 2012/2013: **supply the information needed for the selection of the options for the industrial concept** (with, for some of them, variants and/or back-up solutions) and, coherently with the whole deployment strategy, selection of the technologies applicable for the prototype (i.e. deployable by 2020).

According to the logic described above, the document summarises all the requirements.

The second part summarises the still open technological issues of the ESFR.

The R&D on these issues is addressed within the third part. This part tries to integrate the timing as mentioned above.

The document presents the desirable programme with an exhaustive vision in terms of needs and possible answers. In a second time it is foreseen that a critical analysis of what is realised at the international level has to be achieved to identify the possible complementarities with the current programmes (e.g. generation-IV SFR; national programmes). Following this logic, the future activities, which could be realised under the aegis of the Commission within its Seventh Framework Programme (FP7), will be selected among those identified so as to avoid the duplications and to guarantee the complementarity with the current programmes at the international level.

II. PROJECT OBJECTIVES AND STATE OF THE ART

II.1. Introduction

Europe has the most extensive experience and expertise in sodium-cooled fast reactors and can plan the development of the European sodium fast reactor (ESFR) suitable for common application in several European countries. The implementation of this technology worldwide is foreseen by the selection of the SFR as one of the preferred generation-IV nuclear energy systems. Euratom is already participating in this SFR generation-IV international R&D programme.

Moreover, the increased awareness about the sustainability concerns – utilisation of fissile material for energy production and minimisation of the nuclear waste – is modifying the current international context. Beyond the important efforts deployed by Japan and Russia there are now three new major inputs from the international nuclear community:

– The extremely ambitious sodium-cooled fast reactors programme planned in India and China (tens of units by 2050);

– The US Global Nuclear Energy Partnership (GNEP) that plans the deployment of critical fast reactors for the waste management with two main stages: the implementation of an experimental sodium-cooled reactor by 2014 (advanced-burner test reactor, ABTR) and a prototype (advanced-burner reactor, ABR) by 2025;

– The French President announcement in January 2006 for a generation-IV prototype by 2020, to be built in France within a European collaboration framework, prototype for which the sodium technology is the reference with the gas fast technology as back-up solution.

During the year 2007, under the aegis of the Sixth Euratom Framework Programme (Euratom FP6), the Specific Support Action (SSA) named “Road Map for a European Innovative Sodium-cooled Fast Reactor – EISOFAR” aimed at enabling the European Community to define its specific R&D strategic objectives on sodium-cooled fast reactors. Such an action was fully embedded in the discussions performed within the context of the two actions on the Sustainable Nuclear Fission Technology Platform (SNF-TP) and that of the Sustainable Nuclear Energy Technology Platform (SNE-TP). The *vision report* of the latter prepares a European technology platform on nuclear fission, bringing together the major public and private stakeholders.

Within this context, the EISOFAR road map, which is the result of the action, has the ambition to be a key component of the European strategic research agenda addressing research and development as well as technology demonstration (at the pre-competitive stage) for the sodium technology as preliminary step for the deployment of fourth-generation European sodium-cooled fast reactors (ESFRs).

It is worth noting that the definition of such a road map is perfectly coherent with the FP6 SSA guidelines which ask for the “development of research or innovation strategies” and the road map is today an ideal instrument for the “information and communication activities” among the Member States.

The relevance to the objectives of the specific programme and/or thematic priority versus other FP6 objectives/actions is succinctly recalled in Appendix 1.

II.2. Technical objectives

Coherently with the generic FP6 SSA goal for the development of research or innovation strategies, the EISOFAR SSA pursued several technical objectives:

– The definition of a coherent set of **innovative requirements** applicable, in general, to future liquid-metal fast reactor (LMFR) and in particular to a fourth-generation European sodium fast reactor (ESFR). This set help defining the technical objectives and the scope for a comprehensive international effort to be implemented in the near future for the design of a ESFR.

– To reinforce the credibility of the EISOFAR SSA, and to help the preparation of future activities (cf. below), in parallel to the innovative requirements definition, and without entering within the details for the sodium-cooled reactor design(s), the EISOFAR SSA explored the **feasibility domains and corresponding R&D** effort to answer the requirements. This was done for the core and the system, including the balance of plant (BOP); some plausible technical options have been identified. All this was made by leaning on the acquired and available European experience, as well as by using the available results from the previous R&D efforts.

– The preparation of a preliminary self-standing road map for the ESFR.

Coherently with the generic FP6 SSA purpose[2], the EISOFAR SSA results can contribute actively to the implementation of activities of the framework programme, the analysis and dissemination of results or the preparation of future activities, with a view to enabling the Community to achieve or define its RTD strategic objectives.

Within the newly defined feasibility domains, detailed studies that could be performed in the future could allow meeting the requirements while confirming, identifying and qualifying optimised solution(s) for the ESFR.

A coherent set of innovative requirements

Concerning "Strategies and requirements" the road map content contributes mainly to the following items for the LMFR in general and for the ESFR in particular European strategies and requirements on:

– Overall plant flexibility
– System performance
– Operation
– Safety design
– Analysis and licensing tools
– Physical protection
– Proliferation resistance
– Functional requirements
– Fuel cycle
– Constructability
– Decommissioning
– System economy.

Basic compliance has been ensured with the generation-IV goals and the recommendations from the various "methodology working groups" of the Generation IV International Forum (GIF) and the IAEA/INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) project. Inputs also came from the technical specifications of the EUR document (European Utility Requirements).

Meanwhile European specificities have been the reference for the work with due consideration/integration of the available European expertise on sodium technology. Implicitly, under this item, the action also aimed at analysing the potential market developments, identifying the hard points for the stakeholders' acceptance (especially by the public) and at opening the tracks of reflection to bring the answers. In doing that, the road map will also contribute to the definition of an "industrial deployment strategy" at the EU level.

Agreed requirements, approaches and strategies are essential for the researchers, designers and the suppliers of the LMFR-ESFR plants; this is why the EISOFAR road map can contribute promoting the harmonisation of, inter alias:

[2] Ref. Provisions for Implementing Specific Support Actions; FP6 Instruments Task Force European Commission; Edition: 25 June 2003

- operational design objectives and criteria for the main systems and equipment;
- the safety and safeguards approaches (i.e. PR&PP) for the design and the assessment:: targets, criteria and assessment methods;
- classification methods for the equipment; applicable specifications and standards;
- information required for the assessment of safety, reliability and cost.

The availability of agreed requirements, approaches and strategies can help the development of an ESFR design, broadly acceptable in several European countries with only minor variations; this availability will contribute to the development of a European strategic research agenda and an industrial deployment strategy.

The feasibility domains and corresponding R&D

Concerning "feasibility domains", road map content contributes mainly on the following items for the ESFR:

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

The identification of new feasibility domain aspects is essential to open and engage the link and the coherency between the requirements and the design and assessment activity. The basic essential idea was to prove that the requirements remain compatible with the technology potential.

In the near future, the implementation of an activity to study and assess the potential of the identified feasibility domains has to be done considering relevant research conducted elsewhere (now and in the past, in the EU and abroad). Clear conclusions should be drawn from previous SFR research programmes.

Simulation tools

Research and development of simulation tools is an activity which is already underway in several countries participating to the EISOFAR project. The corresponding effort covers both the simulation of operation and abnormal conditions as well as the severe accident conditions.

The EISOFAR road map, in defining widely agreed requirements, looking for feasibility domains and screening the underway activities is the opportunity to check the pertinence of these efforts and to discuss their priority which is a key step to restructure – if needed – the European research activities in this specific area.

The EISOFAR road map for a European innovative sodium-cooled fast reactor

The EISOFAR road map shows and focuses the "European vision" on the GIF system SFR. Key "boundary conditions" and characteristics justify such specific European vision, e.g. the available background information, the open discussions on the strategic role of breeding versus burning which affect the required performances, the different modes for breeding (homogeneous versus heterogeneous), the plant size range for the European electricity grid, etc.

The achievement within the road map of an agreed set of requirements, approaches and strategies does guarantee the "integration", both in terms of content and schedule for the technology specific R&D. This does not means there must be a unique content and a unique schedule for all the European partners but rather that the "width" of the European approach is clearly identified.

Coherently with these goals, the insights from the road map allow helping the identification of:

– the R&D needs;

– the objectives and content for future activities and the possible Euratom support.

Moreover, as far as the SNE-TP Strategic Research Agenda is concerned, the proposed road map help defining the critical milestones and identifying the success indicators for each milestone.

As far as the “industrial deployment strategy” is concerned, the essential input remains the former European fast reactor (EFR) management experience.

Through this preliminary effort, the R&D plan for the ESFR will be precisely defined and motivated taking full advantage of all the present and past expertise available in Europe.

II.3. Expected benefits

The EISOFAR road map contributes to identify, prepare and motivate the future activities on fast reactors in general and on sodium technology in particular. Besides the achievement of technical objectives, benefits of different nature are obviously expected for the medium to long term; they concern three fields:

1) Improving the licensing of new ESFR nuclear power plants and their acceptance by the stakeholders:
    - by identifying the hard points for the acceptance and at opening the tracks of reflection to bring the answers;
    - by setting common safety and safeguards targets (i.e. including proliferation resistance and physical protection – PR&PP) which are consistent with the best European and international objectives;
    - by promoting, within Europe, common technical responses to safety problems;
    - by indicating possible shared solutions for the waste minimisation and management;
    - by opening the way for setting common agreed requirements on essential topics as for example: low targets for accidents and routine radioactive releases into the environment and consideration of decommissioning aspects at the design stage.
2) Strengthening the nuclear energy production sustainability and competitiveness:
    - by developing sustainable critical fast reactor cores able to address the minor actinides transmutation challenges while producing energy;
    - by controlling construction costs and operating costs through standardisation, simplification and optimisation of maintenance at the design stage;
    - by allowing low operation and fuel cycle costs, through flexible and efficient design features that allow easy adaptation to future plant operating and fuel management schemes.
3) Providing a secure long-term energy supply:
    - by maximising the energy released from natural uranium.

II.4. Organisation (cf. also Appendix 2)

During its one-year period (2006-2007), several parallel activities have been implemented to achieve the EISOFAR’s objectives as described above: definition of an applicable European strategy; review of available and commonly agreed guidelines to achieve the identification of innovative requirements, approaches and strategies; collection and review of available results on feasibility domains and innovative options.

To do all this, the EISOFAR SSA was organised in three main technical work packages (WPs):

1) System integration, design and assessment;

2) Fuel with minor actinides;

3) Component design and balance of plant.

A specific management activity guaranteed the co-ordination of the action's technical activities and provided the needed information and communication. Each WP was asked to provide insights for the main themes: requirements, feasibility domains and innovative options.

The list of participants is presented in Appendix 3.

II.5. Relationships with other international programmes

Relationship with the Generation IV International Forum (GIF)

At this preliminary stage, the action was not formally linked to the generation-IV SFR project. Meanwhile, as indicated above, the EISOFAR SSA, in close relationship with the SNF/SNE-TP activities, provides a European perspective identifying, suggesting and motivating requirements and innovation domains that can help meeting the generation IV SFR goals.

Euratom, as a member of the GIF (Generation IV International Forum), has already elected to participate in the Sodium-cooled Fast Reactor (SFR) project. This EISOFAR SSA creates the conditions to complement the current participation; it contributes to better define the future participation and to feedback the generation IV SFR information to the European Member States.

Relationship with the IAEA/INPRO project

A key objective of the IAEA/INPRO project is to bring together both technology holders and technology users to consider jointly the international and national actions required to achieve desired innovations in Innovative Nuclear Systems (INS). Users' requirements and methodologies for assessment of INS are among the results of the project.

No formal contacts took place between the two projects.

Nevertheless, several organisations, among the EISOFAR contributors, are participating to INPRO; Euratom is also member of the project. This allowed the EISOFAR project to be able to take into account insights from INPRO.

Relationship with the related FP6 and EC-ISTC projects

The objective being the coherency for the requirements as well as the generic European strategic research agenda and contents, contacts have to be organised with the related FP6 projects (e.g. RAPHAEL, GCFR, HPLWR – Phase 2, Education and training activities, etc.) as well as the related EC-ISTC projects.

The participation within EISOFAR of organisations involved in these projects allowed guaranteeing the needed exchanges.

II.6. Role of the EISOFAR road map within the context of the nuclear renaissance

The renaissance of the sodium technology is generating specific challenges that need to be addressed. Societal problems have to be considered as well as the supranational character. The need for training and education activities is an essential part of the context.

Reinforcing competitiveness and solving societal problems

Public and, generally speaking, stakeholders support, is an essential condition to successfully achieve the deployment of nuclear energy. The meeting of generation-IV goals, fully endorsed and adopted by the EISOFAR SSA, represents the best assets for gaining this support.

Coherently with the goals for the fourth generation of nuclear systems, the major EISOFAR SSA impact is the contribution directed to organise the acceptability by the stakeholders of ESFRs, to demonstrate their competitiveness and to prove their potential for the long term and sustainable energy production; all these are essential to guarantee economic stability.

For the acceptability aspects, societal expectations for the safety of nuclear energy and for the waste management problems have to be addressed and solved. For this, the corresponding requirements on safety goals, on PR&PP goals and on waste management are asking for improvement of the core characteristics, new component design as well as for the improvement of general layout performances.

The sustainability aspects are the major intrinsic asset for the fast reactor technology; despite the already proved performances, the requirements will confirm and motivate that core and cycle performances have to be improved to face the sustainability goal.

Concerning competitiveness, even if the past experience showed difficulties, there is now the feeling that these difficulties can be overcome implementing innovative options for the components and the plant layout as well as the implementation of new technologies, e.g. on the conversion systems.

Being conscious of the challenges the future systems must face, it seemed essential to prepare the future action on sodium-cooled technology in a commonly agreed context. This is the reason for the large participation to the SSA. The successful definition of this commonly agreed context was among the key potential impact of the EISOFAR SSA.

European dimension

Europe has one of the most important know how and expertise on sodium technology. The availability of the EISOFAR road map and the future activity represent a unique opportunity to bring together and merge this knowledge with the context of a new common vision. This will facilitate the participation of EU member countries in generation IV SFR international research activity that otherwise would not be possible.

Through this participation the historical and future European contribution could be valued and, in return, significant benefit could be gained from the other international generation IV SFR contributions.

Generally speaking, the road map provides insights for a European harmonisation of approaches, requirements and practices in a number of fields.

For example, as far rules and standards for the design and construction of future ESFR are available in Europe, new requirements (e.g. on operating temperatures) allow identifying and motivating complementary needs. The safety approach for future ESFR was discussed and basically agreed achieving an important European objective.

Exploitation and dissemination plans

The project results are intended to be the foundation of the next step which will organise the European capability to develop the fourth generation of sodium-cooled fast reactors. Within the framework of the EISOFAR SSA, the generated intellectual property was made available to all the participants under the aegis of a consortium agreement(s). The latter defines access rights to information and levels of confidentiality.

Through the road map the results are disseminated to the public and the research community throughout Europe.

The EISOFAR SSA’s results are proposed as a European contribution to the generation-IV SFR project.

Education and training

The road map can be an ideal instrument to communicate with the scientific and technical community, as well as with the public.

Training and education activities and implementation of a "doctoral school" were not within the explicit scope of the project. Nevertheless universities participated actively in the road-map elaboration and a specific effort is recognised as essential among those planned for the near future.

An international dissemination workshop was held at the end of the contract allowing the information of organisms that were not present within the project and the enlargement of the panel of entities interested in the future programme.

III. EISOFAR ROAD MAP: REQUIREMENTS

The table below summarises all the requirements the pertinence of which is recognised by all the participants to the EISOFAR project. These requirements are coherent with the high-level goals which stem from international reflections on the 4th generation reactors.

Their rationale is discussed in detail within the set of EISOFAR deliverables (cf. ref. D7; D10 and D13)

These requirements are presented with a logic which is the one who had been anticipated by the EISOFAR "description of work":

- Overall plant flexibility
- System performance
- Operation
- Safety design
- Analysis and licensing tools
- Physical protection
- Proliferation resistance
- Functional requirements
- Fuel cycle
- Constructability
- Decommissioning
- System economy

System performance

As generic requirement, one of the key conclusions from the brainstorming exercise is that EISOFAR should retain a wide flexibility for the future ESFR. The principal parameters should remain open in the short term (by 2009/10), including both the plant size and the plant type (pool/loop). Later on (by 2012/13), the more promising options will be selected and their performance will be assessed.

For the key representative system parameters, the main preliminary options or ranges are presented with comments within Table III.2. They address: mission; cost; configuration; power rating; electrical energy conversion efficiency; energy conversion system; plant lifetime; availability; fuel cycle; fuel; core design; core outlet temperature; primary gas blanket pressure. Further background and rationale for the selection of these parameters are provided in the following sections.

Table III.1 – Detailed requirements for the European sodium fast reactor

Domain	EISOFAR road map: ESFR detailed requirements
Overall plant	For the current preliminary phase, flexibility for the ESFR has to be kept in terms of : characteristics (e.g. power level); core performances (burning versus breeding); layout (pool versus loop)
System performance	The core design has to guarantee the requested performances : • Conversion efficiency > generation III (WG3) • Compatibility with burning, breeding and recycling Concerning the whole plant's performances, a set of consistent *Generic Requirements for Components and Balance of Plan*t is established to define the allowable parameters ranges: Mission; Cost; Configuration; Power Rating; Electrical Energy Conversion Efficiency; Energy Conversion System; Secondary coolant; Plant lifetime; Availability; Fuel cycle; Fuel; Core design; Core outlet temperature.
Operation	Simplified operation. The favourable features of sodium technology have to be fully exploited: Low pressure, Large thermal inertia involving comfortable grace time for operators, Very low activation of circuits and low activation at roof level compatible with hands-on maintenance. Proven feedback from primary components maintenance after cleaning/decontamination treatment, Design compatible with load-following operation. Periodic demonstration of the efficiency of preventive and mitigative measures and continuous demonstration of the plant monitoring systems over the plant life time in a consistent way with the economical operation constraints. Improved plant availability; i.e. improvement on: Refuelling campaign duration, Components maintenance and ISI outages, Provisions for contingencies and unscheduled problems. High cycle efficiency. The consideration of this requirement through an increase of core outlet temperature is to be taken very carefully considering material concerns. Plant lifetime over 60 years. The issue of failed/unusable major component substitution needs to be addressed, to make unscheduled maintenance not critical, to improve decommissioning, and to create the possibility for plant life extension. Improvement of in-service inspection and repair (ISI&R) through: Reduced needs (for instance, shorter core support line within the reactor and improved redundancy); Improved design and accessibility in particular to core support structures for in-situ examinations; ISI techniques' performances including investigation on new techniques and making large use of feedback from Phénix reactor inspection and repair activities; Simultaneous and interactive design between core components and ISI systems Simplified and optimised fuel handling

Safety design	A new safety approach applicable for a 4th generation European SFR is to be defined based on most recent reactors (like the EPR) and the EFR. Safety objectives at least ≅ EPR i.e.: The radiation protection of staff; The consideration of radiological and non-radiological threat for the public; The exclusion of the need of any off-site countermeasure for the public during accident conditions. The main safety enhancements concern: The improvement of the robustness both of the architecture and of the safety demonstration/response, in particular through the full implementation of the defence-in-depth principles for all the safety functions (reactivity control, decay heat removal, containment) Prevention of abnormal plant conditions through: • Improvement of core inherent characteristics, e.g. optimised reactivity feedback coefficients • Improvement of plant inherent characteristics, e.g. low thermal striping/fatigue Improved management of abnormal conditions through: • If necessary, increased margins for events considered by the design • Review of plant inherent characteristics, e.g. passive response to transients; thermal inertia; natural circulation flow ; reactivity feedback coefficients • Review of grace time available for implementing active measures Improved prevention of severe plant conditions: highly hypothetical eventuality of the whole core melting Deterministic consideration of a set of severe plant conditions to fit with the principles of the DiD (i.e. fourth level). The selected set has to be representative of all the plausible phenomenology of degradation (e.g. mitigation of potential consequences of S.A.) Improved management of severe plant conditions through: • Improvement of plant inherent characteristics, e.g. Thermal inertia; Passive response to transients; • Increased margins for DEC events versus cliff edge effects • Prevention of large energetic release due to core material expansion or Fuel coolant interaction through, e.g. Controlled material relocation Practical elimination of postulated initiators, sequences or situations with unallowable potential consequences. Examples which are examined are the following: Large gas ingress into the core, failure of core support structures or core compaction which leads to prompt criticality; Total and permanent loss of decay heat removal systems Minimisation of water/sodium and water/sodium/air risks Minimisation of sodium fires risk Minimisation of concrete/sodium risk Minimisation of CO_2/sodium risk Provision for fast full unloading of the core Improved treatment of hazards (fire, earthquake, etc.)

Analysis and licensing tools	A new safety approach applicable for a fourth-generation European SFR is to be defined based on most recent reactors (like the EPR) and the EFR. Innovative tools can be useful to address the specificities of the generation-IV SFR characteristics (e.g. increased use of inherent and passive features) CFD and lumped parameter codes describing coolant flow characteristics are requested for sub-assembly design (open-lattice fuel assemblies) CFD and lumped parameter codes are requested for plant design (e.g. for the heat transfer in the core) Seismic evaluation tools Tools for demonstration of mechanical integrity under all conceivable operation and accidental conditions
Physical protection	Coherence with the IAEA & generation-IV guidelines, i.e. very high levels of physical protection should be, as far as possible, "inherent" within the design of generation IV systems Need for the implementation of assessment methodologies able to insure the coherence with the safety architecture from the very beginning of the design
Proliferation resistance	Coherence with the IAEA & generation-IV guidelines, i.e. very high levels of proliferation resistance should be, as far as possible, "inherent" within the design of generation IV systems Need for the implementation of assessment methodologies able to insure the coherence with the guidelines from the very beginning of the design
Functional requirements	Crosscut functional requirements are defined in terms of provisions that have to be implemented to help meeting the sustainability objectives: • Provisions for plant margins – Incorporate margins in order to counter possible component performance deficiencies (heat exchangers, pumps, etc.) • Provision for normal ISI and repair including spare units (again heat exchangers, pumps, other components) • Provisions for reactor structure *in situ* examinations (under gas after sodium partial draining, under sodium with ultra sonic sensors) and associated provisions for replacement and/or repair. • Review of feasibility and cost of provisions for exceptional ISI and repair operations on the primary system

Fuel cycle	The selected advanced fuel composition should be flexible allowing efficient use of natural resources. High burn-up of fuels are required. Improvements are needed both for the fuel and the clad The production of actinide oxide fuels could be based on sol-gel or infiltration methods. MA will require further biological shielding. The possibility for having the reprocessing and fuel fabrication integrated in a single installation at the reactor site should be considered As generic requirements fuel cycle strategy should • include minimisation of waste • be based upon advanced aqueous processing; pyro-processing is another option • be integrated with existing reactors and fuel cycle facilities • minimise the costs • integrate proliferation resistance concerns Strategies for minor actinides burning shall be considered: homogeneous (up to 5 % MA) and heterogeneous (greater than 10 % MA) concepts should be studied Adequate basic fuel properties needed for licensing (including those for fuel bearing MA) shall be provided. Fuel characterisation and qualification tests shall be performed as needed. A “handbook of relevant data for drivers and minor actinide bearing fuels for ESFR” should be elaborated Adequate fuel modelling needed for licensing (including those for fuel bearing MA) shall be provided. Fuel behaviour characterisation and qualification tests under normal and accidental conditions shall be performed as needed. In case of commitment to an operating ESFR DEMO the size of the fabrication plant should be up to 10 tonnes output per year (1/3 of a reactor core per year). For MOX fuel, conventional transport technology is envisaged. For MOX fuel bearing MA the fuel handling facilities should require hot cell type casket unloading procedures and shielding/cooling of the fresh fuel storage facility For MOX fuels current reprocessing concepts are considered, i.e. PUREX. Should a new facility be required (able to implement the new reprocessing process) it should incorporate aspects and design features needed to reprocess MA bearing fuel Though oxide fuel is the reference composition short-term studies, alternatives (carbides and nitrides) have to be assessed for the medium long term; their potential should be re-evaluated, with possible tests being performed.
Construc-tability	To improve the constructability, the key themes to be explored are the following: • Reduced construction time, • Modular construction technology, • Benefit of reactor modularity

Decommis-sioning	The basic decommissioning requirements are: • to minimise waste and radiation doses to the public and operators, • to maximise the amount of materials recycled, and • to achieve decommissioning costs and timescales which are at least as low as those for generation-III reactors. Restoration up to a “green field site” could be the target. The general decommissioning requirements can therefore be expressed as follows: *Decommissioning plan:* A comprehensive, but preliminary, decommissioning plan for the complete ESFR system should be established to a degree of detail compatible with the conceptual design phase. *Sodium management:* A specific strategy for sodium management should be developed including “clean-up”, processing, and recycling where possible. *Materials:* The choice of materials should be made on the basis of minimum waste arising and minimising activity levels. Materials which can be recycled, or processed and recycled, should be preferred. *System and component:* System and component design activities must include consideration of decommissioning operation The EISOFAR decommissioning strategy should also take benefit from available experiences, in particular from that gained from SPX1, PFR and KNK2 decommissioning. For this it seems essential to launch a specific activity, “decommissioning > design” oriented, for the collection of data and guidelines

System economy	The objective is the achievement of costs similar to generation-III+ reactors, at the deployment date, must be the objective. This includes capital, generating, operational, and decommissioning costs. Investment protection has to be considered. *NB: Some partners have a perspective that a cost for ESFR above that for a generation III+ reactor might be acceptable given the potential advantages of ESFR for waste management, fuel cycle management, and energy production sustainability. This can be evaluated in an integrated dynamic system analysis, in which the complete life- and fuel cycle is analysed.* *Plant capital and generating costs:* Topics with significant potential include: Plant architecture and layout; System and component simplification and size reduction; Reduction in the number of safety classified components, where possible; Elimination/simplification of the intermediate-secondary sodium circuit; Alternative energy conversion cycles; Fuel handling simplification; Mutualisation on the same site of auxiliary systems for fuel storage and components maintenance; Materials (selection, quantities) and constructability, including the potential for modular construction and factory build, and; Lessons learned from the construction of generation III+ reactors; A plant lifetime similar to generation III+ reactors is required. *Operational costs:* Operational costs target should be as low as those for generation III+ reactors, including staffing requirements, maintenance/inspection, spares, repair/replacement, waste management costs, general services costs, and support from off-site facilities. Fuel and component handling processes and procedures should be optimised to minimise the associated costs and waste arising (sodium decontamination). Plant load following would be beneficial in order to provide operational and deployment flexibility. Plant efficiency should be optimised: Potential improvements may be derived from consideration of heat exchangers performances, steam cycle parameters such as steam reheat by sodium, alternative energy conversion cycles, or of a gas turbine alternative to a steam cycle. Operational cost can likely be reduced and the flexibility increased widening the spectrum of energy products aside the electricity production: utilisation of the “waste heat”, possibly in providing other energy products e.g. hydrogen, process heat, could also be considered. *Decommissioning costs:* The decommissioning requirements have been discussed above. A complementary requirement can be defined in saying that decommissioning costs should be at least as low as those for generation-III reactors *Investment protection:* Investment protection requires an assured licensing and planning process, and a rapid and assured construction and commissioning schedule. Operational performance must be very high and improved compared to EFR. This requires e.g. that refuelling schedules should be aligned with maintenance schedules and extended. Reliable maintenance and inspection methods and techniques must be developed including the ability to carry these out ‘on-line’ wherever possible. Plant incidents/repair must not give rise to significant unavailability. Provisions for exceptional inspection/repair of the reactor internals will be incorporated if the impact on layout and cost remains acceptable. All plant and equipment must be designed, constructed, and tested coherently with selected design and construction codes

Table III.2 – Preliminary system parameters for the ESFR

System parameters	Preliminary options or range	Comments
Mission	-Electricity generation -Sustainable energy -Waste management -Process heat	-Competitive generating cost -Flexible core and fuel cycle -Flexible core and fuel cycle -Possible in the future
Cost	-Capital cost to be reduced by plant simplification, mass reduction and compactness, pooling of auxiliary systems and modularity	-Competitive generating cost at deployment time
Configuration	-Pool type -Loop type	-Reference: significant and convincing European experience -Potential safety, cost, & ISI benefits to be assessed
Power rating	-Large generator (1000-1500 MWe) -Modular plant (100-500 MWe)	-As for generation III+ stations -Potential safety, cost, & ISI benefits
Electrical energy conversion efficiency	~ 40%	-Aiming at up to 45% but to be balanced with 60 years lifetime requirement
Energy conversion system	-Steam cycle -CO_2 gas turbine cycle -Process heat	-Optimised for securing high efficiency -High efficiency, safety to be assessed -Possible in the future
Secondary coolant	- sodium intermediate circuit - suppression of intermediate circuit with a loop type reactor	- Reference: feasibility proven - to be assessed with Gas Energy Conversion System and/or with innovative heat exchange components
Plant lifetime	60 years	As for generation III+ stations
Availability	To be increased compared/ operational feedback and EFR	Minimum target: 80% Utilities target : 90%
Fuel cycle	Closed	-Compatible with generation II, III, III+ plants -Cost competitive -Proliferation resistant - Flexibility on breeding
Fuel	-Flexible -High burn-up (~150 GWD/MTHM average)	-Pu & MA management -Cost competitive -Proliferation resistance
Core design	-Flexible within safety and cost constraints -Breeding ratio 0.5-1.3	-Pu & MA management -Proliferation resistance
Core outlet temperature	500-550 ^{o}C	-Optimised to meet safety, cost, efficiency, material constraints and 60 years plant lifetime
Primary gas blanket pressure	Reference: ~ 1 bar Alternative: pressurised up to 5 bar	-Increased sodium boiling point -Impact on safety and costs

IV. ESFR: TECHNOLOGICAL ISSUES

The identification of the ESFR technological issues (TI), such as it is presented below, results from a global analysis of requirements listed in the previous paragraph. This analysis ends in "top tier requirements" which can be translated in six key technological issues:

- TI1: Plant (and especially the core) with high safety performances
- TI2: Energy conversion system (ECS) with reduced Na-H_2O risk
- TI3: Materials (improved performances to achieve attractive thermodynamic efficiency, waste minimisation, 60 years of life expectancy and easy dismantling).
- TI4: Simple and robust engineering systems and components (architecture) with high reliability/availability and capable to sustain hazards.
- TI5: Improved technologies for inspection, diagnosis, maintenance and repair
- TI6: Fuel fabrication technology and qualification (dense fuels, MA bearing). Major impacts on SFR are expected

TI1: Plant (and especially the core) **with improved safety performances**, allowing insure simultaneously:

- A sodium void effect significantly reduced with regard to the previous projects and an increased resistance to the compaction;
- An important flexibility versus the plutonium management (example: the case of the iso-generation without axial or lateral blankets) and the minor actinides transmutation;
- In case of core degradation, a mastered evolution of core materials relocation towards a coolable configuration, minimising/excluding the recriticality configurations with the potential for high energy release;
- Favourable performances for resources preservation (Pu inventory, volumetric power, fuel burn up).

TI2: An energy conversion system (ECS) with reduced Na-H_2O risk, i.e. with high thermo-dynamic performances, and allowing to prevent or, if needed, to practically eliminate, the risks of large sodium fires and sodium-water-air reactions susceptible to degrade the safety functions, and in particular the confinement of hazardous materials.

TI3: Materials allowing, in relation with TI2, to maintain attractive thermodynamic efficiency and to guarantee 60 years of life expectancy for the critical components (i.e. the components which are not reasonably dismountable and replaceable).

TI4: Simple and robust engineering systems and components (architecture) with high reliability/availability and capable to sustain hazards. **Simplified engineering systems and components**, with reduced masses and volumes, which can contribute guaranteeing the whole plant competitiveness and anticipating, by design, the simplification of the inspection, the maintenance and the reparability (in relation with TI5), as well as the simplified procedures which can allow optimising the plant operation. Performances versus hazards should be improved.

TI5: Improved technologies for inspection, diagnosis, maintenance and repair, easily implantable on all the critical components (for the safety, the plant availability and the investment protection).

TI6: Fuel fabrication technology and qualification (dense fuels, MA bearing). Major impacts on SFR are expected

With regard to these issues, and in the light of the contributions from the different EISOFAR WP, it is suggested to tentatively resume and structure the whole road-map activity in four main domains:

- Core, fuels, fuel elements and fuel cycle
- Safety including consideration of severe accidents,
- Energy conversion systems and materials,
- Simplification and optimisation of the reactor, systems and plant operation.

V. SAFETY APPROACH FOR THE DESIGN AND THE ASSESSMENT OF FUTURE SFRS

Before entering into a detailed analysis of the R&D on "ESFR technological issues", it seems interesting to shortly describe the results of specific discussions, which took place during the EISOFAR meetings, on the safety approach applicable to future systems in general, and to future ESFR in particular. This is justified for the safety approach for the design and the assessment of the ESFR will strongly influence the R&D content.

Foundation of the safety approach

Deliberations on safety guidelines applicable to fourth-generation systems are conducted at both international and national levels, respectively. The EISOFAR project partners from construction companies, utilities, universities and R&D organisations had the opportunity to succinctly discuss these guidelines with the objective to follow them in the development of the ESFR project.

A short section in Appendix 4 resumes the position of the partners.

Among the essential things to be kept in this position the first concern the safety objectives. The EISOFAR project recognises that those applicable to the new generation of European LWR (namely the EPR) are already very ambitious and guarantee a very high level of protection of persons and of the environment; for the future R&D activities it is proposed to adopt the same quantitative safety objectives if reasonably applicable to a fast reactor system.

Concerning the basic principles, the defence-in-depth is recognised by the EISOFAR partners as the best approach to achieve the safety objectives set for a nuclear facility. It is based on an essentially deterministic approach, but probabilistic studies can be used to identify initiating events and anticipated sequences, to ensure that the processing of scenarios includes uncertainties inherent in the system design and operation and to quantify the uncertainties in terms of frequency and consequences in relation to the studied scenarios.

Another essential principle which is foreseen for the future is the notion of "robust" demonstration which rests on the capacity of the designer to demonstrate:

- The detailed knowledge of the phenomena (events, situations) considered for the design.
- The adequate treatment of these events and situations, through technical solutions, bringing the confidence in the selected options.

In particular this is based on:

- The mastery of the events and situations and their associated uncertainties and the design measures to provide sufficient margins in relation to limit values.
- The minimisation of the impact of the human factor.

An essential condition for the "robustness" is the level of experimental and theoretical qualification of the proposed solution and the recognisance of the whole approach (methods, tools and experimental data base) within the international context.

Application to the ESFR

The recommended approach for the SFR combines a large variety of detailed improvements of plant characteristics ranging from new heat transfer circuits up to the use of new measurement techniques in the domain of core and plant surveillance and control systems. However, one very basic advancement in the safety approach concerns the question of severe accident handling which will become a priority theme as this will have a major impact on the reactor design.

Consideration of generalised core meltdown situations

The group of severe accidents to be considered includes plant states with a significant core degradation during which the risks inherent in the concept become apparent[3]: it covers situations of a generalised core meltdown.

For the fourth level of the defence-in-depth concept, it is intended to consider certain sequences leading to a generalised core meltdown so that their consequences can be attenuated in the SFR design. Reactor containment and the associated provisions will therefore be designed with respect to certain generalised core meltdown situations.

Prevention of generalised core meltdown situations

Despite analogous quantitative objectives compared to the EPR and the previous EFR, in the interests of progress, an additional effort to improve prevention has to be integrated consistently with the objective of improving the robustness of the demonstration. Envelope situations will be considered regardless of the plausible expected frequency.

Mitigation of the consequences of generalised core meltdown situations

The major improvement to be made over earlier sodium-cooled fast reactors is to set up provisions to attenuate the consequences of certain situations of a generalised core meltdown and to provide a robust demonstration of their efficiency.

This will require the sequences potentially resulting in core degradation to be identified as exhaustively as possible. After this the aim will be to set up provisions allowing the consequences of generalised core meltdown situations to be controlled. For the situations concerned, the specific aim will be to limit a possible release of mechanical energy resulting from a reactivity insertion or interaction between the sodium and molten fuel.

Radiological release resulting from the generalised core meltdown situations considered

For the considered generalised core meltdown situations, the objective targeted for the SFR will be at least equivalent to that of the EPR, for which in these situations *maximum conceivable releases would necessitate only very limited protective measures in area and time for the public*. However, as a guideline for SFR design, a more ambitious approach is proposed, complying with the one defined by the GIF, i.e. avoiding the need for technical counter-measures (containment, evacuation, etc.) to protect the public.

"Practical elimination" of situations likely to lead to a loss of the containment integrity

“Practical elimination” will be demonstrated as an additional measure for a limited number of situations in which provisions to attenuate the consequences would not be reasonably feasible. Based on

[3] For sodium-cooled reactors this concerns primarily:

- Risks related to reactivity insertion potentials due to core compaction and/or the modification of material locations in the core (effects of sodium voiding or structure material relocations).
- Risks related to corium cooling failure potentially violating the containment integrity.
- The risk of the loss of the containment integrity for radio-elements released during the core meltdown.

past experience a demonstration of the "practical elimination" of extreme situations such as failure of the core support structure, sudden coherent void effect on core or sudden and excessive compaction of the core may be considered.

ESFR safety – organisation of the R&D

Based on the analysis developed above (§ IV.1), the R&D for the SFR safety should be organised in three main parts:

- Identification of provisions for integrating feedback from sodium-cooled fast reactors, with definition of specific actions for the various safety functions and coverage of sodium-related risks.

- Actions aiming to prevent the occurrence of generalised core meltdown situations with identification of provisions to make each of the sequences leading to them highly improbable.

- Actions aiming to reinforce the demonstration of the ability to manage certain degraded core situations and prove the robustness of containment in the event of characteristic families of accidents and associated phenomena.

VI. EISOFAR ROAD MAP: ANALYSIS OF THE R&D ON "ESFR TECHNOLOGICAL ISSUES"

VI.1. Milestones for the ESFR and the prototype

As indicated above, two intermediate milestones are proposed:

- by 2009/2010: consolidation of the orientations, that is to decide keeping or not, until 2012/2013, promising options related to the considered technological issue, and to deepen their analysis before 2012/2013
- by 2012/2013: supply the information needed for the selection of the options for the industrial concept (with, for some of them, variants and/or back-up solutions) and, coherently with the whole deployment strategy, selection of the technologies applicable for the prototype (i.e. deployable by 2020).

Before entering within the detail of the time schedule for the single R&D activities is seems interesting to detail such milestones in terms of key decisions expected for the ESFR and the prototype. The following Gantt chart try to resume what seems to be the essential steps:

Key milestones

The list of the key decisions associated to the dates of 2009/2010 and 2012/2013 can be resumed as indicated within the following table:

Table VI.1 – EISOFAR suggestion for the ESFR and prototype key decision stages for 2009/10 and 2012/13

	ESFR & Prototype : Key Milestones 2009, 2012	2009/10	2012/13	*> 2012/13*
Safety approach for the design and the assessment	Definition of safety objectives and principles: Designers, Safety authorities, International			
	Preliminary report on safety options appplicable to the industrial reactor and to the prototype			
Requirements	High level Requirements (GENIV) (Iteration and improvement of the already available requirements)			
	Technical requirements from the investors / utilities			
Studies on the SFR concepts including the prototype	Synthesis on feasible industrial reactor images, including fuel maintenance			
	Full set of requirements for the prototype in connection with its power selection			
SFR & Prototype : Core & fuel	Reference SFR core - oxyde & variants: performances, safety, fuel cycle, economy			
	Reference SFR core optimization: operation, surveillance, protection, severe accident behaviour, etc.			
	Prototype's core optimization: operation, surveillance, protection, severe accident behaviour, etc.			
	Material selection for the prototype fuel element and the subassembly			
SFR & Prototype : Safety, severe accidents	Provisions related to the implementation of the whole set of defence in depth levels & assessment (e.g. simplified PSA)			
	Decision about the need for an heavy experimental programme (Go / no Go)			
	Selected provisions : Definition / realisation of supporting experimental qualification programmes			
SFR & Prototype : ECS & Materials	Selection, feasibility and development of innovative water-steam technology (Supercritical water, intermediate fluid)			
	Supercritical CO2 and conventional Gases: ECS technological feasibility (thermodynamic cycle & components), compatibility with Na			
	Go-no Go concerning the gas option			
	IHX Na-gas : representative validation of the principle (thermal & technological view point)			
	Selection of the ECS for the SFR and the prototype			

Milestone
Anticipated Planning Extension
Strong Link
Weak Link

VI.2. R&D actions structured following the four main domains

According to what is anticipated in the previous paragraphs, a set of R&D actions can be structured following the four main domains as they are identified above:

I. Core, fuels, fuel elements and fuel cycles,

II. Safety including consideration of severe accidents,

III. Energy conversion systems and materials,

IV. Simplification and optimisation of the reactor, systems and plant operation.

A complementary specific domain is identified under the generic title "Education and training".

The content of these sections is compiled integrating the inputs from the three EISOFAR work packages:

- System integration, design and assessment;
- Fuel with minor actinides;
- Component design and balance of plant

and more specifically the final reports of their activity (ref. D7; D10 and D13).

VI.3. Domain I: Core, fuels, fuel elements and fuel cycles

The objectives of the activities of this domain are the following ones

- A level of safety comparable to that of the generation III reactors with in particular, with regard to the previous SFR, an improvement towards the risks of severe accident, via the improvement of the intrinsic cores characteristics, in particular the effect of sodium void and the mechanical stability (resistance to the compaction)
- The preservation of acceptable economic performances on the fuel cycle (inventories, power density, burn up),
- A contribution to the strategic objectives of the closed fuel cycle, with or without plutonium breeding: economy of the resources by valuation of the natural uranium and waste minimisation.

It is suggested structuring all the activities in six sub-domains:

1. Cores with optimised characteristics (reactivity feedback coefficients) ;
2. Practical elimination of unallowable core compaction;
3. Improved core control and monitoring;
4. Technologies and materials for the core structures and the fuels;
5. Fuel cycle, minor actinides (MA) recycling, irradiation;
6. Computational tools for the core design and assessment (simulation and uncertainties analysis).

1. Cores with optimised characteristics (reactivity feedback coefficients)

The core design programme gets organised in three iterative stages:

1.1. The search for **coherent and multidisciplinary images of core**, looking for the optimisation of the intrinsic safety parameters. The essential objective is the decrease of the sodium void effect in the central zone of the core, with the follow-up of an indicator also implying the Doppler counter reaction. The hydraulic design of the core (and of the primary circuit) has to guarantee the preservation of a pressure drop compatible with the natural convection. The fuel cycle performances and requirements must be guaranteed.

With cores' images so optimised, the definition of the instrumentation and control (I&C) system must be realised. The necessity of protections compatible with the logic of the defence in depth is also addressed and the needed provisions implemented. The requirements for the maintenance are to be defined and to be taken into account as well as the strategies for the core management.

Thermo mechanical and thermo hydraulic concerns at pins, bundles and sub-assemblies levels, are to be considered.

The behaviour of cores is then verified for conventional transients (ULOF, UTOP, ULOHS).

A comparative evaluation of the "theoretical" re-criticality risks under degraded situations for the various cores must be realised.

1.2. The study of **provisions for the prevention and the management of the severe accidents** and their impact on core design.

The provisions are of geometrical and hydraulic nature on the bundle and\or the hexcan; by creating hydraulic paths these provisions have to contribute to cool the local hot spots and to favour a premature detection of local degradation/melting (e.g. canals to relocate outside the core the melted corium, implementation of absorber or diluting materials intended to mix and/or dilute in the melted fuel). These provisions are an integral part of the specific devices for the core protection.

1.3. The assessment of the provisions impacts discussed above on the core performances during nominal operation.

The whole programme must be organised for three fuels options: the oxide, considered as being the reference for the short and the medium term (i.e. for the prototype), and two dense fuels such as the carbide and the metal for the longer term.

2. Practical elimination of unallowable core compaction

Six domains are considered for this programme:

2.1. SPX1-like core restraint

2.2. Alternative solutions for core restraint by use of hexagonal steel assemblies or with a shell. The interest of two levels of hexcan pads has also to be estimated; the objective being to master the mechanical equilibrium of the core

2.3. **Seismic behaviour** with an improved treatment for the fluid/structure interaction.

2.4. **Critical analysis/comparison of the various solutions** from the point of view of the difficulty of the needed demonstration to prove their efficiency in terms of expected counter reactions.

2.5. Control & monitoring of the core geometry looking for the definition of adequate strategies and innovative control & monitoring tools.

2.5. Comparison between natural core restraint and other solutions organising the analysis over a wide spectrum of situations.

3. Improved core control and monitoring

Six key themes are identified:

3.1. **In-vessel fission chambers**. Considering the available experience it is suggested revisiting the provisions for the monitoring of the power profile with in – core chambers.

3.2. **Development of innovative ultrasounds techniques**. The development of measures based on ultrasounds can result in an interesting alternative to thermocouples for the measure of the outlet sub-assemblies temperatures or even for an early detection of Sodium boiling.

3.3. **Improved detection of delayed neutrons**. The pin failure detection systems can be improved in two manners:

- With detectors integrated within the primary circuit and, as far as possible, near the core,
- Through the implementation of detectors able to discriminate between neutrons from the core and delayed neutrons stemming from fission products.

3.4. Forward-looking for the **monitoring of core vibratory behaviour**. A forward-looking activity (objectives ⇨ provisions) has to be implemented for the vibratory follow-up of the core in relation with its compactness.

3.5. **Monitoring of the primary circuit's cover gas** (chemical and radioactive inventory). Innovative techniques have to be searched for, in particular, to improve the dynamics of the detection of abnormal conditions.

3.6. **Acoustic monitoring** (noise technologies)

4. Technologies and materials for the core structures and the fuels

The programme is structured as follows:

4.1. **Technology for the absorbers** (control rods). The objectives of this activity aim at the improvement of the life expectancy, the washing aspects and a critical analysis on implemented materials (B4C or innovative materials);

4.2. **Technology of the peripheral subassemblies and of the compact neutronic protections**. The objective is the design and validation of the as compact as possible lateral and\or axial protections which allow respecting the dose on the structures;

4.3. **Cladding & wrapper materials**. The objective is to exceed the performances the best current austenitic steels by using materials less sensitive to the swelling up to doses of the order of 200 dpa. For cladding, the R&D should consider the ferritic ODS with, in parallel, the evaluation of advanced austenitic;

4.4. **Fuel (innovative and MA bearing)**. The oxide will be the fuel to start up the prototype even if, during his life, the latter has to load and contribute to qualify innovative fuels. The challenges connected to the oxide are to demonstrate the mastery of the fuel of co-extraction (COEX, whose basic products prefigures the upstream of the future fuel cycle, without separated plutonium, and forward incorporating the minor actinides to be recycled).

For the follow on, it will be necessary to demonstrate the mastery and the good behaviour of the innovative fuel compositions with, in particular, the consideration of the greater presence of minor actinides. For alternative fuels (carbides, metal), the R&D programme has to be more exhaustive for the feedback experience is limited.

5. Fuel cycle, minor actinides (MA) recycling, irradiation

The programme is structured as follows:

5.1. **Studies of scenarios**. These studies are indispensable for the definition of solutions of interest both on the valuation of the resources and on the waste management (of the sodium-cooled reactor fleet and of the light water reactors). The results of these studies define the degree of necessary flexibility for the industrial cores (e.g. available plutonium; ranges for the MA content; etc.).

5.2. **Design/manufacture/licensing for the fuel of the prototype**

The Reference D10 addresses in a comprehensive way the specific activities on fuel cycle for the ESFR. Fuel design, fabrication, and implementation for the first core load of the prototype are dealt with as STEP 1 of these activities. Development of the ESFR prototype MA bearing fuel cycle is dealt with as STEP 2.

Several of these activities are directly related with other activities addressed by this road map especially concerning the "design and assessment" studies. Strong relationships have to be implanted to guarantee the whole coherence of these activities.

The key items and corresponding content for the two steps above are the following:

- STEP 1: Deployment of demonstration in 2020
  - fuel licensing
  - fuel fabrication plant
  - assembly construction facility
  - fuel transportation/storage
  - fuel reprocessing

- STEP 2: Deployment of advanced (MOX and MA bearing) fuel within the prototype
  - Advanced MOX fuel and fuel forms
  - reactor core concept
  - fuel properties and licensing
  - fuel/fabrication/assembly construction/transportation
  - closing the ma fuel cycle
  - global actinide cycle international demonstration (GACID).

Detailed milestones are presented in ref. D10 for each of these items.

5.3. Design/manufacture/licensing of irradiations of **MA bearing oxide fuels for the transmutation with homogeneous strategy**. This action is strongly correlated with the previous one (5.2) but looking for the implementation within the future industrial ESFR. The objective is to resume and to complete the evaluation (beyond the Superfact irradiation results), in the ESFR, of the minor actinides recycling with low concentration in the fuel of the core (2 to 5 %).

5.4. Design/manufacture/licensing of irradiations of **MA bearing oxide fuels for the transmutation with heterogeneous strategy**. This action is strongly correlated with the previous one (5.2) but looking for the implementation within the future industrial ESFR. The objective is to resume and to complete the evaluation (beyond the Superfact irradiation results), in the ESFR, of the minor actinides recycling with high concentration (in proportions from 15 to 25 %) in blanket subassemblies or in targets loaded in the core in diverse ways. *The action must be conducted in contact with the project ACSEPT of Euratom FP7*.

5.5. In strong relation with the activities described in Points 5.2, 5.3 and 5.4, consideration of the **up-stream aspects of the fuel cycle with MA** to select the innovative fuel for the industrial deployment. The integration of minor actinides in the carbide and the metal has to be the object of a preliminary analysis to identify possible showstoppers.

5.6. **Decision about curium management**. The strategy concerning curium management has to be addressed quickly for it strongly affects the fuel production chain

5.7. **Qualification and safety testing**. An adequate qualification and testing programme has to be defined to meet the time schedule for both the prototype and the ESFR deployment.

6. Computational tools for the core design and assessment *(simulation and uncertainties analysis)*

The programme has to be built to guarantee the adequate support to the modelling. The critical analysis of what is available and the identification of specific needs of improvement should be made by the treatment of the following domains:

6.1. Neutronic.

6.2. Thermo-hydraulics for the bundle, the core and the inter-subassemblies.

NB. The interest in coupling neutronic and thermo-hydraulic tools must be assessed.

6.3. Static and dynamic mechanics of the core.

6.4. Fuel modelling in steady states and transients.

7. Planning

The detailed time schedule for the actions listed above is presented within the following table.

	EISOFAR Domains : Key Milestones 2009/10, 2012/13	2009	2010	2011	2012	> *2012*
Core and fuels						
	Fuel, fuel element, core & fuel cycle					
	Coherent and multidisciplinary images of core					
	Provisions for the prevention and the management of the severe accidents and their impact on core design				validation	
	Assessment of the provisions impacts				validation	
	Practical elimination of unallowable core compaction					
	SPX1 like core restraint.	assessment				
	Alternative solutions for core restraint (e.g. two levels of pads)	assessment				
	Seismic behaviour & other hazards			assessment		
	Critical analysis/comparison of the various solutions			assessment		
	Control & monitoring of the core geometry	assessment			validation	
	Comparison between natural core restraint and other solutions				validation	
	Improved core control and monitoring					
	In vessel fission chambers	assessment			validation	
	Development of innovative ultrasound techniques (early detection of Na boiling)	assessment			validation	
	Improved detection of delayed neutrons	assessment			validation	
	Surveillance of core vibratory behaviour	assessment			validation	
	Surveillance of the primary circuit's cover gas (chemical and radioactive inventory)	assessment			validation	
	Acoustic monitoring (noise technologies)	assessment			validation	
	Technologies and materials for the core structures and the fuels					
	Technology for the absorbers	feasability			validation	
	Technology of the peripheral subassemblies and of the compact neutronic protections	feasability			validation	
	Cladding & Wrapper materials	interest			specification	
	Fuel (innovative and MA bearing)					
	Fuel cycle, Minor Actinides (MA) recycling, irradiation					
	Studies of scenarios					
	Design / manufacture / licensing for the fuel of the Prototype					
	STEP 1: Deployment of demonstration in 2020 (cf. Details within the EISOFAR deliverable D10)					
	STEP 2 Deployment of advanced (MOX/driver and MA bearing) fuel within the prototype (cf. Details within the EISOFAR D10)					
	Deployment of MA bearing oxide fuels for the transmutation with homogeneous strategy in ESFR DEMO					
	Deployment of MA bearing oxide fuels for the transmutation with heterogeneous strategy in ESFR DEMO					
	Upstream aspects of the fuel cycle with MA					
	Decision about Curium management					
	Qualification & safety testing					
	Computational tools for the core design and assessment (simulation and uncertainties analysis)					
	Neutronic					
	Thermo hydraulics for the bundle, the core and the inter-subassemblies					
	Static and dynamic mechanics of the core					
	Fuel modelling in steady states and transients					
Milestone						
Anticipated Planning Extension						
Strong Link						
Weak Link						

NB: The table has to be completed and endorsed after assessment of the available means (strongly related to the amount allocated to the future activities on sodium technology)

VI.4. Domain II: Safety and severe accidents

The objectives of the activities of this domain are the following ones:

- The definition (between European partners, in strong connection with the designers, and in contact with the safety authority) of detailed safety objectives and principles applicable to the design and assessment of sodium-cooled technology.
- On this base, for the studied concepts and considering their specificities, it is necessary:
    - Looking for level of safety similar to that of the last European LWR reactors with in particular, with regard to the previous SFR, an improvement towards the management of severe accident
    - To revisit and, if needed, to improve the defence in depth provisions for the whole set of safety function.
    - To study anticipated transients.
    - To study representative hypothetical scenarios of core degradation.
    - To propose robust solutions for the containment, including corium relocation.
    - Develop the needed tools to support the modelling.
    - To propose and to qualify provisions allowing to practically eliminate unacceptable situations
    - Develop the needed tools to support the modelling for the design and assessment.

It is suggested structuring all the activities into six sub-domains:

1. Definition of an adequate safety approach with safety objectives and principles for the design and assessment;
2. Provisions related to the implementation of the whole set of defence in depth levels;
3. Studies of representative transients and scenarios;
4. Studies of provisions to decrease the risks of severe core degradation, and prevent and practically eliminate the strong mechanical energy release situations;
5. Containment and core catcher, design including long term cooling;
6. Modelling of the accidents situations.

1. Definition of an adequate safety approach with safety objectives and principles for the design and assessment

The programme deals with two main themes::

1.1. Safety objectives and design principles susceptible to meet them, methodologies of evaluation and criteria of acceptability for acting of the meeting of the objectives.

1.2. Elements needed to prepare the preliminary safety options reports - for the industrial fleet and the prototype - which could influence the contents of the R&D.

2. Provisions related to the implementation of the whole set of defence-in-depth levels

The programme addresses the safety architecture as a whole. Its content is defined considering inputs from the EISOFAR WPs and especially WP1 (*System integration, design and assessment)* and WP3 *(Component design and balance of plant).* It is structured as follows:

2.1. Synthesis of the safety requirements as function of the various concepts' architectures

2.2. Design of the core and fuel with, in particular, the selection of options favouring the minimisation or the practical elimination, for example, of sodium void effects and pressure waves related to the passage of gas, or the core support failure. The design has also to improve the resistance versus the movements of compaction as well as the capability to sustain earthquake loadings and, in general, all the possible causes of reactivity injection.

2.3. A systematic work has to be organised on the whole safety architecture. It gets organised by the mastery of the safety functions:

- Reactivity control (e.g. the third level of shut down; provisions against the total instantaneous blockage)
- Decay heat removal
- Confinement of dangerous products

Concerns related to proliferation resistance and/or physical protection have to be addressed as early as possible both identifying the needed provisions (intrinsic and/or extrinsic) and implementing adequate tools to check the consistency of the whole resulting architecture.

Detailed research programmes, needs for facilities and time schedules are described within the Reference D13 (§ 4).

2.4. Implementation and fulfilling of the logic of the defence in depth against the consequences of the sodium leaks and the sodium fires.

2.5. Implementation and fulfilling of the logic of the defence in depth against the consequences of reactions between the sodium and the fluid of energy conversion.

The two last points are to be handled in relation with the research activity for alternative intermediate fluids to the sodium, discussed in the domain III.

3. Studies of representative transients and scenarios (cores oxide)

3.1. Study of **representative incidental/accidental transients**; identification, selection and assessment of severe accidents scenarios.

3.2. Study of the possible effects on the **severe accidents phenomenology** evolution due to the higher content of minor actinides in the fuel.

3.3. Impact of Minor Actinides has to be assessed for all representative transients and scenarios.

4. Studies of provisions to decrease the risks of severe core degradation, and prevent and practically eliminate the strong mechanical energy release situations

The choice of one (few) strategy (-ies) of management for the degraded core has to be made in relation with the design options. The selection of additional specific provisions for the implementation of the selected strategy (-ies) has to address two possible tracks:

4.1. The **controlled relocation** of melted corium outside the core.

4.2. The possible incorporation of absorbers in the melted fuel or, generally speaking, its dilution to insure the **sub-criticality and coolability of corium**.

It is to note that these two tracks are not necessarily mutually exclusive.

5. Containment and core catcher, design including long-term cooling

The programme addresses three main themes:

5.1. Definition and justification of the **relocation strategy** in close relation with the results of the previous theme.

5.2. Design of the **provisions for the corium catching and cooling** over a long term period addressing different items such as : location within the plant; geometry; mechanisms of spreading; annexation of absorber, ; decay heat removal; mechanical holding and in service monitoring; mechanical holding during an energetic accident.

5.3. The definition of a **robust containment** versus the mechanical energy release and the confinement of radionuclides

6. Modelling of the accidental situations

The programme has to get organised to allow the treatment (modelling and consequences assessment) of the following items:

6.1. Core evolution and degradation covering all the plausible conditions – **design basis conditions and design extension conditions** – and addressing, for the severe accidents domain, all the phases (if any): primary; transition; secondary; post accidental (medium to long term);

6.3. **Release and transfer of dangerous products**;

6.4. The possible **pool, mixed and sprays sodium fires**;

6.5. The possible **reactions sodium – water and sodium – water – air**;

6.6 The **internal and external hazards.**

All the items above imply the availability (improvement of available tools or development) of adequate simulation tools to guarantee the robustness of the safety demonstration.

7. Planning

The detailed time schedule for the actions listed above is presented within the following table.

	EISOFAR Domains : Key Milestones 2009, 2012	2009	2010	2011	2012	> *2012*
Safety including consideration of severe accidents (+PR&PP)						
	Definition of an adequate safety approach with safety objectives and principles for the design and assessment;					
	Safety objectives and design principles					
	Elements for defining safety options					
	Provisions related to the implementation of the whole set of defence in depth levels					
	Synthesis of the safety requirements					
	Design of the core & fuel					
	Safety architecture organized to master of the safety functions	assessment			validation	
	Consideration of PR&PP concerns					
	Defence in depth against sodium leaks and the sodium fires				assessment	
	Defence in depth against reactions between the sodium and the fluid of energy conversion				assessment	
	Studies of representative transients and scenarios					
	Representative incidental / accidental transients					
	Severe accidents phenomenology					
	Impact of MA					
	Studies of provisions to decrease the risks of severe core degradation, and prevent and practically eliminate the strong mechanical energy release situations	assessment			validation	
	Controlled relocation of corium					
	Sub-criticality and coolability of corium					
	Containment and Core catcher, design including long term cooling	assessment			validation	
	Corium relocation strategy					
	Provisions for the corium catching and cooling					
	Robust containment versus mechanical energy release and confinement of radionuclides					
	Modelling of the accidents situations					
	Core evolution and degradation					
	Release and transfer of dangerous products					
	Pool, mixed and sprays sodium fires					
	Sodium – water and sodium – water – air reactions					

Milestone	
Anticipated Planning Extension	
Strong Link	
Weak Link	

NB: The table has to be completed and endorsed after assessment of the available means (strongly related to the amount allocated to the future activities on sodium technology)

VI.5. Domain III: Energy conversion systems (ECS) and materials

Four main objectives are aimed at by the activities of this domain on the energy conversion systems (ECS):

- A high efficiency. The performances must not be significantly reduced with regard to previous sodium-cooled reactors (e.g. the Superphénix which, with an outlet core temperature of 545 °C and the Rankine cycle, achieved an efficiency of 40 %).
- The decrease/eradication of the inconveniences of the former solutions in terms of acceptability of the sodium technology and the safety (sodium leaks and fires, sodium-water reactions).
- The exploitation of the potential thermodynamic performances of the different considered ECS, while taking into account concerns of:
  - Minimisation of the investment: decrease of the masses (shortening of circuits, decrease of the surfaces of exchange), cost of the materials.
  - Sustainability/durability of the investment (60 years, in particular for the critical components).
  - Increase of the reliability and reparability of the critical components of the system considering both the level of temperature and the fluids aggressiveness.
- A high reliability, compactness, and an efficient iSI&R.

The sub domains proposed to organise the work are the following:

1) Energy conversion systems with water;

2) Energy conversion systems with gas;

3) Heat transfer system using intermediate fluid alternative to sodium;

4) Search for materials in relation with the selected options for the ECS.

Detailed research programmes, needs for facilities and time schedules are described within the Reference D13 (§ 4.6).

1. Energy conversion systems (ECS) with water

The programme on the ECS with water is structured as follows:

1.1. Evaluation of the **supercritical water cycle** which feasibility is dependent, in particular, on a milestone for the materials in relation to the temperatures increase and to the aggressiveness of the supercritical water.

1.2. Evaluation of the rationale for the **steam generator minimising the risk of large sodium-water reaction** (e.g. double wall technology) and implementation, as needed, of the specific R&D in this concept.

1.3. Evaluation of **double components technology**, e.g. intermediate heat exchanger – steam generator, using a fluid compatible with sodium, water and air (fluid searched under the aegis of sub domain 2), 1.4. Development of a **tool and experiments for the SG modelling**. This tool will have to allow the design of components addressing thermal and thermodynamic aspects, and supply the necessary results (e.g. loads) for the thermo mechanical studies, both static and dynamic.

1.5. Improvement of the **leaks detection** both in terms of performances of the available systems as well as the development of innovative means of detection.

1.6. Improvement of the **SG inspection** including re-qualification after water leaks.

2. ECS with gas

The programme is structured as follows:

2.1. **Cycle with supercritical CO_2** (expected net efficiency of 43 % with a core outlet temperature of 550 °C). The subjects of study are the acquisition of all the basic properties of the supercritical CO_2, the selection of the thermodynamic cycles and their stability for all the plant operational regimes, the feasibility of the components of the ECS systems.

2.2. **Cycle with "conventional" gas** (nitrogen, helium nitrogen, argon, helium argon). The key objective is the identification of the necessary provisions to keep an attractive cycles efficiency (at least 40 %). This can result from: the adoption of high pressure, a work on the efficiency of components, the selection of temperatures differences between the primary and the secondary side, the addition of a turbine associated to a reheating by the sodium, finally an increase of the temperature of the sodium. Concerning the possible components it has to be considered that the machines of the cycle could widely take advantage of the industrial conventional experience on gas turbines.

2.3. Technology of the **sodium - gas heat exchangers** (HX). The research effort has to aim at the compactness of the components while allowing to guarantee short times of draining the sodium and to avoid the risks of sodium freezing/blockage. The design must be compatible with the codes and the standards (RCC-MR) and allow the in service inspection and reparability.

2.4. **Protection against leaks** (and their consequences) in the sodium - gas heat exchangers. This study has to elaborate a safety analysis with in particular the exam of the risks related to the reactivity insertion linked to the sodium void effect and/or in the mechanical loadings of the core. In case of temperatures increase, made necessary by the gas selection, the risks connected to the decrease of the margins to boiling have to be considered.

2.5. **Safety assessment** and identification of **safety issues.**

3. Heat-transfer system using intermediate fluid as an alternative to sodium

The goal is to identify and to assess the **potential of alternate fluids to the pure sodium**, for the intermediate circuit, the objective being the prevention of the sodium – water and/or sodium – water – air reactions. The fluids have to be compatible with sodium, water and air. Research tracks turn around alloys, liquid metals such as Pb Bi, Pb Bi Li, Ga, salts (nitrates, chlorides), or additives in the sodium.

4. Search for materials in relation with the selected options for the ECS

The objective being the plant life duration of 60 years, the following themes have to be considered successively:

4.1. The **materials for fixed components/structures** which cannot be dismantled (e.g. those in the hot collector). The following three hypotheses have to be considered for the core outlet average temperature: 550, 600, 650 °C (the two last ones related to the ECS with gas). These temperatures being associated to life of 60 years the studies have to address thermal consequences as the creep and the potential for "corrosion".

4.2. The **materials for the replaceable components** of the hot collector/hot loops. It is typically the case of the rotating plug, the intermediate heat exchangers (conventional or innovative), the piping, the SG envelope.

4.3. The **materials for the replaceable components intended for the thermal exchange** and, as such, in contact also with the candidate fluids for the energy conversion. Specific context and conditions poorly known in sodium technology are: the supercritical water, the supercritical CO_2, the nitrogen or the helium-nitrogen.

4.4. **Associated joining/non-destructive examination (NDE)/surface-treatment technologies**

5. Planning

The detailed time schedule for the actions listed above is presented within the following table.

	EISOFAR Domains : Key Milestones 2009, 2012	2009	2010	2011	2012	> *2012*
Energy Conversion Systems (ECS) and materials						
	Energy Conversion Systems with water;					
	Supercritical water cycle	review of incentives				
	Steam generator minimizing the risk of large sodium-water reaction	incentives/feasibility			pre-design	
	Double components technology (IHX/SG with coupling fluid)	incentives/feasibility			pre-design	
	Tool and experiments for the SG modelling				assessment	
	Improvement of the SG leaks detection				assessment	
	Improvement of the SG inspection including re-qualification after water leaks.	assessment				
	Energy Conversion Systems with gas;	incentives/feasibility			assessment	
	Cycle with supercritical CO2.	incentives/feasibility				
	Cycle with "conventional" gas	incentives/feasibility				
	Technology of the sodium - gas heat exchangers (HX).	feasibility			validation	
	Protection against leaks in the sodium - gas heat exchangers including technology and performances of sodium-gas separators	feasibility				
	Safety assessment and identification of safety issues	feasibility				
	Heat transfer system using intermediate fluid alternative to sodium					
	Potential of alternate fluids to sodium including compatibility with sodium, tertiary fluids and structural materials	selection of best candidates and		first assessment	assessment	
	Search for materials in relation with the potential options for the ECS	incentives			assessment	
	Materials for fixed components/structures					
	Materials for the replaceable components					
	Materials for the replaceable components intended for the thermal exchange					
	Associated joining / NDE / surface treatment technologies					

Milestone

Anticipated Planning Extension

Strong Link

Weak Link

NB: The table has to be completed and endorsed after assessment of the available means (strongly related to the amount allocated to the future activities on sodium technology)

VI.6. Domain IV: Simplification and optimisation of the reactor, systems and processes

The objectives for the studies of this domain are:

- The **economy of the investment and its protection** through the compactness, the simplification/mutualisation of the systems, the simplification of the manufacturing, the inspectability and reparability of the critical components for the safety and the expected life.
- The **optimisation in terms of availability/maintainability** of sensitive systems (handling) looking for the reduction of the durations for the plant shut downs and the replacement/repairs.
- **The comparison of global concepts (general architecture, components) and of elementary systems**

The recommended method aims at studying and comparing global concepts (general architecture, components) and of elementary systems.

These studies allow legitimising the R&D on technological issues of the other domains. They are an indispensable support:

- To verify the coherence of the options which can be integrated in a given reactor image,
- To tighten the range of the interesting images, in particular through the safety and economic evaluations which they allow.

The studies of this domain thus have a key role in the coherence of choices by 2009 and 2012, and versus the transposition industrial concept/prototype with, in particular the validation, by the latter, of options important for the industrial fleet.

The domain covers the following items:

1) Innovative reactors images including the re-examination of the primary circuit.
2) Optimisation of the heat transfer system.
3) Optimisation of components and systems.
4) Reduced duration and simplification of the fuel handling & washing (driver fuels, MA bearing).
5) Temporary storage
6) In service inspection, reparability.
7) Improving and simplifying the provisions with regard to the risk sodium
8) Consideration of the dismantling
9) Provisions for the general layout including civil works
10) Provisions for innovative I&C
11) Tools and experiments in support to the design.

Detailed research programmes, needs for facilities and time schedules are described within the Reference D13 (§ 4).

1. Innovative reactor images including the re-examination of the primary circuit

For each type of concept (loop, pool, modular, etc.) the approach has to integrate the following boundary conditions, results and constraints:

- Taken into account of the detailed performances requirements elaborated by investor(s), developer(s) and the safety requirements (cf. domain II)

- Integration of the results from the core studies performed under the domain I, and results of the studies of items 2, 3, 4, 5 below, by leaning on tools developed under item 6. This is particularly true for the fuel handling aspects (under item 5) which is structuring to reassemble pertinent images.

- Analysis of options with or without intermediate circuit, and integration of the energy conversion systems (Domain III) and of fuel handling.

- Integration of the reflections on the provision to improve the defence in depth performances versus the main safety functions (reactivity control, decay heat removal, confinement) in term of physical performances, diversification of the physical principles and geographic arrangement.

- Modularity: exam of the thresholds effects which could motivate the selection of modular plants based on modules of reduced size, sharing some auxiliaries and – likely – favouring the availability,

- Realisation of studies on incidentals/accidental transients, coherently with the needs expressed by safety objectives.

- Analysis of the peculiarities brought by the new options (with regard to the state of the art) such as the loop concept; for example the safety implications related to the selection of gas ECS (see also domain III) to assess the risks of reactivity insertion (passage of gas through the core, shaking of the core), or the risk related to the margins reduction (for example to the sodium boiling for these systems imply core outlet temperatures increase),

- If needed, detailed analysis of concepts' specific aspects with adequate tools, e.g. thermohydraulics to consider the training of gas, thermal and mechanical pre-conceptual design of the main components, resistance to earthquake, and the other hazards.

1.1. Studies of the loop system

Three stages allow structuring the work:

- The evaluation of the **key questions on this concept** which is less known than that integrated (pool) one. The base could be a design such as the Japanese JSFR. For the **concept as a whole**, the main subjects are: the potential for operating in natural convection to remove decay heat, the potential of compactness, the reduction of the number of loop and the asymmetrical operation, the geometry of the hot collector and of the Rotating Plug, the thermo mechanical behaviour of the primary vessel free-level zone with risks of significant creep.
  For the **primary loops** the main subjects are: the exam of the very short loops technology, the identification and the analysis of incidentals initiating events, etc., the feasibility of the innovative components from the point of view both of the flexibility of exploitation and of the ISI&R, the implementation and the arrangement of the decay heat removal systems and the sensibility to malevolent aggressions, the behaviour under severe accident conditions.

- The search for solutions/alternative innovations, for example: the implementation of four loops and of integrated components into the primary circuit (IHX – electromagnetic pump), the alternative solutions of handling, the cooling of the main vessel.

- The definition of coherent images integrating the results of the previous stages.

1.2. Optimisation of the integrated system (pool)

The work on the pool concept has to begin with a critical analysis of this well known option compared to the evolution of the requirements and of the evaluation criteria since the former realisations (SPX) or previous projects (EFR).

Some tracks of reflections are identified (not exhaustive list): the strategy of management for the sub-assemblies, the size of the IHX, a new reflection on the simplification of the Redan, the feeding of the IHX, the possibility and the interest to arrange equipments of decay heat removal within the cold collector, the reduction of the number of loops with regard to EFR and the decrease of the number of equipments classified to safety, the feedback on the design of the LIPOSO, the reflection to reduce the risks of common modes due to the passage through the roof slab and the hot collector of safety systems components and the sensibility of the decay heat removal systems to the malevolent hazards.

This work should end in updated sketches for pool concepts.

1.3. Comparison loops/pool, comparison large power versus modular size

Sketches will be the object of **rough comparative analyses** from the viewpoint of economy, safety, inspectability / accessibility / reparability, robustness versus mechanical and thermal loads of the components critical for safety, the preservation of the investment and the availability / flexibility of operation. The potential to face and manage severe plant conditions is to be taken into account.

By 2009 and 2012, these studies will allow achieving a **synthesis on the sodium technologies** and will supply elements for the requirements applicable to the prototype. Concerning the latter the set of applicable requirements will also define its role and its possible contribution with regard to the deployment of the industrial concepts.

1.5. Innovative architectures

Looking for innovative architectures (e.g. the consideration of innovative hybrid architectures) has to be considered as a generic parallel task before the first 2009/10 milestone. It addresses both the improved operation and safety objectives. The boundary conditions results and constraints defined above helps defining the framework for this activity.

2. Optimisation of heat-transfer system

The work for the optimisation of the intermediate circuit can get organised in three parallel subjects:

2.1. Evaluation of **integrated components**. It is about concepts of integrated IHX-pumps, and about integrated IHX-SC (or IHX Na gas), as well as electromagnetic pumps.

2.2. Evaluation of **simplified secondary circuits**, the objective being to examine the benefits expected from the use of materials with coefficients of expansion lower than those of austenitic steels.

2.3. Improvement and simplification of the **provisions versus the risk related to the use of sodium**. The objective is the assessment of the monitoring and protection provisions implemented against the leaks and the fires: detection techniques, leak before break, double envelope, inerted casemates (and consequences on the exploitation)

3. Optimisation of components and systems (except handling)

The work of optimisation aims for each component the specific objectives:

3.1. **Heat exchangers (IHX, SG, HX)**: heat exchangers and decay heat removal loops with sodium/sodium and sodium/air.

- IHX Na/gas: see Domain III

- Na/Na IHX: research for more compact geometries and technologies, design facilitating the in service monitoring and the maintenance, and aiming at the economy of the manufacturing processes.

- Na/air IHX: research for compact technologies avoiding the need for safety classified feeding system.

- Evaluation of thermo pumps to help the sodium flow under decay heat removal conditions.

- Evacuation of the residual heat by the vessel: principles of heat exchangers in reactor pit, cooling efficiency under post severe accident conditions.

For the components, identified as replaceable, it is allowed to make the hypothesis of a life expectancy shorter than 60 years which are the objective for the non replaceable structures of the reactor.

3.2. **Core support structures**

E.g. to address the **LIPOSO**s: research for technologies without welds

3.3. **Electromagnetic pumps** (EMP): improvement of the performances (flow, flow stability, modelling).

3.4. Technology of **mechanisms in the reactor**: research for materials less sensitive to the activation.

3.5. **Sodium purification systems** (primary and secondary)

The work on the circuits of purification has to cover the following subjects:

- The choice and the justification of the objectives in term of purity of Sodium (temperatures of cold / hot shut down, margins with regard to the blockage risks, method of management of the clad failures).

- The improvement of the monitoring means.

As for the cold traps, the subjects of interest are the following:

- In the primary: diversification and technology of the provisions,

- In the secondary: strategy for the tritium management. Search for process for the traps regeneration; definition of an ad-hoc strategy in case of absence of SG.

The transfers of mass, the corrosion in sodium and the models of contamination require the availability of tools of which it is advisable to analyze the current status to identify needs for development.

3.6. Argon circuits

The activity has to look for improving the performances of the system for the treatment of the cover gas.

NB: The actions related to the technologies appropriate for the employment and for the mastery of alternate fluids to the sodium are addressed by domain III.

4. Reduced duration and simplification of the fuel handling and washing (driver fuels, MA bearing)

The fuel handling activities use the data coming from studies on concept, management of cores and cycle aspects. They may, in return, influence these studies. The aimed objective is the increase of the cadences which are on the critical path for the availability of the plant. The shortness of the cadences also allows facilitating the core downloading for inspection of the core support structure or under accident conditions.

4.1. **Evaluation of fuel handling chains**

The analysis has to cover the following items:

- Loading path for the new subassemblies taking into account - in particular - subassemblies with minor actinides (thermal power, radiation). Safety, means of cooling, radioprotection have to be addressed.

- Primary: loading of new fuels, downloading of used fuels, failed fuels and reorganisations of the core.

- Secondary / evacuation out of the reactor: wash and final storage in water. The wash is essential to define the global duration of evacuation.

4.2. **Evaluation of specific primary handling technologies**

For each of the handling options specific studies are to be envisaged (examples):

- Solution with unique rotating plug + pantograph: mechanics in sodium, thermo-mechanics, thermohydraulics of the rotating plug and the subassemblies' monitoring

- Solution with dismantled rotating plug + handling flask: R&D on aspects related to the sodium aerosol management,

- Cooling of the storage: treatment of cooling aspects (natural/forced convection), safety.

4.3 **Impact of MA on fuel handling**

These studies are justified by the pursuit of specific objectives as for example the downloading of the subassemblies with high residual power (10 to 15 KW in gas, 20-25 in sodium). They focus, for example, on: the cooling during maintenance; the innovative wash process by fast diving in concentrated salt solution.

5. Temporary storage

The following options have to be addressed: internal storage, external storage, in sodium or gas with choice of transfer technology, etc.

6. In-service inspection, reparability

The work can be organised under three main items:

5.1. Investigation of **new strategies for in service inspection, monitoring, and of reparability** of the critical components for the safety and/or the availability and/or the investment protection. The critical components are identified in relation with the studies on concepts. For these components, the needs in terms of accessibility, draining of sodium, inertage, inspection, repair, dismantling or replacement, have to be assessed on each of the sketches studied under the domain I. The feedback experience is to be capitalized.

5.2. **Development of inspection and monitoring techniques** for the components critical for safety, the availability and the investment protection. These exams are made under shut down conditions (typically 250 °C), the items cover simultaneously the measures under sodium and the measures from the outside (vessels).

7. Improving and simplifying the provisions with regard to the risk sodium

The activity has to look for provisions of monitoring and protection against leaks and fires: detection techniques, leak before break, inertage by double envelop, inertage by bunkers, looking for both innovative solutions and improved performances.

8. Consideration of the dismantling

The studies should investigate new materials and strategies to facilitate the dismantling.

9. Provisions for the general layout including civil works

A specific activity must be dedicated to the general installation layout with two main purposes:

9.1. An optimised **response to the safety objectives**: external hazards, earthquake, diversification of the means of mitigation, confinement.

9.2. The **optimisation of the costs** of construction and operation.

These aspects have a strong connection with the concept studies done under the item 1, including on the technical-economic aspects.

10. Provisions for innovative I&C

Innovative I&C strategies have to be defined and assessed. Innovative materials have to be developed and qualified.

11. Tools and experiments in support of the design

The objective is the availability of adequate tools of calculation to guarantee the robustness of the design and the demonstration of safety (improvement of available tools or development). A specific activity has to allow reviewing the state of the knowledge and the available tools and to identify the needs in terms of development in three different domains:

11.1. The tools for the **whole system simulation & PRA**.

11.2. The tools of **thermo-hydraulics, mechanics and chemistry**.

11.3. The **updating of codes and standards**.

12. Planning

The detailed time schedule for the actions listed above is presented within the following table.

	EISOFAR Domains : Key Milestones 2009, 2012	2009	2010	2011	2012	> 2012
Simplification and optimization of the reactor, systems and plant operation						
	Innovative reactors images including the re-examination of the primary circuit.					
	Innovative architectures		review			
	Studies of the loop system	assessment			pre-design	
	Optimization of the integrated system (pool)	assessment			pre-design	
	Comparison loop / pool, comparison large power Vs modular size				assessment	
	Consideration of innovative hybrid architectures				assessment	
	Optimization of heat transfer system					
	Evaluation of integrated components.				specification	
	Evaluation of simplified intermediate circuits				specification	
	Optimization components and systems	review			assessment	
	Heat exchangers (IHX, SG, HX)					
	Core support structures					
	Electromagnetic pumps					
	Technology of mechanisms in the reactor					
	Sodium purification systems (primary and secondary)					
	Reduced duration and simplification of the fuel handling & washing (driver fuels, MA bearing)				assessment	
	Evaluation of fuel handling chains					
	Evaluation of specific primary handling technologies					
	Impact of MA on fuel handling					
	Temporary storage				assessment	
	Internal storage, external storage, in sodium or gas with choice of transfer technology, etc.					
	In service inspection, reparability					
	Strategies for in service inspection, monitoring, and reparability	First Assessment			agreement on ISI approach & specification	
	Development of inspection and surveillance techniques	review/assessment			Confirm reference methods	
	Improving and simplifying the provisions with regard to the risk sodium					
	Provisions of monitoring and protection against leaks and fires: detection techniques, leak before break,	review			assessment	
	inertage by double envelop, inertage by bunkers	review			assessment	
	Consideration of the dismantling	review			assessment	
	New materials and strategies to facilitate the dismantling					
	Provisions for the general layout including civil works	review			assessment	
	Response to the safety objectives.					
	Costs optimization for the construction and operation					
	Provisions for innovative I&C			review		
	Innovative I&C strategies & materials					
	Tools and experiments in support to the design					
	Whole system simulation & PRA.		review			
	Thermohydraulic, mechanics, chemistry, etc..					
	Update of codes and standards		review		assessment	

Milestone

Anticipated Planning Extension

Strong Link

Weak Link

NB: The table has to be completed and endorsed after assessment of the available means (strongly related to the amount allocated to the future activities on sodium technology)

VI.7. Domain V: Education and training

Appendix 5 addresses in detail the rationale and the content for a education and training (E&T) Strategy applicable for the SFR technology. Below are summarised the key objectives.

Within the R&D activities foreseen at the European level it is strongly suggested that a list of main topics to be included in an updated specific E&T programme is identified for the ESFR. Many of these topics will be common with other nuclear technologies, while others will be partially or totally new or up-dated.

The effort of selection of issues to be considered within the R&D programmes and their scheduling should foresee a simultaneous and parallel activity aimed at translating the information and know-how acquired, the methodologies developed, the design criteria, and, where feasible, the tools themselves, into educational/training packages that will be spread and disseminated for European education and training activities.

The activities of preparation of the educational/training packages should proceed in parallel (and with a limited delay) with respect to the activities that should generate the information to be included into the packages (the **educational and training road map** would follow the road map of the main R&D activities originating the relevant information/data/tools).

Once the selected educational/training packages will be available, dedicated “Euro courses” could be envisaged, but only if an absolute priority is given in allocating the budget available into the preparation of the educational/training packages themselves.

The possibility of financing some PhD scholarships could be foreseen, with an involvement of some skilled young person in contributing in the preparation of the educational packages. This would have the double effect of contributing in the preparation of the education/(eventually) training packages and of helping the professional growth of the individuals selected.

VI.8. EISOFAR domains – summary of the key milestones

	EISOFAR Domains : Key Milestones 2009/10, 2012/13	2009	2010	2011	2012	> *2012*
Core and fuels						
	Fuel, fuel element, core & fuel cycle				validation	
	Practical elimination of unallowable core compaction	assessment		assessment	validation	
	Improved core control and monitoring	assessment			validation	
	Technologies and materials for the core structures and the fuels	feasability/interest			validation/specification	
	Fuel cycle, Minor Actinides (MA) recycling, irradiation					
	Computational tools for the core design and assessment (simulation and uncertainties analysis)					
Safety including consideration of severe accidents (+PR&PP)						
	Definition of an adequate safety approach with safety objectives and principles for the design and assessment;	Definition			Availablilty of needed elements	
	Provisions related to the implementation of the whole set of defence in depth levels	assessment			Validation/assessment	
	Studies of representative transients and scenarios			As needed		
	Studies of provisions to decrease the risks of severe core degradation, and prevent and practically eliminate the strong mechanical energy release situations	assessment			validation	
	Containment and Core catcher, design including long term cooling	assessment			validation	
	Modelling of the accidents situations					
Energy Conversion Systems (ECS) and materials						
	Energy Conversion Systems with water;	review of incentives/feasibility			pre-design:assessment	
	Energy Conversion Systems with gas;	incentives/feasibility			assessment	
	Safety assessment and identification of safety issues	feasibility				
	Heat transfer system using intermediate fluid alternative to sodium	selection of best candidates and first assessment			assessment	
	Search for materials in relation with the potential options for the ECS	incentives			assessment	
Simplification and optimization of the reactor, systems and plant operation						
	Innovative reactors images including the re-examination of the primary circuit.	assessment	review		pre-design/assessment	
	Optimization of heat transfer system				specification	
	Optimization components and systems	review			assessment	
	Reduced duration and simplification of the fuel handling & washing (driver fuels, MA bearing)				assessment	
	Temporary storage				assessment	
	In service inspection, reparability	First Assessment			agreement on ISI approach & specification	
	Improving and simplifying the provisions with regard to the risk sodium	review			assessment	
	Consideration of the dismantling	review			assessment	
	Provisions for the general layout including civil works	review			assessment	
	Provisions for innovative I&C			review		
	Tools and experiments in support to the design		review		assessment	

Milestone	
Anticipated Planning Extension	
Strong Link	
Weak Link	

NB: The table has to be completed and endorsed after assessment of the available means (strongly related to the amount allocated to the future activities on Sodium technology)

VII. EISOFAR ROAD MAP – GUIDELINES FOR ROAD-MAP IMPLEMENTATION

The preparation of the road map was the first step for the development of the ESFR. Its implementation has to be done, within the general framework of the SNE-TP Strategic Research Agenda.

This could be concretised by a large-scale integrate project (LIP-ESFR) achieved under the aegis of Euratom FP7. Several different aspects have to be considered for the specification of decision points and priorities

- Agreement on boundary conditions for the plants development not put into question during the next five to six years
- Specification of reference solutions selected for decision processes on advantages and disadvantages of new evolutionary as well as visionary design proposals
- Selection of priority items on the time axis to be taken as reference for structuring the work programme
- Listing of design options identified as potentially supportive and necessary to meet generation IV objectives but which need more continuous basic qualification and integral demonstration of its feasibility prior to realisation
- Guaranteeing the complementarity with currently underway or foreseen programmes at the international level, e.g. the generation IV – SFR activity, in order to represent a valuable and recognised contribution to the international effort.

1) Agreement on boundary conditions for the plants development not put into question during the next five to six years

An agreed safety approach/concept: A preliminary proposal was developed by the French Advisory Group on Reactor Safety and globally agreed by the EISOFAR partners. Among others, this implies the following:

- Simplification of the plant design to the maximum amount admissible to achieve economic competitiveness and clear demonstration of a robust safety system architecture
- Development of simplified handling procedures for subassemblies, in-vessel components etc. to ease core surveillance, repair strategies and in-service inspection methodologies.
- Consider the options to use conventional fuels, advanced fuel and fuels containing minor actinides from the very beginning of the concept development, evaluate the respective consequences on safety, radio-protection means etc. and last not least the impact on cost
- Strengthening of the prevention measures to the largest amount reasonably feasible.
- Provide design measures to cope with consequences of unprotected accidents leading to large-scale core degradation within the limits of the plant.
- Specification of so-called “practically eliminated single events” or “practically eliminated event sequences” according to the definition of the generation-IV Risk & Safety Working Group
- Subassembly, core and primary system design options should provide the relatively best conditions for realisation of the concept of an as early as possible core material relocation concept to be considered in case of core disruptive accidents.
- Design solutions need to be established which allow demonstration of the long-term in-place cooling ability of partially destructed or relocated core material. This implies demonstration of

a long term availability of systems for removal of decay heat even in case of the occurrence of significant core degradation accidents i.e. including survival to non negligible mechanical loads.

Such proposal has to be developed and detailed to allow defining applicable requirements for the design and the assessment of the innovative options.

2) Specification of reference solutions selected for decision processes on advantages and disadvantages of new evolutionary as well as visionary design solutions

- It is agreed upon that, where applicable, solutions provided by the EFR plant design will serve as a reference point for decisions about advantages and/or disadvantages of new design options.
- In case of basically different approaches than envisaged in the EFR design, other design options as the ones followed in the JSFR project or in the BN 800 project should serve for the purpose of comparison.

3) Selection of priority items on the time axis to be taken as reference for structuring the work programme – important issues for the next two to three years

- Pool-to-loop-type design assessment in view of the economic targets and the potential to realise new innovative design proposals, e.g. the elimination of the intermediate heat transfer circuit, other kinds of innovations as the ones related to the diversity and redundancy of reactor shut-down, to the decay heat removal, to the ISI & R options, to the modularity of the component design, to potential limitations of construction time and other aspects etc..
- Pool-to-loop-type design assessment in view of the safety objectives set for the whole design basis domain (former design basis + design extension, i.e. including severe accidents), e.g. establishment of an optimised set of passively activated and actively initiated prevention and mitigation measures to prevent abnormal situations and limit the consequences of incidents and accidents within the design basis.
    - Within the severe accidents domain, different options of the containment system architecture including consequences of different core catcher designs need to be considered for the comparison of the Loop- and Pool- type design.
    - Defence-in-depth considerations related to requested mitigation capabilities of the fuel pin, the core arrangement, the reactor vessel and roof, the inner containment and the outer confinement should be developed and explored in view of their consequences for Pool- and Loop type designs early in the project time.
    - The resistance to internal and external hazards as well as physical protection concerns have also to be addressed.
- Once a recommendation for the selection between a pool- and loop-type design become matured – hopefully within two years – aspects of proliferation resistance should become of more importance in the options selection process.

4) Selection of priority items on the time axis to be taken as reference for structuring the work programme – longer-term objectives

- The characteristics of the core design, the primary system and the decay heat removal system, and generally speaking the plant architecture characteristics, need to be specified early within the project but only with the objective to specify upper and lower limit values which serve for the purpose of defining an appropriate interface to the other plant design activities.

- Questions of detailed specific optimisation of the core design are seen as a long-term activity which should not be taken as basis for a decision point of the overall system and plant characteristics within the next three to five years. The same holds for the detailed selection of core materials as fuel, fuel composition, clad material, structure materials etc. These items are seen as long term research topics i.e. five to ten years from now where short term solutions i.e. those for the next three to five years should be taken on basis of the available information.

5) Listing of design options identified as potentially supportive and necessary to meet generation-IV objectives but which need more continuous basic qualification and integral demonstration of its feasibility prior to realisation

- It is felt that all proposed options intending to use either alternatively or additionally new fluids as heat transfer media belong to this category which needs integral demonstration of its feasibility prior to realisation. (New fluids in the sense that there is hardly experience available from reactor design and/or operation in a reactor environment.)
- In addition it appears that design proposals aiming at the elimination of the intermediate heat transfer circuit should be allocated to this category of research topics.

6) Guaranteeing the complementarity with current or foreseen programmes at the international level, e.g. the generation IV – SFR activity, in order to represent a valuable and recognised contribution to the international effort

The EISOFAR road map looks for exhaustiveness in terms of requirements and needs' identification. The set of identified/suggested R&D is also exhaustive. The LIP-ESFR intended to be performed under the aegis of the Euratom FP7 need to select the themes which have to be addressed by the European effort which amplitude remain limited due to budget constrains. Several boundary conditions, both strategic and technical, have to be considered in doing the selection.

The strategic conditions are the following:

- The implementation of the road map and the selection of priority themes have to guarantee the complementarity with the activities which are realised in different contexts: international programmes (e.g. the work of the generation IV SFR), national programmes and the other projects – current or foreseen – within the framework of the Euratom framework programmes (6th and 7th).
- In spite of a will to contribute to the generation IV SFR programme, it is not indispensable to make all the LIP-ESFR activities corresponding to the priorities set for the generation IV SFR. Some among the requirements identified in EISOFAR are specifically European (e.g. the heterogeneous way for the management of the minor actinides) and they can deserve a separate treatment. A degree of freedom has so to be kept in selection the LIP-ESFR content.
- Besides the national activities which feed the generation IV-SFR project (e.g. that of France & of the Commission), the result of the LIP-ESFR will represent the contribution to the generation IV SFR of the EU member states, under the aegis of the European Commission.
- The intended work and the network so organised have to allow maintaining the role of leadership of Europe in the Sodium technology by creating the bases, for example by means of educational specific activities and training, to support the revival of nuclear based on the sodium-cooled fast neutrons technology. The project has to be the occasion for the participating organisations and their young engineers to get acquainted with the sodium technology and the neutron physics peculiarities of fast reactor systems. It has to contribute to favour the transfer of knowledge towards the new generations.

Among the technical criteria for the selection, the list of which remains to be completed, two themes seem to be essential:

- To orient the preliminary work on the innovative solutions for the long term which simplify the management of the problem of intellectual property rights (IPR).
- To concentrate on the broadening of the basic research, which is applicable to the principally available technologies of core surveillance and control, in-service inspection and repair and of the optimisation of pool- and loop- type design concepts and to basic improvements of methods and to the refinement of the respective safety system architectures, rather than to efforts of R&D the vocation of which would be limited to niche solutions.

VIII. REFERENCES

1) Generation IV technology road map – October 2002

2) The Sustainable Nuclear Energy Technology Platform, A vision report – September 2007

3) EISOFAR Final report on system integration, design and assessment
Deliverable D7

4) EISOFAR Final report on fuel cycle requirements for ESFR deployment
Deliverable D10

5) EISOFAR Final report on component design & BOP
Deliverable D13

APPENDIX 1 – RELEVANCE TO THE OBJECTIVES OF THE SPECIFIC PROGRAMME AND/OR THEMATIC PRIORITY

Nuclear energy has the potential to provide Europe with a secure and sustainable electricity supply at a competitive price and to make a significant contribution to the reduction of greenhouse gas emissions. Today's thermal nuclear reactors have reached a high stage of development and are able, economically, to make a significant contribution to the world energy supply. However, essential elements of a programme for the long-term energy supply are the efficient utilisation of the natural uranium resource for the energy production and the optimised management of the waste material from the fuel cycle; these two elements are the particular characteristics of critical fast spectra.

This EISOFAR project, which answers the topic NUCHORIZ-2003-3.5.1 (Specific Support Actions), is directed towards the specific topics requested in the European Commission call "*To assess the critical scientific issues and the technical feasibility of fourth-generation reactor systems and fuel cycles*". Implicitly, several objectives are pursued.

a) Within the context of management of radioactive waste, the EISOFAR SSA is an essential step to prepare the exploration of technical, economic and societal potential of nuclear energy generation through sodium-cooled technology that will make better use of fissile material and will generate less waste. The requirements will be defined considering the scope and the objectives considered within *NUWASTE-2005/6-3.2.2.1-1 (Nuclear Waste Transmutation in critical reactors)*:

- *Feasibility of plutonium and minor actinide (MA) recycling.*
- *Consequences of incorporating MA and on their safety and operation.*
- *The impact of such an incineration on waste minimisation and management and on the entire fuel cycle.*
- *The economical feasibility of using critical reactors for nuclear waste transmutation.*

b) As far as the development and the deployment of fast reactor technology with potential for minor actinide transmutation is addressed, the EISOFAR SSA will also help defining the strategic road map asked by the *NUWASTE-2005/6-3.2.2.1-3 (A strategic road map for unified research in the EU with a view to establishing a true European Research Area in partitioning and transmutation*).

c) The action is obviously coherent with the objectives pursued by the "*Activities in the field of Nuclear Technologies and Safety*". Through this action, and the future activities, the goal is to ensure that European capability is maintained at a high level within the domain of "*Advanced Innovative Sodium-cooled Reactor Systems"* coherently with the scope and objectives defined by the *NUCTECH-2005/6-3.4.1.1-1*. The basic idea being the definition of requirements, approaches and strategies for an acceptable ESFR as well as the domains of feasibility, the action will contribute to define the needed *potential of innovative concepts* and to identify the guidelines to develop *improved and safer processes in the field of nuclear energy*.

This EISOFAR SSA could complement the current Euratom participation to the generation-IV SFR project, and will contribute to better define the future participation through the FP7. As indicated within the previous section, if agreed by Euratom, its results are being integrated in the generation-IV SFR R&D programme through the appropriate project management boards (PMBs). In return, the participation to the generation-IV SFR PMBs should provide significant added value to the EISOFAR SSA through feedback from the other generation-IV members' contributions.

The related FP6 and EC-ISTC projects

Complementary benefits are expected from the contacts with the related FP6 and EC-ISTC projects in terms of the whole Euratom programme coherency.

APPENDIX 2 – PROJECT MANAGEMENT AND EXPLOITATION/DISSEMINATION PLANS

Project management

During its one-year duration (2006-2007), several parallel activities were implemented within the different work packages to achieve the SSA's objectives:

– Applicable European strategy(s) will be derived coherently with the available European guidelines and results of the *coordination action* project SNF-TP.

– Expert groups will be implemented to review available and commonly agreed requirements, approaches and strategies on sustainability, safety, PR&PP, environment and economy and to explore options for improvements; Workshops will be organised – as needed - to help defining these innovative requirements, approaches and strategies. Insights and criteria for the assessment will be derived from generation-IV goals and from the generation-IV crosscutting methodology groups (Economy, Risk & safety, PR&PP) as well as from the IAEA/INPRO deliverables; this will allow guaranteeing the pertinence of the results.

– Working groups will collect and review preliminary studies, analyses, benchmarking activities and mapping exercises which will allow identifying the new feasibility domains where the objectives are met; innovative options will be suggested to fit with the identified domains; advantage should be taken from relevant research conducted elsewhere (now and in the past, in the EU and abroad). Insights should be drawn from previous SFR research programmes and should be discussed and documented. Best-practice guidelines and tools will be implicitly implemented using the expertise of the work package coordinators.

– A specific management activity will guarantee the co-ordination of the action's technical activities in order to achieve the preparation of a preliminary road map for the ESFR; it will provide the needed information and communication. Strong contacts have to be implemented with related FP6 projects, with the education and training activities of FP6 as well as with generation IV, IAEA/INPRO, EC/ISTC and, as far as feasible, with other related RTD programmes; these interactions have to be organised, e.g. through common workshops; etc.. Feedbacks from these contacts will be reflected within the appropriate deliverables.

The organisation of ad-hoc technical exchanges (e.g. specialist workshops) was launched, as needed, by the different WPs responsible.

The main goal being both the innovative requirements definition and the rough identification of feasibility domains and innovative technology options able to allow the future ESFR concept(s) meeting the above mentioned requirements, the EISOFAR SSA adopted, as already indicated, a structure which is organised in three main technical work packages (WPs)[4]:

– System integration, design and assessment;

– Fuel with minor actinides;

– Component design and balance of plant.

Each WP was asked to provide insights for the main themes: requirements, feasibility domains and innovative options. The needed R&D was identified.

A coordination WP managed the selection of the SSA's strategy, the definition of the detailed technical objectives and scope, and the selection of the suggested innovative requirements. With the help of the WP responsibles, it assessed the pertinence and the coherence of the selected feasibility domains and the realism of the suggested technology options. Finally, it assured the whole coherency of the SSA, provided the assessment vis-à-vis the generation-IV goals, had the charge for the road map

[4] It is worth noting that the suggested structure is analogous to the one implemented for the generation-IV SFR project. This would help organising the exchanges if needed/decided.

preparation and managed the preparation of future activities. A specific activity was devoted to disseminate the results to the EC partners.

A steering committee reviewed the whole work and validated the result. It was responsible for delivering the road map.

A consultancy committee with members from all the partners brought the single organisations' views. It helped ensuring the acceptability at European level of the road map.

Figure A2 resumes the full organisation.

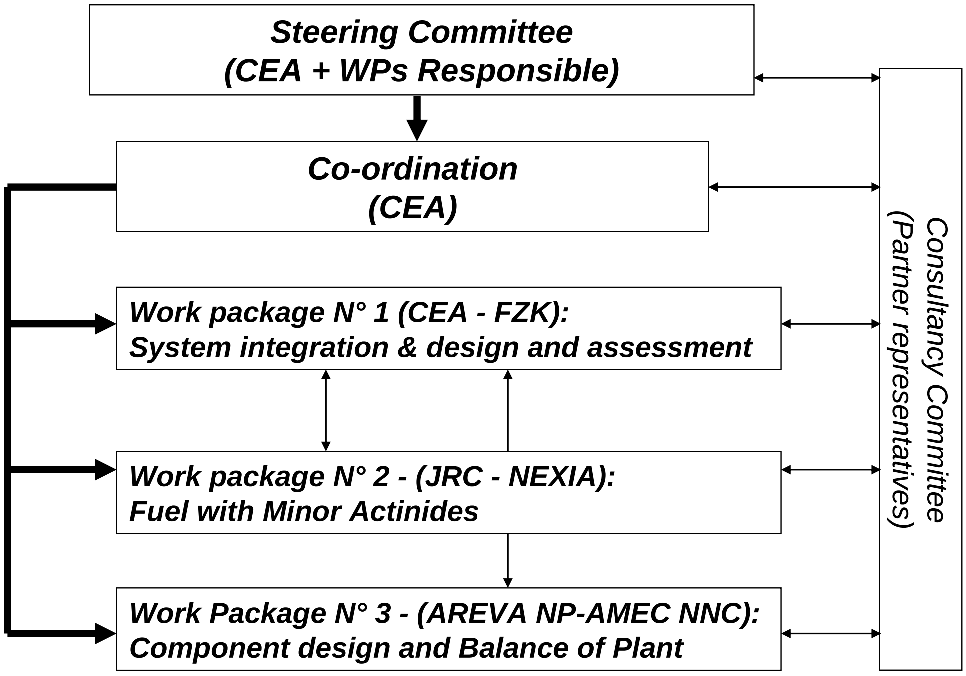

Figure A.2 – EISOFAR full management structure

APPENDIX 3 – PARTICIPANTS LIST AND CONSORTIUM DESCRIPTION

Participant role		Participant N°	Participant name	Participant short name	Country
Senior partner	Junior partner				
CO		1	Commissariat à l'énergie atomique	CEA	France
	CR	2	Cesi Ricerca	CESI	Italy
	CR	*3*	*Cranfield University*	*Withdrawn*	
	CR	4	Empresarios Agrupados	EA	Spain
	CR	5	Électricité de France	EDF	France
	CR	6	Energovyzkum	EVM	Czech Rep.
CR		7	AREVA NP	AREVA NP	France
CR		8	Forschugszentrum Karlsruhe	FZK	Germany
CR		9	Joint Research Centre	JRC-ITU	EU
	x			JRC-IPSC	EU
	x			JRC-IE	EU
	CR	10	Nuclear Research and Consultancy Group	NRG	Netherlands
	CR	11	Nuclear Research Institute Rez plc	NRI	Czech Rep.
CR		12	NEXIA Solutions	NEXIA	United Kingdom
CR		13	AMEC NNC	NNC	United Kingdom
	CR	14	ENEA	ENEA	Italy
	CR	15	Paul Scherrer Institute	PSI	Switzerland
	CR	16	ENDESA Generation S.A.	ENDESA	Spain
	CR	17	University of Karlsruhe	Uni-Karlsruhe	Germany
	CR	18	Università degli Studi di Roma "La Sapienza", DINCE	Uni-Rome	Italy

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Consortium description

The EISOFAR SSA represented a unique opportunity to bring together countries experienced in sodium technology. Some of these countries never stopped working on this technology, designing or operating plants. Others want to renew their competences engaging young engineers which will be formed to the whole nuclear system design.

The broad view brought simultaneously by experienced people as well as by young engineers is a tremendous asset to meet the EISOFAR SSA goal for the definition of the requirements for the fourth-generation sodium-cooled systems that must meet stakeholders' expectations, and for exploring innovative ways to answer these requirements.

The success of the EISOFAR SSA required the implementation of a dialogue between R&D organisations and industry. Universities were integrated to make the link with the students that are interested by the renewal of nuclear technology. Moreover, it seemed essential to bring together organisations with national and international influences; this guaranteed the SSA's credibility and allowed mobilising interest in support of the ESFR development.

The important areas of expertises in SFR technology that the partners have to bring to the projects are:

- core design and neutronic performance analysis;
- reactor and balance of plant design;
- fuel behaviour and performance analysis, fuel manufacturing and fabrication;
- thermo-hydraulics;
- risk and safety analysis and licensing;
- economic and PR&PP assessments.

All the above requirements are fully satisfied by the group of 17 partners consisting[5] of 9 partners from R&D organisations, 4 partners from industry, 2 utilities, and 2 universities.

On the other side, especially for the requirements definition that is the key objective for the EISOFAR SSA, it appeared unlikely that all the interested candidates can contribute to the same level of expertise. This is why the notion of senior and junior partners was suggested for this EISOFAR SSA: senior partners taking the lead with regard to specific tasks and the junior partners contributing mainly in the final phase of discussion of the final product.

As indicated the EISOFAR SSA was organised in three main technical work packages (WPs). A specific management activity guaranteed the co-ordination of the action's technical activities and provided the needed information and communication.

The table below indicates the share of the organisational responsibility for each of these WP.

<table>
<tr><th>EISOFAR Specific Support Action</th><th colspan="2">Lead organisation(s)</th></tr>
<tr><td>EISOFAR coordination</td><td colspan="2">CEA</td></tr>
<tr><td>• System integration, design and assessment</td><td>CEA</td><td>FZK</td></tr>
<tr><td>• Fuel with minor actinides</td><td>JRC-ITU</td><td>NEXIA</td></tr>
<tr><td>• Component design and balance of plant</td><td>AREVA NP</td><td>AMEC-NNC</td></tr>
</table>

[5] It is worth noting that each partner is experienced in performing complex multi-partner projects on a research and industrial level, has already been involved in EC-funded projects as coordinators or partners, and is acquainted with the funding and reporting regulation.

APPENDIX 4 – SAFETY APPROACH FOR THE DESIGN AND ASSESSMENT OF FUTURE SFRS

1. Context, objective and adopted principles

Deliberations on safety guidelines applicable to fourth-generation systems are conducted at both international and national levels, respectively. The EISOFAR project partners from construction companies, utilities, universities and R&D organisations had the opportunity to succinctly discuss these guidelines with the objective to follow them in the development of the ESFR project.

At technical level, the design of the fourth-generation ESFR should include major innovations when compared with the current reactor generation. A suitable safety approach must be chosen for these innovations, ensuring that the design process makes allowance for new safety requirements from the earliest stages of the concept development. Work on harmonisation of views within Europe and abroad aims at preparing a joint approach applicable to the ESFR and also ensuring that R&D work is concentrated on the most relevant issues and optimised in its approach. In addition, this harmonization should assist the dialog with safety authorities.

The safety approach, which in principle has been endorsed by the EISOFAR partners, is based mainly on the "defence-in-depth" concept. It aims at preventing abnormal situations but also includes reasonable (in the ALARP sense) design measures to minimise their consequences and it accepts a reduced and limited need for countermeasures outside the site in the extremely rare event of a severe accident. The deterministic application of the "defence-in-depth" approach is complemented by inputs from probabilistic studies (PSAs) but, when applied to innovative reactor concepts, the contribution from the latter remain affected by large uncertainties for the available statistical data bases are quite poor.

To supplement the requirements for establishing basic safety functions, it is proposed that the design of the ESFR takes into account a mixture of conventional and innovative aspects concerning protection of the environment and operational staff such as control of chemical reactions, control of dangerous products containments, safety and radiological protection of personnel and minimisation of doses due to effluents and waste from operation and dismantling.

2. Safety objectives and principles

Concerning the safety objectives it is recognised that those applicable to the new generation of European LWR (namely the EPR) are already very ambitious and guarantee a very high level of protection of persons and of the environment. An additional and prescriptive reduction of the risk level already achieved for the EPR, especially in terms of probability, is not justified and could even be counterproductive in the current state of knowledge. This is why it is proposed to adopt the same quantitative safety objectives if reasonably applicable to a fast-reactor system.

The safety level was targeted and achieved for the EPR by, among other things, extending the design basis in comparison to the previous reactor generation. One specific aspect was to take mitigation of consequences of severe accidents into account at the design stage.

Another contributing factor was the structured and pragmatic use of the "practical elimination" principle. It was applied – on the basis of a supporting robust demonstration of safety features of the plant design and making use of all the available tools – to degraded situations for which attenuation of consequences is not reasonably feasible at the technical level.

2.1. Defence in depth

Defence in depth is recognised by the EISOFAR partners as the best approach to achieve the safety objectives set for a nuclear facility. It aims to compensate for materials or human failure by implementing, at various levels, provisions such as a series of barriers to prevent or control any accidental release of radioactive products into the environment. It guarantees satisfactory control of basic safety functions, with adequate margins for minimising risks relating to equipment failure and human error, by taking into account uncertainties associated with assessment of these failures and errors. This concept includes monitoring and protection of the barriers by appropriate provisions and additional measures to protect the public and the environment if these barriers lose some of their effectiveness. Defence in depth is based on an essentially deterministic approach, but probabilistic studies can be used to identify initiating events and anticipated sequences, to ensure that the processing of scenarios includes uncertainties inherent in the design and operation of the system and to quantify the uncertainties in terms of frequency and consequences in relation to the studied scenarios.

This approach involves (i) applying a set of principles resulting in deterministic criteria allowing the management of the dominating phenomena and their uncertainties and (ii) organising and implementing a series of lines of protection against anticipated occurrences and their consequences. The principles applied include:

- The exhaustive coverage of initiating events,
- The ability to prevent accidents and, if necessary, the necessity of keeping their consequences as low as reasonably achievable and under all circumstances to demonstrate that they do not violate safety criteria,
- Consideration of uncertainties relating to the performance levels of provisions (equipment, procedures implementation, intrinsic characteristics),
- Permanent availability of functional or material redundancies aiming to prevent unacceptable releases of radioactive materials.

2.2. Main requirements for safety demonstration

As indicated, the EISOFAR partners consider that safety requirements additional to those of the EPR could be defined and included in the design of fourth-generation systems insofar as they provide both a real and demonstrable benefit and especially a greater degree of assurance in the safety demonstration and therefore in its robustness. The notion of “robust” demonstration rests on the capacity of the designer to demonstrate:

- The detailed knowledge of the phenomena (events, situations) considered for the design.
- The adequate treatment of these events and situations, through technical solutions, bringing the confidence in the selected options.

In particular this is based on:

- The mastery of the events and situations and their associated uncertainties and the design measures to provide sufficient margins in relation to limit values.
- The minimisation of the impact of the human factor.

An essential condition for the “robustness” is the level of experimental and theoretical qualification of the proposed solution and the recognisance of the whole approach (methods, tools and experimental data base) within the international context.

3. Basic safety options

To achieve the safety objectives, the design and assessment approach developed for the technical options must be based on several notions considered to be essential for its implementation. To justify the robustness of the demonstration, EISOFAR partners propose to adopt the notion of "safety architecture" through which all the provisions which participates to the safety mission will be identified and considered.

For the assessment, the contributions deduced from the experimental data base including operation experiences and the contributions of tools such as PSAs and other characteristics as the type of systems implemented (active or passive) to justify the robustness of the demonstration are also considered, leading to proposals for R&D actions concerning methods, tools and experimental programmes

4. Application to the ESFR

The main safety themes for which a progress initiative is planned are identified on the basis of feedback acquired from design, operation, and safety analysis of the Creys-Malville power plant and the projects following it (SPX2 and EFR). Innovative safety options are developed and proposed on this basis.

The R&D actions to be undertaken are consistent with this approach and the associated options.

4.1. ESFR safety objectives

The recommended approach for the SFR combines a large variety of detailed improvements of plant characteristics ranging from new heat transfer circuits up to the use of new measurement techniques in the domain of core and plant surveillance and control systems. However, one very basic advancement in the safety approach concerns the question of severe accident handling which will become a priority theme as this will have a major impact on the reactor design.

❖ *Consideration of situations with significant core degradation*

The group of severe accidents to be considered could include plant states with a significant core degradation during which the risks inherent in the concept become apparent[6]; the amplitude of the core degradation remain to be defined by the designers.

For the fourth level of the defence-in-depth concept, it is intended to consider certain sequences leading to significant core degradation so that their consequences can be attenuated in the SFR design. Reactor containment and the associated provisions will therefore be designed to cope with these situations.

❖ *Prevention of generalised core-meltdown situations*

Despite analogous quantitative objectives compared to the EPR and the previous EFR, in the interests of progress, an additional effort to improve prevention has to be integrated consistently with the objec-

[6] For sodium-cooled reactors this concerns primarily:

- Risks related to reactivity insertion potentials due to core compaction and/or the modification of material locations in the core (effects of sodium voiding or structure material relocations)
- Risks related to corium-cooling failure potentially violating the containment integrity
- The risk of loss of containment integrity for radio-elements released during core meltdown.

tive of improving the robustness of the demonstration. Envelope situations will be considered regardless of the plausible expected frequency. If necessary this will lead to installing provisions to attenuate the consequences, which in particular will ensure that these situations do not degenerate into generalised core meltdown.

With regard to internal or external hazards, which also have the potential to initiate generalised core meltdown, the aim will be to improve prevention of the potentially resulting accidental sequences. The corresponding objectives in terms of severity of the hazards considered and the methodology for taking them into account in the dimensioning will be defined in detail later.

❖ *Mitigation of the consequences of situations with significant core degradation*

The major improvement to be made over earlier sodium-cooled fast reactors is to set up provisions to attenuate the consequences of certain situations of significant core degradation and to provide a robust demonstration of their efficiency.

This will require the sequences potentially resulting in core degradation to be identified as exhaustively as possible. After this, the aim will be to set up provisions allowing the consequences of these situations to be controlled. For the concerned situations, the specific aim will be to limit a possible release of mechanical energy resulting from a reactivity insertion or interaction between the sodium and molten fuel.

The containment structures and the specific systems providing safety functions during the selected situations with significant core degradation will be designed to withstand the loads induced by these situations.

❖ *Radiological release resulting from the considered situations with significant core degradation*

For the considered situation with significant core degradation, the objective targeted for the SFR will be at least equivalent to that of the EPR for which in these situations *maximum conceivable releases would necessitate only very limited protective measures in area and time for the public*. However, as a guideline for SFR design, a more ambitious approach is proposed, complying with the one defined by GIF, i.e. avoiding the need for technical counter-measures (containment, evacuation, etc.) to protect the public.

❖ *"Practical elimination" of situations likely to lead to a loss of the containment integrity*

"Practical elimination" will be demonstrated as an additional measure for a limited number of situations for which the implementation of provisions to attenuate the consequences would not be reasonably feasible. Based on past experience a demonstration of the "practical elimination" of extreme situations such as (the list is not exhaustive): failure of the core support structure, sudden coherent void effect on core or sudden and excessive compaction of the core may be considered.

4.2. ESFR safety – organisation of the R&D

Based on the analysis developed above (§ IV.1), the R&D for SFR safety should be organised in three main parts:

- Identification of provisions for integrating feedback from sodium-cooled fast reactors, with definition of specific actions for the various safety functions and coverage of sodium-related risks
- Actions aimed at preventing the occurrence of generalised core meltdown situations with identification of provisions to make each of the sequences leading to them highly improbable

- Actions aimed at reinforcing the demonstration of the ability to manage certain degraded core situations and proving the robustness of containment in the event of characteristic types of accidents and associated phenomena.

APPENDIX 5 – EDUCATION AND TRAINING STRATEGY APPLICABLE FOR SFR TECHNOLOGY

The need of education and training in the nuclear field

The unfavourable perception in several countries of nuclear energy as an energy source to be widely exploited that has characterised the two decades starting in the mid-1980s has created a negative effect on the side of education and training in the nuclear field. Young people looking for education issues able to open perspectives of employment and/or of a personal growth in a challenging technological sector were not any more attracted by nuclear studies; nuclear operational training activities, so relevant in preceding years, started suffering for the generalised decrease of job opportunities in the nuclear sectors in several countries, specially regarding research, design, and operation of new plants.

Even if some exceptions may be recognised like in France (INSTN diploma in Nuclear Engineering), a generalised and progressive reduction of education and training services demand and offer has occurred during the same period. This is true in Europe, but applies to most industrial countries in the world.

The nuclear education and training activities that have "survived", even with a considerable reduction, have mainly dealt with LWRs, owing to the predominant relevance of NPPs in operation, moderated and cooled by light water; other technologies have faced an even worse destiny: among them are LMFBRs and fuel-cycle plants.

The lack of skilled nuclear technicians, educated in dedicated educational departments in universities and engineering schools, has been underlined already in the 1990s.

With the new attention versus nuclear energy as a viable energy source and with the decisions taken by several governments to pay more attention to the use and to the development, again, of nuclear technologies, the need of an increased offer of nuclear education and training becomes even more urgent.

Several European countries are moving towards a new involvement in nuclear electric production development programmes: this requires the availability of engineers with a sound nuclear background and knowledge, as well as the availability of technicians skilled in all the disciplines applicable in the nuclear field.

The need of education and training applicable for SFR technology

In the field of SFRs, the requirements of education and training have some special features.

The reasons include:

- The lack of a very well internationally sheared background, as in the case of LWRs much more installed in various countries, with well proven and extensively used rules, regulations, design guides, codes, standards, operational practices, simulation tools, etc. In the case of LWRs, the continuous process of development and the introduction of innovations are based on solid certainties which contribute to the confidence in the technology and make decisions easier. This lack of education and training open to students from various countries has to be underlined even if several technical committee meetings are organised by IAEA within the framework of the International Working Group on Fast Reactors, and internal education and training is provided internally in different research organisations, like CEA and JAEA

- Safety features that intrinsically are more critical with respect to other technologies (as LWRs), for the lack of a moderator, the possibility of prompt criticality, the high chemical reactivity of sodium, the opacity of liquid metals, etc. In the case of SFRs, a more important effort must be devoted to the identification of plant/component solutions that allow reaching a sufficiently high value of overall safety

- The new requirements of generation-IV NPPs that make more difficult the identification of solutions

- The necessity to extend the existing knowledge recently developed in countries like France, Japan, Russia, and the USA to some new EU countries potentially involved in SFR.

For these reasons, the development of SFRs in Europe requires that a special attention is dedicated to the provision of education and training services on issues that partially have still to be completely assessed.

The Sodium and Liquid Metal School (ESML) located in Cadarache (France) since 1975 has provided continuously education and training to nuclear and non-nuclear users of sodium. This technical school is operated in collaboration with French INSTN (National Institute for Nuclear Science and Technology). A strong collaboration has been developed between CEA and JAEA "sodium schools".

In general terms, education at the university level should include, among others, all basic disciplines on nuclear physics, reactor physics, heat and mass transfer, thermal-hydraulics related to liquid metal, strength and behaviour of materials, coolant chemistry, reactor control, plant component behaviour and design; they should include a special focus on the behaviour of sodium (more generally, of liquid metals), on material selection, on nuclear core analyses with fast neutron spectra. The history of SFRs should be analysed, to identify the areas of improvement and development. A basic knowledge on fuel cycle processes should be included.

An outcome of a European development effort for the design and construction of a ESFR, to be proficiently utilised within educational programmes should be the identification of a design process to be applied to SFRs, including the types and importance of analyses to be carried out, the rules, regulations, codes, standards (partially existing; partially new) to be applied in the design of an innovative SFR and of its components. Another very important outcome should be also the ability to identify and develop research and development activities to contribute to the design support.

From the results of new R&D activities, from the past experience of design, construction and operation of SFRs in Europe and worldwide, from the results of the ESFR development process, and, obviously from the bulk of relevant training activities of priority for sodium (i.e. ESML) and for other nuclear technologies (as LWRs), the requirements of an European training applicable and needed for SFR construction, operation and maintenance will be identified.

Road-map criteria for the preparation of education and training applicable for SFR technology

Within the R&TD activities foreseen at the European level it is strongly suggested that a list of main topics to be included in an updated programme of education and training applicable to SFRs is identified. Many of these topics will be common with other nuclear technologies, while others will be partially or totally new or updated, as mentioned above.

The effort of selection of issues to be considered within the R&TD programmes and their scheduling should foresee a simultaneous and parallel activity aimed at translating the information and know-how acquired, the methodologies developed, the design criteria, and, where feasible, the tools themselves, into educational/training packages that will be spread and disseminated for European education and training activities. The activities of preparation of the educational/training packages should proceed in parallel (and with a limited delay) with respect to the activities that should generate the information to be included into the packages (the education and training road map would follow the road map of the main R&TD activities originating the relevant information/data/tools).

Once the selected educational/training packages will be available, dedicated “euro courses” could be envisaged, but only if an absolute priority is given in allocating the budget available for the preparation of the educational/training packages themselves. The possibility of financing some PhD scholarships could be foreseen, with an involvement of skilled young persons in contributing to the preparation of educational packages. This would have the double effect of contributing to the preparation of the education/(eventually) training packages and of helping the professional growth of the individuals selected.