Status and perspectives of Supply Chain for Fast Reactors

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Abstract. Fast reactors, selected at European level as next generation Nuclear Energy Systems, pose undeniable challenges from a technological point of view. In order to support the foreseen deployment strategy, a survey of the existing industrial Supply Chain have been thoroughly carried out in terms of its capabilities and potentialities with respect to Fast Reactors needs. The main challenges found to potentially affect the deployment strategy of Fast Reactors have been found to be related to maintaining the current Supply Chain capabilities, defining specifications of Critical Components, developing new materials and fabrication/inspection techniques, ensuring the necessary accreditation and quality. The main Critical Components of Fast Reactor concepts have characteristics and requirements that will require further investments on R&D and qualification. This will represent a stimulus for the Supply Chain and, in perspective, is considered a good market and a business opportunity for industry. Implementation of requirements for Fast Reactors into the nuclear codes and standards is still a key aspect. The nuclear industry is country-specific and different efforts aimed at international harmonization of codes and standards have not been very successful up to now. Top-level initiatives should be encouraged, as far as possible, and, at least at European level, for the ESNII concepts. A challenge for Fast Reactor development in the long term is to minimize or avoid code/country-related barriers, in order to assure the suppliers a larger, open and attractive market. The analysis also covers the capacities and technologies that the European industry will need to maintain in the medium to long terms to develop and build Fast Reactor projects. Any identified shortfall or weakness represents an opportunity for improvement, by strengthening the involvement of industry in the European sustainable nuclear program.

Key Words: Fast Reactors, Supply Chain, Critical Components.

1. Purpose and Scope

The current status of European Union (EU) industrial capacities is assessed as regards Fast Reactor technologies. The analysis identifies the challenges faced by the nuclear Supply Chain in terms of design, selection of materials, manufacturing and testing, as well as the need for research and development activities. Technical choices related to nuclear fuel are expected to also affect the contractual approaches for Gen-IV Fast Reactor NPPs

The key aspects and inherent requirements applicable to the Supply Chain in the EU regulatory framework – such as Regulations, Codes and standards, Quality requirements and certification, Technical requirements – do represent a potential challenge to the competitiveness in a global nuclear market. Gaps potentially benefitting from international harmonization, cross-cutting R&D needs and synergies, as well as long-term perspectives, are worth dedicated actions at international level.

Starting from the available information about the design of the three ESNII concepts (i.e., ALFRED, ALLEGRO, ASTRID), the Critical Components can be identified in terms of associated manufacturing, thus representing potential challenges for the Supply Chain. This will allow the verification of the current capability of EU industry to cover the complete Supply Chain of Fast Reactors goods and services, while focussing on Critical Components. A survey covering the EU localization and international opportunities will be proposed.

2. Challenges of the EU nuclear industry with respect to Fast Reactors

The strong development of the nuclear sector in some EU countries has improved their industrial capabilities and has contributed to upgrading EU technology also in other industrial sectors. Preserving this leadership requires facing some challenges, such as:

- Maintenance of EU nuclear experience.
- Maximise EU technology and economic activity.
- Promote new generations of professionals and qualified personnel and maintain existing knowledge in nuclear technologies.
- Promote availability of institutional support.
- Facilitate access to the industry to become a nuclear supplier.
- Encourage a competitive nuclear industry.
- Opportunity for EU nuclear suppliers to fill a niche in the growing low-carbon emission energy market, for both electricity and heat generation, to which Fast Reactors are expected to contribute.

On the other hand, the development of Fast Reactor technologies in other countries currently investing in demonstration projects (China, Japan, USA, Russia, India) will make the expansion of the Supply Chain for the EU's nuclear sector more and more challenging.

Moreover, the nuclear sector is traditionally characterized by reduced competitiveness, mainly due to costs related to maintaining a strong safety culture, guaranteeing strict quality requirements and undergoing a though accreditation process, which have also represented access barriers for newcomers (e.g. from conventional industry and other organizations).

Another challenge to be faced for the deployment of Fast Reactors in EU is related to the business models. Those commonly used by nuclear industry for new projects are applicable also to Fast Reactors. However, the presence of two additional actors, notably the reprocessing company and the MOX fuel manufacturer, is a specificity of this new business. The extremely large investment required for establishing a reprocessing or MOX facility will not encourage a quick multiplication of such facilities. Build-Own-Operate model seems the most favorable ownership model, since it involves the reprocessing company in the development of the business, instead of keeping it as an external supplier allowing the maximum sharing of risks.

3. EU Framework affecting fast reactors and related supply chain

Figure 1 below represents the Legislative framework for Fast Reactors in the EU, which seems reasonable to be maintained also for the future nuclear fission plants based on Gen-IV technology, such as the ALFRED, ASTRID and ALLEGRO. While the approach is flexible enough to adapt to any advanced reactor technology, the guides, requirements, codes and standards are, in some instances, not directly applicable to specificities of new technologies.

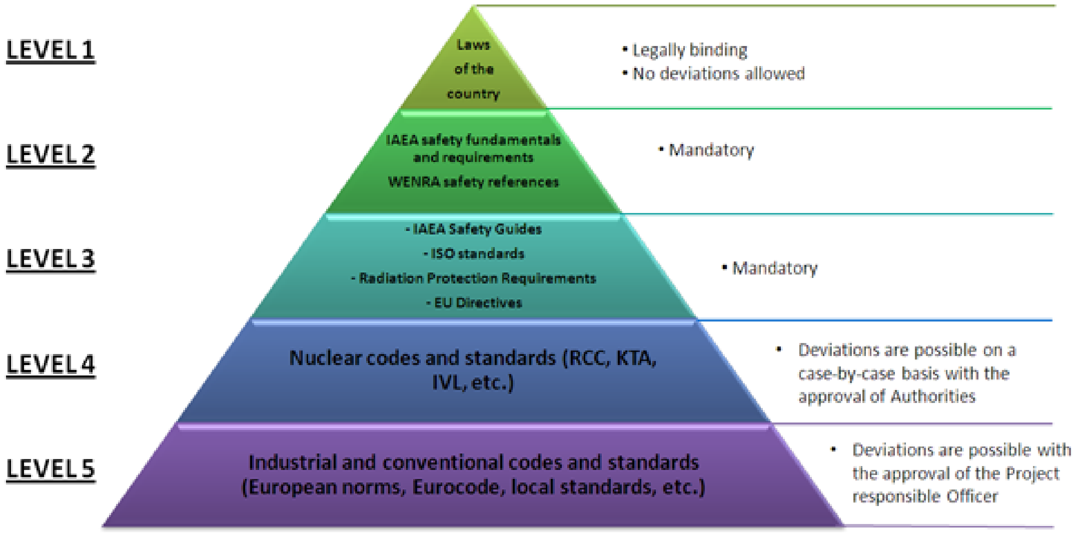


FIG. 1. Legislative framework for Fast Reactors in the EU.

All companies and organizations participating in the Supply Chain have to implement a Quality Management System that will ensure the required level of compliance with the nuclear requirements defined in the nuclear guides, regulations, codes and standards and specifications. It applies to both nuclear and non-nuclear products and services. However, the level of the quality requirements applicable to nuclear components is higher than for non-nuclear components.

The following paragraphs include the most relevant quality regulations currently applicable in the nuclear sector: ISO 9001; IAEA GSR-3; ASME NQA-1 and NSQ-100.

The QA activities and requirements that apply to the Supply Chain of current Nuclear Power Plants and other nuclear facilities will most probably also apply to the Fast Reactor Supply Chain.

The Nuclear Safety Authorities must be informed of and approve the QA System and have the right to audit the processes and works performed by any supplier of goods and services at any time. The QA System will apply to the complete Supply Chain, design, procurement, materials manufacturing, installation and construction, inspection and testing activities of the Fast Reactors.

The following are typical aspects to be defined in the product specifications that apply to all suppliers and products that conform the Supply Chain:

- Design inputs and criteria.
- Applicable design bases, codes and standards.
- Functional and technical requirements.
- Quality requirements and quality plans.
- Schedule of works and documentation.
- Materials requirements and certifications.

- Manufacturing processes and procedures.
- Inspection and test procedures and acceptance.
- Control of deviations and non-conformities, traceability and records.
- Cleaning, packing, shipping and handling requirements.
- Final dossier, including QA and as-built (as-manufactured) documentation.

The validation process that has to be undergone to become part of the nuclear Supply Chain includes Quality Audit Schedule, as part of the Quality Management System, and audits of the supplier by the Nuclear Authorities (Nuclear regulator and licensee (owner)) of the work. This includes the right to access supplier premises to verify that the product and services conform to the technical and quality requirements.

In order to assure the compliance of all nuclear Supply Chain suppliers with technical and quality requirements, specifications and QRA's, checking, verification and independent review (Third Party Inspection) are required.

The suppliers of Fast Reactor nuclear products shall provide evidence that their products will be capable of performing their specific function and of working in the specified conditions pertaining to the Fast Reactor. For that reason, qualification plans shall be developed by suppliers for their products. To develop the qualification plans the Suppliers need to know the products technical requirements and conditions in advance.

Having the Fast Reactor designs accepted and licensed by the safety authorities of different countries with minor changes and the Supply Chain components manufactured in different countries taking advantage of globalization without significant modifications would be a key asset for competitiveness of nuclear energy.

For that purpose, nuclear regulations, as well as the codes and standards used by technology providers and component manufacturers should be harmonised internationally as much as possible. Of course each nuclear facility must comply with national laws of the country where it is built, with in addition specific site conditions and requirements from the utility that will operate it. Nevertheless, local practices in most cases refer to general requirements concerning safety regulations, as well as codes and standards.

At the level of nuclear safety, design bases and criteria, there has always been an effort for international harmonization, led by international organizations like the IAEA.

However, this effort has not been accomplished successfully at the country level and is one of the main problems encountered in obtaining the different licenses, permits and authorizations for component delivery, resulting in longer periods and larger costs. The result is limited competitiveness since supply, manufacturing and qualification are in accordance with one design code and are country-specific. It is very difficult for suppliers to export these country-specific components to other countries and even within EU countries this situation implies barriers to an open market.

4. Supply Chain and Critical Components

Although there are some NPPs being constructed in the EU, the market is very reduced for large and Critical Components and there are not expected new comers in the short term. It is expected that these selected suppliers will keep and maintain their capabilities to supply the Fast Reactor equipment and components.

However, there are many important nuclear components (pumps, heat exchangers, electric motors, transformers, etc.) and other standard components (valves, filters, electric cabins, instruments, etc.) that are supplied and manufactured by the current industry (for both the nuclear and conventional areas).

Two major assumptions have been combined in this approach to developing the Supply Chain:

- EU as a whole is considered as the “country” of origin of the technology. The Reactor Designer and the Main Contractor (Vendor) will be a consolidated enterprise belonging to the European industry. The licensing process, regulations, codes and standards, site and local requirements, EU supplier participation, etc. will fully comply with EU legislation and administration network.
- The analysis of the Supply Chain should focus only on the critical nuclear components and on those complex or sophisticated ones that require higher level technologies, supported by previous research, and are subject to technology disclosure restrictions and patent rights.

Not all the Critical Components of the selected Fast Reactor (ALFRED, ASTRID, ALLEGRO) have been currently developed to a stage allowing to perform an assessment about the related Supply Chain. In any case, critical and complex components of the ESNII Fast Reactor concepts can be identified, highlighting the main characteristics and requirements that render their design, materials, manufacture and constructability a potential challenge for the industry.

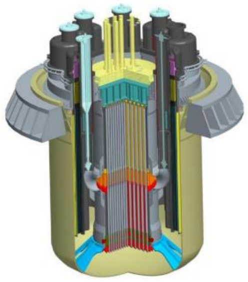
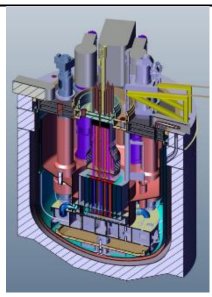
In accordance with the above-indicated criteria, Critical Components may be categorised in the following groups, in order to systematically approach the Supply Chain analysis:

- Nuclear fuel
- Fuel (sub-) assemblies and racks
- Fuel handling control rods and mechanisms
- Reactor core materials and internals
- Reactor pressure vessel(s)
- Other safety vessel(s)
- Reactor coolants (Na, Pb, He)
- Primary pumps
- Primary heat exchangers
- Coolant and secondary loop heat exchangers
- Primary piping and special fittings
- Primary and special valves
- Primary collectors and ducts
- Severe accident mitigation devices and core catcher
- Containment and features (liners, airlocks and penetrations)
- Primary coolant special components (filters, seals, heaters, etc.)

- Refuelling equipment
- Radwaste systems
- Instrumentation and monitoring for systems and components
- Primary coolant instrumentation
- Inspection tools condition monitoring and repair techniques
- Technological services (engineering, inspection, simulation)
- Specific nuclear cogeneration components (to be defined)
- Inspection tools condition monitoring and repair techniques (to be defined).

Each category of main equipment defined above may be subdivided into components, subcomponents, parts, items, etc. Clearly, most of the Critical Components strictly depend on the corresponding fast reactor technology. Based on the conceptual design currently available and qualitatively shown in TABLE I, the main parameters for the Critical Components of the ESNII concepts were collected, through the contribution of the main organizations in charge of the design.

TABLE I: Fast Reactors ALFRED, ASTRID and ALLEGRO.

ALFRED	**ALLEGRO**	**ASTRID**
		

The definition of the technical requirements for the components of the next generation Fast Reactors is critical for the identification of the prospective suppliers and their later acceptance to become part of the Supply Chain. The first step is to identify those Fast Reactor components that have specific characteristics and are not currently available in the market.

There are three main aspects that the industry needs to know before making a decision to supply a specific component:

- Component Data sheets.
- Safety classification of the component and applicable codes and standards.
- Component Technical Specifications.

Two technical documents are the basis for the requirements of LWR reactors, and are the reference of the industry and participants in NPP projects: URD (USA) and EUR (EU).

There are some requirements to be defined by the Reactor Designer and be transmitted to the prospective component suppliers.

5. EU Localization of Supply Chain

The NEI methodology has been used in this document to describe the Supply Chain of Fast Reactors.

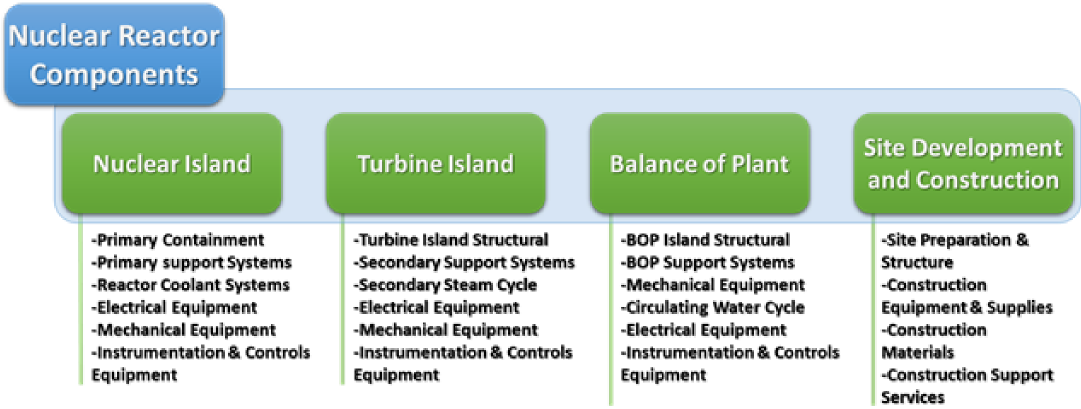


FIG. 2. Subsections of the PWR Supply Chain.

The following potential EU suppliers are listed in TABLE II, on a component basis, considering both

- components that belong to PWR and may also form part of the Fast Reactor Supply Chain, but do not have specific requirements, and are thus considered conventional or commercial grade,
- components that are new for Fast Reactors and need unique development of new technologies and research work by suppliers or technical providers.

TABLE II: Potential EU suppliers of nuclear components for Fast Reactors.

Component	Potential supplier	Notes
Nuclear fuel	*AREVA, BIL (BNFL) CEA, ENUSA*	Complementary studies have to be done for new fuel licensing and manufacturing.
Fuel subassemblies and racks	*AREVA, NUKEM, ENUSA, NIS GmbH, FNSha, GRADEL*	It will be necessary to develop new designs to face new conditions considered for the new types of fuel and new coolant characteristics
Fuel handling, control rods and mechanisms	*AREVA, NUKEM, ENUSA, NIS GmbH, FNSha, GRADEL*	New designs shall be developed and adapted to new fuels. Already existing suppliers have the technology to develop these components.
Reactor core and internals	*AREVA, ENSA, SKODA, ANSALDO*	Materials to support new conditions (coolants, corrosion, erosion, etc.) shall be developed. Manufacturing techniques shall be implemented.
Reactor pressure vessel(s)	*AREVA, ENSA, SKODA*	Experience for large CWR and ITER vessel technology shall be applied.

Other reactor safety vessels	*AREVA, ENSA, SKODA, ANSALDO, Sheefield Forgemasters, Davy Markham*	It will be necessary to develop vessels and internals to face new conditions and new coolants.
Reactor coolants (Na, Pb, He)	*ALTEC, Metaux Speciaux*	Na, Pb and He are already available in the industry. He is not produced in large quantities. There is a new field for suppliers with experience in handling and treatment systems of these coolants.
Primary pumps	*Flowserve, Andritz, Weir, AREVA, Sulzer*	Pump design shall be implemented for new coolants. Current experience from large CSP (molten salt) plants is available.
Primary heat exchangers	*AREVA, Vallourec, ENSA, Balcke-Dürr, STF*	
Coolant and Secondary loop Heat Exchangers	*AREVA, ENSA*	Strict requirements for leak tightness and compact design.
Primary piping and special fittings	*ENSA, Outokumpu, Sheffield Forgemasters*	It will be necessary to develop new classes of pipe to face new conditions coolants.
Primary and special valves	*RINGO, KSB, Velan, Flowserve*	It will be necessary to develop new valves to face new conditions and new coolants.
Primary collector and ducts	*Vost Alpine, ENSA*	High temperature ducts with double pipe configuration thermal insulation and leak requirements need to be developed.
Severe accident mitigation devices and Core catcher	*AREVA, ANSALDO*	Complementary studies have to be performed with regard to the loss of coolant in severe accident conditions.
Containment and features (liner, airlocks and penetrations)	*AREVA, NIS/NUYEM, ANSALDO, ENSA, SKODA, SCK•CEN*	The technology for the current containment and related equipment (lines, penetrations, airlocks) shall be adapted to the fast reactor characteristics.
Primary coolant special components (filters, seals, heaters, etc.)	*AREVA, ENSA*	Complementary studies have to be performed to evaluate the impact of the new fast reactor conditions in order to adapt the current equipment.
Refueling equipment	*AREVA, ENSA, ANSALDO, SCK•CEN, SKODA*	Currently existing refueling equipment shall be adapted to the characteristics of new fuels or reactor configurations.
Radwaste Systems	*ANSALDO, Belgatom, AREVA, GNS, NUKEM/NIS,*	It will be necessary to develop gaseous, liquid and solid radwaste treatment and storage systems considering new fuel and

	Studswik	radiation source characteristics.
Instrumentation and monitoring for systems and components	*QSA Global, RADOS GmbH, BIL*	Current radiation monitoring equipment for CWR shall be adapted to fast reactors.
Primary coolant instrumentation	*Oxford Industries, Rolls Royce, Siemens*	New instruments shall be developed to provide accurate information about the primary coolant (Na, Pb, He, etc) during normal and accident conditions.
Inspection tools condition monitoring and repair techniques	*Intercontrole, Tecnatom, INS Innovation, NUKEM*	New fast reactors shall incorporate robotic tools and service inspection instrumentation.
Technological services (engineering, inspection, simulation)	*AREVA, ANSALDO, Empresarios Agrupados, VTT, Ansys, Aegis*	Include engineering thermal and stress analysis thermohydraulics, simulation tools
Specific nuclear cogeneration components	*Intercontrole, Tecnatom, INS Innovation, NUKEM*	

6. Conclusions

The identified challenges of the EU nuclear industry with respect to Fast Reactors are mainly related to maintaining the current Supply Chain capabilities, defining specifications of Critical Components, developing new materials and fabrication/inspection techniques, ensuring the necessary accreditation and quality.

Key aspects and requirements applicable to the Supply Chain are mainly related to the implementation of requirements for Fast Reactors into the nuclear codes and standards, the extension of quality requirements and certifications. A challenge for fast reactor development in the long term is to minimize or avoid code/country-related barriers.

The main Critical Components of Fast Reactor concepts have characteristics and requirements that might represent a challenge for their design, materials, manufacture and constructability for the industry, thereby requiring further investments on R&D and qualification. This will represent a business opportunity for industry.

A wide variety of companies in the European nuclear might be able to supply most of the identified components, based on their current capabilities. Unfortunately, technical specifications for Critical Components are not readily available and further analysis will be needed.

7. Acknowledgement

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