Overview of the international cooperation and collaboration activities initiated and performed under the Technical Working Group on Fast Reactors in the last 50 years

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Abstract. The Technical Working Group on Fast Reactors (TWG-FR), the very first such international collaboration forum of the International Atomic Energy Agency (IAEA), was established in 1967 (under the name of International Working Group on Fast Reactors, IWG-FR). Since then it has been the foundation of the Agency's activities in the field of fast reactor research and technology development. For the last five decades the group of experts under the umbrella of the TWG-FR has provided advice and supported the implementation of the Agency's programme. The TWG-FR assists in defining and carrying out the Agency's activities in the field of fast reactor research and technology development, promotes the exchange of information on national and multi-national programmes, fosters new developments and experience, with the goal to identify and review problems of importance and to stimulate and facilitate cooperation, development and practical application of fast reactor and sub-critical hybrid systems technology. There have been numerous technical meetings, education and training workshops, consultants' meetings, and coordinated research projects delivering a significant number of technical documents, and nuclear energy series publications supporting member states in their pursuit of research and development in this field. With a current membership of more than 25 countries, the TWG-FR plays a significant role in addressing major issues, finding coordinated solutions to overcome technological/research barriers and effectively communicating and transferring knowledge amongst its members. A combined vision of all the members helps in overcoming challenges and increasing efficiency.
The paper discusses and highlights major past activities implemented by the TWG-FR, its major achievements, ongoing activities and future plans.

Key words: Fast reactor, Technical Working Group, TWG-FR, IAEA

1. The role of the IAEA Technical Working Group on Fast Reactors

During the past 50 years the IAEA has been serving Member States interested in fast reactor research and technology development as a focal point for information exchange and collaborative research and technology development. Since 1967, the keystone of the Agency's activities in this field is the Technical Working Group on Fast Reactors (TWG-FR, originally called the International Working Group on Fast Reactors, IWG-FR).

The TWG-FR is a group of experts from interested Member States who meet every year and provide advice and support IAEA's programme implementation, reflecting a global network of excellence and expertise in the area of advanced technologies and R&D for fast reactors and sub-critical hybrid systems (e.g. accelerator driven, and fusion/fission systems) for energy production and for utilization/transmutation of long-lived nuclides.

The TWG-FR offers the largest international forum for exchange and transfer of information in the areas of fast neutron systems. Through 50 years of functioning of the TWG-FR the IAEA has been supporting the Member States with a number of activities in the fields of

safety, research and technology development, modelling and simulation, education and training, as well as fast reactor knowledge preservation.

Currently the TWG-FR consist of twenty full members (eighteen IAEA Member States, as well as the OECD/Nuclear Energy Agency, the European Commission (EC) and eight observers including seven Member States and the Generation IV International Forum (GIF) (Table 1 and Fig.1)

TABLE I: MEMBERS OF THE IAEA TECHNICAL WORKING GROUP

ON FAST REACTORS

Full Members	
Belarus	Brazil
China	France
Germany	India
Italy	Japan
Kazakhstan	Korea, republic of
Netherlands	Russian Federation
Slovak Republic	Sweden
Switzerland	Ukraine
UK	USA
European Commission	*OECD/NEA*
Observers	
Argentina	Belgium
Czech Republic	Mexico
Romania	Spain
Sweden	*Generation-IV International Forum (GIF)*

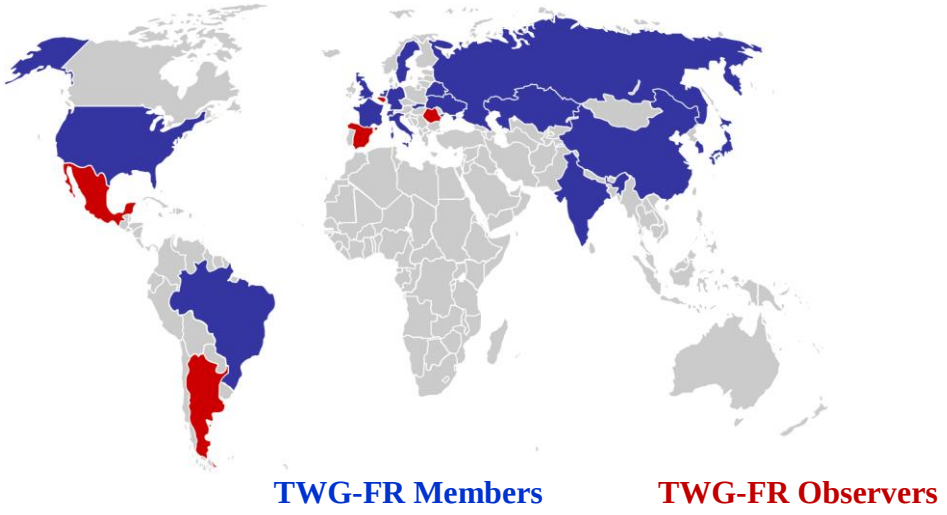

FIG. 1. TWG-FR full members and observers

The TWG-FR assists in formulating an international vision applicable to current and advanced fast reactors and to sub-critical hybrid systems for energy production and utilization/transmutation of long-lived radioactive nuclides.

The defining elements of this vision are:

- *Improved economics* - fundamental to all successful technology advances;
- *Sustainable development* - in which resource utilization and waste management strategies lead to advanced fuel cycles, including those based on the utilization of thorium;
- *Enhanced safety* - maintaining current high levels with increased design simplification, and passive systems.

Technical areas for R&D and innovation in support of GEN-IV FR development considered by the TWG-FR include:

- *Advanced structural materials*
- *Innovative fuels (including minor actinides (MA)-bearing fuels)*
- *Core performance*
- *Primary and secondary system simplification*
- *Compact heat exchangers*
- *New power conversion systems*
- *Coolant technologies and advanced instrumentation*
- *In-service inspection*
- *Safety and security*
- *Advanced simulation and modelling with higher level of precision and reduction of uncertainties*

In this framework, the TWG-FR assists in defining, prioritising and carrying out the Agency's activities in the field of nuclear power technology development for fast reactors and sub-critical hybrid systems in accordance with its statute and established priorities.

It promotes the exchange of information on national and multi-national programmes and new developments and experience, with the goal to identify and review problems of importance and to stimulate and facilitate cooperation, development and practical application of fast reactors and sub-critical hybrid systems.

Finally, the TWG-FR provides Member States with information about the current status and development trends of advanced technologies for fast neutron systems.

The members of the TWG-FR are appointed by the Deputy Director General and Head of IAEA’s Department of Nuclear Energy, following consultation with the respective national authorities or organizations, and they are recognized experts in the field of advanced technologies and R&D for fast reactors and sub-critical hybrid systems

The TWG-FR has its meetings at regular intervals but no more than once in a year. The last 49th meeting took place on 25-29 May 2015 in Obninsk, Russian Federation.

2. Scope of TWG-FR activities

The scope of the TWG-FR consideration includes:

- Design and technologies for current, evolutionary and innovative fast reactors (experimental, prototype or demonstration, and commercial size fast reactors) and sub-critical hybrid systems, including non-sodium cooled fast reactors and sub-critical hybrid systems;
- Economics, performance and safety of fast reactors and sub-critical hybrid systems;

- Advanced fuel cycles and fuel options for the utilization and transmutation of actinides and long-lived fission products, including the utilization of thorium.

Many specific technologies are addressed in detail by other projects within the IAEA and in other international organizations. The TWG-FR keeps abreast of such work to avoid unproductive overlap and engages in cooperative activities with other projects where appropriate.

The TWG-FR thus coordinates its activities with other IAEA projects, especially those of the Technical Working Group on Nuclear Fuel Cycle Options (TWG-NFCO), the International Project on Innovative Reactors and Fuel Cycle (INPRO), and the Department of Nuclear Safety, in interfacing areas, as well as with related activities of other international organizations (e.g. OECD/NEA, EC-JRC, ISTC, JINR).

3. Overview of activities initiated and supported by the TWG-FR

As was already noted, the TWG-FR offers the largest international forum for exchange and transfer of information in the areas of fast neutron systems.

Regular conferences and technical meetings on fast reactor physics, analysis and design were regularly held since the beginning of the nuclear era. Unfortunately, due to various socio-economic and political reasons, there was a long hiatus of nearly 20 years in such large international conferences dedicated to fast reactors until, in 2009, IAEA's TWG-FR rekindled the tradition of and convened on 7–11 December 2009 in Kyoto, Japan, the "International Conference on Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR09)".Since then, at four years interval, two (including this one) international conferences on fast reactors and related fuel cycles have been organised by the IAEA following the recommendation and thanks to the assistance of the TWG-FR Member States and TWG-FR members themselves.

As mentioned, the first International Conference on Fast Reactors and Related Fuel Cycles (FR09) was held in Kyoto, Japan, in 2009 and was subtitled "Challenges and Opportunities" [1]. FR09 was attended by 622 experts from twenty countries and three international organizations. A total of 304 scientific and technical contributions (150 oral presentations and 154 posters) were made to FR09. The second conference (FR13) was held in Paris, France, in 2013 with the theme "Safe Technologies and Sustainable Scenarios" [2] and was attended by some 700 experts from 27 countries and 4 international organizations representing different fields of fast reactor and related fuel cycle technologies. Currently, the third international conference is held in the Russian Federation [3]. The Russian Federation's State Atomic Energy Corporation "Rosatom" is hosting the conference in Yekaterinburg. One of the main reasons for this proposed venue is that the sodium cooled fast reactor BN-800 was connected to the grid in December 2015 at the Beloyarsk nuclear power plant complex (NPP), which is located in the vicinity of Yekaterinburg. BN-800 is the successor of the BN-600 reactor that has been in operation at the Beloyarsk NPP since 1980.

These major events for the world fast reactor community brought together at every conference six to seven hundred participants and a growing number of contributed papers and posters.

National and multi-national strategies and programmes have been widely presented and discussed at these forums, which, according to the feedback provided to the IAEA, in some cases helped in tuning national programmes and establishing international cooperation.

As mentioned, through the TWG-FR, the IAEA has been supporting the Member States with a number of activities in the fields of safety, technology development, modelling and simulation, education and training, as well as fast reactor knowledge preservation. These topics have been comprehensively covered, *inter alia*, in several status reports prepared and published by the IAEA in close cooperation with TWG-FR members.

Starting from 1985, status reports on liquid metal cooled fast breeder reactors and accelerator driven systems [1]were published [4 – 10].

Moreover, reports on national fast reactor programmes, as well as on advances and conceptual designs of fast reactors were published [11-16].

Advances in FR technologies and new concepts have been always in focus of TWG-FR. Collaborative research activities initiated by the TWG-FR have been organised by the IAEA through the mechanism of the Coordinated Research Project (CRP), which resulted in publication of many technical documents (TECDOCs) and Nuclear Energy Series (NES) reports.

For example, TECDOCs on advances in fast reactor technology [14], conceptual designs of advanced fast reactors [15], advanced NPP design options to cope with external events [16], power reactors and sub-critical blanket systems with lead and lead-bismuth as coolant and/or target material [17].

Examples of the tangible results of the TWG-FR activity include CRPs organised by the IAEA on India's Fast Breeder Test Reactor (FBTR) and Prototype Fast Breeder Reactor (PFBR), performed in cooperation and under the leadership of TWG-FR members. The importance of these CRPs in terms of information exchange and joint R&D activities should be highlighted, since PFBR design decisions were often based on FBTR analyses and benchmarks.

Special attention was given through the years to thermal hydraulics and liquid metal coolants. CRPs, organised by the IAEA following recommendations and in-kind support of the TWG-FR members resulted in publication of the TECDOCs and proceedings on theoretical and experimental studies of heavy liquid metal (HLM) thermal hydraulics [18], liquid metal coolants for FR [19], comparative assessment of thermophysical and thermohydraulic characteristics of lead, lead-bismuth and sodium coolants for FR [20], primary coolant ripe rupture event in liquid metal cooled reactors [21]. Handbook on Sodium Properties, Materials Compatibility, Thermal-hydraulics and Technologies is currently under preparation in the framework of NAPRO CRP [22].

TWG-FR responsibly paid most attention to safety aspects of fast reactors. Thus, the largest number of IAEA publications on fast reactors (about 15 including those in progress) are dedicated to safety studies performed in the framework of CRPs or by other initiatives of TWG-FR members [23-37]. The topics of these studies varied from influence of high dose irradiation on core structural and fuel materials in advanced reactors [23] to inter-comparison of liquid metal fast reactor seismic analysis [24-27], from fission and corrosion product

[1] The TWG-FR considers advanced partitioning and transmutation to be a technology, which can play an important role for the successful deployment and expansion of nuclear power on a long-term basis.

behaviour in LMFR [28] and creep-fatigue damage rules for advanced FR [29] to acoustic signal processing for the detection of sodium boiling or sodium-water reaction in LMFRs [30].

Transient and accident analysis have been performed for BN-800 type LMFR, and it was reported in [31].

In the recent years the activities in the area of fast reactor safety supported by the TWG-FR have been focused on passive fast reactor shutdown systems. The related CRP is expected to be finalised by publishing a technical report.

Moreover, summarising past experience of operation of liquid metal cooled facilities is considered to be very useful for future LMFR development. In this regard, reports on best practices for the design and operation of sodium experimental facilities and guidelines for the safe operation of sodium experimental facilities are being developed and will be published in the years to come.

The verification of analysis methods for predicting the behaviour of fast reactors under different external and internal conditions was also the topic of TWG-FR consideration, e.g. the verification of analysis methods for predicting the behaviour of seismically isolated nuclear structures have been reported in [32].

Several benchmark studies have been performed in Member States institutions and then considered by the TWG-FR. Such exercises started in 1990s by the evaluation of benchmark calculations on a fast reactor core with near zero sodium void effect [33] and then have been extended to full-scope CRP studies coordinated by the IAEA under the leadership of the TWG-FR: BN-600 MOX core benchmark analysis [34], benchmark analyses on the natural circulation test of the PHENIX end-of-life experiments [35], benchmark analyses of sodium natural convection in the upper plenum of the Monju reactor vessel [36]

Two benchmark studies have been recently concluded, and publication of technical reports is expected: benchmark analyses of an EBR-II shutdown heat removal test (a paper on it is included in the materials of FR17 conference) and analytical and experimental benchmark analysis of ADS.

The TWG-FR continues to play a key role in managing and disseminating critical knowledge on fast reactor technologies. In particular, development and promotion of databases and knowledge portals on fast reactors is strongly supported by the TWG-FR. The fast reactor database [37], catalogue of facilities in support of liquid metal-cooled fast neutron systems (LMFNS Catalogue) [38], protected FR nuclear knowledge portal (FRKP) [39] and FR entries to the advanced reactor information system (ARIS) [40] have been developed and promoted with active participation of TWG-FR members.

The TWG-FR also considers accelerator driven systems and fusion/fission systems for energy production and for utilization/transmutation of long-lived nuclides. Based on these considerations by the TWG-FR “the IAEA has given a high priority to projects on advanced partitioning processes as these processes, based on either aqueous or pyro, play an important role for the successful deployment and expansion of nuclear power on a long term basis. The objectives of these processes include reuse of separated fissile materials from spent nuclear fuels to obtain energy, enhancement of resource utilization, reduction in the disposal of toxic radionuclides and improvement of the long term performance of geological repositories. Many Member States are involved in the development of an advanced nuclear fuel cycle that could effectively incorporate actinide recycling involving advanced partitioning processes, based on either aqueous or pyro, to reduce inventories of plutonium and minor actinides.”

(Ref.2). As was already mentioned, a technical report on analytical and experimental benchmark analysis of ADS will be published.

Having extensive links with national technical communities, the TWG-FR members contributed to a number of IAEA publications on advanced reactor technology options for utilization and transmutation of actinides in spent nuclear fuel [41], use of fast reactors for actinide transmutation [42], ADS for energy generation and transmutation of nuclear waste [43-44] and safety and environmental aspects of partitioning and transmutation of actinides and fission products [45].

Last, but not least, fuels for existing and future FR are also in the focus of the TWG-FR consideration. Several publications summarised the results of coordinated research on advanced fuel for fast reactors [46-51].

4. Recommendations of the TWG-FR on priorities for new implementations

The TWG-FR at its annual meetings monitors and prioritises the fast reactor related activities. At the last meetings the TWG-FR experts recommended that future FR activities should focus on:

- *Simulation and modelling, including verification and validation of codes, in particular on neutronics, thermal-hydraulics and safety, on the basis of experimental data coming from new and existing fast reactors. The TWG-FR recognized that this topic is also very useful for training and education of young experts and the IAEA is the ideal place to carry out this activity;*
- *In service inspection and repair;*
- *Advanced technologies for fuel handling;*
- *Core monitoring;*
- *Inherent and passive safety features, both for reactivity control and decay heat removal.*

The TWG-FR developed several practical recommendations. In particular, the following recommendations helped to structure the FR activities led by the IAEA:

- The IAEA should promote the diffusion of information on the technical advantages related to the deployment of FR to the whole nuclear energy community and to the public;
- It is recommended that the IAEA supports the education of young professional, from the university education level, in the field of FR. This should be implemented in particular through the organization of regular FR schools and seminars (e.g. at ICTP Trieste);
- The TWG-FR welcomed the new initiative on the development of an innovative SFR basic principles simulator and recommends the IAEA to take action in the coming months in order to define the specifications of the SFR simulator and launch the project, in interaction with the interested MSs;
- It was recommended to organize a technical meeting on passive shutdown systems for LMFR. At that meeting two new safety-related studies should be considered, i.e.: i) unusual occurrences during LMFR operation, lessons learned and progress in reliable operation and ii) passive shutdown systems for LMFR;
- The IAEA should continue to promote knowledge preservation for fast reactors; in this context it was recommended to develop advanced tools and platforms for Fast Reactor Knowledge Portal (FRKP) (a paper on FRKP is included in the materials of the FR17 conference).

The IAEA follows advises on high, medium and low priorities defined by the TWG-FR. For example, in planning and proceeding the recent technical meetings, workshops, CRPs and preparing technical reports the IAEA followed the high priority tasks set by the TWG-FR:

- Severe accidents, in particular impact of Fukushima accident on the safety aspects of existing and planned FRs;
- Passive safety features of current and future FR;
- Safety criteria for SFR;
- Under sodium viewing for in-service inspection and repair (ISI&R);
- Risks of sodium as coolant technology;
- Modelling and simulation;
- Regular meeting in FR physics and technology;
- CRP on sodium properties and design and safe operation of experimental facilities in support of the development and deployment of SFR;
- Benchmark exercise on neutronic calculations for a mixed-oxide fuelled core of an industrial size Sodium-cooled Fast Reactor;
- CRP on source term for radioactivity release under fast reactor core disruptive accident (CDA) situations;

- **Conclusions**

Considerable R&D is being done on advanced fast reactors with enhanced safety characteristics. The TWG-FR has an important role in gathering the operational experience accumulated by countries which have been operating fast reactors and related fuel cycle facilities in recent decades.

The TWG-FR assists Member States interested in the development of FR technology in identifying gaps between current programmes and medium/long term goals and then promoting international cooperation to fill the gaps. The TWG-FR assists in defining and carrying out the Agency's activities in the field of nuclear power technology development for fast reactors, in accordance with its Statute, and ensuring that all the activities are in line with expressed needs from Member States. It promotes in-depth scientific and technical exchange of information on national and multi-national programmes and new developments and experience, with the goal to identify and review problems of importance and to stimulate and facilitate cooperation, development and practical application of fast reactors and sub-critical hybrid systems. The TWG-FR also supports the publication of IAEA technical documents on different topics of fast reactors research and technology development.

The TWG-FR coordinates its activities with other IAEA projects, TWGs and units, especially the Technical Working Group on Nuclear Fuel Cycle Options (TWG-NFCO), the Department of Nuclear Safety and Security, and the International Project on Innovative Nuclear Reactors and the Fuel Cycle INPRO. It also cooperates with other fast reactors initiatives, implemented within the framework of international programmes such as the Generation IV International Forum (GIF), the Nuclear Energy Agency (OECD/NEA), the European Sustainable Nuclear Industrial Initiative (ESNII), etc.

The IAEA TWG-FR remains the unique collaboration forum for ensuring continued progress in fast reactor technology. It also provides an umbrella for knowledge preservation, information exchange and collaborative R&D in which resources and expertise are pooled.

Cooperation on FR topics established by the IAEA with many international organisations reaffirms the key role of the TWG-FR as the focal point for information exchange and collaborative research and technology development.

Acknowledgements for these distinguished results of 50-years TWG-FR activity go to all its numerous chairmen and members and, in particular, to the IAEA Scientific Secretaries who took the leadership and organised the work of the group: Mr. Victor Arkhipov, Mr. Anatoly Rineyskiy, and Mr. Alexander Stanculescu. The recent and the active fast reactor group leaders in the IAEA are, respectively, Mr. Stefano Monti and Mr. Vladimir Kriventsev.

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