Study on the benefits of Broader Approach activities under the current agreement and the expected benefits of continued participation

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Disclaimer

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Abstract

English

This study analyses the Broader Approach agreement, an international fusion energy collaboration between the EU and Japan which began in 2007, and which in 2020 entered a 2nd phase. The Broader Approach encompasses three projects: (1) the JT-60SA, a superconducting tokamak in Japan which is planned to achieve first plasma in 2021; (2) IFMIF-EVEDA which has developed and will validate an experimental fusion neutron source (LIPAc); and, (3) IFERC, a project encompassing various design and engineering activities, including supercomputing and remote experimentation and control technologies.

This work analyses the scientific and technical achievements of the Broader Approach to date (see section 2.1), evaluates the impacts for participants and funders (see section 2.2) and assesses the governance and project management of the Broader Approach (see chapter 3). It also assesses cooperation of the Broader Approach with ITER (chapter 4) and the potential cooperation with other nations (section 5.2), and addresses future objectives (section 5.1), external communication (section 5.3) and funding arrangements (section 5.4). Looking forward, the study also assesses the medium-long term considerations for the Broader Approach and its projects (chapter 6). A set of detailed, prioritised recommendations for the future of the Broader Approach is also provided (chapter 7).

French

Cette étude analyse l'accord sur l'Approche Élargie (« Broader Approach »), une collaboration internationale sur l'énergie de fusion nucléaire entre l'UE et le Japon qui a débuté en 2007 et qui est entrée dans une deuxième phase en 2020. L'Approche Élargie englobe trois projets : (1) le JT-60SA, un tokamak supraconducteur au Japon qui produira son premier plasma en 2021 ; (2) IFMIF-EVEDA, qui a développé et validera une source expérimentale de neutrons de type fusion (LIPAc) ; et (3) IFERC, un projet englobant diverses activités de conception et d'ingénierie, y compris des technologies de calcul intensif et d'expérimentation, et de contrôle à distance.

Ce travail analyse les réalisations scientifiques et techniques de l'Approche Élargie jusqu'à ce jour (voir section 2.1), évalue les impacts pour les participants et les contributeurs (voir section 2.2) et évalue la gouvernance et la gestion de projet de l'Approche Élargie (voir chapitre 3). Il évalue également la coopération entre l'Approche Élargie et ITER (chapitre 4) et la coopération potentielle avec d'autres nations (section 5.2), et aborde les objectifs futurs (section 5.1), la communication externe (section 5.3) et les modalités de financement (section 5.4). Dans une perspective d'avenir, l'étude évalue également les considérations à moyen et long terme pour l'Approche Élargie et ses projets (chapitre 6). Un ensemble de recommandations détaillées et hiérarchisées pour l'avenir de l'Approche Élargie est également fourni (chapitre 7).

Abbreviations

A-FNS – Advanced Fusion Neutron Source

ASIPP -- Institute of Plasma Physics Chinese Academy of Sciences

BA – Broader Approach

BASC – Broader Approach Steering Committee

BPM – Beam instrumentation

CCFE – Culham Centre for Fusion Energy

CEA – French Alternative Energies and Atomic Energy Commission

CERN – Conseil Européen pour la Recherche Nucléaire

CIEMAT – Spanish Centre for Energy, Environment and Technology

CLIC – Compact Linear Collider

CNR – Italian National Research Council

COVID-19 – Corona Virus Disease 2019

CRPP – Centre de Recherche Paul Pascal

CSC – Computational Simulation Centre

DEMO – Demonstration Power Station

DONES – DEMO-Oriented Neutron Source

EC – European Commission

ECB – European Central Bank

EF – Equilibrium Field

EFCC – Error Field Control Coil

ELTL – EVEDA Lithium Test Loop

ENEA – Italian National Agency for New Technologies, Energy and Sustainable Economic Development

ESS – European Spallation Source

EU – European Union

EURATOM – European Atomic Energy Community

F4E – Fusion for Energy

FPCC – Plasma Control Coils

FUTTA – Fusion Technology Transfer Activities

HPC – High-Powered Supercomputer

HTS – High-Temperature Superconducting

I-DTT – Italian Divertor Test Tokamak

IFERC – International Fusion Energy Research Centre

IFMIF-EVEDA – International Fusion Materials Irradiation Facility—Engineering Validation and Engineering Design Activities

INFN – Istituto Nazionale di Fisica Nucleare

IO – ITER's International Organisation

IP – Intellectual Property

IPP – Institute for Plasma Physics (a.k.a. MPI – Max Planck Institute)

ITER – International Thermonuclear Experimental Reactor

ITPA – International Tokamak Physics Activity

JAEA – Japanese Atomic Energy Agency

JET – Joint European Torus

JT-60SA – Japan Torus-60 Super Advanced

KIT – Karlsruhe Institute of Technology

LIPAc – Linear IFMIF Prototype Accelerator

LLRF – Low-Level Radio Frequency

MEXT – Ministry of Education, Culture, Sports, Science and Technology–Japan

MW – Megawatt

NIFS – National Institute for Fusion Science, Nagoya

QMS – Quality Management System

QPC – Quench Protection Circuits

QST – National Institutes for Quantum and Radiological Science and Technology—Japan

R&D – Research and Development

RAFM – Reduced Activation Ferritic/Martensitic

REBCO – Cuprate superconductor ceramic compounds

REC – Remote Experimentation Centre

RI – Radioisotope

RWMCC – Resistive Wall Mode Control Coils

SCK-CEN – Belgian Nuclear Research Centre

SCMPS – Superconducting Magnet Power Supplies

SNS – Spallation Neutron Source

SOFT – Symposium on Fusion Technology

STP – Satellite Tokamak Programme

TF – Toroidal Field

UKAEA – United Kingdom Atomic Energy Agency

VC – Voluntary Contributor

WEST – W-Environment in Steady-state Tokamak

Executive summary (EN)

Introduction

This study into the 'Benefits of Broader Approach activities' has three principal aims:

- To evaluate the Broader Approach (BA) projects' technical impact and scientific benefits within the broader fusion research landscape and in relation to its costs;
- To analyse the BA's organisational and political impacts on European stakeholders, i.e. the analysis of the benefits for BA participants in Europe;
- To evaluate possible benefits of continuing the BA agreement beyond 2025.

The study was carried out between December 2019 and August 2020 and addressed each of these points. The analysis was developed on the basis of a desk review of project documents, an online survey of participants and contributors, interviews with key stakeholders and bibliometric analysis.

Benefits of the Broader Approach

Scientific and technical achievements

The scientific achievements of the Broader Approach activities are well-respected in the field of fusion research. The Japan Torus-60 Super Advanced tokamak (JT-60SA) project team successfully designed and constructed what will remain the world's largest superconducting tokamak until the International Thermonuclear Experimental Reactor's (ITER's) eventual commissioning. It oversaw the production, transport, and installation of larger and more technically complex tokamak components than ever manufactured. Its researchers developed an advanced research agenda based on experiments that will advance understanding of plasma physics and fusion reactor engineering.

IFMIF-EVEDA's (the International Fusion Materials Irradiation Facility—Engineering Validation and Engineering Design Activities) project team advanced the fusion community towards a fusion materials testing facility. To do so, the team designed, constructed, and commissioned the world's most advanced lithium test loop facility and built one of the most advanced linear accelerators in the field of nuclear physics research, which can operate continuously at high currents. Simultaneously, researchers prepared and planned for the construction of an eventual integrated materials testing facility with a fusion-like neutron source.

The International Fusion Energy Research Centre's (IFERC's) team coordinated planning activities for R&D on DEMO (the eventual demonstration fusion power station) between Japan and the EU and sponsored and published multitudes of institutional research on DEMO design. In parallel, it commissioned an advanced, reliable supercomputer used by physicists to model different regimes of plasma operation and advance their understanding of plasma behaviour in ITER-like conditions. IFERC also oversaw the development of a cohesive remote experimentation centre that will allow for international virtual participation in experiments run at large tokamaks, a programme supported by ITER's International Organisation.

The BA projects also prompted significant expansion of scientific and technical collaboration between the EU and Japan. This is supported by bibliometric analysis which corroborates extensive feedback from stakeholders that the Broader Approach motivated increased scientific cooperation between

Japanese and EU fusion labs, but also technical cooperation between EU and Japanese industry players who worked on in-kind contributions for the JT-60SA and for IFMIF-EVEDA.

Within the fusion community, the BA projects are considered models of technical success. The commissioning of the JT-60SA and the first stages of IFMIF-EVEDA's linear accelerator (LIPAc) was considered especially impressive, as other projects of comparable complexity and scale typically experience more significant technical delays. Fusion researchers will look to the results from future JT-60SA experiments to inform ITER operation and DEMO design, while materials researchers will look to results from LIPAc experiments to inform DONES (DEMO-Oriented Neutron Source) design and eventual operation. Any future initiatives coordinating DEMO R&D will rely on the basis of research developed by IFERC's teams, including the results of modelling conducted on its high performance computer. All three projects will contribute to the de-risking of ITER and eventually DEMO operations.

Benefits for BA participants and governance of the BA

The study assessed the benefits for BA participants as well as the governance of the overall BA and its specific projects. The assessment employed desk research, interviews with 32 stakeholders and responses to an online survey by 30 more stakeholders.

The Broader Approach is a high-level agreement between the EU and Japan with significant political benefits. The BA strengthens the relationship in research and technology, and between Japanese and EU governments more broadly. Stakeholders agree that the BA has had a positive impact in building trust between the EU and Japanese government authorities and fusion research communities.

LIPAc and JT-60SA have encountered significant difficulties in the BA Phase I, leading to a slippage of 6 years for the commissioning of each project. This was due to the underestimation of challenges at the start of the BA, the absence of an integrator role for Fusion for Energy (F4E) in LIPAc, difficulties in attracting EU and JP personnel to Rokkasho, and other issues. Project schedules are now stable, although the COVID-19 pandemic may cause further slippage.

Apart from the initial delays, the BA results are positive so far, which is corroborated by both interviews and survey responses. The simplified governance arising from having only two parties, the use of in-kind contributions and the strong motivation and trust developed by organisations and experts are important factors for the projects' achievements.

There is evidence that the BA has resulted in additional benefits to EU companies in the Voluntary Contibutor (VC) Member States, including specific cases of technology development and transfer to other sectors, as well as winning ITER contracts. Surveyed research organisations and companies have effectively indicated that the BA had a positive impact for them, although the limited data obtained from companies suggests the BA contribution made up a small share for the activities of most companies.

The total (nominal) EU spending of $€_{2005}$ 339 million between 2009-2020 has mostly benefited the VCs (as anecdotal evidence suggests the VC countries in-kind contributions were procured mostly from companies based in their country) and Japan (as host country). Feedback from interviews indicates the original budget estimates for the different projects were generally adequate. However, there were issues with the annual allocation of funds by national policymakers during the government budgeting activities. EU contributions to the BA phase I amount to around 5% of Euratom contributions to ITER up to 2020, and around 2.5% of the estimated contributions from 2007 to 2035.

The BA has led to an improved relationship between the EU and JP, including in the context of ITER. Cultural differences require(d) adaptation and trust-building by both European and Japanese participants. Other factors also played in the collaboration, including difficulties in attracting European and Japanese researchers to Rokkasho and outdated or conservative information security procedures. According to EU interviewees, Japan has gained trust in F4E, and prefers that F4E remains the (single) EU counterpart; this increases the importance of coordination on the EU site, which is effectively conducted by the Contact Persons and the F4E-EUROfusion meetings.

Access to data and (remote) participation in experiments are amongst the main barriers, for both BA European participants and ITER; the BA Agreement and ITER-BA cooperation arrangement provide an overall framework for this, but continued cooperation, trust-building and addressing of specific issues with the Japanese to address the issues should be a point of focus.

In 2019, IO, F4E and QST signed a cooperation arrangement between the BA activities and ITER. This agreement is expected to lead to an important upscaling of collaboration. There is a risk of asymmetric benefits to ITER, as ITER members are not obliged to share knowledge with ITER (and therefore this would also not be shared with the BA) and the direct relevance of JT-60SA to ITER compared to less clear links from ITER to BA. Identifying relevant ITER knowledge in the BA projects' annual work programmes and agreeing on collaboration activities useful to the BA would increase the benefits to both Parties and reduce the risks of asymmetric benefits.

Continuation of the Broader Approach

The agreement on a Joint Declaration to initiate a phase II of the BA means that the short term continuation of the BA is clear with plans made for this phase through to 2024 and with indications per project of the likely timeline and activities beyond this date. Nevertheless, it was also useful to take stock of the problems that the BA should address, the objectives it should have, the key issues to consider and the project specific needs.

Objectives of a post 2024 BA

Analysis found that the key objective of BA post-2024 should be (1) De-risking ITER and its construction, assembly and operation – particularly through the activities of JT-60SA; (2) Contributing to DEMO development, and particularly supporting IFMIF-DONES and DEMO design and R&D; (3) Positive returns on investment for EU industry and scientists; (4) Joint priority on improving the cooperation and relationship with Japan, which was noted as already strong, and also capacity building for the fusion field in general and ITER; and, (5) Joint priority on guiding fusion research, in particular through contributions to DEMO and technical achievements in fusion technology.

Governance

The analysis noted the importance of continuing the successful collaboration with Japan, particularly to maintain the trust that has been established. The role of EUROfusion in BA is one of the trickier areas of governance as whilst they are becoming the major EU funder and participant in BA, F4E will remain the implementing agency and EU representative at Steering Committee level. Adjusting the formal arrangements to officially upgrade the role of EUROfusion was not recommended, but it was recommended to evaluate the governance arrangements between F4E and EUROfusion in the coming years to assess their effectiveness and efficiency. The cooperation with ITER IO is only in its infancy but will likely become an increasing area of activity in the coming years as ITER draws closer to commissioning.

Involvement of new partners

The involvement of new partners is an important consideration for BA as JT-60SA approaches commissioning and other countries find it attractive to get access to what will be the largest tokamak in the world. Stakeholders noted there is an important balance to strike between the desire for international collaboration, expertise and funding a partner could bring, and the potentially disruptive influence on the successful existing BA partnership, the fairness of letting a new partner 'free-ride' on the EU-Japan investment and concerns on intellectual property. Ensuring a proportionality between contributions and access is crucial. It should also be noted that it may be too disruptive to be worthwhile to bring 'full partner' into BA. The United States was seen as the leading candidate to engage with for any 3rd party involvement in BA, with appropriate safeguards puts in place.

External communication

The external communication of BA and its activities has a number of deficiencies. These include unclear responsibilities, low priority being given to it, and lack of resources. As a result, the dissemination of results and promotion of BA has not been very successful. Turning the new communication strategy into action, particularly for JT-60SA, and stronger partnerships on communication with other leading parties in the fusion space are amongst the key recommendations.

Funding and access

The funding modes for BA have changed as it moves into Phase II, it is yet to be determined how effective and efficient these will be, and also how the move to annual funding reviews may affect the reliability of funding and the ability to make larger multi-year investments. The COVID-19 crisis and expected pressures on public spending will test the BA funding mechanism in the coming years.

There are remaining concerns from European researchers on how access to the BA assets, JT-60SA in particular, will work in the coming years. Although procedures are established, there remain practical issues with software and security processes on the Japanese side, that whilst not major barriers when on-site, can make remote access difficult. Remote access would be very much welcomed by the EU research community as it would place less pressure on budgets and would avoid travel to the relatively isolated sites in Japan.

JT-60SA

The JT-60SA has the clearest defined project pathway of the BA projects, with planned experiments, upgrades and activities up to 2024 and beyond already clearly specified. In the medium term the collaboration with ITER IO will be among the most important activities, to ensure that as a satellite programme it provides valuable knowledge and first-hand experience to help de-risk ITER operation. There remain some important considerations in the longer term, post-2024. For example, larger upgrades such as the replacement of the carbon walls with metals, such as tungsten, which would be a major investment in both time and money.

IFMIF-EVEDA

Post-2024 IFMIF-EVEDA will continue operations to validate the LIPAc accelerator, and there are various experiments and potential upgrades that could be undertaken. However, the main objectives of the IFMIF-EVEDA activities will have been largely achieved by this time and the next step in developing a fusion neutron source will need to be taken. The cost estimates for this next step in Europe, for IFMIF-DONES, suggest a project cost of €1 billion or more and at this cost level it is impossible to host under BA. Nevertheless there are important lessons that can be learnt from IFMIF-EVEDA and strong reasons to ensure Japanese participation in the EU DONES project as this moves forward. LIPAc could continue to operate until the full fusion neutron source is ready (around 2030), whilst an exit strategy, including exploring alternative uses with other scientific disciplines is developed.

IFERC

The IFERC project was the least loved by stakeholders and participants, with the most questions raised about its continuation as a whole or of specific sub-projects, this was at least partially due to a lack of familiarity with the IFERC activities. Reasons for continuation included the continued relevance of the activities and the value placed upon IFERC by Japan. Post-2024 there are a number of potential ways in which IFERC could move forward including (1) the computer simulation centre (CSC) which could provide a renewed EU-Japan cooperation on supercomputing for fusion; (2) DEMO design and R&D activities to consolidate and feed BA lessons into tokamak design – with, amongst others, a focus on affordability; (3) the Remote Experimentation Centre to continue to explore and provide remote experimentation facilities; (4) Other smaller projects such as BA knowledge management systems, technology transfer or summer schools.

Recommendations

Based on the analysis of the impacts of the Broader Approach and the assessment of issues relevant to its continuation, the following recommendations are made. Firstly that the objectives for the BA, beyond the objectives enshrined in the BA agreement should include:

	Summary
Recommended Objectives	The objectives are recommended in order of priority as: 1. De-risking ITER (construction, assembly and operation) 2. Contributing to DEMO - including by progressing on IFMIF-DONES and contributing to EU DEMO design improvements 3. Positive return on investment for EU Member States – through contributing to progress on the EUROfusion roadmap and ensuring commercial opportunities for EU participants in BA 4. Improving cooperation and relationship with Japan / Capacity building 5. Guiding fusion research / Technical achievements in fusion energy – contributing to DEMO and overall fusion science

And secondly, that the specific high priority recommendations for the BA should be the following. Other medium and lower priority recommendations are presented in chapter 7.

Priority	Recommendation type	Recommendation
High	Impacts for participants	1. LIPAc completion and commissioning should be followed closely to maintain progress and address disruptions in order not to further delay DONES and the overall DEMO roadmap.
	Governance	2. Continue assigning staff for management positions according to their availability and expertise, and increase involvement of EUROfusion members as part of the project teams. 3. Evaluate F4E-EUROfusion collaboration on BA in 2022 to understand how effective and efficient the arrangement is. 4. Ensure EUROfusion is involved throughout the drafting of agreements related to the BA where it will be a co-signer with F4E and European laboratories.
	Project Management	5. Update and expand QMS in 2021-2022 in agreement with QST as JT-60SA and LIPAc start operating. 6. Work to ensure remote working and meeting arrangements are further developed and brought to a level of implementation comparable to other international projects with remote participation. 7. Foresee contingency funds from F4E and EUROfusion for addressing difficulties in commissioning, enhancements and experimentation campaigns. 8. Agree and define procedures for remote access to data by end-2021.
	BA links to ITER and DEMO	9. Review the effectiveness and efficiency of the BA-ITER collaboration agreement before 2024. 10. The end goal of affordable nuclear fusion energy should be reinforced as a main criteria in planning and monitoring the DEMO Design activities and the overall EU fusion roadmap – studies on relevant aspects should be promoted, e.g. on the Tritium fuel cycle or materials. Opportunities to carry out this work under the IFERC project should be explored.
	External Communications	11. Assign the responsibility for coordination of the BA external communication activities to the BASC secretariat from 2021. 12. Define and approve by the BASC a separate budget for communication activities from 2021. 13. Use the communication budget to 'reserve' part of time of communications team experts in F4E and QST to spend on BA.
	IFERC	14. Assess (in 2023-2024) progress with REC activities scheduled for phase II, in light of these refine EU needs and wishes for remote access to plan for future REC activities.

Executive summary (FR)

Introduction

Cette étude sur les "Avantages des Activités de l'Approche Élargie" a trois objectifs principaux :

- Évaluer l'impact technique et les avantages scientifiques des projets de l'Approche Élargie dans le cadre plus large de la recherche sur la fusion nucléaire et par rapport à ses coûts ;
- Analyser les impacts organisationnels et politiques de l'Approche Élargie (par la suite appelée BA, pour *Broader Approach*) sur les parties prenantes européennes, c'est-à-dire l'analyse des avantages pour les participants de la BA en Europe ;
- Évaluer les avantages possibles de la poursuite de l'accord sur la BA au-delà de 2025.

L'étude a été réalisée entre décembre 2019 et août 2020 et a abordé chacun de ces points. L'analyse a été élaborée sur la base d'une étude des documents de projet, d'une enquête en ligne auprès des participants et des contributeurs, d'entretiens avec les principales parties prenantes et d'une analyse bibliométrique.

Avantages de l'approche élargie

Réalisations scientifiques et techniques

Les réalisations scientifiques des activités de l'Approche Élargie sont très respectées dans le domaine de la recherche sur la fusion nucléaire. L'équipe du projet *Japan Torus-60 Super Advanced tokamak* (JT-60SA) a conçu et construit avec succès ce qui restera le plus grand tokamak supraconducteur au monde jusqu'à la mise en service éventuelle du réacteur thermonucléaire expérimental international (ITER). L'équipe a supervisé la production, le transport et l'installation de composants de tokamak plus grands et techniquement plus complexes que jamais produits auparavant. Ses chercheurs ont élaboré un programme de recherche avancée basé sur des essais qui avanceront la compréhension de la physique des plasmas et de l'ingénierie de réacteurs à fusion.

L'équipe du projet IFMIF-EVEDA (*International Fusion Materials Irradiation Facility - Engineering Validation and Engineering Design Activities*) a fait progresser la communauté de la fusion vers une installation d'essai des matériaux de fusion. Pour cela, l'équipe a conçu, construit et mis en service l'installation de test d'une boucle lithium la plus avancée au monde et a construit l'un des accélérateurs linéaires de particules les plus avancés dans le domaine de la recherche en physique nucléaire, qui peut fonctionner en continu à des courants élevés. Simultanément, les chercheurs ont préparé et planifié la construction d'une éventuelle installation intégrée de test des matériaux avec une source de neutrons de type fusion.

L'équipe du Centre international de recherche sur l'énergie de fusion (IFERC) a coordonné les activités de planification de la R&D sur DEMO (l'éventuelle centrale de fusion de démonstration) entre le Japon et l'UE et a parrainé et publié de nombreuses recherches institutionnelles sur la conception de DEMO. En parallèle, elle a mis en service un superordinateur avancé et fiable utilisé par les physiciens pour modéliser différents régimes de fonctionnement du plasma et faire progresser leur compréhension du comportement du plasma dans des conditions similaires à celles d'ITER. IFERC a également supervisé le développement d'un centre d'expérimentation à distance cohésif qui permettra une participation virtuelle internationale aux expériences menées dans les grands tokamaks, un programme soutenu par l'Organisation internationale ITER (ITER IO).

Les projets de la BA ont également entraîné une expansion significative de la collaboration scientifique et technique entre l'UE et le Japon. Ceci est soutenu par une analyse bibliométrique qui corrobore les nombreuses informations reçues des parties prenantes selon lesquelles l'Approche Élargie a motivé une coopération scientifique accrue entre les laboratoires de fusion japonais et européens, mais aussi une coopération technique entre les acteurs industriels européens et japonais qui ont travaillé sur des contributions en nature pour le JT-60SA et pour l'IFMIF-EVEDA.

Au sein de la communauté de la fusion, les projets de la BA sont considérés comme des modèles de réussite technique. La mise en service du JT-60SA et les premières étapes de mise en service de l'accélérateur linéaire de l'IFMIF-EVEDA (LIPAc) ont été jugées particulièrement impressionnantes, car d'autres projets de complexité et d'échelle comparables connaissent généralement des retards techniques plus importants. Les chercheurs en fusion se tourneront vers les résultats des futures expériences du JT-60SA pour éclairer l'exploitation de l'ITER et la conception de DEMO, tandis que les chercheurs en matériaux se tourneront vers les résultats des expériences du LIPAc pour éclairer la conception et l'exploitation éventuelle de DONES (DEMO-*Oriented Neutron Source*). Toute initiative future coordonnant la R&D de DEMO s'appuiera sur les recherches développées par les équipes de l'IFERC, y compris les résultats de la modélisation réalisée sur son calculateur haute-performance. Ces trois projets contribueront à réduire les risques liés à l'exploitation d'ITER et, à terme, de DEMO.

Avantages pour les participants à la BA et gouvernance de la BA

L'étude a évalué les avantages pour les participants à la BA ainsi que la gouvernance de la BA dans son ensemble et de ses projets spécifiques. L'évaluation s'est appuyée sur une recherche documentaire, des entretiens avec 32 parties prenantes et les réponses à une enquête en ligne menée par 30 autres parties prenantes.

L'Approche Élargie est un accord de haut niveau entre l'UE et le Japon qui présente des avantages politiques importants. Elle renforce les relations dans le domaine de la recherche et de la technologie, et plus généralement entre les gouvernements japonais et européen. Les parties prenantes sont en accord que la BA a eu un impact positif sur l'établissement de la confiance entre les autorités gouvernementales européennes et japonaises et les communautés de recherche sur la fusion.

LIPAc et JT-60SA ont rencontré des difficultés importantes dans la phase I de la BA, entraînant un retard de 6 ans pour la mise en service de chaque projet. Ce retard est dû à la sous-estimation des difficultés au début de la BA, à l'absence d'un rôle d'intégrateur pour Fusion for Energy (F4E) au sein de LIPAc, aux difficultés à attirer le personnel de l'UE et du JP à Rokkasho, et à d'autres problèmes. Les calendriers des projets sont désormais stables, même si la pandémie COVID-19 pourrait entraîner de nouveaux dérapages.

Hormis les retards initiaux, les résultats de la BA sont positifs jusqu'à présent, ce qui est corroboré par les entretiens et les réponses à l'enquête. La gouvernance simplifiée résultant du fait de n'avoir que deux parties, l'utilisation de contributions en nature et la forte motivation et confiance développée par les organisations et les experts sont des facteurs importants pour les réalisations des projets.

Il est prouvé que la BA a apporté des avantages supplémentaires aux entreprises européennes dans les États membres étant contributeurs volontaires (VC, ou *voluntary contributors*), notamment des cas spécifiques de développement technologique et de transfert vers d'autres secteurs, ainsi que l'obtention de contrats ITER. Les organismes de recherche et les entreprises interrogés ont effectivement indiqué que la BA a eu un impact positif pour eux, bien que les données limitées obtenues des entreprises suggèrent que la contribution de la BA n'a représenté qu'une petite part des activités de la plupart des entreprises.

Les dépenses totales (nominales) de l'UE, qui se sont élevées à 339 millions d'euros entre 2009 et 2020, ont principalement bénéficié aux sociétés situées dans les pays qui étaient contributeurs volontaires (comme l'indiquent les données anecdotiques, une grande partie des contributions en nature a été fournie par des entreprises situées dans ces pays) et au Japon (en tant que pays d'accueil). Les entretiens indiquent que les estimations budgétaires initiales pour les différents projets étaient généralement adéquates. Toutefois, l'allocation annuelle des fonds par les décideurs politiques nationaux lors des activités de budgétisation du gouvernement a posé quelquefois des problèmes. Les contributions de l'UE à la phase I de la BA s'élèvent à environ 5 % des contributions d'Euratom à l'ITER jusqu'en 2020, et à environ 2,5 % des contributions estimées de 2007 à 2035.

La BA a permis d'améliorer les relations entre l'UE et le JP, y compris dans le cadre de l'ITER. Les différences culturelles exigent une adaptation et un renforcement de la confiance de la part des participants européens et japonais. D'autres facteurs ont également joué dans la collaboration, notamment les difficultés à attirer des chercheurs européens et japonais à Rokkasho et des procédures de sécurité de l'information dépassées ou conservatrices. Selon les personnes interrogées dans l'UE, le Japon a gagné la confiance en F4E, et préfère que F4E reste l'homologue (unique) de l'UE ; cela accroît l'importance de la coordination du coté de l'UE, qui est effectivement assurée par les réunions des agent de liaison et entre F4E et EUROfusion.

L'accès aux données des projets et la participation (à distance) aux expériences figurent parmi les principaux obstacles, tant pour les participants européens à BA que pour ITER ; l'accord BA et l'accord de coopération ITER-BA fournissent un cadre général à cet effet, mais il convient de mettre l'accent sur la poursuite de la coopération, l'instauration d'un climat de confiance et le traitement de questions spécifiques avec les Japonais pour résoudre ces problèmes.

En 2019, IO, F4E et QST ont signé un accord de coopération entre les activités de la BA et ITER. Cet accord devrait conduire à une importante intensification de la collaboration. Il existe un risque de bénéfices asymétriques pour l'ITER, en raison de que les membres de l'ITER ne sont pas obligés de partager ses connaissances avec l'ITER (et qui par conséquent ne serraient pas partagées avec la BA) et de la pertinence directe du JT-60SA pour l'ITER en comparaison avec des liens moins clairs entre l'ITER et la BA. Identifier les connaissances ITER pertinentes dans les programmes de travail annuels des projets de la BA et convenir d'activités de collaboration utiles à la BA augmenterait les avantages pour les deux parties et réduirait les risques de bénéfices asymétriques.

Poursuite de l'Approche Élargie (BA)

L'accord sur une déclaration commune visant à lancer une phase II de la BA signifie que la poursuite à court terme de la BA est claire, avec des plans établis pour cette phase jusqu'en 2024 et des indications sur les calendriers de projet et les activités probables au-delà de cette date. Néanmoins, il a également été utile de faire le point sur les problèmes que la BA devrait aborder, les objectifs qu'elle devrait avoir, les questions clés à prendre en compte et les besoins spécifiques des projets.

Objectifs d'une BA pour l'après 2024

L'analyse a montré que l'objectif clé de BA post-2024 devrait être (1) de réduire les risques liés à ITER et à sa construction, son assemblage et son exploitation - en particulier par le biais des activités de JT-60SA ; (2) de contribuer au développement de DEMO, et en particulier de soutenir IFMIF-DONES et la conception et la R&D de DEMO ; (3) d'assurer un retour sur investissement positif pour l'industrie et les scientifiques de l'UE ; (4) une priorité commune à l'amélioration de la coopération et des relations avec le Japon, qui ont été jugées déjà solides, ainsi qu'au renforcement des capacités dans le domaine de la fusion en général et pour ITER ; et (5) une priorité commune à l'orientation de la recherche sur la fusion, notamment par des contributions à DEMO et des réalisations techniques dans le domaine de la technologie de la fusion.

Gouvernance

L'analyse a souligné l'importance de poursuivre la collaboration fructueuse avec le Japon, en particulier pour maintenir la confiance qui a été établie. Le rôle d'EUROfusion dans la BA est l'un des domaines les plus délicats de la gouvernance car, bien qu'EUROfusion devienne le principal bailleur de fonds du côté de l'UE et participant à la BA, F4E restera l'agence d'exécution et le représentant de l'UE au niveau du comité directeur. Il n'a pas été recommandé d'ajuster les dispositions formelles pour améliorer officiellement le rôle d'EUROfusion, mais il a été recommandé d'évaluer les dispositions de gouvernance entre F4E et EUROfusion dans les années à venir pour évaluer leur efficacité et leur efficience. La coopération avec ITER IO n'en est qu'à ses débuts, mais il est probable qu'elle s'élargira dans les années à venir à mesure que l'ITER se rapprochera de sa mise en service.

Implication de nouveaux partenaires

L'implication de nouveaux partenaires est une considération importante pour la BA à l'approche de la mise en service du JT-60SA et à mesure qu'autres pays trouvent intéressant d'avoir accès à ce qui sera le plus grand tokamak du monde. Les parties prenantes ont noté qu'il y a un équilibre important à trouver entre le désir de collaboration internationale, l'expertise et le financement qu'un partenaire pourrait apporter, et l'influence potentiellement perturbatrice sur le succès du partenariat BA existant, l'équité de laisser un nouveau partenaire "profiter" de l'investissement UE-Japon et les préoccupations sur la propriété intellectuelle. Il est essentiel de garantir une proportionnalité entre les contributions et l'accès. Il convient également de noter qu'il peut être trop perturbateur pour qu'il soit intéressant d'intégrer un "partenaire à part entière" dans la BA. Les États-Unis ont été considérés comme le principal candidat avec lequel s'engager pour toute participation d'une tierce partie dans BA, avec la mise en place de garanties appropriées.

Communication externe

La communication externe de la BA et de ses activités présente un certain nombre de lacunes. Ces lacunes sont le manque de clarté des responsabilités, la faible priorité qui lui est accordée et le manque de ressources. En conséquence, la diffusion des résultats et la promotion de la BA n'ont pas été très fructueuses. La mise en œuvre de la nouvelle stratégie de communication, en particulier pour le JT-60SA, et le renforcement des partenariats en matière de communication avec d'autres acteurs majeurs de l'espace de fusion figurent parmi les principales recommandations.

Financement et accès

Les modes de financement de la BA ont changé alors qu'elle entre dans la phase II. Il reste à déterminer dans quelle mesure ils seront efficaces et efficients, et aussi comment le passage à des examens annuels de financement peut affecter la fiabilité du financement et la capacité à réaliser des investissements pluriannuels plus importants. La crise COVID-19 et les pressions attendues sur les dépenses publiques mettront à l'épreuve le mécanisme de financement de la BA dans les années à venir.

Les chercheurs européens restent préoccupés par la manière dont l'accès aux actifs de la BA, en particulier le JT-60SA, fonctionnera dans les années à venir. Bien que des procédures soient établies, il reste des problèmes pratiques liés aux logiciels et aux processus de sécurité du côté japonais, qui, s'ils ne constituent pas des obstacles majeurs lorsqu'ils sont sur place, peuvent rendre l'accès à distance difficile. L'accès à distance serait très bien accueilli par la communauté de recherche de l'UE, car il permettrait de réduire la pression sur les budgets et d'éviter de se rendre sur les sites relativement isolés du Japon.

JT-60SA

Le JT-60SA a le cheminement le plus clairement défini des projets de la BA, avec des expériences, des mises à niveau et des activités prévues jusqu'en 2024 et au-delà déjà clairement spécifiées. À moyen terme, la collaboration avec ITER IO sera l'une des activités les plus importantes, afin de garantir qu'en tant que programme de satellite, il apporte des connaissances précieuses et une expérience de première main pour aider à réduire les risques liés à l'exploitation d'ITER. Il reste quelques considérations importantes à plus long terme, après 2024. Par exemple, des mises à niveau plus importantes telles que le remplacement des parois en carbone par du métal, comme le tungstène, ce qui représenterait un investissement important en temps et en argent.

IFMIF-EVEDA

Après 2024, l'IFMIF-EVEDA continuera les opérations de validation de l'accélérateur LIPAc, et diverses expériences et mises à niveau potentielles pourraient être entreprises. Toutefois, les principaux objectifs des activités de l'IFMIF-EVEDA auront été largement atteints à cette date et la prochaine étape dans le développement d'une source de neutrons de fusion devra être franchie. Les estimations de coût pour cette prochaine étape en Europe, pour IFMIF-DONES, suggèrent un coût de projet d'un milliard d'euros ou plus et à ce niveau de coût, il est impossible de l'accueillir dans le cadre de la BA. Néanmoins, il y a d'importantes leçons à tirer de l'IFMIF-EVEDA et de bonnes raisons d'assurer la participation du Japon au projet DONES de l'UE à mesure que celui-ci avance. LIPAc pourrait continuer à fonctionner jusqu'à ce que la source de neutrons à fusion complète soit prête (vers 2030), tandis qu'une stratégie de sortie, comprenant l'exploration d'autres utilisations avec d'autres disciplines scientifiques, est mise au point.

IFERC

Le projet IFERC a été le moins aimé des parties prenantes et des participants, et le plus de questions ont été soulevées quant à sa poursuite dans son ensemble ou de sous-projets spécifiques, en partie en raison d'un manque de familiarité avec les activités de l'IFERC. Les raisons pour la poursuite du projet sont notamment la pertinence continue des activités et la valeur accordée à l'IFERC par le Japon. Après 2024, l'IFERC pourrait aller de l'avant de plusieurs manières, notamment (1) le centre de simulation informatique (CSC) pourrait permettre de renouveler la coopération UE-Japon dans le domaine du calcul intensif pour la fusion ; (2) les activités de conception et de R&D de DEMO pour consolider et intégrer les enseignements de la BA dans la conception de tokamaks – avec, entre autres, un accent sur l'accessibilité des coûts; (3) le centre d'expérimentation à distance pour continuer à explorer et à fournir des installations d'expérimentation à distance ; (4) d'autres projets plus petits tels que les systèmes de gestion des connaissances de la BA, le transfert de technologie ou les écoles d'été.

Recommandations

Sur la base de l'analyse des impacts de l'Approche Élargie et de l'évaluation des questions pertinentes pour sa poursuite, les recommandations suivantes sont formulées. Premièrement, les objectifs de la BA, au-delà des objectifs inscrits dans l'accord de la BA, devraient inclure :

	Résumé
Objectifs recommandés	Les objectifs sont recommandés par ordre de priorité : 1. Dé-risquer ITER (construction, assemblage et exploitation) 2. Contribuer à DEMO - y compris en progressant sur IFMIF-DONES et en contribuant à l'amélioration de la conception du DEMO Européen 3. Un retour sur investissement positif pour les États membres de l'UE - en contribuant à faire progresser la feuille de route d'EUROfusion et en garantissant des opportunités commerciales dans la BA aux participants de l'UE 4. Améliorer la coopération et les relations avec le Japon / Renforcement des capacités 5. Orienter la recherche sur la fusion / Réalisations techniques dans le domaine de l'énergie de fusion - contribuant à DEMO et à la science de la fusion en général

Et deuxièmement, que les recommandations spécifiques de haute priorité pour la BA devraient être les suivantes. D'autres recommandations de priorité moyenne et moins élevée sont présentées au chapitre 7.

Priorité	Type de recommandation	Recommandation
Haute	Impacts pour les participants	1. L'achèvement et la mise en service de la LIPAc devraient être suivis de près pour maintenir les progrès et remédier aux perturbations afin de ne pas retarder davantage le projet DONES et la feuille de route générale de DEMO.
	Gouvernance	2. Continuer à affecter du personnel à des postes d'encadrement en fonction de leur disponibilité et de leur expertise, et accroître la participation des membres d'EUROfusion au sein des équipes de projet. 3. Évaluer la collaboration F4E-EUROfusion sur la BA en 2022 pour comprendre l'efficacité et l'efficience de l'arrangement. 4. Assurer la participation d'EUROfusion tout au long de la rédaction des accords relatifs à la BA où elle sera cosignataire avec F4E et les laboratoires européens
	Gestion de projet	5. Mettre à jour et étendre le QMS en 2021-2022 en accord avec QST, à mesure que JT-60SA et LIPAc commencent à fonctionner. 6. Garantir que les dispositions relatives au travail et aux réunions à distance soient développées d'avantage et amenées à un niveau de mise en œuvre comparable à celui d'autres projets internationaux avec participation à distance. 7. Prévoir des fonds de réserve de F4E et d'EUROfusion pour faire face aux difficultés de mise en service, d'amélioration et de campagnes d'expérimentation. 8. Convenir et définir les procédures d'accès à distance aux données d'ici fin 2021.
	Liens de la BA vers ITER et DEMO	9. Examiner l'efficacité et l'efficience de l'accord de collaboration BA-ITER avant 2024. 10. L'objectif final d'une énergie de fusion nucléaire abordable devrait être renforcé en tant que critère principal dans la planification et le suivi des activités de conception DEMO et de la feuille de route globale de l'UE sur la fusion - les études sur les aspects pertinents devraient être encouragées, par exemple sur le cycle du combustible tritium ou les matériaux. Les

Priorité	Type de recommandation	Recommandation
		opportunités pour mener ce travail dans le cadre du projet IFERC devraient être explorées.
	Communications externes	11. Attribuer la responsabilité de la coordination des activités de communication externe de la BA au secrétariat de la BASC à partir de 2021. 12. Définir et approuver par la BASC un budget séparé pour les activités de communication à partir de 2021. 13. Utiliser le budget de communication pour "réserver" une partie du temps des experts de l'équipe de communication en F4E et QST pour les consacrer à la BA.
	IFERC	14. Évaluer (en 2023-2024) l'état d'avancement des activités du REC prévues pour la phase II, à la lumière de ces besoins et souhaits affinés de l'UE en matière d'accès à distance afin de planifier les futures activités du REC.

CONTENTS

1 Introduction

The Broader Approach (BA) agreement established three projects designed to de-risk ITER's construction and operation, to accelerate progress on designing DEMO, and to ultimately enable the early realisation of fusion energy. The Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA) project focused on advancing the design of a materials testing facility tailored to conditions of a nuclear fusion reactor. The International Fusion Energy Research Centre (IFERC) oversaw teams of researchers working to model plasma behaviour, conduct fusion experiments remotely, and design a next generation tokamak beyond ITER. And the Satellite Tokamak Programme (STP) constructed the world's largest superconducting tokamak (the JT-60SA) and mapped out a research plan intended to expand scientific understanding of plasma behaviour at extreme conditions while facilitating the commissioning of ITER.

The BA projects started up in 2007. As the first phase of their activity comes to a close and they move into a second phase of extended research, this study aims to retrospectively examine the impacts of the projects and to assess how they should evolve beyond their current phase. The study has three primary objectives:

- To evaluate the technical and scientific impacts of the Broader Approach activities within the international fusion research landscape
- To analyse the BA's organisational and political impacts on European stakeholders, and
- To consider the implications of continuing the Broader Approach agreement beyond its second phase, post-2024.

Approach and methodologies

To gauge the past and potential future impacts of the Broader Approach, our team relied on several research methods. A detailed literature review was conducted to understand the technical achievements of the BA activities. A digital survey was circulated to a database of around 80 companies involved in the BA projects, several European fusion research associations, including EUROfusion, Fusion for Energy (F4E), and national fusion labs; 30 respondents to this survey provided input on their experiences with the BA. Their feedback was analysed to assess perceived scientific relevance of the projects as well as perceived efficacy of project governance. Respondents were also questioned regarding the future of the BA and asked for their views on its most important roles.

In conjunction with the digital survey, 30 face-to-face interviews were conducted with a wide range of stakeholders related to the Broader Approach activities. Our team spoke via video calls with fusion scientists, project leaders, policy makers, and private sector contributors who were involved with (or in some cases, merely aware of) the BA activities in order to collect a wide range of diverse opinions on the strengths and weaknesses of the projects. Interviewees provided rich and detailed insights into the functioning of all three BA programmes and offered their views on how (or if) they believed the programmes should progress. Their responses were compared and synthesised to develop a holistic view of the impacts of the BA agreement. We analysed their experiences and suggestions to assess how the BA might be improved as it evolves.

Structure of the report

This report presents our findings regarding the impacts of the Broader Approach and our assessment of its proposed continuation beyond phase II.

Chapter 2 summarises the phase I impacts of the Broader Approach activities. Section 2.1 highlights the main technical achievements of the JT-60SA, IFMIF-EVEDA, and IFERC projects. Their scientific impacts are examined in the context of EU fusion research objectives, and bibliometric analysis is used to assess their relevance within the international field of fusion research. Section 2.2 presents analysis on the main impacts of the BA activities on European participants, including EU fusion organisations, Voluntary Contributor countries who provided in-kind contributions to the projects, and private sector companies who worked with fusion labs. The governance and project management of the Broader Approach is assessed in detail.

Chapter 3 considers continuation proposals for the Broader Approach. It summarises the problems and objectives that could be addressed by a third phase of the BA and identifies potential improvements. Possibilities for expanding or restructuring the agreement – by e.g., including additional partners or discontinuing sub-projects – are examined in detail and at the project level.

Chapter 4 synthesises the study’s conclusions and recommendations.

Background to the Broader Approach

Readers unfamiliar with the origins, structure and activities of the Broader Approach – including the main changes introduced for Phase II which began in 2020 - are recommended to read the short introduction and background provided in Annex G.

2 Impacts of the Broader Approach

2.1 Technical review of the scientific results and achievements of the three BA projects

This chapter details scientific progress enabled by the BA agreement; metrics of the projects' outputs and technical efficacy are measured against metrics for peer labs' and institutions' in the field of nuclear fusion, and the accomplishments and objectives of the projects are contextualised with respect to EUROfusion's Roadmap and with respect to ITER's project planning.

Table 2-1 Summary of BA technical impacts

	Summary
Main impacts and overall evaluation	- The BA activities achieved their phase I engineering objectives and are well-prepared to deliver on their phase II technical goals - Bibliometric analysis corroborates extensive feedback from stakeholders that the Broader Approach spurred increased scientific collaboration between Japanese and EU labs - All three BA projects will substantially contribute to de-risking ITER and eventually DEMO operation
Positives	- Completion of the JT-60SA was considered technically impressive by the fusion community, especially as projects of comparable complexity and scale typically experience more significant technical delays - IFMIF-EVEDA delivered on the long-standing technical objective of fusion community to prepare and test machinery that will be used in a vital materials-testing facility - The successful manufacturing, delivery, and installation of JT-60SA and IFMIF-EVEDA components built up new technical knowledge in EU companies - Fusion researchers will look to results from future JT-60SA experiments to inform ITER operation and DEMO design, while materials researchers will look to results from LIPAC experiments to inform DONES design and eventual operation - IFMIF's linear accelerator (LIPAc) is valued beyond the fusion community by particle physicists who are considering its potential use in additional experiments once its BA experiments conclude - IFERC is viewed by scientists as a useful forum for coordinating DEMO planning activities between Japan and the EU - IFERC's (HELIOS) supercomputer was been praised by fusion physicists for its accessibility and reliability, and its remote experimentation centre is considered a key success of the project by scientists
Negatives	*No criticisms of the BA activities pertained directly to their technical impacts.*
Recommendations	- Ensure continuity in technical project teams so activities can fulfil their phase II research plans - For JT-60SA, emphasise focus on de-risking ITER operation to ensure its technical achievements can have large impacts in the short-term as ITER is commissioned

2.1.1 *Technical feats of the JT-60SA, IFMIF-EVEDA, and IFERC*

The main technical achievements of each project in their respective sub-fields of nuclear fusion research are summarised below. Additional details on the scientific achievements of each project are included in Annex A.

JT-60SA – Preparing for research on superconducting tokamaks and advanced plasmas

The completed JT-60SA is the largest and most advanced superconducting tokamak ever constructed.[1] It has been designed and built to confine plasmas at higher temperatures, at more elongated configurations, and for longer durations, than ever before tested. When it comes online in 2021, the

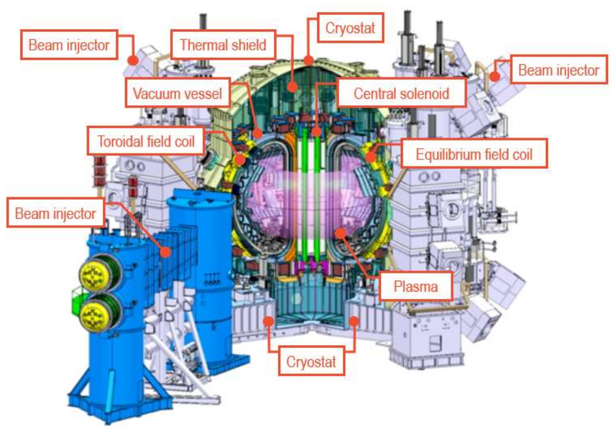
[1] As confirmed in interviews with experts, March 2020.

tokamak will be operated to experiment with extended plasma runtimes and plasmas sustained under extreme conditions.[2,3]

Until now, however, most JT-60SA project activities have centred on the design and construction of the tokamak such that thus far the JT-60SA's technical achievements have been feats of engineering. In conjunction with peer institutions in Europe, the JT-60SA team has planned, manufactured, tested and installed the core components of the tokamak which will enable it to generate and confine plasmas at envisioned technical levels.

The figure below is a schematic of the tokamak. It comprises three core structures: a magnet system, a vacuum vessel with a thermal shield and cryostat, and extra-torus plant systems.[4] The reactor's magnet system will collectively confine and control plasma shape, current, and position during operation. Its vacuum vessel includes elements designed to protect the vessel, to control for plasma impurities, to test passive control of plasma position and for fuelling, and to provide for vacuum pumping and cooling. Plant systems account for water cooling, cryogenics, power and heating supplies, control systems, as well as heating, ventilation and air conditioning of the building. Its design also includes a remote handling centre, which will be required to manage materials which become highly irradiated during reactor operation (like Hot Cells).[5,6]

Figure 2-1: Schematic of the tokamak design for the JT-60SA[7]



To create the modular equipment required for each of these sub-systems, researchers worked for years in European and Japanese facilities. As of March 2020, all major components have been manufactured, tested, transported to Japan, and installed at the tokamak site. Reactor structures will be further tested before it starts up, but JT-60SA engineers have succeeded in delivering the most advanced superconducting tokamak so far constructed.[8] The production of each of its systems – larger and more advanced than systems built for other tokamaks – represents a technical feat widely respected within the fusion community.

[2] JT-60SA STP project leader (2020), The Satellite Tokamak JT-60SA:BA Phase II – Summary Plan.
[3] ITER (2019), JT-60SA "ITER satellite" to begin operating next year – accessible via https://www.iter.org/newsline/-/3273.
[4] JT-60SA, The Device – Design – accessible via http://www.jt60sa.org/b/index_nav_3.htm?n3/Design.htm
[5] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project – accessible via https://conferences.iaea.org/event/151/papers/6030/files/5061-Paper_Barabaschi_IAEA_2018_-_OV.pdf
[6] Shirai, Barabaschi, Kamada, and the JT-60SA Team in Nuclear Fusion (2017), Recent Progress of the JT-60SA project – accessible via https://iopscience.iop.org/article/10.1088/1741-4326/aa5d01
[7] Adapted from JT-60SA (2017), The Device – Design – accessible via http://www.jt60sa.org/b/index_nav_3.htm?n3/Design.htm
[8] JT-60SA STP project leader (2020), The Satellite Tokamak JT-60SA:BA Phase II – Summary Plan.

A more detailed consideration of the JT-60SA's advanced systems based on their technical specifications is included in Annex A.

Targeted scientific aims

So far the JT-60SA's technical achievements relate to the tokamak's design, manufacturing, and assembly. However, the project team has laid out scientific objectives it plans to achieve once the reactor starts up and can be used to conduct advanced experiments. Achieving these objectives would substantially advance the field of nuclear fusion research and help prepare scientists to design, build and operate viable next-generation nuclear fusion reactors.[9,10]

The JT-60SA is designed to confine **break-even equivalent high-temperature deuterium plasma.** Crucially, experiments at the JT-60SA will be able to explore **high beta plasma regimes** better than any existing tokamak. Any future economically viable fusion power will be generated with high beta plasmas, but their operation using sufficiently large magnetic systems is still insufficiently understood.[11] The JT-60SA is also designed to operate a **wider range of plasma shapes** than produced at other big tokamaks – including elongations and triangularities that have not yet been tested at longer pulses. The results of testing different plasma shapings will inform the design of future nuclear reactors so they are optimised for power generation. [12,13] At the same time, the JT-60SA will allow for testing of plasmas at lower aspect ratios – i.e., the ratio between a torus's outer and inner radius – moving towards the point at which magnetic pressure generated by a torus can be maximised. The results of JT-60SA's tests will help ITER in order to achieve this as well.[14]

Tests at the JT-60SA will explore **high density plasma regimes** that are relevant to ITER, as ITER will aim to confine the highest density plasmas ever run in a tokamak. A defining feature of the JT-60SA is its capability to maintain plasmas for **longer run times**, which will enable researchers to study plasma dynamics and particle handling at runtimes of up to 100s at high power for the first time.[15,16] Operating the JT-60SA might also enable scientists to observe **plasma disruptions** – instances in which plasmas unexpectedly drop out, losing their thermal and magnetic energy. Causes of plasma disruptions are not always evident to scientists, and the opportunity to observe a plasma disruption especially in a larger reactor could advance physicists' and engineers' understanding of their disruptions and theories on disruption mitigation techniques and technologies.[17,18]

Finally, the JT-60SA will be equipped with a remote handling system to allow maintenance of in-vessel components that become irradiated as they are subjected to high neutron fluxes. This will allow for testing of key technical safety mechanisms at the reactor and would represent a major technological advance in the field of tokamak research.[19]
A more detailed consideration of the JT-60SA's targeted scientific aims is included in Annex A.

[9] Giruzzi et al in Plasma Physics and Controlled Fusion (2019), Advances in the physics studies for the JT-60SA tokamak exploitation and research plan – accessible via https://iopscience.iop.org/article/10.1088/1361-6587/ab4771/meta
10 Oyama on behalf of the National Institutes for Quantum and Radiological Science and Technology (2020), Progress in preparing research plan and construction of JT-60SA – accessible via http://aappsdpp.org/DPP2018Program/wholeitem/PlenaryPDF/P293131.pdf
[11] Corroborated through interviews with experts conducted in March 2020.
[12] Windsor in Philosophical Transactions of the Royal Society A (2019), Can the development of fusion energy be accelerated? An introduction to the proceedings – accessible via https://royalsocietypublishing.org/doi/10.1098/rsta.2017.0446#d3e647
[13] Giruzzi et al in Plasma Physics and Controlled Fusion (2019), Advances in the physics studies for the JT-60SA tokamak exploitation and research plan – accessible via https://iopscience.iop.org/article/10.1088/1361-6587/ab4771/meta
[14] JT-60SA (2015), Project Objectives – accessible via http://www.jt60sa.org/b/index_nav_1.htm?n1/objectives.htm
[15] Ibidem
[16] Los Alamos National Laboratory, Dense Plasma Theory Physical Regimes – accessible via https://www.lanl.gov/projects/dense-plasma-theory/background/physical-regimes.php
[17] Lehnen on behalf of ITER (2017), Addressing the challenge of plasma disruptions – accessible via https://www.iter.org/newsline/-/2678
[18] Corroborated through interviews with experts conducted in March 2020.
[19] JT-60SA (2015), Project Objectives – accessible via http://www.jt60sa.org/b/index_nav_1.htm?n1/objectives.htm

IFMIF-EVEDA – Enabling the development of a high-neutron intensity materials testing facility

IFMIF-EVEDA is responsible for validating the devices and processes that will ultimately be deployed in a materials irradiation facility. IFMIF-EVEDA was included as a Broader Approach project because the fusion community recognises the necessity of testing materials which can inform the development of ITER and DEMO.

In the long-term, advanced fusion reactors like DEMO will need to withstand high neutron fluxes at high energy levels; it is therefore essential to test the materials that could be used in these reactors to understand how they are impacted by neutrons at higher intensities. An effective materials testing facility will require technologies that can produce fusion-like neutrons (concerning their energies and quantities) at intensities large enough to allow for accelerated testing, to assess how materials might be damaged at levels beyond what could be expected during the operational lifetimes of reactors. It will also need to irradiate volumes of materials of interest large enough to allow for characterising their macroscopic properties.[20]

IFMIF-EVEDA has focused on, first, producing a fully integrated engineering design for the eventual International Fusion Materials Irradiation Facility – a project that nuclear fusion scientists have been working on for three decades. Secondly, IFMIF-EVEDA has focused on proving the consistent and stable operation of IFMIF sub-system prototypes: an accelerator, a lithium target facility, and high-flux, medium flux and low-flux small specimen test modules.[21]

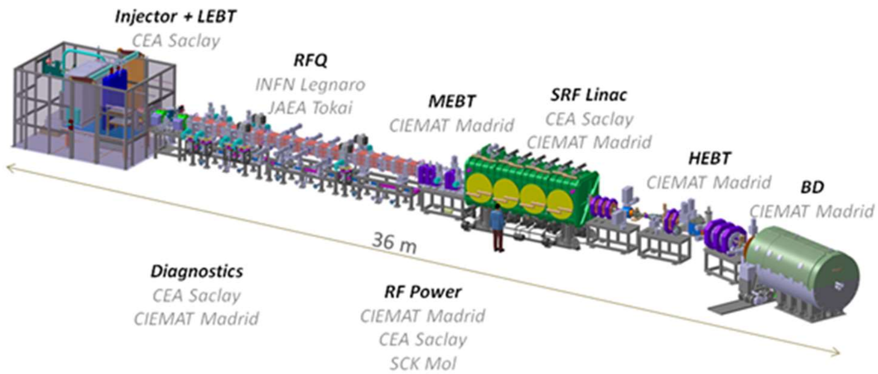
At IFMIF, these sub-systems will feed into one another; the accelerator facility will generate and accelerate deuteron beams aimed at the lithium target facility, which will form, shape, and accelerate neutron beams before they are directed towards test modules, where materials will be bombarded with high-, medium- and low-neutron fluxes. During IFMIF-EVEDA, however, these sub-systems are being tested separately, as they all still require further study and advancement.[22,23]

LIPAc

IFMIF-EVEDA's linear accelerator prototype was constructed at JAEA's site in Rokkasho, Japan. The institutions CEA, CIEMAT, INFN, and SCK-CEN constructed and tested many of its components in the EU before delivering them to Japan.[24] These components are identified in the figure below, which depicts the structure of the linear accelerator prototype.

[20] González de Vicente et al in Nuclear Fusion (2017), Materials testing facilities and programmes for fission and ion implantation damage – accessible via https://iopscience.iop.org/article/10.1088/1741-4326/aa6a67/meta
[21] IFMIF/EVEDA (2015), IFMIF/EVEDA Phase – accessible via https://www.ifmif.org/?page_id=114
[22] Ibidem
[23] Knaster et al in Nuclear Fusion (2017), Overview of the IFMIF/EVEDA project – accessible via https://iopscience.iop.org/article/10.1088/1741-4326/aa6a6a

Figure 2-2: Indicative laboratory contributions of LIPAc components[25]



Key: LEBT=Low-energy beam transport; RFQ=Radio Frequency Quadrupole; RF=Radio Frequency; MEBT=Medium-energy beam transport; SRF Linac=Superconducting Radio Frequency Linear Accelerator; HEBT=High-energy beam transport; BD=Beam Dump

Though the completion of LIPAc was stalled several times by delays in deliveries and manufacturing, it began operating both proton and deuteron beams last year. LIPAc deuteron beams are generated by injectors and focused and filtered in the low-energy beam transport unit. The beams are accelerated initially by the radio frequency quadrupole and then further by eight superconducting resonators in the SRF Linac (the latter to be completed). The beams are measured and controlled before they are stopped at the beam dump. A cryoplant is deployed to cool the SRF Linac to a steady operating temperature.[26]

In successfully developing LIPAc, which began consistent operations in 2019, IFMIF-EVEDA oversaw the construction of a linear hadron accelerator that is now world-leading in power beam range. It will be overtaken only by IFMIF when it is operational.[27]

ELTL

The EVEDA lithium test loop has been operational since 2011. ELTL activities are overseen and implemented jointly by the JAEA (now by QST) and by ENEA.[28] Lithium target validation has consisted of constructing and operating a test loop that includes purification systems, analytical diagnostics for the lithium target, conducting erosion and corrosion tests for loop structure materials and testing remote handling apparatus.[29]

Physically, the test loop itself is nearly equivalent to the loop that will be built at IFMIF (though it differs in width and lacks a comparable heat removal system). The main loop includes the target assembly, a quench tank, an electromagnetic pump, an electromagnetic flow meter, a lithium cooler, and a dump tank. Argon gas cylinders and vacuum pumps are used to control the loop's pressure and vacuum.[30,31]

ELTL is being used to run diagnostics on the surface of a cross-flowing lithium jet in the target assembly, akin to the jet that will absorb deuterium beams in IFMIF. It will be necessary in IFMIF to control the thickness and waviness of the lithium target jet, and researchers at ELTL are developing methodologies to accurately measure and understand jet shape dynamics; contact probe-based and optical mechanisms will be tested at the loop site. Experimenting with these measurement mechanisms will inform how technical operators at IFMIF can accurately control for lithium jet shapes.[32,33] Simultaneously, a collaborator team of researchers at ENEA in Italy are experimenting with a target assembly mock-up on which they can test remote handling mechanisms that will be required to construct and maintain structures in the lithium target at IFMIF.

Test modules

KIT in Germany, in conjunction with CIEMAT, SCK-CEN, CRPP and the JAEA, are leading the design and validation of materials test facilities. Their research focuses on prototyping a high- and medium-flux test modules and developing small-specimen testing techniques. The labs are experimenting with different designs for high-flux test modules that would allow for irradiation testing at extremely high temperatures, as would be required for certain materials at IFMIF.

Continued relevance of IFMIF-EVEDA

Overall, IFMIF-EVEDA has made significant technical progress on the devices that will be integrated into a comprehensive fusion material testing facility, which researchers aim to start constructing in the next few years. The project has kept EU and Japanese understanding of fusion materials testing on par with China's, which has also made substantial technical progress in the field and also aims to construct its own facility in the short-term. The ongoing technical activities of IFMIF-EVEDA — especially now that LIPAc can run and analyse beam experiments - will directly determine the success of the EU in achieving its goal of constructing and operating its long-awaited fusion materials testing facility.[34,35]

Also, once the use of LIPAc concludes at IFMIF-EVEDA, it will likely be repurposed by experimental particle physicists who are designing their own experiments that will rely on the distinctive and innovative accelerator.

IFERC – Coordinating DEMO design and testing ancillary simulation and remote experimentation systems

IFERC is tasked with the planning and oversight of three auxiliary projects crucial to the technical realisation of ITER and DEMO. IFERC's three subsidiary projects include a DEMO design coordination centre, a computational simulation centre and a remote experimentation centre.

DEMO design and R&D Coordination Centre

The DEMO design and coordination centre was established to implement scientific and technological activities relevant to prepare for the construction of DEMO. The research coordination centre hosts workshops and conferences among its members to discuss physical theories and engineering strategies related to DEMO's design.[36] As the members of the centre belong to separate universities and laboratories, the technical outputs of IFERC's R&D coordination are disaggregated and typically attributed to external institutions. The R&D coordination centre is not the only body tasked with

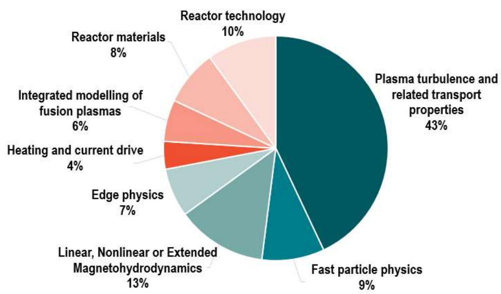
[34] IFMIF/EVEDA (2015), Target Facility
[35] Knaster et al in Nuclear Fusion (2017), Overview of the IFMIF/EVEDA project
[36] Araki et al in Fusion Engineering and Design (2010), Progress of IFERC project in the Broader Approach Activities – accessible via https://www.researchgate.net/publication/251604346_Progress_of_IFERC_project_in_the_Broader_Approach_Activities

overseeing DEMO's design, and outside of the purview of the BA, EUROfusion oversees DEMO design contributions from EU labs.[37]

Computational Simulation Centre

IFERC simultaneously ran the CSC, which provided access to and exploited a supercomputer that was used to simulate large-scale fusion activities to analyse experimental data on fusion plasmas. The HELIOS supercomputer at the CSC was used by researchers to prepare and test scenarios for JT-60SA operation in the short-term and ITER operation in the longer-term, as well as to run models that predict how ITER and DEMO will perform.[38,39] It was also used to run simulations on a wider range of topics relevant to advancing fusion research; its run-time allocated per topic area is depicted in the following figure.

Figure 2-3 CSC modelling time allocated per topic area[40]



The supercomputer was commissioned, constructed, and operated by IFERC, and used by many physicists and engineers to run simulations that could contribute to their ongoing research. It finished its operation in December 2016 and was decommissioned in 2017.[41]

Collaboration in supercomputing within IFERC was continued under the 'Joint EU-JA HPC simulation projects' initiative. It consisted in the allocation of computing time from April 2019 to March 2020 to joint research proposals by Japanese and EU researchers in respectively the QST JFRS-1 and the EUROfusion Marconi-Fusion supercomputers.

Remote Experimentation Centre

IFERC's REC focuses on preparing the equipment and software that will be used to conduct remote experiments in ITER. The REC has progressed in its technical objectives: it has integrated its software and equipment into a remote experimentation room at the JT-60SA site, where the first in-situ testing of its devices will take place as soon as the reactor comes online (scheduled for April 2021, following COVID-19 delays). The REC has already conducted verification tests of remote functionality at the site. The REC has additionally tested its equipment and software at the WEST tokamak in France and has completed fast data transfer tests with ITER's facilities while collaborating with Japan's National Institute of Informatics and with its National Institute for Fusion Science.[42]

[37] Corroborated through interviews with experts conducted in March 2020.
[38] Araki et al in Fusion Engineering and Design (2010), Progress of IFERC project in the Broader Approach Activities
[39] Corroborated through interviews with experts conducted in March 2020.
[40] IFERC (2013), Report of Standing Committee on the 2nd Call for Proposals of IFERC-CSC Helios Computer – accessible via https://www.iferc.org/img/csc/csc_report_on_stc2ndcall.pdf
[41] IFERC (2017), CSC – accessible via https://www.iferc.org/CSC_Scope.html#Activities
[42] Ozeki et al in Fusion Engineering and Design (2016), Progress on ITER remote experimentation centre – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379616301351

The REC will continue to conduct tests and experiments at relevant tokamaks in preparation for working within ITER in the medium-term.[43]

2.1.2 *The scientific relevance of the BA projects in context*

The detailed technical achievements of the Broader Approach projects are significant to the field of fusion research on their own. It is also important to consider these achievements in context, by comparing their output to other nuclear fusion research institutions', and by framing their work with respect to EUROfusion's principal objectives, including the development of ITER and DEMO. Contextualising the achievements of the BA projects reveals their long-term relevance to the field of fusion.

Bibliometric analysis

The BA projects are three relatively small projects in the field of global nuclear fusion research. They coordinate closely with established national fusion research labs in Europe and in Japan. To relate the technical output of the BA projects to that of their peer institutions, simple bibliometric analysis was performed. For this analysis, a database was constructed on scientific publications published by the BA projects, by Japanese fusion labs, by voluntary contributor institutions and other EU fusion labs, and by international fusion labs.

The bibliometric database on BA projects and their close collaborators referenced Google Scholar's extensive collection of scientific publications on nuclear fusion research. Google Scholar was used in this analysis because of its accessibility and its comprehensiveness; however, it did not allow for extensive filtering, such that the database required additional processing before it could be analysed.[44] It should be noted that Google Scholar queries did not capture articles that were associated with a project but were not directly published by the project, especially if authors of such articles worked at institutions separate from the project. For this reason, separate data is presented on IFERC, for which Google Scholar results were non-representative. Please see Annex A for additional details on the bibliometric analysis methodology and its limitations.

Once raw data from Google Scholar was cleaned, the processed database on scientific publications was analysed to calculate three indicators for each in-scope institution: number of relevant scientific publications as a proxy for scientific output, average number of citations per relevant article as a proxy for scientific impact, and instances of collaboration with other institutions as proxies for referencing and joint scientific work. The results of this analysis are synthesised and presented in the figures below.

Scientific output and impact of the BA projects

Figure 2-4 and Figure 2-5 provide an overview of the scientific output and impact of the JT-60SA and IFMIF/EVEDA projects over their lifespans. Figure 2-4 shows the articles associated with each activity published between 2006-2019. **IFMIF/EVEDA published a steady number of articles each year** (~100 on average), while **the JT-60SA increased its article output over time**, such that the JT-60SA outperformed IFMIF/EVEDA in recent years.

[43] Ibidem
[44] For further context on the use of Google Scholar in bibliometric analysis, see Delgado López-Cózar et al in Research Analytics: Boosting University Productivity and Competitiveness through Scientometrics, Google Scholar: The Big Data Bibliographic Tool – accessible via https://www.researchgate.net/publication/324531110_Google_Scholar_The_Big_Data_Bibliographic_Tool

Figure 2-4 Scientific output of the JT-60SA and IFMIF/EVEDA

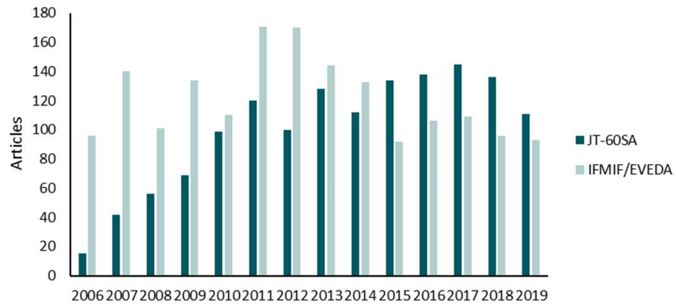
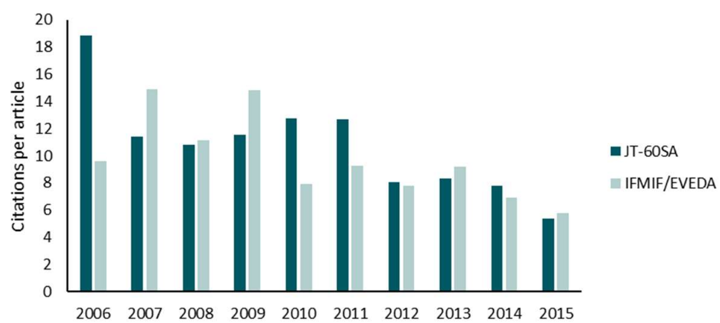


Figure 2-5 shows the average number of citations received per article published for each BA activity between 2006-2015, which allows for a lag of four years after publication in which articles can be cited. Over time, **citations per article gradually decreased for each project** and in particular for the JT-60SA. Even allowing for a delay, **this is largely attributable to timing**: articles published earlier had additional opportunities to be cited over time and contributed to a basis of research which acted as a reference to subsequent activities. The trend is also partly attributed to an increase in articles published relevant to the JT-60SA, which did not all receive the high levels of citations achieved by its early articles; **even as the JT-60SA continued to produce several articles per year which received significant citations, its average citations/article decreased as it began to produce more and more articles**. Because of this, the number of citations received by JT-60SA articles converged more closely to the average level of citations received by articles in the field of fusion research over time.[45]

Figure 2-5 Scientific impact of the JT-60SA and IFMIF-EVEDA



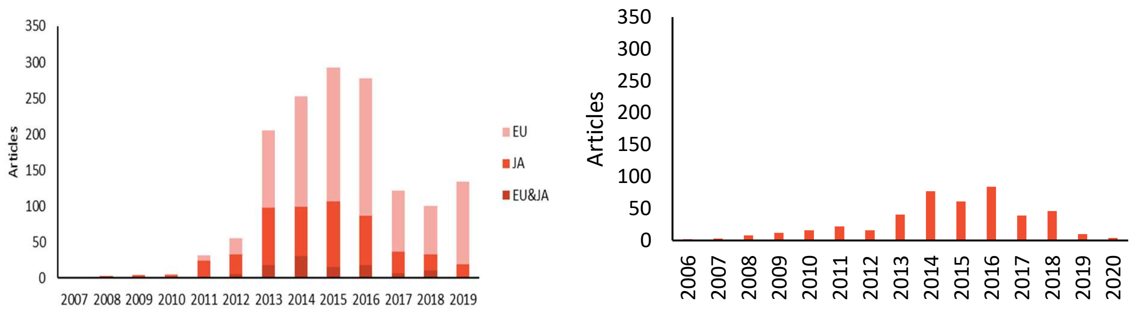
Data on IFERC's scientific output is presented separately in Figure 2-6. As Google Scholar data does not fully capture the number of articles associated with the project since its inception, it is presented alongside data on scientific articles tracked by IFERC's project team. The articles included below in Figure (a) represent the cumulative output from the DEMO Design & R&D, CSC, and REC sub-projects. While **initial publication output remained low, the number of articles produced by IFERC researchers increased in 2011 and spiked between 2013-2016**. The substantial increase in output was driven primarily by articles from EU institutions; articles published jointly by EU and Japanese institutions remained at relatively low levels.

[45] In general, citations are relatively lower in the field of fusion than in comparable fields of physics.

Figure 2-6 Scientific output of IFERC

a) As reported by IFERC's project team

b) As accessible in Google Scholar



These output levels, as tracked and reported by IFERC, far exceed the output levels reflected in Google Scholar's database, as depicted in part (b) of the figure above. The IFERC coordinators total includes conference papers and collaborative articles in their total count which may overstate their strictly scientific output. The comparable data from Google Scholar has its own limitations as this does not credit the project with output published by separate institutions, even if they are affiliated with IFERC activities. Because of this, IFERC's records indicate that the project is responsible for over three times as much output as Google Scholar records reflect. The actual scientifically relevant output is very likely somewhere in-between the two totals and therefore comparable to, or higher than, JT-60SA and IFMIF-EVEDA from around 2013-2016 but lower than the other projects in more recent years.

As the JT-60SA and IFMIF/EVEDA do not collect similar, project-level data on their scientific publications. Articles associated with the JT-60SA and IFMIF/EVEDA were not always tracked by project teams, so data on output between projects (beyond Google Scholar figures) cannot be directly compared in the same basis.

BA projects in the context of the international fusion community

Figure 2-7 again presents Google Scholar data on prominent international fusion labs which have contributed to and collaborated on BA projects. Japanese fusion labs are highlighted in red and include the National Institutes for Quantum and Radiological Science and Technology in Naka (QST) and the National Institute for Fusion Science in Nagoya (NIFS). These labs work closely with the BA project teams and have contributed significant resources and expertise to all three activities.

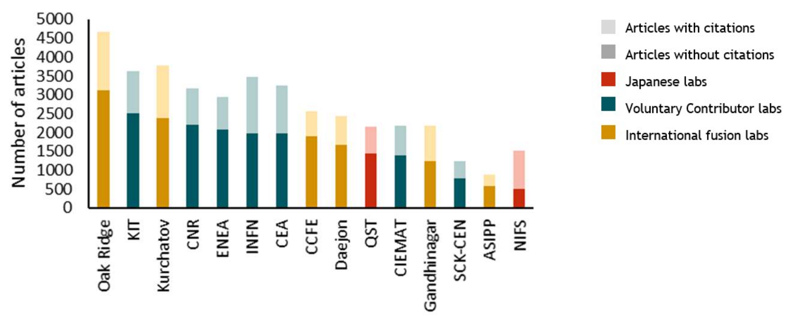
Voluntary contributor labs are highlighted in Green and include: Germany's Karlsruhe Institute of Technology (KIT), the Italian National Research Council (CNR), the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), the Italian National Institute for Fusion Research (INFN), the French Alternative Energies and Atomic Energy Commission (CEA), the Spanish Centre for Energy, Environment and Technology (CIEMAT), and the Belgian Nuclear Research Centre (SCK-CEN). These labs have all provided in-kind contributions to the BA projects and have committed resources and staff to project teams. They remain closely involved in project management.

International fusion labs – each of which oversees its country's contributions to ITER – are highlighted in yellow. They include: the US's Oak Ridge National Laboratory, Russia's Kurchatov Institute, the UK's Culham Centre for Fusion Energy, South Korea's National Fusion Research Institute in Daejeon, India's Institute for Plasma Research in Gandhinagar, and China's Institute of Plasma Physics Chinese Academy of Sciences (ASIPP).

These labs all coordinate national fusion research in their respective countries, except NIFS (as QST oversees fusion research for Japan). Figure 2-7 compares the cumulative scientific output and relative impact of these labs between the years 2006-2020, to provide a sense of their prominence within the international fusion community. Note that all articles published by China's ASIPP are not catalogued in the Google Scholar database such that its output and impact are likely underestimated in the figure.

Oak Ridge National Laboratory produced more articles than any other lab during between 2006-2020, of which 60% received citations. The Kurchatov institute produced the second highest number of articles, though KIT produced more articles that were cited than Kurchatov. **Overall, European labs perform well against their international counterparts; Japanese labs, contrastingly, produce slightly fewer articles than most of their international counterparts.**

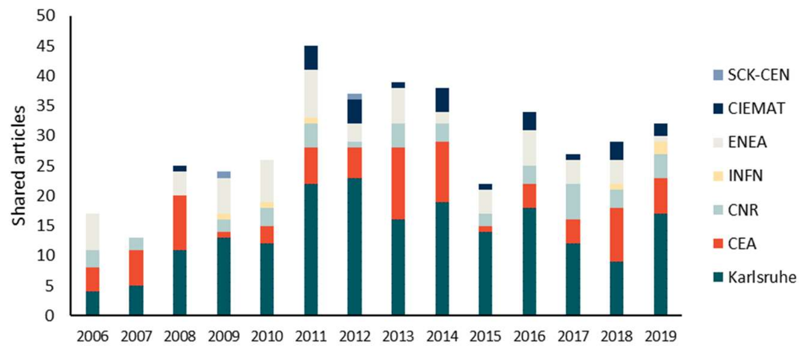
Figure 2-7 Proportion of articles with citations (2006-2020) per national fusion lab



Given the relative roles of these labs, it's interesting to consider collaborations between them; "shared articles" – i.e., articles tied to two labs in the bibliometric database – are used as a proxy to gauge collaborations between fusion institutions. Shared articles over time between Japanese labs and the Voluntary Contributor labs are illustrated in Figure 2-8. The figure depicts data on articles published by QST or NIFS in collaboration with respective VC institutions, i.e., it only shows one side of the collaborations to avoid redundancies.

The BA activities have contributed to increased collaboration over time. Between 2006 and 2019, Japanese labs worked more and more often with EU labs, particularly with KIT, CEA and CIEMAT. The highest periods of Japanese-EU collaboration correspond to the years (2011-2016) in which labs were developing their in-kind contributions for the JT-60SA and IFMIF-EVEDA projects. Maintained collaboration through 2018 and 2019 indicates that the labs will likely continue to collaborate, even if at slightly reduced rates, as the BA projects evolve and the labs work less directly with one another.

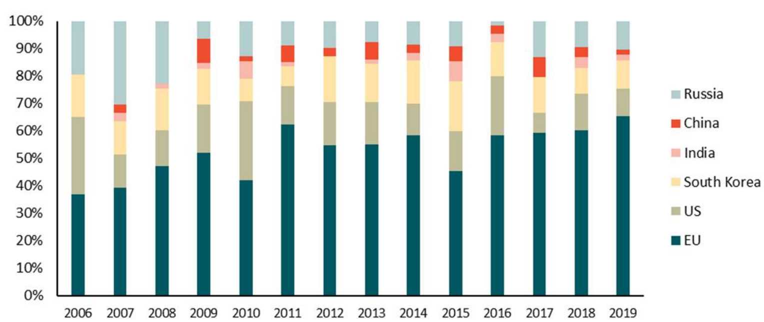
Figure 2-8 Japanese collaborations with Voluntary Contributor labs



Collaborations between Japanese and European labs are compared to collaborations between Japanese and international labs in Figure 2-9. The figure shows the proportion of all collaborative articles published by QST and NIFS shared with respective international fusion institutes, labelled by country. “EU” institutions include the VC labs listed above and CCFE, considered a European institution until the UK left the EU in 2020. **Analysis indicates that the proportion of Japanese collaborations with the EU increased over the lifespan of the Broader Approach, while the share of collaborations with the US and Russia gradually decreased.** The proportion of collaborations with China and India initially increased before fluctuating, while the share of collaborations with South Korea remained relatively steady over time.

Since 2006, Japanese labs have worked on joint articles more frequently with European labs and less frequently with other international partners. Between 2006 when the Broader Approach was created and 2019, the proportion of shared articles between Japanese and EU institutions increased from 37% to 65%

Figure 2-9 Proportion of Japanese collaborations with international fusion labs



BA project alignment with EUROfusion objectives

From the outset, the BA projects were designed to support European and Japanese progress towards fusion objectives – they were set up to address needs in the fusion community that as of 2007 had not yet been fulfilled. The JT-60SA project was tasked with progressing tokamak design, construction, and operation, IFMIF-EVEDA was tasked with validating the engineering designs for a nuclear fusion materials testing facility, and IFERC was tasked with advancing DEMO project planning while testing remote reactor operation and computational experimental simulations.

The BA projects are well-positioned to fulfil their envisioned technical roles; the results of the three projects will be directly relevant to half of EUROfusion's core challenges in the fusion research.[46] The BA projects therefore act as significant contributors to tackling the challenges set out by EUROfusion for realising fusion energy. Their missions are outlined in the table below and juxtaposed with BA project objectives and results which will directly contribute to accomplishing half of EUROfusion's stated goals.

Table 2-2: Challenges in fusion research – BA project relevance with respect to EUROfusion's Missions for the realisation of fusion energy

Challenge	Description[47]	Relevance of BA activities
M1. Plasma regimes of operation	• Plasmas must be confined at extremely high temperatures • To achieve these high temperatures, energy losses due to turbulence must be minimised and plasma instabilities must be controlled through carefully configured magnetic confinement • Experiments and theory-based models need to be developed to test different plasma regimes of operation • Advances in plasma confinement techniques ultimately need to be fully integrated with the engineering design	• IFERC's supercomputer was used by physicists to model theoretical plasma regimes which will be tested at the JT-60SA and at ITER • The JT-60SA will begin testing plasma containment at the extreme conditions required in next-generation fusion reactors • Research on JT-60SA experiments will allow physicists and engineers to better understand, model, and theorise on the behaviour of plasmas at high temperatures, densities, pressures, and elongations • Experts working on JT-60SA experiments will be gain knowledge they can directly apply to their work on future reactors like ITER and DEMO
M2. Heat-exhaust systems	• While plasma-facing materials and exhaust systems have been developed, their operation needs to be tested and improved • A solution for the much more robust heat exhaust system required in DEMO still needs to be developed and tested experimentally	• The heat-exhaust system at the JT-60SA will be the most advanced ever tested • Studying its response to high-heat plasma generation and confinement will enable technical engineers to better understand how heat-exhaust systems can be improved
M3. Neutron tolerant materials	• Materials that can withstand a flux of neutrons at higher energy levels and maintain their structural integrity over time have been developed for use in ITER, but not yet for use in DEMO and commercial power plants • Theoretical and experimental research is still required to produce materials that exhibit reduced activation under high levels of neutron flux	• It is the purview of IFMIF-EVEDA to validate the design of a materials testing facility that can be relied on to run experiments which will fill knowledge gaps on material reactions to high-intensity neutron fluxes • Experiments at the JT-60SA will provide further practical knowledge on how materials are altered in fusion reactors (though not at levels akin to DEMO operation)
M4. Tritium self-sufficiency	• Tritium self-sufficiency – essential for DEMO and future commercial fusion power plants – requires efficient breeding and extraction systems • A "Test Blanket Module" programme will be conducted at ITER to validate proposed designs for DEMO, but will require additional R&D support to address performance uncertainties and feasibility issues	• IFERC's programme on DEMO R&D oversaw research on the development of tritium technologies and tritium durability, as well as advanced tritium breeders for a DEMO blanket
M5. Implementation of the intrinsic safety features of fusion	• Passive resistance in reactors to any incidents must be ensured through methods to reduce the presence of tritium in components extracted for disposal, and methods to appropriately dispose and recycle these components	• While experiments at the JT-60SA will allow for the testing of fusion reactor safety features, they will not allow for testing of intrinsic features related to the behaviour of tritium-deuterium plasmas

[46] Corroborated through interviews with experts conducted in March 2020.
[47] Adapted from EUROfusion (2018), European Research Roadmap to the Realisation of Fusion Energy, Long Version – accessible via https://www.euro-fusion.org/fileadmin/user_upload/EUROfusion/Documents/2018_Research_roadmap_long_version_01.pdf

M6. Integrated DEMO design and system development	• ITER's design and operation will serve as a basis for DEMO's design • However, DEMO will need to integrate a self-sufficient tritium-producing blanket, more efficient technical solutions for remote maintenance, and components that are as reliable as possible	• The results of all three BA projects will feed directly into the design, construction, and operation of DEMO (see subsequent sections)
M7. Competitive cost of electricity	• DEMO will serve as a test site for minimising capital and operational costs • Research activities on fusion energy will incorporate socioeconomic analysis	N/A
M8. Stellarator	• The stellarator design will continue to be developed with the caveat that their physics basis is not yet mature enough to achieve electricity from fusion within the 21st century	N/A

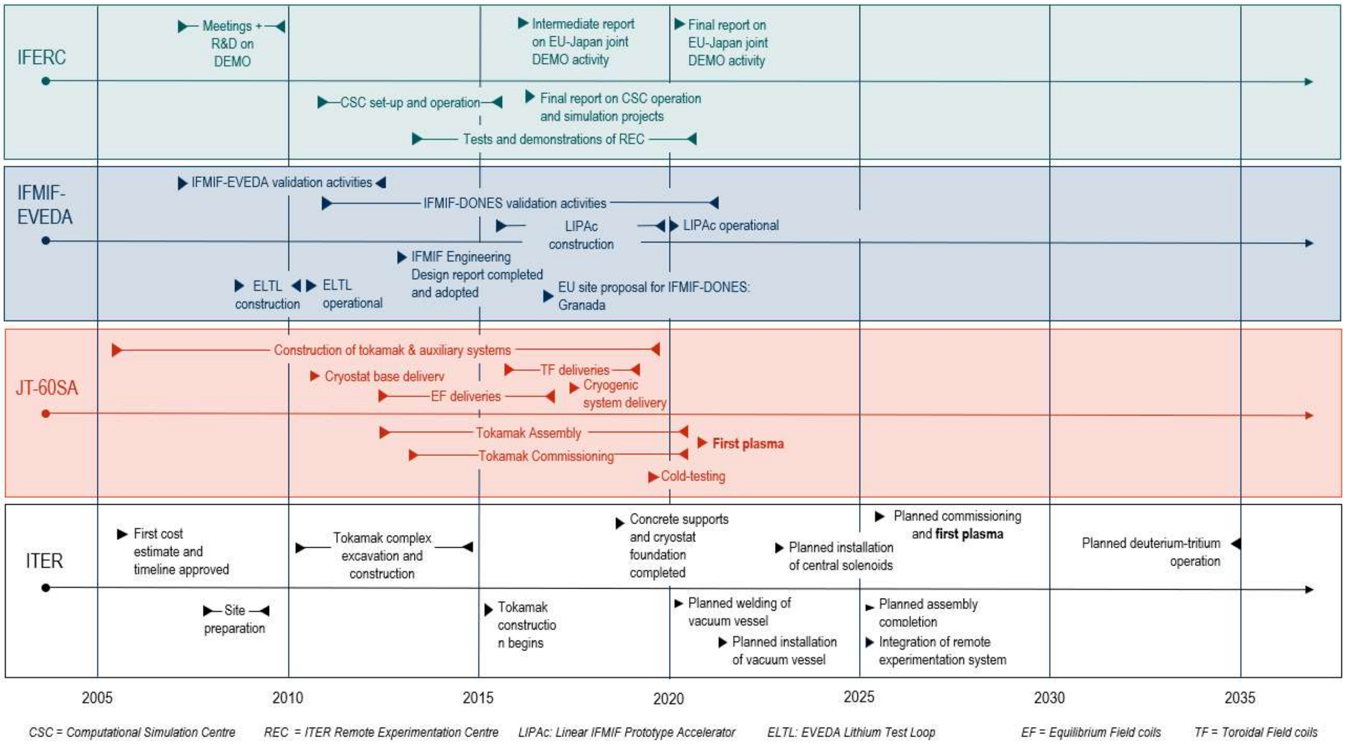
Additional analysis mapping Broader Approach project timelines and objectives to the EUROfusion roadmap is included in Annex A.

Assessment on how BA projects have reduced and can continue to reduce risks for ITER and DEMO

As described in the previous sections, the BA projects were devised in part to support the fusion community's preparations for designing and building ITER, and for designing DEMO. Section 2.1 describes how the technical achievements of the BA projects will directly contribute to ITER's development and operation; in particular it highlights how the activities of the JT-60SA have and will contribute to de-risking ITER's operations.

Figure 2-10 depicts timelines for the BA projects juxtaposed with ITER's project timeline, which is more concrete than DEMO's. It shows how the **principal milestones of the BA projects directly correspond to and precede ITER's principle milestones**. Again, the activities of the JT-60SA are most closely linked to ITER's upcoming activities; knowledge amassed during the procurement and construction of the largest tokamak will inform the procurement and construction of its successor, ITER. Of the three BA projects, IFMIF-EVEDA is least linked to ITER; its primary objective is rather to validate a facility that will test materials for use in DEMO and reactors beyond DEMO. Still, all three projects have undertaken activities that have reduced and will continue to reduce risks ITER; **project teams at the JT-60SA, IFMIF-EVEDA, and IFERC have built up bases of knowledge in subsectors of fusion research that will serve them well as they begin to work more intensively on implementing ITER**.

Figure 2-10: Mapped timelines for the Broader Approach projects and ITER[48]



Contributions of the JT-60SA to risk reduction for ITER and DEMO

The first stated objective of the JT-60SA project is to "provide supporting research for the ITER project to accomplish its technical targets."[49] But it was also designed to address gaps in fusion research and tokamak experimentation that must be better understood before finalising design plans for DEMO.

Knowledge built up in European labs and institutions while they manufactured and transported the JT-60SA's magnet systems, cryoplant, and in-vessel remote handling systems will be deployed to develop the same components for ITER. The JT-60SA is intended to act as a satellite project to ITER; though the JT-60SA will start up before ITER, the two tokamaks will eventually run in parallel and will explore different regimes of plasma operation in order to cover the wide basis of experiments necessary to inform DEMO design. In the short-term, though, many of the tests at the JT-60SA will inform ITER's development. Procurement and construction processes for the two large-scale tokamaks significantly overlap; their construction time schedules have been interlinked to ensure complementarity.

Beyond construction of the tokamak, **early experiments at the JT-60SA will bridge the gap between existing tokamak understanding and know-how and the understanding necessary to successfully operate ITER at its target levels**. The JT-60SA will conduct the first experiments that scientists can analyse to better understand plasma containment at extreme conditions; the JT-60SA will run plasmas at elongations, energy levels, and time-scales formerly untested, and the observed behaviour of these plasmas will determine how researchers at ITER will prepare for their own plasma runs.

[48] Adapted from the timelines available on the sites of the three BA projects and on ITER's project site.
[49] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project

Annex A contains more detailed technical analysis on how the key design features and target regimes of the JT-60SA will directly inform the operation of ITER and the design of DEMO.

Contributions of IFMIF-EVEDA to risk reduction for ITER and DEMO

IFMIF-EVEDA's objectives are more closely linked to risk reduction for DEMO, rather than ITER. Materials for use in ITER have already been tested and validated; the facility that IFMIF-EVEDA's work will contribute to will test materials for use in a larger-scale, commercially viable reactor. IFMIF-EVEDA's technical achievements will inform the design of IFMIF-DONES (with a DEMO Oriented Neutron Source), the ultimate fusion materials testing facility. Its potential for risk mitigation will be realised only in the long term, and more for DEMO than for ITER.[50]

That said, experts working on IFMIF-EVEDA are integrated into the European fusion research communities. Through their work on the project they have built up knowledge on generating beams with neutron intensities and fluxes at the levels found in reactors and have theorised on how materials might respond to the extreme conditions experienced in a large-scale fusion reactor. This could serve ITER's project team if they encounter any difficulties with materials during their experiments, or as they design experiments (in the long run) that are tailored toward DEMO preparation.

Contributions of IFERC to risk reduction for ITER and DEMO

Two of IFERC's three subsidiary projects have generated knowledge that will de-risk ITER's operation. **Its supercomputer at the CSC was used by physicists and engineers who were modelling how large-scale plasmas might behave at ITER**. The results of their modelling informed the research plan that they then developed for the large-scale tokamak, and are discussed in further detail in the previous section of this chapter.[51]

IFERC's REC – which will be tested at the JT-60SA – will ultimately be used to provide remote access to experiments at ITER. This will expand the field of researchers with access to ITER and will enable a wide ranging technical collaboration and knowledge diffusion.[52] **The ability to participate remotely in experiments at the tokamak is considered particularly important by scientists in its contributing countries and could potentially mitigate political risks related to exclusion or unequal access between contributors**. Multiple stakeholders emphasised that the development of remote experimentation capacities is a significant step forward for the fusion community, and that similar REC facilities will likely be created at other fusion labs for more widespread use.

IFERC's sub-projects on DEMO Design and R&D activities were designed to establish a common basis for DEMO planning. The sub-project has overseen significant scientific output that advanced knowledge on silicon carbide composites, tritium technologies, materials engineering relevant to DEMO, advanced neutron multipliers relevant to DEMO, and advanced tritium breeders necessary for DEMO.

2.2 Analysis of the BA implementation and impacts for participants in Europe

This section complements the technical review of the scientific results of the BA projects by focusing on the impacts for European BA participants (especially companies) and the BA governance and project management. This section is based on a number of sources, especially: analysis of BA-related

[50] Corroborated through interviews with experts conducted in March 2020.
[51] Corroborated through interviews with experts conducted in March 2020.
[52] Araki et al in Fusion Engineering and Design (2010), Progress of IFERC project in the Broader Approach Activities

documents, interviews with 32 stakeholders and survey responses of 30 other stakeholders (see further details in Annex C).

2.2.1 Impacts for the EU, contributors and companies

Table 2-2 Summary of the impacts of BA for the EU, contributors and companies

	Summary
Main impacts and overall evaluation	• The BA demonstrates that the fusion community is able to deliver on its commitments on budget. • The BA provides various technical, economic and managerial benefits to research organisations and companies. • The original estimate of the resources required for the different projects were generally adequate and the financial contributions by the implementing agencies were well managed.
Positives	• Research organisations and companies benefit from networking, access to BA knowledge, guidance regarding their own research agenda, increased alignment with ITER activities and non-technical competences. • In addition to procurement contracts, there are cases where the BA has allowed suppliers to enter the fusion or high energy physics sectors, transfer technology to other sectors or enter the Japanese market. • Italy and Germany did not significantly deviate from their planned budget commitment. • National organisations sometimes leveraged additional sources of funding as the BA was in their line of research, which allowed them to make additional contributions.
Negatives	• There were issues with the annual allocation of funds by national policymakers during the government budgeting activities. Spain had a small budget overrun and also possibly France. • JT-60SA requires metallic walls (such as tungsten) to fully contribute to ITER, but the choice was made to start with carbon walls. • Companies supplying products and services to Voluntary Contributors are not included in F4E technology transfer marketplace.
Recommendations	On-going actions to maintain/further develop: • LIPAc completion and commissioning should be followed closely to maintain progress and address disruptions in order not to further delay DONES and the overall DEMO roadmap. • External communication should highlight the importance of the BA to the EU and JP fusion roadmaps, and that the fusion community is able to deliver within budget • EUROfusion and F4E should increase collaboration in technology transfer activities within the F4E marketplace and the EUROfusion FUTTA II. New actions: • F4E should aim to also include in its technology transfer initiative companies providing products and services to the BA through Voluntary Contributors, not only through F4E. • F4E and QST should agree on showcasing each other's technologies in technology transfer platforms.

BA impacts for the EU

The Broader Approach has significant political benefits for the EU. The BA strengthens the relationship in research and technology, and between Japanese and EU governments more broadly. EU and Japanese stakeholders strongly agree that the BA has had a positive impact in building trust between the EU and the Japanese government authorities and fusion research community. The collaboration between the EU and Japan increased their alignment for discussing and negotiating fusion-related aspects outside of the BA, including for ITER, as highlighted by multiple EU and Japanese interviewees.

BA impacts for companies

There is evidence that the BA has resulted in additional benefits to EU companies in the VC Member States in addition to procurement contracts for the BA in-kind contributions (discussed under the spending section in Annex B). The BA provided the opportunity for specific companies to supply products and services to enter the fusion or high energy physics sectors, as in the case of a German company with over 200 employees. In some cases, participation in the BA allowed for the development of new markets, products or services, for research organisations and companies.

Three case studies of benefits of the BA to companies and technology transfer are presented at the end of this section, namely regarding:

- ✓ Seven Solutions (a Spanish company) and the provision of ultra-accurate timing solutions to IFMIF/EVEDA;
- ✓ High-temperature superconducting electricity transport in Germany using technology partially developed for the BA;
- ✓ ASG (an Italian company) and the provision of JT-60SA toroidal field coils, which allowed it to improve their positioning to supply products and services to ITER.

Another example of technology transfer is the use of materials technology developed within the IFERC project by German automotive industry SMEs. The French company Atos, which provided the IFERC Helios HPC, established a partnership with Hitachi Data Systems as a direct result of its participation in IFERC.[53] It was indicated in the interviews that participation in the JT-60SA also enabled other EU companies to enter the Japanese market, as they learnt how to deal with Japanese clients and suppliers, became familiar with safety standards and overcame linguistic barriers. One EU stakeholder indicated that Japanese companies also benefited from their involvement in the BA by being exposed to work practices of EU companies.

Companies and research organisations participating in the Broader Approach have indicated that it has had a positive impact for them. Networking, access to BA knowledge, guidance regarding their own research agenda, increased alignment with ITER activities and non-technical competences are the main impacts listed as 'positive' or 'very positive' by survey respondents (see annex B). Specific examples include becoming part of the fusion network for an industrial stakeholder, and positive collaboration with multiple EU and JP laboratories in the case of an EU research organisation. Details provided on the non-technical competences impacts highlighted the benefits of working in a positive, multi-disciplinary international collaboration environment. Fewer survey respondents indicate DEMO activities as beneficial, since DEMO activities are 1) in the initial R&D and conceptual design phase; and, are 2) less relevant to companies. The perception of BA stakeholders regarding the benefits from DEMO activities could be re-assessed in the medium term to identify changes as the activities become more concrete.

The BA could more actively pursue opportunities for such technology transfers. A few of the national organisations interviewed have specific departments focusing on technology transfer to industry. However, such synergies vary per country and between companies. It may also depend on efforts by research organisations to transfer knowledge to industry (for example, one German organisation indicated that they have this as a particular focus). Technology transfer could benefit both the EU and JP, and further develop the relationship between the two parties. F4E itself has a technology transfer marketplace[54], but an October 2020 webinar announcement[55] referred only to ITER

[53] See Hitachi (2018) A Winning Partnership in Digital Transformation infographic.
[54] https://techtransfer.fusionforenergy.europa.eu
[55] F4E (202) Technology Transfer activities: new business opportunities from fusion. https://www.eventbrite.fr/e/billets-f4e-technology-transfer-activities-new-business-opportunities-from-fusion-124580117485

activities – the BA and technology developed for it should be highlighted alongside ITER in the initiative. Seven Solutions is the only company which provided services to the BA activities that is listed in the 14 technologies offers in the F4E marketplace. The in-kind contributions approach of the BA is a barrier to increasing the participation in the F4E technology transfer marketplace of companies supplying products and services to the BA, as most companies have not provided those directly to F4E. F4E could consider including these companies, even if through Voluntary Contributors. F4E and QST could furthermore agree on showcasing each other's technologies in technology transfer platforms. The EUROfusion FUTTA II (Fusion Technology Transfer Activities)[56] also promotes fusion technologies with seven brokers (in FR, IT, DE, UK, ES and BE), and EUROfusion will set up a fusion technology transfer office. EUROfusion and F4E should collaborate in technology transfer activities. There are synergies between the F4E and EUROfusion initiatives, as they employ the same network of brokers. However, there are differences in the target organisations of the technology transfer initiatives (companies for F4E, and labs for EUROfusion) and in the readiness level of the technologies (higher for F4E).[57]

The employment and turnover impact due to the BA varies per company, although it is limited (no impact, or less than <10% of total turnover and employment) for the majority of companies (see annex B). Of the 14 companies which responded to the survey, the BA led to a turnover and employment impact of 10-30% in 2 companies, and of 30-50% in one company (indirect). For the majority of companies which responded, the BA had some impact on the turnover and employment due to new products, service or projects developed.

Case study: Seven Solutions and the provision of ultra-accurate timing solutions to IFMIF/EVEDA [58]

Seven Solutions provides 'embedded systems and leading accurate sub-nanosecond time transfer and frequency distribution for reliable industrial and scientific applications'.[59] Seven Solutions hardware and software employs technology developed by the White Rabbit project, an international collaboration to develop synchronisation solutions for CERN, whose open source approach led to the adoption and further development of the technology in other applications.

Starting with a contract to CIEMAT with whom they had worked with previously, Seven Solutions has in total provided products and services for IFMIF/EVEDA in four different BA contracts, including by direct contracting by F4E. The tasks realised relate to the development of hardware and software for the control system (LLRF), beam instrumentation (BPM) and radio frequency and time distribution system of LIPAc.

All BA contracts were technically challenging to Seven Solutions, requiring the development of new technology, as well as providing a point of entry to the fusion energy and particle accelerator sector. As a consequence, the High Energy Physics department was created in the company, and besides the four BA contracts, the company is working with CEA in the design of advanced LLRF and BPM on another accelerator project, as well as having a small contract with ITER and ESS to providing technical support. Hence, while accounting for around or less than 10% of the total company revenue and employment, the BA has led to other concrete business opportunities. The BA has also provided experience in

[56] http://techtransfer.euro-fusion.eu/
[57] F4E (2020) Technology Transfer activities: new business opportunities from fusion. Webinar held on October 2020.
[58] Based on an interview with SevenSolution, the company website and CERN "The White Rabbit Project", availabe at https://white-rabbit.web.cern.ch/
[59] SevenSolutions. Company website. Available at http://sevensols.com

providing services as on-site/off-site support, and some of the quality management system procedures (such as the development of a risk plan) were incorporated in the company's internal processes.

Case study: High-temperature superconducting electricity transport[60]

One example of non-fusion applications of technology (partially) developed within the Broader Approach is the use of high-temperature superconducting (HTS) cables for electricity transmission and distribution by network operators. KIT (DE) was, within the BA, responsible for the development, manufacturing and supply of 26 HTS current leads for the toroidal, equilibrium and central solenoid field coils of JT-60SA. Within the KIT work for the JT-60SA, steps were taken to move from BiSrCaCuO to REBCO ceramic superconductors and to improve manufacture. The latter has significant potential cost reductions, which would enable HTS technology partially developed for this work to be routinely applied for electricity transmission.

The HTS CrossConductor (CroCo) technology developed during the JT-60SA research led KIT to be awarded, along the Swiss Plasma Centre, the EU SOFT Innovation Prize for Fusion Research, in a large part due to its applicability outside the field of fusion. HTS technology has recently started to find practical applications in electricity transport. The AmpaCity project in Essen is a direct result of the transfer of KIT HTS technology to non-fusion applications. Launched in 2011, the collaboration with Innogy, Nexans and others led to the commissioning in 2014 of a 1 km HTS cable in Essen (then the longest in the world), which is still in operation.

Case study: Industrial synergies between the BA and ITER: the toroidal field coils case[61]

ASG Superconductors, based in Italy, has significant experience in superconducting coils for fusion applications, supplying for example JET and Wendelstein 7-X coils. ASG was contracted to supply part of the toroidal field coils both for ITER and the JT-60SA. It received the contract for supplying 10 out of the 19 ITER TF coils in 2010, as part of a consortium. Then, ASG was awarded in 2011 the contract for the manufacture of 9 out of the 18 toroidal field (TF) coils of the JT-60SA (plus one out of the two spare coils). In 2012 ASG was also awarded a further engineering integration contract related to the ITER poloidal field coils. Japan is responsible for the delivery of the remaining 9 ITER TF coils (including the one ITER spare coil).

The experience in the manufacturing of the BA TF coils had a positive impact to the ITER delivery. Although the ITER TF coils were contracted earlier, the delivery of the JT-60SA TF coils occurred before, as assembly in Japan was finished by mid-2018 while the first TF coil to ITER from F4E was ready for delivery in 2020.

Here, a link can be made to the simplicity and effectiveness of the common quality management system (QMS) of the JT-60SA, which one BA management staff indicated to having helped the BA suppliers improving their own QMSs, particularly SMEs. Nonetheless, the separation of the BA TF coils manufacturing between two different suppliers in Italy and France (ENEA and CEA were responsible for the in-kind delivery of the BA TF coils) was not without issues. The coils quality and initial expertise of

[60] Based on interviews and: Wolf et al. (2016). HTS CroCo - a Stacked HTS Conductor Optimized for High Currents and Long Length Production. IEEE Transactions on Applied Superconductivity 26(2); KIT (2016) EU Grants EUR 50,000 Prize to Energy Researchers; innogy. AmpaCity superconductor project page.

[61] Based on interviews and: ASG Superconductors. ITER TFC, ITER PFC and JT-60SA TF coils project pages; Polli et al. (2019). JT-60SA toroidal field coils procured by ENEA: A final review. Fusion Engineering and Design 146(B); IO (2020) Industrial milestone - Europe completes D-shaped magnet.

the suppliers differed – but this can be expected for any two given companies. Eventual quality issues were addressed, although this highlights the importance of product and process technical specifications being followed by all suppliers, especially by those responsible for the delivery of a number of units of the same component (as is the case for some ITER components, including the TF coils).

Impacts of Voluntary Contributors

Feedback from interviews suggests that **the original estimate of the resources required for the different projects (reflected in the BA units of account) were generally adequate, and EU and Japanese interviewees indicate the financial contributions by the implementing agencies were well managed.** Italy and Germany did not significantly deviate from their planned commitment, whilst Spain had a small overrun, and also possibly France. Voluntary Contributors have not made public any consolidated and accurate accounts of BA-related expenditures, therefore it is not possible to draw strong conclusions. Direct and indirect benefits from the BA to research organisations and companies was a central motivation for the voluntary contributions. An analysis of the resource spending in the BA is provided in Annex B. Organisations have leveraged additional (national) sources of research funding to address eventual small overruns, as their main motivation to voluntarily contributing to the BA was often the development of new knowledge in-house. Anecdotal evidence also indicates that these other funding sources allowed national organisations to make additional contributions to the BA, as it was in their line of research, hence delivering more than was originally agreed.

However, there were issues with the annual allocation of funds by national policymakers during the government budgeting activities, which in some cases have impacted the delivery of in-kind contributions. This had an impact and caused delays in the project timelines, especially IFMIF/EVEDA and JT-60SA, which required spreading the project budget across a longer period of time. Risks related to the new funding arrangements for phase II are addressed in section 4.1.5.

Future of Voluntary Contributors

The EU contributions in phase II will be funded via F4E and EUROfusion, not the Voluntary Contributors as in phase I, this raises a question for VCs on how they wish to stay involved with BA. It is still the case in phase II that the original (and any new) Voluntary Contributors could nonetheless make (limited) contributions to the budget of the BA, most likely in the form of in-kind contributions for specific project enhancements. In-kind contributions can be an effective way to enhance ownership by VC organisations as they provide returns on the investments of VCs and can constitute a better learning opportunity than just conducting experiments with e.g. JT-60SA. As JT-60SA and LIPAc reach their full performance (subject to further enhancements), calls will be launched for the experimentation with the machines. The contributions made by VCs may be reflected to some extent in the access to the machines, for example through EUROfusion giving priority or additional points to experiment proposals with participation of organisations from the original VCs. This could be an incentive to Member States providing further contributions to future enhancements. It could be useful to check with each of the original VCs and other EURATOM countries if they envisaged such a contribution in phase II and what could be done to incentivise this.

3 Governance and project management of the Broader Approach

3.1 Governance structure of the Broader Approach

This section explores the governance structure of the Broader Approach as defined by its main bodies (the project & steering committees, integrated project teams, and EU and JP home teams) and their connections, both internally as well as with other relevant organisations such as F4E, EUROfusion, ITER, MEXT and others. The analysis presents the formal governance structure and identifies (informal) governance arrangements which have arisen since the Approach implementation. A more detailed description as well as a mapping of the governance structure of the Broader Approach is presented in Annex B.

Table 3-1 Summary of the BA governance structure evaluation

	Summary
Main impacts and overall evaluation	• The evaluation of the governance structure of the overall Broader Approach is positive. Despite the formality of the Committee meetings, the overall governance structure is flexible and effective as long as parties are committed to the main goals. • The role of EUROfusion in the BA programme is increasingly important. Strong coordination with F4E is paramount, especially as F4E is the formal Implementing Agency and it is not worthwhile to change the BA agreement to formalise a role for EUROfusion. • Japan has gained trust in F4E, and prefers that F4E remains the (single) counterpart (according to EU interviewees); this increases the importance of coordination on the EU side, which already has adequate mechanisms (Contact Persons, EUROfusion-F4E meetings).
Positives	• The bilateral natural of the Broader Approach, the use of in-kind contributions and the strong motivation and trust developed by organisations and experts are positive factors for the BA governance. • Minor changes to the governance structure (e.g. number of BASC members) are not deemed necessary at the moment. • The delivery structure focused on in-kind contributions, with F4E playing an important role in overall integration and management and contributing to eventual contingencies, was effective. • The Contact Persons and the F4E-EUROfusion meetings are essential mechanisms for coordination between European parties. The F4E-EUROfusion MoU solidifies their cooperation. • Ad-hoc bi-monthly meetings have been set-up due to COVID-19 travel restrictions, maintaining high-level coordination between the Parties.
Negatives	• The BA Steering and Project Committees meetings are very formal, but difficult to change given the reluctance of the Parties to alter the BA Agreement. • There is a risk that IP rights issues could constitute a long-term risk for European commercial nuclear fusion reactors.
Recommendations	On-going actions to maintain/further develop: • Maintain current governance structure. Continue ad hoc bi-monthly meetings with JP to provide a communication channel more flexible than BASC meetings, review the approach in the 2nd half of 2021. • Continue the coordination meetings (Contact Persons and F4E-EUROfusion) to allocate and monitor EU activities as well as agree on a common position on negotiations with JP. • Continue assigning staff for management positions according to their availability and expertise, and increase involvement of EUROfusion members as part of the project teams. • Consider streamlining project governance, such as creating a unified framework for sending researchers to JP, with harmonised financial incentives. • Ensure EUROfusion is involved throughout the drafting of agreements related to the BA where it will be a co-signer with F4E and European laboratories, to avoid delays and re-negotiations. • Maintain the practice to invite EUROfusion to all BASC meetings as an observer. For some topics EUROfusion could take the lead in discussing with Japanese counterparts, after agreement with F4E on the specific matter.

	New actions: • Evaluate following completion the joint F4E-EUROfusion procurement for JT-60SA diagnostics to identify improvements and best practices. • Evaluate F4E-EUROfusion collaboration on BA in 2022 to understand how effective and efficient the arrangement is. • Consider employing the BA approach for other bilateral international collaboration activities, including replicating its Quality Management System. • Consider regular bilateral meetings between DG Energy and DG RTD to complement the Contact Persons meetings.

3.1.1 High-level Broader Approach governance between the Parties and EU organisations

The evaluation of the governance structure of the overall Broader Approach is positive, as corroborated by the F4E BA audit, BA project documents, interviewees (both from the EU and Japan) and survey respondents. It must be noted that the scope of governance of the BA left to the Steering and Project Committees was somewhat restricted (especially in phase I), as aspects such as the budget, in-kind and financial contributions, and overall structure of the integrated project teams were defined in the BA Agreement.

Some interviewees highlighted the highly formalised nature of the Broader Approach Steering and Project Committees meetings as cumbersome, requiring substantial preparation ahead and with much of the discussions and decisions taking place outside of the BA Steering and Project Committees. The meetings themselves being a less active exercise for major decisions. Nonetheless, the formal approach provides a framework for taking joint decisions and guaranteeing that these are honoured by both parties, and for escalating issues which could not be solved within the project teams, although it is difficult to raise new issues during the meetings themselves.

Despite the formality of the Committee meetings, interviews as well as survey responses confirm that the overall governance structure is flexible and can work effectively as long as parties are committed to the main goals. Therefore, no major changes in the governance structure were proposed by stakeholders, also considering that it would be difficult, as it would require changing the BA Agreement. A European management staff member also indicated that ‘tweaking’ a governance arrangement which is working well could have unintended consequences.

The BA governance structure could be a potential model for other bilateral (EU-third parties) international cooperation initiatives. The governance of the Broader Approach is facilitated by its bilateral nature, being an agreement between Euratom and Japan. Most of the governance structure would hence be applicable to bilateral international cooperation initiatives. Strong coordination on the EU side as well as the clear commitment of (and benefits to) the other party are imperatives to the success of the governance structure.

The onset of the COVID-19 crisis has impeded physical meetings of the BASC. To address this, bi-monthly informal online meetings of the BASC have been set-up. The effectiveness of these meetings should be assessed and they could be continued even after travel restrictions and social distancing measures are phased out.

The EU Contact Persons meeting with Commission, F4E and VC representatives acted as an efficient platform for coordinating the EU work in the Broader Approach, and to taking joint decisions and positions towards Japan. Japan values the ability to interact with F4E as the main point of contact on the BA, and in that regard the Contact Persons meeting was instrumental for discussions and decisions among European organisations which could not be taken in the formalised setting of the BA Steering Committee.

Continuous cooperation between DG Energy and DG RTD is necessary as F4E and EUROfusion are under these Commission Services, respectively. This strengthens the importance of the Contact Persons meeting as the main joint governance mechanism for the BA, as the organisations are under different Commission Services (DG Energy for F4E and DG RTD for EUROfusion). Some EU and JP stakeholders thought better coordination was required between the two services. Regular bilateral meetings between DG Energy and DG RTD could be considered to complement the Contact Persons meetings.

3.1.2 Broader Approach governance within projects

The BA governance set-up has worked largely due to the high level of trust between parties, which was built up over time. EU and Japanese stakeholders were unanimous in that there is a spirit of collaboration in the BA, which is a main factor for the success of the projects. Building this spirit of collaboration demanded that management and project staff overcome important cultural barriers, described below. The increased presence of EU staff on-site and the need for closer collaboration due to the delivery and assembly of components and commissioning of the projects contributed to trust-building.

The delivery structure focused on in-kind contributions by EU voluntary contributors and Japan, with F4E playing an important role in overall integration and management, and contributing to eventual contingencies. It was generally seen as effective in meeting the BA objectives. There is a perception by stakeholders that the interaction with F4E in the context of the BA is more positive than in the context of ITER. Factors explaining this include: the importance of in-kind contributions in the BA, which implies a different role for F4E than in ITER (where F4E plays a more important role regarding procurement); the complexity of the ITER negotiations arising from the multi-lateral nature of IO; the additional coordination taking place in the Contact Persons meeting; and the pragmatic quality management system of the BA projects (discussed below). As responsibility for delivery of in-kind contributions is spread across different organisations, the project lead should take decisions with representatives from all contributing organisations, closely monitor the delivery of products and services, and escalate issues to the BASC when necessary. The participation of EUROfusion in commissioning and experimentation could centralise the provision of certain products and services in the next phases.

Staff for management positions for each BA party in the project teams are chosen from available experts of the respective party organisations. Interviews indicate that the current EU management staff for the integrated project teams of all three BA projects are strong. The flexibility in setting-up the management teams allows the selection of the most appropriate person considering expertise and past relationship with Japanese counterparts, but is also conditional on their availability and willingness. The flexibility can be seen for example, in the early phases of the projects, the integrated project teams were defined, with the allocation of responsibilities for the system integration to appropriate staff in the different participating institutions. This is unorthodox compared to the more usual hierarchical approach to multi-organisation projects, with clear deliverables and management roles per organisation.

When JT-60SA and LIPAc are both commissioned and experiments start, a revision of some governance aspects may be warranted. A unified framework for sending researchers to JP could be developed, harmonising the financial incentives provides to researchers of different research organisations – as currently these incentives can differ significantly.

3.1.3 Role of and coordination with EUROfusion

The role of EUROfusion in the BA programme will become increasingly important due to its budget contributions and the shift to experimentation as IFMIF/EVEDA and JT-60SA are commissioned. The coordination meetings between F4E and EUROfusion in Garching have significantly improved the cooperation between the two organisations, leading to better communication, information sharing and joint planning. In September 2019 F4E and EUROfusion signed a Memorandum of Understanding (MoU)[62] for increased collaboration. The MoU includes collaboration in BA projects as well as the design of DEMO, tritium breeding blankets, development and qualification of fusion materials, ITER operation and further research. The objective of the MoU was to combine the industrial expertise of F4E with the research expertise of the EUROfusion members. This solidifies increasing collaboration between the organisations including through coordination meetings of F4E Garching and EUROfusion, which should be maintained in the future (and continued despite the COVID-19 crisis). There is no evidence that future conflicts of opinion or interest between F4E and EUROfusion are probable, and any conflicts between F4E and EUROfusion should be addressed by cooperation through existing channels, and only ultimately upscaled to DG RTD and DG Energy. F4E-EUROfusion and the Contact Persons meetings should remain the main mechanisms for coordination.

Japan considers F4E a trusted counterpart, and thus would prefer that F4E remains the (single) official counterpart in the future. This was expressed previously by Japanese stakeholders, according to EU interviewees, although it was not explicitly confirmed by Japanese interviewees. As F4E is the BA Implementing Agency, the involvement of EUROfusion in the programme has depended on the positive collaboration between F4E and EUROfusion. For Phase II, EUROfusion's role in the BA will be that of a voluntary contributor. It was also agreed it will follow the BA projects' common quality management system, which is sensible for any party participating in the projects. Increasing the trust of QST through the involvement of EUROfusion staff and member organisations' experts should be a focus of phase II. Their involvement should include being members of the project teams and, if relevant, as advisors and experts in the Project Committees. Given the difficulty in changing the BA Agreement, it is not worth revising it solely for formalising EUROfusion's role. An efficient solution would be to maintain the practice to invite EUROfusion to all BASC meetings as an observer. For some topics EUROfusion could take the lead in discussing with Japanese counterparts, after agreement with F4E on the specific matter. EUROfusion supports this, given changing the BA agreement is not practical.

Good coordination between F4E and EUROfusion will be crucial for the commissioning and experimentation campaigns. For example, F4E and EUROfusion launched joint procurement activities for JT-60SA diagnostics. This process should be evaluated in the future for identifying improvements. Also, EUROfusion will assign a leader who will work on-site at the JT-60SA realising the coordination of the EU team with Japan. The creation of the EUROfusion team and sending the leader has been delayed

[62] Based on F4E (2019) F4E and EUROFUSION sign Memorandum of Understanding. Available at https://fusionforenergy.europa.eu/mediacorner/newsview.aspx?content=1368

due to COVID-19. It is recommended that the F4E-EUROfusion cooperation is evaluated by 2023 to examine if changes should be made, i.e. more formalised arrangements put in place.

EUROfusion should be involved in drafting and signing agreements between F4E and European laboratories for the BA. Often the budget for procurement activities is provided by EUROfusion. Therefore, to guarantee the coordination between EUROfusion and F4E in procurement activities as well as to reflect the funding sources, it is desirable that EUROfusion participates in the process.

3.2 Project Management of the Broader Approach

This section explores the project management of the Broader Approach as defined by the actual implementation of the projects, collaboration with Japan in project-related activities and other main issues identified.

Table 3-2 Summary of the BA project management evaluation

	Summary
Main impacts and overall evaluation	• The overall evaluation of the current management of the projects is positive. • All three BA projects are commissioned/on track to commissioning, largely on budget, although covid-19 caused important issues and will lead to slippage in all projects (4-6 months for JT-60SA and LIPAc). Previously, a delay of 6 years for these two projects occurred. • Access to data, software and project facilities is a main recurring issue.
Positives	• JT-60SA and IFMIF/EVEDA: Integrated engineering was central for work of parties in developing components. Strong role of F4E as integrator, especially for design-to-budget of JT-60SA. • All projects: Quality Management Systems at BA project and home team/sub-project levels allowed for experts from different organisations to follow common processes, defined decision-making process between EU and JP staff, and contributed to create a 'BA culture'. • All projects: Adequate management by project and home team leads. Improved management of LIPAc as assembly phase started, with increased staff on-site. • All projects: Positive collaboration between EU and JP teams, based on strong commitment, increased trust as projects were implemented. • All projects: Broader Approach Agreement establishes provisions regarding information sharing and intellectual property.
Negatives	• JT-60SA and IFMIF/EVEDA: Underestimation of the time required for integrated engineering and R&D in beginning. • JT-60SA and LIPAc: Japanese health & safety regulations restrict the participation of EU staff in commissioning activities. • All projects: Limitations on the EU and JP teams resources, especially due to difficulties to attract staff to Rokkasho. • All projects: Covid-19 restrictions on physical meetings, work in closed spaces and travel of EU and JP staff to project sites.
Recommendations	On-going actions to maintain/further develop: • Ensure integrated engineering is in place from the beginning and time is foreseen in the planning for complex projects like e.g. JT-60SA. • Update and expand QMS in 2021-2022 in agreement with QST as JT-60SA and LIPAc start operating. • Work to ensure remote working and meeting arrangements are further developed and brought to a level of implementation comparable to other international projects with remote participation. • Foresee contingency funds from F4E and EUROfusion for addressing difficulties in commissioning, enhancements and experimentation campaigns. • Agree on a specific item in the next annual work programmes (especially for the JT60-SA) with Japan to investigate and define actions to improve data access while maintaining network security. New actions: • Agree and define procedures for remote access to data by end 2021. • Agree and define procedures for remote participation in experiments by end 2022.

	• Consider the BA QMS as a model for other international collaboration initiatives, e.g. by foreseeing in international agreements the creation of a QMS by the management staff of the project(s), to be approved by the Steering Committee or other decision-making body

3.2.1 Implementation of the BA projects

Difficulties encountered, especially in the early years of BA, led to significant delays in the target date for commissioning for the projects, especially JT-60SA and LIPAc (six years each, before COVID-19, as shown in Table 3-3). This is acknowledged by the F4E BA audit, which noted several slippages in the yearly project plans of the completion date for LIPAc activities.[63] As the BA projects were technically very challenging, difficulties were to be expected to be encountered in all projects, but this risk should have been better identified in drafting the BA schedule and assessing required resources. Nonetheless, BA has moved forward successfully since these mostly early delays. Delays in ITER have minimised the impact of delays in JT-60SA itself. In 2018 the BA audit considered the updated JT-60SA plan stable, despite the previous delays, thereby representing lower risks than for LIPAc. It should be ensured that integrated engineering is in place from the beginning and time is foreseen in the planning for complex projects.

Table 3-3 Original and /actual forecasted date for commissioning of main BA (sub-)projects before COVID-19

Project	Original target commissioning date[64]	Date/forecast before COVID-19
JT-60SA	2014	2020
IFERC: CSC	2012	2012
IFERC: REC	2015	2017
IFMIF/EVEDA: LIPAc	2013	2019-2022[65]

Further risks of slippage for concluding the main original targets of the BA are limited as major milestones were reached. However, the COVID-19 crisis has led to a 4-6 month delay in the commissioning of LIPAC and JT-60SA (also corroborated by a Japanese interviewee). JT-60SA assembly reached completion in June 2020, when integrated commissioning began.[66] The LIPAc sub-project has remained within schedule after the F4E BA audit (before covid-19 delays), concluding commissioning phase B in 2019 (operation of a 125 mA deuteron beam at 5 MeV, 0.1 % d.c.). IFERC is consistently well-evaluated by survey respondents regarding the efficiency and effectiveness of its governance. However, REC delays were caused, according to the audit, due to delays in ITER. Also, COVID-19 has impeded the IFERC project leader from moving to Rokkasho, although measures were being taken in September 2020 in this regard (for Japan granting a visa, clarifying quarantine requirements).

Initial delays in IFMIF/EVEDA were caused by difficulties in integrated engineering, R&D complexity, limitations on the EU and JP teams, and Japanese health & safety regulations. The F4E BA management staff confirmed that original LIPAc plans underestimated the R&D complexity and the resources and time needed, and highlighted that for LIPAc F4E did not play an integrator role as in the

[63] F4E (2020) Consolidated Annual Activity Report 2019
By March 2020, 7 out of the 9 actions recommended in the BA Audit by F4E had been implemented, with the remaining two scheduled for completion by mid-2020.
[64] As per DG RTD and MEXT (2006) Final Report of Negotiations on the Broader Approach Agreement.
[65] Commissioning Phase B was concluded in 2019 by the operation of a 125 mA deuteron beam at 5 MeV, 0.1 % d.c. Commission Phase H is scheduled for completion in 2022, with the operation of a 125 mA beam at 9 MeV in continuous wave.
IFMIF/EVEDA project Leader and JA/EU Project Managers (2019) Project Summary plans for BA Phase II
[66] F4E (2020) Europe and Japan complete JT-60SA, the most powerful tokamak in the world!

case of JT-60SA.[67] There were difficulties in attracting EU and especially JP researchers to the site as well as coordination between teams from both Parties. European staff could not physically contribute to the assembly of the machines due to Japanese regulations and the fact that contact with local safety authorities had to take place in Japanese. A Japanese interviewee noted the insufficient quality of a LIPAc component required mitigation measures. Difficulties with LIPAc are reflected in the evaluation by survey respondents, which rate the IFMIF/EVEDA governance lower regarding efficiency and effectiveness, albeit only a few responses were received on this aspect (6 responses concerning the IFMIF/EVEDA management). A Japanese interviewee confirmed the difficulty in attracting Japanese fusion researchers, although measures were taken to address this by 'outsourcing' some of the activities to private Japanese companies. With time, the EU team became stronger and the delivery and installation of equipment at Rokkasho required greater coordination with Japan and increased the relevance of adequate staffing on site. A Japanese interviewee also considers that the project management and team improved with time. Improving the quality of some assembly and commissioning instructions for European in-kind contributions could have facilitated these assembly issues.

JT-60SA faced similar challenges as IFMIF/EVEDA. Small budget overruns for certain equipment and VCs arose from the time needed at the start phase of IFMIF/EVEDA and JT-60SA for integrated engineering (especially the latter) and the underestimation of difficulties. Interviewees have indicated that the JT-60SA project was able to remain within the estimated budget due to a focus on design-to-cost during the integrated engineering phase (especially thanks to the head of the Broader Approach Programme & Delivery department at F4E), and the use of the contingency budget, which could be employed by F4E to address difficulties (with a critical assessment prior to the disbursement of funds). Although the IFMIF/EVEDA contingency fund is smaller than for the JT-60SA, this was not a factor in the delays. Eventual overruns for one component were compensated in at least one organisation by savings in others. Contingency funds from F4E and EUROfusion for addressing difficulties in commissioning, enhancements and experimentation campaigns should be maintained for phase II and beyond.

The BA Common Quality Management systems (QMS) system were instrumental in the achievements of the three BA projects. Covering aspects such as data processing, conducting meetings and decision-making for the integrated project teams, the QMS for each project allowed for experts from different organisations to follow common processes and contributed to a large extent to creating a 'BA project culture', increasing commitment, while striving for simplicity in order not to burden processes. This allowed staff from different European and Japanese organisations to wear a 'BA hat' when working on BA activities, regardless of the culture and processes of their organisation. Lower level compatible QMSs were then established for the home teams or sub-project teams (for IFERC).[68] With this processes involving both EU and Japanese staff are defined in the main BA projects' QMSs, and other ones are addressed in home team QMSs. The QMS also benefitted companies supplying products and services to the BA, as mentioned. The merits of the BA QMS were also recognised in the BA audit.[69] The QMS could be updated and expanded in agreement with QST as JT-60SA and IFERC start operating, but defining common processes while not becoming a burden to BA experts should remain a central guideline. The BA audit indicates that it is important to 'initiate completion, review and approval of the missing CQMS

[67] F4E (2020) Consolidated Annual Activity Report 2019
By March 2020, 7 out of the 9 actions recommended in the BA Audit by F4E had been implemented, with the remaining two scheduled for completion by mid-2020.
[68] Ibid.
[69] Ibid.

documentation for the three BA Projects', also considering some QMS documents were not updated since the early phases of the BA or were absent. [70] The QMS could be used as a model for other international collaboration initiatives in order to define common processes assuring processes are compatible with the initiative's agreement and to create a project culture independent of the participants' organisations. This could be implemented by foreseeing in international agreements the creation of a QMS by the management staff of the project(s) to be approved by the Steering Committee or other decision-making body of the agreement.

3.2.2 Collaboration with Japan

Collaboration with Japan within the Broader Approach is very positive. Japanese counterparts are genuinely committed to the programme and interviewees have indicated that there is a sense that all those working in the BA do so towards a common goal. This perception also applies within Europe, to the collaboration between national and EU-level stakeholders.

Cultural differences between Europeans and Japanese are nonetheless apparent and have required (and still require) European and Japanese participants to learn and adapt. Cultural differences may lead to misunderstandings on the agreements reached in meetings, affecting the subsequent implementation of (supposedly) agreed actions, and to issues in collaboration between European and Japanese counterparts within an integrated project team. Europeans see important difficulties in bringing changes to the Approach and its projects to increase its impact, requiring continuous discussion to convince the Japanese counterparts, for example for the use of metallic, e.g. tungsten, walls in the JT-60SA. However, these differences can be generally overcome through discussion and bring an added value to the project. Also, once actions are clearly agreed, the Japanese are committed to their implementation. It is recommended therefore to identify, raise and argue critical EU goals for BA well ahead of decisions.

Collaboration can be negatively affected whenever a EU or JP staff member is rotated, as the replacement has to learn how to interact with and build the trust of their new counterparts. Facilitating remote meetings and experimentation could reduce the need for EU staff on-site and thus potentially their rotation, but it is recommended for the EU to avoid large or too frequent staff rotations, to reduce these disruptions to collaboration.

Cultural differences between European staff also exist, but there were no indications it impacted the collaboration within the BA. Small differences noted by one interviewee which may have been observed are rather between, on one side, staff involved in phase I and thus with significant experience in the BA projects and, on the other side, newer staff from non-VC countries, starting to participate through EUROfusion in phase II and therefore not having the same project experience. This is not regarded as an issue and there is respect of the knowledge of all parties on the EU and JP side.

In addition to cultural differences, other underlying factors seem to play a role in the collaboration with Japanese counterparts. Difficulties in attracting Japanese researchers to work in the Rokkasho site (more than for European researchers) was cited by a majority of interviewees, and this has caused issues with the continuity of personnel and the maintenance of institutional knowledge. Possible causes for this difficulty are the lack of financial incentives for JP staff working in Rokkasho (while EU staff

[70] Ibid.

generally receive additional financial compensation) and limited availability of nuclear fusion researchers. Outdated and inconsistent information security procedures on the Japanese side are also relevant and were mentioned by a few stakeholders. These limit possibilities for structural solutions allowing e.g. working on the cloud and sharing data with European counterparts, which have required ad hoc measures and work-arounds instead. This may not be a high priority issue as these could be resolved in the future, e.g. when the focus on JT-60SA moves from commissioning to operation. F4E could nonetheless propose the review of and further discussions regarding information security procedures of both Parties.

3.2.3 Access to data and (remote) participation in experiments

As LIPAc and the JT-60SA are commissioned, it is necessary to agree and define procedures for (remote) access to data, and for the realisation of experiments in the case of the JT-60SA. EU organisations have not encountered difficulties accessing IFERC data, although this needs to be cleared with Japanese counterparts, which have usually been more restrictive on who should have access. The overall framework for access to data and machine time is set by the BA Agreement and Phase II negotiations. Machine time access for JT-60SA was defined (60/40% for Japan/EU, approximately proportional to phase II contributions), and similarly for IFMIF/EVEDA. In IFMIF/EVEDA European teams have a leading role, with significant participation for JT-60SA, which should theoretically facilitate access to data.

Nonetheless, difficulties for JT-60SA were indicated, with actual implementation of the BA Agreement provisions regarding data sharing and remote participation in experiments proving difficult. While full remote participation in experiments is impractical, facilitating it would limit the necessity of sending EU staff to conduct experiments and for extended stays in Japan. Currently, the remote experimentation centre of JT-60SA is scheduled to be operational in 2023, for the second operational campaign. Reluctance from the Japanese side during implementation may be one reason for the delays and lack of remote participation in the first campaign. An argument for delaying data sharing and (remote) participation is the need to avoid cybersecurity breaches and thus to restrict access to some systems. An EU stakeholder mentioned another justification given by Japan was the need to adhere to the JT-60SA commissioning deadline and to demonstrate results to Japanese policy makers, and that hosting EU experts would divert resources from these objectives. Continued cooperation, trust-building and addressing specific issues are the way forward for addressing the access to data and (remote) participation issues, as the BA agreement is seen as providing an adequate framework and the barriers are seen as being of a technical and cultural nature.

Necessity to be present on-site can be an issue, there is a desire from EU researchers to implement remote access. It was noted that data access and sharing was significantly smoothed by presence on-site in Japan, but that there were a number of difficulties with this, including the long distance from Europe, the relative unattractiveness of the Rokkasho and Naka locales to European staff and their families, the cost and the number of places. It will be important for Europe to ensure the right resources are available to fund and support staff to be on site, to fully utilise and contribute to BA and to continue to build the human relations and trust with Japanese counterparts. At the same time the point of remote access, especially to JT-60SA, was raised. That the technology now exists for European staff to participate remotely from Europe, and indeed that the REC project under IFERC has successfully tested different aspects of such remote access. However, it is perceived that there is reluctance among Japanese counterparts to allow for such access and that plans for such a remote access/control facility at JT-60SA will need to be pushed more forcefully to try to secure a way forward for this (options for further remote access through IFERC are discussed in section 4.4). A Japanese interviewee has highlighted that collaboration activities and the facilities should be located in Japan. It was noted by one stakeholder that the COVID-19 situation may soften attitudes to remote working and access in Japan. This is supported by a Japanese interviewee also indicating that COVID-19 might lead to e.g. enhanced use of remote meetings to maintain access of EU and Japan researchers.

Some problems are practical, not fundamental – software and processes can be improved. Some stakeholders noted that data sharing and access wasn't an issue, at least not fundamentally so. The BA Agreement requires sharing, and those working on the projects were supportive of sharing data. Issues more often arose from the process and security considerations on the Japanese side. It was highlighted that network security software and processes were quite old and based on concerns carried over from the nuclear fission community, i.e. on proliferation. Japanese efforts to update and improve software and procedures to streamline access, whilst maintaining security, would be welcomed by European researchers. It is recommended that this issue is raised with Japanese counterparts to see what changes may be possible. A specific item in the work programmes (especially for the JT60-SA) should be agreed with Japan in order to investigate and define actions to improve data access while maintaining network security. This could involve the investigation of how the issue is addressed in other collaboration activities between the EU and Japan, such as those taking place in the context of the Euratom or Horizon 2020 programmes.[71] This would be necessary to provide more concrete actions.

[71] For an overview see European Commission (2018) Roadmap for EU-Japan S&T Cooperation

4 BA and links to ITER and DEMO

This section focuses on the links of the BA to ITER and DEMO, both of which are important to judge the past and future success of the BA and progress in the field of fusion energy. As highlighted in section 5.1 de-risking ITER and contributing to DEMO are seen as the two most important high-level objectives for BA going forward.

Table 4-1 Summary of the BA links to ITER and DEMO

	Summary
Main impacts and overall evaluation	• The BA strengthens the EU-JP alignment on fusion-related aspects within ITER, and the relationship between governments in research and technology and other areas. • Adequate implementation of the BA-ITER Arrangement should enable an important upscaling of structured collaboration between the BA and ITER. • JT-60SA and IFER are important to ITER and DEMO, whilst IFMIF-EVEDA is crucial especially to DEMO.
Positives	• BA provides a positive example to policy makers that fusion energy projects can be a success and be delivered on budget. • Lessons in assembly and commissioning of JT-60SA are valuable for ITER, as is development of staff with experience in operating a large tokamak • Capacity building is an important benefit of all BA projects, contributing to both ITER and DEMO
Negatives	• Lack of metallic walls (such as tungsten) on JT-60SA reduces its potential usefulness to ITER • There is a risk of free-riding in the BA-ITER collaboration, i.e. that it benefits ITER parties other than the EU and JP which do not contribute to the BA • There is a risk that BA activities and the overall work by the European fusion community do not sufficiently focus on the long-term achievement of affordable nuclear fusion energy.
Recommendations	On-going actions to maintain/further develop: • The end goal of affordable nuclear fusion energy should be reinforced as a main criteria in planning and monitoring the DEMO Design activities and the overall EU fusion roadmap - studies on relevant aspects should be promoted, e.g. on the Tritium fuel cycle or materials. Opportunities to carry out this work under the IFERC project should be explored. New actions: • In 2021 assess areas for collaboration with ITER which could benefit the BA in the annual work programmes and agree on related collaboration activities with ITER. • Review the effectiveness and efficiency of the BA-ITER collaboration agreement before 2024 • Consider joint ITER-BA(JT-60SA) teams for sharing of information and data, engineering experience, technology development. • Ensure that the BA activities are explicitly considered in the Euratom Research and Training Programme Regulation and its impacts assessed in the Programme's evaluations

4.1 Relevance of the BA to ITER and DEMO

The Broader Approach demonstrates that the fusion community is able to deliver on its commitments on budget (despite the significant delays occasioned by the projects complexity and technological challenges). This is central to convincing policy makers to fund additional projects critical to the European fusion roadmap, such as IFMIF-DONES, and was highlighted by several interviewees. Japanese interviewees have indicated that the Broader Approach is essential to the Japanese fusion roadmap also, along with ITER. This should be highlighted in external communication.

BA projects lead to important knowledge to de-risk ITER and DEMO. The relevance of the BA to ITER is confirmed by the trilateral collaboration agreement between the EU, Japan and IO. The Italian experience in providing the BA in-kind contributions has also been instrumental for the development of the Divertor Tokamak Test (DTT) facility.

JT-60SA strongly supports ITER in its integrated commissioning, commissioning of specific components (such as the cryoplant and magnets), and operation. For example, Japan has conducted a review of assembly and installation procedures which led to a shortening of the total assembly duration of the ITER tokamak and tokamak complex. The JT-60SA also contributed to the ITER design and construction. Benefits to ITER in this regard included for example the qualification and manufacturing technology of high performance and large scale cable-in-conduit superconductor and its winding technology

IFMIF/EVEDA is most aligned to DEMO activities. IFMIF/EVEDA and DONES are regarded as essential to developing fusion materials for DEMO. In contrast, it won't be possible to employ the materials developed as a consequence of the work done in IFMIF/EVEDA in ITER, nor will it be necessary, as ITER will have a low number of displacements per atom. A stakeholder indicated that given the fact that there is no common concept for DEMO, DONES needs to remain 'generic', i.e. flexible to execute R&D on a wide range of materials. Another stakeholder also highlighted the contributions of the research part of the IFMIF/EVEDA project, highlighting its importance to providing guidance to the fusion community. The delays in IFMIF/EVEDA are critical due to the project's importance to DONES (further detailed in section 3.3). LIPAc completion and commissioning should be followed closely to maintain progress and address disruptions in order not to further delay DONES and the overall DEMO roadmap.

The IFERC sub-projects make various contributions to ITER or DEMO. The IFERC DEMO R&D focuses on materials research, especially on test blanket modules. Concrete examples of results of the DEMO R&D and Design sub-projects include choosing potential material solutions, to recovering tritium in DEMO, understanding tritium retention in inner walls, benchmarking of systems codes, developing a common process for evaluating parameters in different DEMO designs, and creating a Materials Properties Handbook and a central fusion materials database. Besides contributing to the design of ITER and DEMO, the CSC supports de-risking their operation by e.g. enabling a better understanding of plasma operation. To one stakeholder, IFERC had a major role in creating a strong scientific community in fusion supercomputing, especially concerning EU-JP collaboration, which now has around nine years of experience and will be highly useful for preparing plasma physics experiments. The IFERC REC will help with remote experimentation through the software, control procedures and organisational structures developed, as well as the lessons learned in the JT-60SA test. The survey nonetheless indicates BA stakeholders not directly involved with the IFERC sub-projects are unfamiliar with them and their impacts (see annex B). Internal communication across BA projects could be improved in this regard.

Capacity building is regarded as an important benefit of the BA contributing to both ITER and DEMO by both EU and Japanese interviewees. The BA supports the development of human capital, which is useful for ITER, as the latter relies on the hiring or secondment of highly-qualified experts. A stakeholder also indicated the BA facilitated the secondment of engineers which had previously worked on JT-60SA, supported by high-level management at Japanese industrial conglomerates, in order to provide qualified personnel and fill the Japanese hiring quota at ITER (and generally to address the shortage of qualified nuclear fusion researchers in Japan). The BA guarantees greater continuity in the procurement of fusion components. This would be particularly relevant as in fusion, and more broadly all nuclear research, there is the risk of cyclical loss of expertise as the flow of projects is not continuous.

Insufficient attention is given to the Broader Approach in the evaluation of the Euratom research and training programme. The Broader Approach activities are not mentioned at all in the Commission's interim evaluation of indirect actions in the Euratom research and training programme.[72] The more extensive supporting evaluation of the Group of Experts[73] from 2017 mentions the BA a few times in passing, dedicates two paragraphs to the JT-60SA and does not mention either IFMIF/EVEDA nor IFERC (while several pages are dedicated to JET). There seems to be limited visibility on the expertise needs for the EU fusion programme and the role of the BA in that regard, at least in the public Euratom research and training programme documents. The BA activities should be explicitly considered in the Euratom Research and Training Programme Regulation and its impacts assessed in the Programme's evaluations.

Some barriers exist for the BA projects to support ITER and DEMO. Difficulties in accessing data and for remote experimentation as well as the lack of IP rights arrangements for sharing information with ITER was one of the barriers most frequently mentioned (detailed in section 3.2.2). Specifically for JT-60SA, a particularly relevant modification to increase its relevance to ITER will be the switch from carbon to metallic (e.g. tungsten) walls sometime after 2025. A lack of familiarity of the Japanese with the technology as well as the higher loads occasioned by the density and weight of metals such as tungsten (which would require further modifications to the project) were raised as some of the arguments for starting with carbon walls for JT-60SA. The eventual switch to metallic walls will take time, possibly over 5 years, and the JT-60SA summary plan for phase II only indicates it would take place 'a few years after' the high plasma pressure steady-state experiment start. JT-60SA Phase II detailed activities and a specific timeline for the switch to metallic walls post-2025 should be agreed with Japan.

There is a risk that the BA activities and the overall work by the European fusion community does not sufficiently focus on the affordability of nuclear fusion energy. There would be (with ITER, JT-60SA and other devices e.g. in the UK, Italy and globally) sufficient nuclear fusion machines to conduct the necessary plasma research, while it was necessary to adopt a more pragmatic approach focusing on permitting aspects (i.e. addressing nuclear safety aspects to ensure that nuclear regulators would authorise fusion reactors) and on making nuclear fusion energy affordable.[74] The development of suitable materials and the tritium fuel cycle would be key. The end goal of affordable nuclear fusion energy should be reinforced as a main criteria in planning and monitoring the DEMO Design activities and the overall EU fusion roadmap.

4.2 Cooperation between the BA activities and ITER

In 2019, IO, F4E and QST signed a cooperation arrangement between the BA activities and ITER, aiming to improve the structure of the cooperation. The arrangement covers the exchange of data and information, of experts, equipment and of material & instrumentation, the realisation of joint

[72] European Commission (2017) Interim evaluation of indirect actions in the Euratom research and training programme. SWD(2017) 427 final.
[73] Group of Experts for DG RTD (2017) Interim evaluation of indirect actions of the Euratom Research and Training Programme 2014-2018
[74] As supported by four senior management staff at national research/educational organisations active in fusion

experiments, and other aspects. The cooperation arrangement is centred on the JT-60SA, which will make the most direct contributions to ITER. Access to CSC supercomputing facilities will nonetheless be helpful to ITER.

So far collaboration between ITER and BA teams has been at a personal rather than organisational level and the depth of discussions have been limited, given the lack of an agreement and the consequent reticence (possibly greater from the Japanese side due to more formalised procedures) to share information. There has been some successful collaboration between the BA and ITER prior to the arrangement, for example in the design of ITER components using Helios computing resources, which took place through EU organisations rather than through direct ITER-BA collaboration (i.e. access to Helios was indirect). Adequate implementation of the arrangement should provide for an important upscaling of structured collaboration between the BA and ITER. A Japanese stakeholder suggested establishing joint ITER-JT-60SA teams. This would be particularly valuable once ITER also reaches first plasma. The idea is that such teams would go beyond information and even staff exchange, by defining an integrated team with (partially) common staff working and executing related experiments in both machines. This would maximise learning and the transfer of knowledge between both projects. Alternatively, at least mirrored team structures in JT-60SA and ITER could be foreseen, to facilitate interaction, if joint teams are deemed impractical or the EU and/or Japan are reluctant. Joint training exercises could also be foreseen. It is recommended that the BASC consider this idea further.

Due to the more advanced state of the BA activities, the benefits of the cooperation are likely to be more important to ITER than to the BA. Despite this asymmetry, the cooperation arrangement is positive, as supporting ITER is one of the objectives of the BA agreement. The arrangement foresees that the BA will also benefit from cooperation (e.g. with the provision of sensors or the use of IO tools for JT-60SA operational scenarios design). BA project leaders should assess areas for collaboration with ITER which could benefit the BA in the annual work programmes.

Maintaining a simple governance structure and building trust should be a central measure in phase II to increase the impact of the BA. Interests of EU and JP parties have been, and should continue to be, a factor influencing the sharing of information with ITER and consequently other parties. As for the BA agreement, the BA-ITER arrangement provides the overall framework, but the success of the cooperation will depend on the goodwill of the parties. Guaranteeing the BA activities themselves benefit from the cooperation will allow building trust further and demonstrating the advantages to both programme.

IP rights could in the future constitute a barrier to transfer knowledge to ITER. The arrangement contains provisions regarding information and intellectual property. The arrangement's provisions leave the choice to disclose and grant licenses for the use of pre-existing information and IP up to each participant. Regardless of whether or not there were barriers to sharing information and IP with ITER previously, knowledge can be non-codified and with important knowledge sharing taking place through joint design and conduction of experiments, as noted by the arrangement annex itself. While the BA-ITER arrangement and the BA agreement may provide the overall framework for knowledge sharing, policy makers may be reluctant to share critical fusion technology information to other ITER parties. This constitutes a long-term risk regarding the sharing of technologies critical for commercial nuclear fusion reactors. Opinions of stakeholders are mixed on whether IP rights constitute a barrier.

As a principle for phase II and beyond, information and data sharing as well as remote experimentation in the BA should not prioritise ITER over EU organisations. CN, IN, KR, RU and the US do not need to share knowledge they develop with ITER. Given the financial resources provided by the EU and Member States to the BA, there is a need to guarantee EU fusion research organisations do not have worse access to BA data and information than ITER, given the potential difficulties in accessing BA data mentioned above. Identifying relevant ITER knowledge in the annual work programmes and agreeing on collaboration activities useful to the BA, as suggested above, could minimise the risk of asymmetric benefits between the BA and ITER parties.

The tasks of the arrangement should be reviewed by the BA-ITER coordination committee in alignment with a multi-annual plan, to account for the evolution of ITER and BA activities and accomplishment of the original 'topics of importance' of the BA-ITER arrangement. Nonetheless, immediate work should be focused on the agreed areas, although preparatory work can be conducted to obtain the firm commitment of all parties, including Japan, on a detailed plan for the transition to metallic (e.g. tungsten) walls at JT-60SA and remote experimentation. A review of the cooperation agreement is recommended before 2024 to make necessary adjustments prior to ITER first plasma.

5 Continuation of the Broader Approach post-2024

This chapter provides an assessment of the future objectives of the BA, a consideration of how new partner countries may be involved, advice on external communication and an assessment of funding arrangements.

5.1 Objectives of a post-2024 BA

The vast majority of stakeholders interviewed and surveyed agreed that the Broader Approach should continue beyond Phase II. Whilst the overarching objectives of the BA Agreement remain relevant and continue to form the basis for the project activities and actions (see Annex F), it is also the case that a practical evolution of the objectives that sit under those in BA Agreement is natural. Towards this purpose, and to understand which goals will remain most important to any future iteration of the BA, stakeholders were asked to rank objectives that should be priorities for a continued BA programme. They are subsequently presented in order of most important to less important, as averaged across respondent views; two objectives each are tied for 4th and 5th most important.

Table 5-1 Objectives of the BA post-2024

	Summary
Recommended Objectives	The objectives are recommended in order of priority as: 1. De-risking ITER (construction, assembly and operation) 2. Contributing to DEMO - including by progressing on IFMIF-DONES and contributing to EU DEMO design improvements 3. Positive return on investment for EU Member States – through contributing to progress on the EUROfusion roadmap and ensuring commercial opportunities for EU firms from BA continue 4. Improving cooperation and relationship with Japan / Capacity building 5. Guiding fusion research / Technical achievements in fusion energy – contributing to DEMO and overall fusion science

Adoption of these objectives would also benefit from adopting indicators to track progress and assess their achievement. The nature of the objectives and the field is such that there is necessarily a qualitative element to each, but some suggestions for indicators include the following. We propose that future evaluation work further develops and refines these indicators:

Table 5-2 Potential indicators for the objectives

Recommended Objectives	Potential indicators
1. De-risking ITER (construction, assembly and operation)	• Successful information or staff exchanges under the BA-ITER Cooperation Agreement • Rating of success of the BA-ITER Cooperation Agreement • (former) BA staff involved in ITER operation • Successful ITER construction, assembly and operation
2. Contributing to DEMO	• Rating of BA contributions to DEMO • Proven contributions to IFMIF • Changes to EU DEMO design resulting from BA experimental results
3. Positive return on investment for EU Member States	• Rating of benefits of BA to EUROfusion Roadmap • Companies participating and commercialising techniques, technologies and processes developed through BA
4. Improving cooperation and relationship with Japan / Capacity building	• Increased scientific collaboration with Japan – could replicate the bibliometric analysis used • Number of EU staff participating in BA experiments

5. Guiding fusion research / Technical achievements in fusion energy	• Technical landmarks in tokamak operation achieved

5.1.1 #1 – De-risking ITER (construction, assembly, and operation)

Most stakeholders believe that de-risking ITER should remain the top priority of the Broader Approach. They acknowledge that as ITER's construction is already underway and its assembly is scheduled to be completed during the BA's Phase II timeframe, future BA activities should focus on de-risking ITER's operation as much as possible.

The JT-60SA can play the largest role fulfilling this objective. Its research plan has been designed to generate experimental results that will expand physicists' and engineers understanding of plasma containment at extreme configurations. When the first wall of the JT-60SA is replaced with metallic walls (e.g. of tungsten), its operational conditions will closely mimic those in ITER, and it can be used to test smaller-scale versions of experiments that will be run at the larger scale tokamak.

IFERC's activities might also play a role fulfilling this objective. In Phase I of the BA, its supercomputer was used by fusion scientists to model potential experiments they intend to run during ITER's operations. Results of modelling directly contributed to ITER's research plan. IFERC also oversaw the development of remote experimentation initiatives whereby international teams of scientists can participate in tokamak experiments without being on site. This will de-risk the operation of ITER, as researchers familiar with the JT-60SA and its operation can directly participate in similar experiments at ITER. Because IFERC is a flexible programme, it might be able to accommodate new activities focused on de-risking ITER operation if continued into a third phase.

5.1.2 #2 – Contributing to DEMO

Similarly, most stakeholders state that a continued BA should prioritise contributions to DEMO. This would require, according to multiple viewpoints, a focused strategy that identifies concrete areas where the Broader Approach's activities would be best positioned to contribute to DEMO. This strategy would need to be developed close to the end of Phase II, once the fusion community has progressed as far as possible on its post-ITER plans.

IFERC Phase I oversaw a DEMO Design and R&D programme that will continue into Phase II. But interviewees acknowledged that DEMO design work is still fragmented and not consolidated. They acknowledged that IFERC's programme provided a useful forum for Japanese and European researchers to collaborate and "compare notes" on their design plans, but that the programme remained one of many focused on advancing DEMO research and planning. If a similar programme is included in Phase III of the Broader Approach it will need to expand its influence and authority to more scale up its contributions to DEMO.

IFMIF-EVEDA's successor will significantly contribute to DEMO by enabling the materials testing necessary for finalising reactor design. Engineers still do not understand how candidate materials will behave when subjected to ongoing plasma runs; they will need to select materials that can withstand fusion-like neutron fluxes for use in a DEMO reactor. This testing will be performed at the successor facility to IFMIF-EVEDA, likely IFMIF-DONES. It is unlikely that IFMIF-DONES will be included under Broader Approach but important lessons can be taken from IFMIF-EVEDA (see section 4.3).

Before phase III is finalised, it will be possible for stakeholders to take stock of the field of nuclear fusion and identify areas of research that would most positively contribute to DEMO design. The Broader Approach steering committee could note where they might address gaps in understanding in order to accelerate progress toward DEMO and design programmes specifically tailored to those needs, just as they did when designing phase I of the agreement in 2006.

5.1.3 #3 – Positive return on investment for EU Member States, academia and industry

Stakeholders overwhelmingly agree that it's important they profit from their investment in the BA projects by exploiting the technologies that have been developed. Researchers are looking forward to running experiments at LIPAc and the JT-60SA after years of design, construction, and assembly work. They anticipate that the scientific return on investment will be significant, with the caveat that they will still require sufficient funding in order to operate the machines.

Stakeholders caution against allowing other partners to exploit these Euro-Japanese devices without paying their fair share for the privilege of access and operation. If "free" or even cheap access is offered to partners who did not invest in the construction of the machines, they feel it will effectively diminish the value of their own investments and prevent them from seeing real returns. Most stakeholders accept or even advocate for the potential inclusion of new partners, but only if they contribute funding to the projects. Arguments for and against including new partners are discussed further in section 5.2.

5.1.4 #4 – Improving cooperation and relationship with Japan

Some stakeholders selected this objective as most important; they believe that a signature success of the Broader Approach agreement is its strengthening of the EU-Japanese collaborative framework even beyond the field of fusion research. They testify that the BA has enabled exchanges of EU-JP academic talent, expanded the networks of European researchers, increased the friendliness between EU and Japanese delegations to ITER and facilitated EU-Japanese industry collaboration. They maintain that it should always remain a principle objective of the Broader Approach to improve cooperation and working relationships with Japan.

Other stakeholders disagree, while citing the same evidence. In their view, the Broader Approach has already advanced the EU-JP relationship, especially in the field of fusion where the two powers collaborate frequently and effectively. As they regard EU-JP cooperation as already quite strong, they believe that further improving the relationship does not need to be a primary objective of the next BA phase.

5.1.5 #4 – Capacity building

Several members of ITER's International Organisation believe that capacity building should be a primary objective of a BA phase III. They anticipate that researchers and technicians can be trained at the JT-60SA before being transferred to work on ITER's commissioning; in their view, the JT-60SA is an ideal environment for educating the generation of researchers that will oversee ITER and ultimately DEMO in the basics of steady-state superconducting tokamak operation. Capacity building through this kind of exchange already took place in phase I of the BA and will continue and be expanded throughout phase II, but in order to optimise this in line with ITER and DEMO's envisioned timeframes, capacity building will need to be an explicit priority of the BA's phase III.

Other stakeholders did not rank capacity building as an important objective; some viewed it as overlapping with De-risking ITER, some did not consider it significant as the fusion community includes many institutions where capacity can be built up, of which the JT-60SA is only one project.

5.1.6 #5 – Guiding fusion research

Guiding fusion research is considered a less important objective of the BA partly due to the size of its programmes, and partly due to the large number of organisations working to direct fusion research. Stakeholders reflect that while significant insights from experimental results at the JT-60SA will inform fusion research plans, the BA activities do not directly determine fusion research roadmaps; rather, like their peer projects, they generate useful knowledge that is processed and accounted for by scientists and leaders at larger institutions (like EUROfusion) who set high level fusion research goals.

One stakeholder argued that it would be inevitable for the results of the BA project to indirectly guide fusion research and it was therefore unnecessary to include it as a top priority objective.

Another stakeholder argued that to the contrary, guiding fusion research should become increasingly important as the BA moves into a third phase. At that time, the concrete short-term objectives of larger fusion organisations will have been reached (given that ongoing experiments are executed successfully); in his view, fusion scientists will then look to machines like the JT-60SA for testing new ideas and designing experiments that push the limits of tokamaks in order to enhance designs for DEMO and even reactors beyond DEMO. In the midst of an innovative period, the super-advanced JT-60 could offer researchers the opportunity to experiment with new theories and expand their understanding of plasma behaviour at a machine slightly smaller and less internationally well-known than ITER. In these circumstances, guiding fusion research might implicitly become the key objective of a BA phase III.

5.1.7 #5 – Technical achievements in fusion technology

Several stakeholders state that because a plan for a BA phase III is not yet set, they are unsure how to gauge the relevance of pursuing technical achievements in fusion technology. The BA's phase I resulted in substantial advancements in fusion technologies; it oversaw the construction of the world's largest superconducting tokamak with modified coils and cryogenic components, and oversaw the construction of a linear accelerator that could generate beams for testing materials at near fusion-like energy conditions. This was a clear objective of the first phase of the BA, which set targeted goals to develop advanced fusion technology. It is not clear if it should remain the primary objective of a BA phase III, especially given that phase II is more focused on exploiting the advanced technology to generate experimental results. If a BA phase III remains primarily research-focused, rather than incorporating a new design-and-construction-based project, then stakeholders agree this should not be the most important objective of the agreement.

5.2 Involvement of new partner countries

Table 5-3 Summary of advantages and disadvantages of the involvement of 3rd countries

	Summary
Advantages	• Collaboration fits with the ethos of the fusion field • New partner can bring new funding • New partner could bring new specific technical expertise • New partner could shake (speed) up decision making in BA

Disadvantages	• New partner could risk undermining strengths of current EU-Japan partnership • New partner would take time to build new working relationships and trust • New partner could 'free-ride on previous investments of EU-Japan in BA
Recommendations	• Focus on the US as a primary prospective partner, other potential partners have potentially significant risks of culture clash or intellectual property issues, or are unlikely to be able to provide sufficient financial or relevant technical input • In concluding any partnership arrangement ensure that safeguards are put in place for proportional access and against funding withdrawal • Clarify how IP would be dealt with for new countries in any new partnership arrangement, to safeguard the original investments of the EU and Japan

The BA allows for the participation of other parties to the ITER Agreement under Article 25 of the BA[75]. Whilst we understand some interest was expressed by Korea to participate in the IFMIF-EVEDA project in around 2013 this was not taken further at the time. As the JT-60SA tokamak approaches operation we also understand that other parties have begun to express an interest in using the facility. This raises a number of important questions for the EU and Japan on if and how to involve new partners. The process for the participation in BA by new partners has been agreed by the BASC as part of phase II of the BA.

Firstly, we note that **fusion is a collaborative research field**, the spirit of international collaboration underpins both ITER and the BA, with the ideal that all Parties are working towards a common goal and can share in the benefits of successful research and commercialisation of fusion energy. With the commercialisation still probably more than 20 or 30 years in the future, normal concerns on intellectual property and economic competitiveness are felt by many to be much less relevant in the field of fusion energy. International cooperation and making use of all expertise available is therefore seen as positive, normal, and essential even, as a way to move the field forward as a whole, with experts in the field in general very open and welcoming to the idea of new partnerships. Nevertheless there remain some important considerations in bringing new partners into BA.

Proportionality of access and contributions

The crucial issue for the expert stakeholders that we spoke to revolved around reconciling the investments that the EU and Japan have already made against the potential contributions that a new partner could provide and what access they may wish in return. Through the BA the EU and Japan have spent around €$_{2005}$675 million (see Table B-0-1), of which around €$_{2005}$320 million was spent on the JT-60SA, which is the likely primary source of interest for new partners. These are considerable investments, and ones from which a return in terms of scientific access and results are expected, an agreement on machine time between Japan and the EU has already been struck as part of phase II of BA (a JP 60:40 EU split).

Stakeholders noted that it should not be the case that new partners can 'free-ride' on the JP-EU investments, and that if they join the BA to use JT-60SA that they should also make a contribution. The involvement of the partner should then be proportional to the contribution and the past/current contributions of the EU and Japan.

[75] The other parties to the ITER Agreement are the US, Russia, China, Korea and India.
Article 25 of the BA states 'Participation of other ITER parties. In the event that any other party to the ITER Agreement expresses its intention to participate in a project of the Broader Approach Activities, the project leader concerned shall, after consultation with the Project Committee, submit to the Steering Committee a proposal concerning the terms and conditions of the participation of that party in such project. The Steering Committee shall decide on the participation of that party upon the proposal of the project leader, and subject to the approval of the Parties following their internal procedures, may conclude agreements and arrangements with that Party on such participation.'

Modes of participation

The feedback from stakeholders suggested a few main ways in which new partners could be most usefully and proportionally involved:

- (1) the new partner would make a relatively minor contribution, providing direct funding and/or staff to support the operation of the JT-60SA, and for which an agreement on access to machine time could be made reflecting the size of any such contribution.
- (2) the new partner would make a more substantial contribution, for example in funding a major upgrade to the JT-60SA, such as metallic walls, at an appropriate time in its lifetime, and then either:
    - Similar to (1) an agreement of access to the machine could be struck.
    - Or (3) the partner country would also formally join the Broader Agreement as a new partner, this would be a more involved step and involve additional considerations

The first two modes would appear to be quite likely and feasible to manage in an agreeable way for each Party. The third mode could be more challenging.

Concerns about integrating a new partner

Experts were concerned about the costs of adding a full partner to BA. Integrating a full new partner was identified as having a number of potential advantages and drawbacks. Among the advantages highlighted, there was a particular focus on new funding opportunities, potentially enabling BA to do more. One stakeholder mentioned the possibility that a new partner could help to speed up BA, whilst another mentioned that involvement of new partners may leverage greater interest (and funding and visibility) for fusion in that country, which would benefit the field as whole. However, the main balance of opinion was weighted towards the challenges and drawbacks of absorbing a new partner. The key theme was that the BA had established a successful partnership across the various EU countries and institutions and their Japanese counterparts, and that this had already taken significant time and effort. Adding a new partner would risk upsetting the existing balance and would take time to integrate, as they would need to be 'brought up to speed' with the existing teams, but also that it would need new ways of working, new trust and all this would cost time and resources before the collaboration would be as effective and efficient as it is currently. It was noted that this risk would be reduced if the new partner accepted the existing governance structures, but that the greater role they wished to play in these (i.e. joining the BASC), the greater the change and disruption could be. Once more the consideration would circle back to what the new partner might bring in terms of funding, contributions and expertise.

Prospective partner countries

Discussions on the partners provided insights into some of the potential advantages and reservations that stakeholders hold. In summary:

- **The United States** – was considered the most 'natural' prospective partner country for the EU and Japan in the BA. Where good working relationships politically and scientifically are already established. It would bring significant expertise in some relevant fields such as supercomputing, and there was a recognition that there are leading scientists that would benefit the experiments and results of the programme. At the same time there were reservations, firstly that the US has not invested significantly in its own tokamak and has a history of 'parachuting' into prestigious programmes as they become operational, free riding on the investment of others. The US would be able to fund minor (i.e. diagnostics) or major (e.g. metallic walls) upgrades, subject to funding, with a concern that funding was too politically dependent and therefore unstable. Nevertheless, the US was seen by most stakeholders as the best of the available partners.

- **China –** was considered as a good potential partner by many, as it is rapidly gaining experience and is investing in fusion, but a few reservations were expressed relating to intellectual property and potential difficulties working with Japan for historical and cultural reasons.
- **Russia** – was not raised by many stakeholders, an impression was given that the programme in Russia is in some state of decline, with ageing expertise. Therefore whilst past collaborations have been good and Russia has some strengths in manufacturing, any future collaboration in BA could be politically tricky. Overall, it was not considered a major prospect as a new partner.
- **Korea** – was mentioned by a few stakeholders, although these reflected on its relative inexperience in fusion. The main frame of reference for involvement was IFMIF-EVEDA, with an expectation that Korea may be a potential partner for a follow-up phase of IFMIF such as DONES.
- **India** – none of the stakeholders considered India a logical or interesting partner for the BA.
- **UK** – as a member of EUROfusion (and F4E) the UK has already has access to Broader Approach. At the same time, although the Political Declaration for Brexit supports continued UK involvement in EURATOM (and F4E) and EUROfusion, and there are other avenues to continue involvement, there remains the possibility that the UK could end up leaving EURATOM and EUROfusion and losing access. In this case, and with JET approaching the end of its operational lifetime, future UK involvement in BA could be an attractive possibility for all Parties.

On the basis of this assessment we recommend that, following the procedures for 3rd country involvement outlined in the phase II agreement, the BA give first preference to the US in any efforts to engage a 3rd country. However in doing so, safeguards should be put in place to ensure US participation i.e. machine access, is proportional to the contribution being made; and also that any financial commitments made by the US are guaranteed against political withdrawal as far as possible.

Intellectual property a barrier or non-issue?

The potential for issues relating to sharing of intellectual property (IP) was also raised by a handful of those interviewed. Of those that flagged it as an issue, opinion was split between those that believed this could be an important but also reasonable barrier to the involvement of new partners, and those that saw that the technologies were so far from commercialisation that the actual value of any IP would be so low as to make this a non-issue. On balance, in our opinion, we note that this can be a politically sensitive issue, as public authorities would need to justify the value for money of their spending on BA. IP is currently dealt with through Article 19 of the BA, which defines the rights of the Parties. Access of new partners to previously created IP should be clarified in any new partnership arrangement, to respect the principles of the agreement, with protections for the EU and Japan for IP generated prior to 3rd country involvement.

Alternatives

An alternative to direct collaboration with partners within the projects of the BA approach could be through alternative international collaboration mechanisms such as the IEA/International Tokamak Physics Activity (ITPA, of ITER) Joint Experimental Planning program. This would provide an option for international collaboration involving the JT-60SA. The programme employs large tokamaks worldwide to conduct experiments and share information for ITER and DEMO. The benefits of this cooperation in knowledge and expertise could be important and would allow EU and Japanese teams to conduct experiments with JT-60SA aligned not only to ITER but also to other (large) tokamaks. These would have fewer concerns for IP rights while allowing for (controlled) information sharing. Whilst it is understood that many researchers involved in BA already participate in this, it may be an avenue to consider to further strengthen international collaboration.

5.3 External communication

Table 5-4 Summary of strengths and weaknesses of BA external communication

	Summary
Strengths	• BA has important successes to communicate, and will have more as JT-60SA enters operation • Recognised as a weak point in audit and by BASC, first actions are being taken – including the development of a strategy and appointment of working groups
Weaknesses	• Lack of clear responsibilities • Lack of resources • Low priority given to external communication • BA websites are incomplete, often out-of-date and rarely updated
Recommendations	• Assign the responsibility for coordination of the BA external communication activities to the BASC secretariat from 2021 • Define and approve by the BASC a separate budget for communication activities from 2021 • Use the communication budget to 'reserve' part of time of communications team experts in F4E and QST to spend on BA • Agree and monitor at the BASC a target number of actions per year and per action type • Define the main stakeholder groups, as this is not defined in the communication strategy Focus on JT-60SA if financial constraints are significant

External communication is evaluated as requiring improvements by a majority of interviewees, which is corroborated by the F4E internal audit.[76] The main causes relate to the lack of clear responsibilities and mandates, lack of resources and skills and external communication not being considered a priority. Given its positive results so far, the BA could be used as a 'poster programme' for fusion research. However, this is largely not the case. The deficiencies in external communication lead to a lack of awareness of highly interesting projects and positive results, difficulties for external stakeholders (for example students) to understand the BA projects, and also to a lack of knowledge amongst BA staff on the other BA projects, IFERC especially. A Japanese interviewee also confirmed that further outreach activities should take place.

BA websites are infrequently updated, although this has improved for JT-60SA and IFMIF/EVEDA. The central BA site (ba-fusion.org) provides very limited information and some sections are offline. The update frequency of the individual project websites varies. IFMIF/EVEDA and JT-60SA provide more detail on their websites than IFERC does. The websites of the three projects do provide lists of publications and conference proceedings, and an effort has been made more recently within the BA, and with the support of the European Commission, to increase the number of publications. The BA audit identified a number of shortcomings in the management of websites,[77] due to unclear responsibility, lack of resources, litigation and data protection risks linked to website management, and de-prioritisation.

[76] F4E Internal Audit Capability (2018) Audit of Implementation of the Broader Approach Agreement.
[77] F4E Internal Audit Capability (2018) Audit of Implementation of the Broader Approach Agreement.

The BA EU management has taken steps to address the Audit recommendations, in collaboration with Japan, but actions to improve external communication were deprioritised due to covid-19. DG Energy and the BASC secretariat have developed a communication strategy, and working groups were set-up with Japan. The strategy defined which communication activities should be done in collaboration between the Parties, and which should be conducted independently by F4E and QST. The BA projects websites were updated as a result, and a BA brochure was also produced. On the EU side, a table of milestone events was provided to the F4E communication unit, so it could request communication pieces from the BA staff when the moment came. However, staff had difficulty responding in time or in non-technical language.

The main recommendations for improving external communications are:

- ✓ Assign the responsibility for coordination of the BA external communication activities to the BASC secretariat from 2021 on;
- ✓ Define and approve by the BASC a separate budget for communication activities of the order of 0.1-0.3% of the BA annual budget;
- ✓ Finance part-time communications experts at both F4E and QST with the allocated budget;
- ✓ Identify in BA project annual work programmes the main project milestones to be communicated;
- ✓ Agree at the BASC a target number of actions per year and per action type (see below for action types);
- ✓ Conduct a review of external communication actions (employing a tracker maintained by the BASC secretariat) in BASC meetings and agree remediation actions for F4E/QST, if necessary
- ✓ Define the main stakeholder groups, as this is not defined in the communication strategy;

The difficulty of the BA Parties in implementing previously-agreed communication actions indicates there is a need for a stronger follow-up mechanism which can give them the necessary priority. As the body assisting the Steering Committee, the BASC Secretariat is well placed to play the role of following-up on agreed actions. However, the BASC is the appropriate body for agreeing on overarching communication goals, while coordination on practical matters can agreed in informal meetings between F4E and QST.

A separate (moderate) budget could be allocated specifically for communication activities. F4E's annual communication budget was estimated at 300 k € in 2013 (less than 0.1% of its budget), and IO's communication expenses was 503 k € in 2018 (around 0.15% of its budget for that year).[78] The total communication budget for BA would be more limited, considering the relative budget sizes as well as synergies with other communication activities of F4E, QST, EUROfusion and IO (e.g. all these organisations already have a twitter account and produce content related also to the BA). If 0.1% of an estimated BA annual spend of €40 million / year was used as an estimate, then around 40 k € would be available for these activities.

As neither the BASC Secretariat staff nor the project team members have the necessary communications expertise or skills, the role of the Secretariat would be largely managerial. The main actions can be delegated, with support from the project and home team leads for content creation. Communication actions would comprise updating websites, editing and publishing communication

[78] See F4E (2013). Decision of the of the governing board of Fusion for Energy endorsing a communication policy. Available at https://fusionforenergy.europa.eu/downloads/aboutf4e/decisions/Communication%20Policy.pdf
IO (2019) Financial Report 2018.

pieces and posting on social media. Around 40 k € of funding would not cover a full time employee with the required skills, nor the supplementary web-design, hosting or other costs associated with a more developed approach to communication – but it could allow a communications expert to dedicate a significant part of its time. Alternatively, the responsibility could be contracted to a communications agency, but the budget is likely insufficient. Likely most effective and efficient would be to utilise existing infrastructure and skills in the communication units of F4E and QST. These may allow for efficiencies and economies of scale as F4E and QST also conduct their communication activities related to ITER, and are familiar with the fusion field and the BA.

Therefore, a workflow for developing communications activities could be:

1. Project leaders develop in the annual work programme the main project milestones to be communicated;
2. The BASC agrees on a target number of communication actions per year and per type;
3. The BASC secretariat coordinates with F4E and QST for the execution of the agreed actions;
4. The F4E and QST communication units track actions and request content from BA staff;
5. Project and home teams provide the necessary content to F4E and QST;
6. The F4E and QST communication units publish communication pieces / update websites;
7. The BASC secretariat maintains an implementation tracker;
8. The tracker is reviewed in the BASC meetings and remediation actions agreed for F4E/QST, if necessary.

If financial limitations are important, then giving priority within limited budgets to JT-60SA is recommended given its wider appeal, major upcoming milestones and longer term relevance compared to the other projects. A particular point of attention should be the maintenance of the BA projects' websites and launch of communication pieces in F4E and QST's websites.

5.4 Funding arrangements

Table 5-5 Summary of future funding arrangements for BA

	Summary
Summary	• Move to annual funding decisions provides flexibility but introduces risks – COVID-19 and pressure on public budgets is a particularly acute risk in the coming years • Funding for longer term investments less certain • Concerns that any funding cuts may lead to underutilisation of BA project assets
Recommendations	• Agree longer term investments, such as metallic (e.g. tungsten) walls for JT-60SA, as far in advance as possible to increase chances of multi-annual funding (also see JT-60SA recommendations in chapter 6)

Following from the earlier section (3.2.1) on the spending on BA to date, **funding arrangements for Phase II of the BA have been agreed and involve significant changes**. Whilst the crediting system has been maintained and extended, the main funding streams on the EU side will no longer be from Voluntary Contributors but will be through F4E and EUROfusion. This is a natural evolution in two ways, firstly, that the first phase of BA was effectively a compensation for ITER to Japan, funded by in-kind contributions by the Voluntary Contributors. Now that these contributions have been made, this part of the programme is complete and it is normal to move to a new mode of funding. Secondly, that as Phase II is focused on scientific exploitation of the equipment, that stronger involvement and funding via EUROfusion is also normal.

Planning documents indicate that that annual contributions from the EU in Phase II will total approximately 46k BAUA, corresponding to approximately EUR_{2005} 35m annually (approx. EUR 41 million in current values). The EU contribution will represent 3/8th of the total budget of phase II, with the remaining 5/8th being contributed by Japan (representing an equal contribution to Europe plus a Host country contribution). This will result in an ongoing budget for BA as a whole of roughly EUR 100m per year in the coming years.

Move to annual funding provides flexibility but introduces risks. In Phase II funding decisions by the EU and Japan will be made on an annual basis such that each Party *'contribute with a certain amount of credit on an annual basis and subject to budget availability'*. This allows for potential variation in budget over time, which could have both positive and negative consequences for BA, e.g. if policy decisions are made to reduce budgets there is no fixed long term commitment to BA. Three issues are particularly important to this, (1) in the short-medium term the COVID19 crisis and recovery funding needing to be repaid public spending is likely to come under significant pressure in all areas, this could pose a risk to the overall funding of fusion and BA; and, (2) funding in the EU is not yet confirmed as part of the MFF which is also in flux due to COVID-19, with potential cuts to Horizon Europe, the umbrella of funding under which EUROfusion sits, being discussed; and (3) funding for fusion energy, particularly in Japan, but also relevant for the EU, covers both ITER and the BA, ITER is still considered the primary goal in the fusion field, and therefore if further funding is required for ITER then it is possible that this will be taken from BA budgets.

Longer term investments become more uncertain. The annual funding model also has a drawback that long-term larger investments, such as upgrades to JT-60SA[79] would not fit within annual budgets. A process has been introduced to accommodate this so that these investments can be planned and funded in practice, but the overall certainty of funding the investment appears lower than in phase I, this is an important concern for some stakeholders. Working within the agreed structure it is recommended that longer term investments are discussed and agreed as far in advance as possible. Major expenditure items that should be considered are the metallic wall upgrade for JT-60SA and any potential new supercomputing collaboration in IFERC.

Some stakeholders are concerned that the BA assets will not be fully utilised. The funding risks are noted especially for JT-60SA, and to a lesser extent IFMIF-EVEDA, as both have significant running costs due to large electricity and other inputs; and in the case of JT-60SA a number of major investments in upgrades that are planned. Some stakeholders fear that the flexible funding arrangements could allow budget cuts which result in reduced running times, scaled back experiments and/or postponed upgrades which do not fully utilise the capacities of the machines.

[79] such as upgrades to the heating systems and divertor, or the upgrade of walls to metal, e.g. tungsten

6 Future considerations for the BA Projects

Table 6-1 Summary of future considerations for the BA projects

	Summary
JT-60SA	• Short-medium term plan for JT-60SA is already quite firmly set out • Upgrades to metallic walls and a metallic divertor (both possibly from tungsten) are amongst the main changes expected between 2025-2030 • Collaboration arrangements for seconded staff will be important to define Recommendations: • EU should ensure that upgrade to metallic (e.g. tungsten) walls goes ahead in 2025-2030 period as planned, detailed discussions with Japan, on how this should be funded, and fit into operational plans should begin, and work towards a draft agreement by 2024. • Collaboration arrangements should be defined for non-EU/Japan staff prior to the involvement of these staff in experiments
IFMIF-EVEDA	• IFMIF-EVEDA should in the coming years fulfil its primary purposes to prove the function and reliability of the device, further progress on IFMIF, via DONES or A-FNS, will need to continue outside of BA • Continued use of LIPAc until operation of the new fusion neutron source can be anticipated Recommendations: • Various recommendations relating to using IFMIF for DONES/A-FNS, (see section 6.2), these should be shared with DONES and regular contacts (i.e. 2x per year) arranged between DONES leads and the IFMIF-EVEDA project leader • The Project Lead should explore by 2024 the potential continuation or exit strategies for the BA forevolution strategies for LIPAc, including exploring which other concrete opportunities exist for non-fusion scientific research or industrial uses.
IFERC	• The CSC and Helios supercomputer was a success of phase I of BA, but a new joint supercomputer under IFERC would be costly, it is unclear if this would be feasible under the revised funding arrangements. Purchase of machine time elsewhere may strike a better balance between costs and benefits • DEMO design activities are relatively low cost, but with good potential research benefits. They are also well suited to involving 3rd parties. • REC remains relevant for JT-60SA and IFMIF-EVEDA, particularly in the context of COVID19 and the increased cultural acceptability and technical options for remote working. There are significant options to continue these activities in future, activities in phase II will provide greater insight Recommendations: • Assess the costs and benefits of new supercomputing collaboration under CSC by 2023 to reach agreement on the best way forward for BA • Discuss with Japan whether to initiate contact with other ITER countries regarding joint DEMO research • Assess (in 2023-2024) progress with REC activities scheduled for phase II, in light of these refine EU needs and wishes for remote access to plan for future REC activities. • Re-start knowledge management system activities in 2021 once main COVID-19 issues are resolved.
Other potential projects	• Whilst there are potential options for new projects, there was not significant evidence or support for new initiatives under the BA. This question could be re-visited towards the end of phase II

6.1 JT-60SA

Of the three Broader Approach activities, the short- and medium-term future of the JT-60SA is best defined. Because of its design and its mechanical specificities, its continuation options are technically limited. Its research plans are drafted and will be adapted every few years to anticipate and detail the experiments that will be run at the JT-60SA multiple years in advance. Even beyond 2025, its experimental plans have already been outlined.

It is expected that the JT-60SA integrated project team will collaborate closely with ITER and DEMO researchers, such that any likely evolutions to its programme will be justified as benefitting either ITER or DEMO. Indeed, physicists and engineers have been working for decades to design the experiments that should be run at the JT-60SA to de-risk ITER's eventual operation, and these are the experiments that will dominate its first five years of operation. The tokamak's programming is well set. Any opportunities for adaptation are likely to remain limited to its organisational or collaborative frameworks, rather than its operational objectives.

Short-term operation objectives

Scientists leading the project have already set a roadmap of experiments that will be conducted at the JT-60SA between 2020-2025. The tokamak is in the midst of its Operation 1 phase – Integrated Commissioning. Five months of machine commissioning with plasmas will follow its first plasma, scheduled for the end of 2020. Plasma operation during Integrated Commissioning will demonstrate the controllability of diverted plasmas up to 2.5 Mega Amperes.

Once its commissioning is complete, the JT-60SA will enter into a Machine Enhancements phase, during which the machine will be prepared for high-power heating with deuterium. Its cryopumps, neutron shields, and in-vessel components will be installed along with a set of plasma diagnostics that project physicists can use to collect data for use in their initial research phase. Machine maintenance and enhancements are scheduled to last for ~2 years, into 2023.

During the JT-60SA's Operation 2 phase beginning in the second half of 2023, integrated commissioning will be completed. Experiments will be run focused on two purposes: ITER risk mitigation and scenario development for efficient initial hydrogen operation at ITER. The Operation 3 phase will continue with these experiments in late 2024, in addition to further experiments on disruption mitigation. It will conclude with steady-state high plasma pressure scenario development for DEMO in early 2025.

Stakeholders anticipate that the JT-60SA's initial research phase will generate interesting results and will contribute to ITER de-risking before its first plasma in 2025, but acknowledge that there is little opportunity for adjusting its objectives or adapting its focus, as the programme is set for years.

Collaboration with ITER

The JT-60SA team will work closely with ITER during its initial research phases; the terms of their partnership are outlined in a collaboration agreement adopted in early 2020. ITER's International Organisation (IO) specifies three categories where it could benefit from the work performed at the JT-60SA: insights from technical programming, access to experimental data, and in-person, on-site collaboration.

The IO considers in-person collaboration particularly important: "physical presence during activities because the information is largely the learning process and it is impossible to record and report on learning."[80] It has already outlined several technical areas that collaborative teams will focus on, but the agreement is flexible enough that new focus topics could be adopted. The presence of a seconded ITER team will facilitate this flexibility; stakeholders believe that in addition to building capacity, in-person collaboration will strengthen relationships between ITER's IO and the JT-60SA research team, potentially allowing for more informal exchanges of information.

Some stakeholders suggest that it might be possible to use the ITER collaboration agreement as a model framework for establishing other secondment programmes at the JT-60SA. While there's little flexibility

80 Fusion for Energy, ITER and QST (2020), Annex – Topics of Importance to ITER in JT-60SA

in the technical objectives of the programme, there is more flexibility in its outreach/collaboration programmes. JET's outreach could serve as a reference for the JT-60SA: over its years of operation it regularly welcomed international teams of researchers and established exchange programmes.

Several stakeholders noted that it might be difficult to establish collaborative agreements with any organisation other than ITER. The protection of intellectual property is important to protect the investments made by the EU and Japan. Culturally, stakeholders are concerned that the JT-60SA will operates formally and that it will be difficult to secure access to its experiments and data without undergoing negotiations, which can be time-intensive and can deter potential collaborators.

Long-term operation objectives

The long-term research objectives and technical aims of the JT-60SA are also detailed in its research plan. Of its long-term objectives, stakeholders affirm that replacing the tokamak's carbon wall with metallic walls (e.g. tungsten) should be prioritised. A metallic wall coupled with a metallic divertor would allow researchers at the STP to test plasmas at more extreme conditions; as ITER's (and likely DEMO's) inner walls will be metallic (tungsten-based), scientists could conduct proxy experiments at the JT-60SA that would allow them to better understand potential operational conditions at ITER down the line.

The JT-60SA has already announced its intention to carry out this wall replacement, but likely not until 2027 or beyond. In 2026, it plans to conduct high power long-pulse (>100s) experiments. Replacing the carbon wall with metallic walls (e.g. tungsten) would be time-intensive; once it was installed, the machine would need to be re-commissioned and tested. It is likely that a metallic-walled JT-60SA will need to repeat its initial operation phases into 2028-2029 or even beyond, which would temporarily limit the technical scope of the experiments that could be performed there. During these re-assembly and re-commissioning phases, the research plan for experiments that should be performed in a metallic-walled environment can be refined.

Beyond 2030, the operation objectives of the JT-60SA will likely be more DEMO-focused than ITER focused. By then, the fusion community is expected to have a more refined plan for DEMO, and the JT-60SA will act as a satellite tokamak to ITER where experiments can be run that conditions not tested at ITER, conditions that will be important to refining DEMO design. Physicists and engineers are already working to design these experiments, which will likely be incorporated into forward-looking JT-60SA research plans around 2025.

6.2 IFMIF-EVEDA

The main ongoing IFMIF-EVEDA project activity at the current time is the operation of the LIPAc facility, which was commissioned in 2019, with the main purpose of validating the engineering and design of a fusion neutron source. By demonstrating the availability, reliability and maintainability of LIPAc it can contribute to the design of IFMIF in future.

The project summary for phase II of the BA highlights key objectives for the 2020-2025 period, including:

- Demonstrating reliable Continuous Wave (CW) operation of LIPAc at 125 mA Deuteron beam at 9 MeV. Enhancements to the injector, RF power system and control systems will be required for this purpose and are scheduled for 2023-2024.
- Enhancement of the target and test facilities to improve reliability
- Contributing to the design of the neutron source facility

In the longer term it is expected that LIPAc could continue to operate until the full neutron source facility is available. Continued operation would be geared towards demonstrating high availability, as a test stand and to optimise beam operation strategies. Other research disciplines may also have an interest in experimentation using the LIPAc. Further exploration of this options would be worthwhile to develop an exit strategy for BA once its primary purpose is fulfilled, this action should be taken up by the IFMIF-EVEDA project lead, we would advise this to occur as part of the agreement of a post-2024 work programme.

The next steps in developing a fusion neutron source will occur outside BA

The roadmap for IFMIF-EVEDA is clear that the project was intended to serve as a stepping-stone towards a full fusion neutron source facility (IFMIF) which is regarded as essential to test the materials required for a fusion reactor. The next step towards IFMIF has been elaborated in the EU under the name of **DONES** and in Japan as **AFN-S**.

Amongst the main questions for IFMIF-DONES or IFMIF-AFN-S is whether either project could be envisaged under the umbrella of Broader Approach. The initial work and planning for DONES suggests that the project would cost in the order of €1.3 billion in capital costs, design, preparations and construction[81]. This size of budget is massively higher than that for IFMIF-EVEDA and around double the whole commitment to BA. Given the existing structure of BA and the funding constraints it is impossible to envision this size of investment to occur within the BA, and indeed it would be stretching the terms of the BA Agreement to include it.

IFMIF-DONES/A-FNS main issues and areas to build upon BA

Although it will not be feasible to move forward with DONES or A-FNS under the BA umbrella there remain options to utilise the work of IFMIF-EVEDA and to continue the collaboration between the EU and Japan. Stakeholders identified the following important considerations:

- **DONES is waiting on IFMIF-EVEDA** – a full decision to go-ahead on DONES will need to wait for validation of the LIPAc accelerator in Japan.
- **IFMIF/DONES is crucial to DEMO and the overall fusion roadmap** – ITER will not provide useful validation of the materials required for a commercial fusion reactor. A fusion neutron source is essential to validate materials that can handle the displacements likely to be faced in a fusion reactor over a long period of time.
- **Time starts to become critical, work on a fusion neutron source needs to start soon** – a fusion neutron source such as DONES will need to test materials for a long period of time, e.g. 10-15 years to validate their effectiveness, to usefully contribute to DEMO design then the neutron source would need to be operational from around 2030. The timelines of the EU and Japanese programmes differ in this respect, the EU programme hoping to deliver a device by around 2030, but the Japanese programme (A-FNS) is less advanced.

[81] http://www.roadmap2018.esfri.eu/projects-and-landmarks/browse-the-catalogue/ifmif-dones/

- **Japanese involvement in DONES would be highly beneficial and efforts should be made to ensure this** – assuming that the EU pushes ahead with DONES then stakeholders are clear that it is important to secure a collaboration or participation by Japan in DONES. The joint workshops on DONES / A-FNS are a good start and should be continued. Japanese involvement would be particularly important as:
    - It would continue the strong collaboration under BA – one stakeholder suggested that a privileged position/access should be offered to Japan
    - Japan may be able to bring financial contributions to the project – stakeholders noted that a promise of reciprocal EU contributions to A-FNS when this begins could help.
    - If the A-FNS project was for any reason (e.g. budget cuts) cut or delayed then Japan could potentially scale up their involvement in DONES
    - Japan has developed some crucial components, e.g. the Lithium target, for which their expertise in DONES would be valuable.
    - A-FNS and DONES can be complementary to each other and the goals of IFMIF
- **Siting in Granada is likely to be more attractive than Rokkasho,** at the very least for the European research community, although for the latter there is often a reluctance to locate outside Japan regardless of location, i.e. it also a difficulty for the IO to attract Japanese staff.
- **The EU could do more to coordinate its multiple neutron source research programmes** – as although the types of research are different there are many overlapping aspects and potential benefits which are not being taken advantage of as there are not the resources to make such connections. Programmes of interest include CERN (CLIC), ESS, Myrrah, SPIRAI.
- **Other international partners can be of interest** – there can be useful connections to the US programme, e.g. their work on the SNS neutron source; China who have been active in making a first small neutron source; and also Korea who expressed earlier interest in involvement in IFMIF-EVEDA.

6.3 IFERC

This section discusses the continuation of IFERC according to the following separate sub-projects:

- ✓ Computational Simulation Centre;
- ✓ DEMO design and R&D;
- ✓ Remote Experimentation Centre;
- ✓ Other potential sub-projects.

Computational Simulation Centre (CSC)

The short-term objectives (2020-2024) for the CSC sub-project as stated in the IFERC phase II summary plan are to:

1. Decide by the end of 2020 on 'whether to proceed with a joint EU-JA HPC', which could then start operating by 2023;
2. Foster collaboration research projects between JA and EU by sharing computer resources and by further jointly developing state-of-the art models.

In either case, the projects addressing the IFERC sub-projects and other BA projects as well as the 'topics of importance' listed in the BA-ITER cooperation arrangement should be a priority.

As is implicit by the objectives listed above, collaboration on supercomputing between the EU and JP post-2024 can occur independently of whether a new joint HPC is commissioned. Moreover, given the rapid obsolescence of supercomputers, a joint HPC commissioned in 2023 would likely be decommissioned or significantly upgraded by 2027-2028. Based on estimates for the potential Phase II HPC, investments in order of 200 million EUR would be necessary, whether in a joint HPC or separated but shared EU and JP HPCs. This could be difficult to find within future BA funding arrangements.

Investing in a new joint HPC or sharing time on existing HPCs would result in benefits such as arising from: cooperation with Japanese researchers; availability of computing resources prioritised to the needs of the other BA activities; the availability of an HPC customised to fusion research. Also, the IFERC project was included in the BA activities partly due to the interest from Japan, so continuation of IFERC has political advantages.

The experience with Helios, e.g. its procurement on time and on budget as well as high utilisation, and the high number of publications are arguments that support the continuation of cooperation in computation simulation. Such cooperation would also strengthen the EU and JP expertise on supercomputing. A joint dedicated HPC could provide some economies of scale in procurement costs and optimisation of the HPC utilisation. Furthermore, it would make it more likely to procure an HPC dedicated to fusion research. Purchasing time on existing HPCs would likely be lower cost, but not as beneficial. Ending EU involvement in CSC would have the lowest costs, but the EU would miss the benefits, and may incur a loss of goodwill with their Japanese counterparts if this was not a mutual decision.

The HPC could be located in Rokkasho or another site in Japan, but also in the EU. EU interviewees do not have objections to any location in Japan, as long as the software and EU-Rokkasho bandwidth allow remote simulations to be conducted. It should be noted that there can be an economic benefit to the host countries arising from expenditure in O&M services and supplies.

DEMO design and R&D

DEMO design and R&D will be increasingly relevant in the medium- to long-term, though stakeholders indicate that it will need to be focused and consolidated over the next few years. In the phase II IFERC summary plan, considering the review of phase I results, the following 2020-2024 topics for priority activities were defined concerning DEMO design, and ITER and JT-60SA exploitation:

- ✓ Plasma scenario development,
- ✓ Divertor and power exhaust,
- ✓ Breeding blanket and tritium extraction and removal,
- ✓ Remote maintenance, and
- ✓ Safety.

These activities will include support to ITER and ‘possible validation tests in JT-60SA of long pulse DEMO relevant scenarios’. It must be noted that high—power in JT-60SA will be feasible only after 2026.

DEMO R&D objectives listed in the phase II IFERC summary plan focus on four areas: (1) Tritium technology (tritium recovery and inventory evaluation); (2) Development of structural materials for fusion reactors in-vessel components: Breeder Blanket and Divertor, RAFM steels, Cu-alloys and Wbased materials; (3) Neutron irradiation experiments of Breeding Functional Materials (BFMs); and, (4) Development of a material corrosion database.

Continuation of DEMO R&D activities, would require a re-assessment of the focus areas near the end of phase II to develop a multi-annual plan. This assessment could build on a mapping of common aspects for the design of EU, JP and potentially other parties' DEMO, as suggested by some stakeholders. This sub-project provides an area where 3rd party collaboration could be envisaged and could be explored.

Stopping this sub-project would eliminate coordination costs, although these are estimated to be low, and potentially allow EU researchers to advance on DEMO design and R&D unencumbered by the need to cooperate with Japan and potential delays in the JP DEMO roadmap. However, the topics of the phase II IFERC plan will remain relevant after 2025, while others may be added as ITER reaches first plasma, DONES is constructed and experimental data from IFMIF/EVEDA and JT-60SA are produced. Moreover, DEMO R&D involve activities value added is the production of knowledge which can be shared, such as regarding material properties – hence cooperation can provide significant sharing of costs.

A significant part of the DEMO R&D activities could take place in locations other than Rokkasho or remotely. Indeed, most of the DEMO R&D meetings and workshops in phase I were already conducted in more accessible EU or JP cities. However, currently Rokkasho hosts the radioisotope (RI) handling facility, so there remain practical, as well as political, reasons to maintain part of these activities at the Rokkasho site.

REC

Remote experimentation within the BA is an important mechanism to develop the facilities, tools and processes for remote experimentation of ITER as well as to facilitate the participation of EU researchers. It can play an important role in training EU staff for ITER commissioning and experimentation ITER and DEMO design. Remote experimentation with JT-60SA and LIPAc has been delayed to phase II, whose objectives (for 2020-2024) indicated in the IFERC summary plan are:

- ✓ "JT-60SA: the first phase of JT-60SA including OPE-1 and the shutdown until 2023 will be dedicated to refine the tools for remote participation in experiment execution developed in BA Phase I. These tools will be tested in collaboration with JT-60SA in the OPE-2 phase in 2023;
- ✓ IO: collaboration under the ITER-BA agreement will start in April 2020 to advance test technologies for remote experiments and data transfer, including remote CODAC application testing, remote data access, live data viewing for ITER, fast data transfer, secure remote connection;
- ✓ IFMIF/EVEDA: the control room provided by REC for LIPAc at the end of BA Phase I will be further developed, and remote participation tools for the accelerator will be developed jointly with IFMIF/EVEDA project, in order to facilitate the tasks of commissioning, operation and analysis for the LIPAc contributors."

Phase II should therefore focus on the development and operationalisation of the tools and processes for effective joint operation of LIPAc and JT-60SA. As long as the EU and Japan continue to cooperate on IFMIF/EVEDA and JT-60SA within the BA, remote experimentation will be an important method of facilitating the participation of EU experts, reducing the need for long-term assignments in Japan. Cooperation will also allow the development and use of remote experimentation facilities, tools and processes for ITER, an aspect which interests Japan. The subject of remote working has received a significant increase in attention and acceptability out of its necessity during the COVID19 crisis. This also provides an opportunity and boost to the rationale for REC within the Broader approach.

As experience in remote participation in experiments is consolidated in phase II, remote experimentation of IFMIF/EVEDA and JT-60SA by EU researchers could be conducted without the involvement of REC. However, collaboration with IO for remote experimentation of the JT-60SA and of ITER would then take place within the JT-60SA, which may not be a core objective of the project. Moreover, the EU may want to develop a dedicated tokamak remote control room for JT-60SA in e.g. the WEST facilities, as well as other passive monitoring rooms in other locations. Therefore, REC could be continued post-2024, with the following objectives:

- Promote the remote experimentation by EU researchers of JT-60SA and LIPAc;
- Develop and execute remote experimentation of ITER from the Rokkasho control room;
- Develop a JT-60SA (and LIPAc) remote experimentation control room in an EU Member State.

Other potential IFERC sub-projects

BA knowledge management system

At present neither the BA nor ITER have a knowledge management system to organise the information produced through the design, commissioning and use of the machines. The 2018 F4E audit of the BA[82] indicated to “consolidate and disseminate the know-how gained in the execution of the BA projects” was an important recommendation. Developing shared or parallel management systems would enhance the codification of knowledge, especially as the volume of information produced grows with commissioning and the subsequent experimentation campaigns.

Several stakeholders have indicated that the establishment of a common knowledge management process and system across the BA projects would be highly useful to share knowledge between the EU and JP participating organisations and ITER, as well to external stakeholders. Whilst this is acknowledged as an important issue within BA, actions in this area have been put on hold/deprioritised due to COVID-19.

Currently, more than 10 years of experience has been built up across the various BA projects, but whilst this is shared within a BA project through a document management system, it is unclear if it can be shared with the other BA projects. For external users this would be a greater challenge still, not only from a permissions perspective but also as there is still an important need to consolidate and condense what has been produced. These two actions (1) guaranteeing documents can shared internally within BA; and (2) integrating knowledge for the fusion research community, are seen as the main steps for a system. It is understood that Japanese counterparts would be supportive of such a formalised system.

A transversal knowledge management system would allow a consolidation of the knowledge already developed regarding design, procurement, commissioning and experimentation with equipment developed in all three BA projects as well as ‘immaterial’ knowledge regarding e.g. DEMO design. The design and fabrication of fusion devices and knowledge related to research infrastructures were both identified as specific areas to prioritise for such a system. Knowledge coded in such a system could be classified according to confidentiality, and non-confidential aspects made public. Expected target

[82] F4E Internal Audit Capability (2018) Audit of Implementation of the Broader Approach Agreement.

groups would include mainly fusion researchers for things such as design guidelines for fusion devices, but the audience would be much wider for things such as guidelines for management of projects built across many organisations and culture, where managers and researchers in other fields, plus policy makers may also be of interest.

Starting topics for a management system have been identified as: (1) Overall integration/optimisation of tokamaks, as it is hard to find knowledge on the topics, and it is very important to designing the next generation of machines; (2) On project management how to integrate diverse teams and combine individual competences with adequate communication.

It is recommended to re-start this activity once the main COVID-19 issues are resolved.

Fusion summer schools and other network events

A few stakeholders have noted potential future human capital bottlenecks as an issue requiring attention. One stakeholder suggested the organisation of fusion summer schools by the BA would allow young fusion professionals to develop technical skills and networking, as well as scope new positions. Such an initiative could build on the experience of FuseNet, the European Fusion Education Network. There are already similar initiatives in the EU by research organisations, such as by FuseNet itself, or the KIT (DE) “Karlsruhe International School on Fusion Technologies”, the IPP (DE) Summer University for “Plasma Physics and Fusion Research”, and the Kudowa (PL) Summer School "Towards Fusion Energy".

6.4 Other potential projects to the BA continuation post-2024

This section analyses potential projects which could be added to the BA post-2024 and which would not fit in any of the three existing BA projects. These projects would serve to address gaps identified by the stakeholders in the BA and the EU fusion roadmap in general. As such, although the projects are discussed as potential additions to the BA, given eventual difficulties in adding new projects and parties to the BA agreement, the options discussed here could also constitute stand-alone initiatives or be part of other existing initiatives than the BA – such as the IEA/International Tokamak Physics Activity (ITPA, of ITER) Joint Experimental Planning program (while DONES is covered in the section on IFMIF/EVEDA).

Potential suggestions received from stakeholders comprise the following, aligned with the EUROfusion roadmap challenges:

- ✓ **Heat exhaust**: will be a main challenge for DEMO design - an integrated programme for advanced divertor designs “including experiment, theory development, modelling, technology, engineering and system design”[83] could leverage the knowledge of Japan (which is making an important contribution to ITER’s divertor, and given heat exhaust in the divertor and 1st walls in JT-60SA and IFERC) and tested in the Italian Divertor Test Tokamak (I-DTT). This would be well-aligned with the BA objectives and overall timeline of the I-DTT, DEMO and end of the BA phase II;
- ✓ **Tritium self sufficiency**: stakeholders have frequently highlighted the importance of further research to guaranteeing tritium self-sufficiency, and the EU has proposed in some instances to collaborate further on test blanket modules with Japan. Specific experiments could be developed in this area, although it is a particularly sensitive area due to the importance to

[83] EUROfusion (2018), European Research Roadmap to the Realisation of Fusion Energy, Long Version

achieving affordable fusion energy and the dual-purpose (i.e. military) of tritium-related technology;

- ✓ **Stellarators**: Japan runs the second largest superconducting stellarator in the world after Wendelstein 7-x and has a cooperation agreement with EUROfusion already; Some stakeholders support the eventual inclusion of stellarators within the BA, given the synergies in some research areas with tokamaks and the advantages of streamlining contact with Japanese fusion research organisations. However, the research roadmaps for stellarators and tokamaks are different and thus this would imply a deviation from the current focus of the current BA activities, although it would fit with the BA agreement objectives.

7 Recommendations

Based on the analysis of the impacts of the Broader Approach and the assessment of issues relevant to its continuation, the following recommendations are made. Firstly that the objectives for the BA, beyond the objectives enshrined in the BA agreement should include:

	Summary
Recommended Objectives	The objectives are recommended in order of priority as: 1. De-risking ITER (construction, assembly and operation) 2. Contributing to DEMO - including by progressing on IFMIF-DONES and contributing to EU DEMO design improvements 3. Positive return on investment for EU Member States – through contributing to progress on the EUROfusion roadmap and ensuring commercial opportunities for EU firms from BA continue 4. Improving cooperation and relationship with Japan / Capacity building 5. Guiding fusion research / Technical achievements in fusion energy – contributing to DEMO and overall fusion science

And secondly, that the specific recommendations for the BA, differentiated between high, medium and low priority are:

Priority	Recommendation type	Recommendation
High	Impacts for participants	1. LIPAc completion and commissioning should be followed closely to maintain progress and address disruptions in order not to further delay DONES and the overall DEMO roadmap.
	Governance	2. Continue assigning staff for management positions according to their availability and expertise, and increase involvement of EUROfusion members as part of the project teams. 3. Evaluate F4E-EUROfusion collaboration on BA in 2022 to understand how effective and efficient the arrangement is. 4. Ensure EUROfusion is involved throughout the drafting of agreements related to the BA where it will be a co-signer with F4E and European laboratories, for a more efficient process.
	Project Management	5. Update and expand QMS in 2021-2022 in agreement with QST as JT-60SA and LIPAc start operating. 6. Work to ensure remote working and meeting arrangements are further developed and brought to a level of implementation comparable to other international projects with remote participation. 7. Foresee contingency funds from F4E and EUROfusion for addressing difficulties in commissioning, enhancements and experimentation campaigns. 8. Agree and define procedures for remote access to data by end-2021.
	BA links to ITER and DEMO	9. Review the effectiveness and efficiency of the BA-ITER collaboration agreement before 2024. 10. The end goal of affordable nuclear fusion energy should be reinforced as a main criteria in planning and monitoring the DEMO Design activities and the overall EU fusion roadmap – studies on relevant aspects should be promoted, e.g. on the Tritium fuel cycle or materials. Opportunities to carry out this work under the IFERC project should be explored.
	External Communications	11. Assign the responsibility for coordination of the BA external communication activities to the BASC secretariat from 2021. 12. Define and approve by the BASC a separate budget for communication activities from 2021. 13. Use the communication budget to 'reserve' part of time of communications team experts in F4E and QST to spend on BA.
	IFERC	14. Assess (in 2023-2024) progress with REC activities scheduled for phase II, in light of these refine EU needs and wishes for remote access to plan for future REC activities.
Medium	Technical and Scientific Recommendations	15. Ensure continuity in technical project teams so activities can fulfil their phase II research plans. 16. For JT-60SA, emphasise focus on de-risking ITER operation to ensure its technical achievements can have large impacts in the short-term as ITER is commissioned.

Priority	Recommendation type	Recommendation
	Governance	17. Maintain current governance structure. Continue ad hoc bi-monthly meetings with JP to provide a communication channel more flexible than BASC meetings, review the approach in the 2nd half of 2021. 18. Continue the coordination meetings (Contact Persons and F4E-EUROfusion) to allocate and monitor EU activities as well as agree on a common position on negotiations with JP. 19. Consider streamlining project governance, such as creating a unified framework for sending researchers to JP, with harmonised financial incentives. 20. Maintain the practice to invite EUROfusion to all BASC meetings as an observer. For some topics EUROfusion could take the lead in discussing with Japanese counterparts, after agreement with F4E on the specific matter. 21. Evaluate following completion the joint F4E-EUROfusion procurement for JT-60SA diagnostics to identify improvements and best practices. 22. Consider regular bilateral meetings between DG Energy and DG RTD to complement the Contact Persons meetings.
	Project Management	23. Agree on a specific item in the next annual work programmes (especially for the JT60-SA) with Japan to investigate and define actions to improve data access while maintaining network security. 24. Agree and define procedures for remote participation in experiments by end 2022.
	BA links to ITER and DEMO	25. In 2021 assess areas for collaboration with ITER which could benefit the BA in the annual work programmes and agree on related collaboration activities with ITER. 26. Ensure that the BA activities are explicitly considered in the Euratom Research and Training Programme Regulation and its impacts assessed in the Programme's evaluations.
	Involvement of new partners	27. Focus on the US as a primary prospective partner, other potential partners have potentially significant risks of culture clash or intellectual property issues, or are unlikely to be able to provide sufficient financial or relevant technical input. 28. In concluding any partnership arrangement ensure that safeguards are put in place for proportional access and against funding withdrawal.
	External communications	29. Agree and monitor at the BASC a target number of actions per year and per action type. 30. Define the main target stakeholder groups, as this is not defined in the communication strategy. 31. Focus on JT-60SA if financial constraints are significant.
	Funding	32. Agree longer term investments, such as metallic (e.g. tungsten) walls or divertors for JT-60SA, as far in advance as possible to increase chances of multi-annual funding (also see JT-60SA recommendations).
	JT-60SA	33. EU should ensure that upgrade to metallic (e.g., tungsten) walls goes ahead in 2025-2030 period as planned. Detailed discussions with Japan, on how this should be funded, and fit into operational plans should begin, and work towards a draft agreement by 2024. 34. Collaboration arrangements should be defined for non-EU/Japan staff prior to the involvement of these staff in experiments.
	IFMIF-EVEDA	35. Recommendations relating to using IFMIF for DONES/A-FNS should be taken into account (see section 6.2), these should be shared with DONES and regular contacts (i.e. x2 per year) arranged between DONES leads and the IFMIF-EVEDA project leader. 36. The Project Lead should explore by 2024 potential evolution strategies for LIPAc, including exploring which other concrete opportunities exist for non-fusion scientific research or industrial uses.
	IFERC	37. Assess the costs and benefits of new supercomputing collaboration under CSC by 2023 to reach agreement on the best way forward for BA. 38. Re-start knowledge management system activities in 2021 once main COVID-19 issues are resolved. 39. Discuss with Japan whether to initiate contact with other ITER countries regarding joint DEMO research.
Low	Impacts for participants	40. External communication should highlight the importance of the BA to the EU and JP fusion roadmaps, and that the fusion community is able to deliver within budget. 41. EUROfusion and F4E should increase collaboration in technology transfer activities within the F4E marketplace and the EUROfusion FUTTA II. 42. F4E should aim to also include in its technology transfer initiative companies providing products and services to the BA through Voluntary Contributors, not only through F4E. 43. F4E and QST should agree on showcasing each other's technologies in technology transfer platforms.

Priority	Recommendation type	Recommendation
	Governance	44. Consider employing the BA approach for other bilateral international collaboration activities, including replicating its Quality Management System.
	Project management	45. Ensure integrated engineering is in place from the beginning and time is foreseen in the planning for complex projects like e.g. JT-60SA. 46. Consider the BA QMS as a model for other international collaboration initiatives, e.g. by foreseeing in international agreements the creation of a QMS by the management staff of the project(s), to be approved by the Steering Committee or other decision-making body.
	BA links to ITER and DEMO	47. Consider joint ITER-BA(JT-60SA) teams for sharing of information and data, engineering experience, technology development.
	Involvement of new partners	48. Clarify how IP would be dealt with for new countries in any new partnership arrangement, to safeguard the original investments of the EU and Japan.

Annex A – Additional details on the technical impacts of the BA activities

Advanced systems developed for the JT-60SA

Magnet system

The central pillar of the JT-60SA is its magnet system. Entirely superconducting – designed to enable long pulse durations – the magnet system comprises 18 toroidal field (TF) coils, six equilibrium field (EF) coils, and four central solenoid (CS) stacked modules.[84] The development of a fully functioning system necessitated the manufacturing of the most advanced magnetic components so far designed in the field of nuclear fusion.

The **toroidal field coils** were modelled and constructed by building on knowledge from existing tokamak projects (e.g., JET), but with the design of ITER and future tokamaks in mind.[85,86] The size and structure of the JT-60SA's TF coils are juxtaposed with JET's and ITER's in Figure A-0-1. The JT-60SA's TF coils exceed JET's in size but will be dwarfed by the size of ITER's TF coils.

Figure A-0-1: Comparison of the plasma volumes of JT-60SA, JET, and ITER[87]

Following their manufacture, all TF coils were delivered to the CEA-Saclay TFC (toroidal field coil) Test Facility in France, where they were tested at cryogenic temperatures and at full currents like in the JT-60SA. Once tested, each coil was coupled with a self-standing Outer Intercoil Structure (OIS), which house and radially guide each coil during tokamak operation. This pre-assembly at one of CEA's workshops ensured proper alignment between components and reduced on-site assembly time.

The TF coils were transported – alternately by ship and by plane – to the JT-60SA's site in Naka, Japan. There, they were lowered into their slotted positions within the vacuum vessel and its thermal shield, which had already been partially installed.[88] The TF coils were installed and aligned meticulously by

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[84] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project
[85] Davis, Hajnal, Hayawaka et al in Fusion Engineering and Design (2018), JT-60SA TF Magnet Assembly – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379618308366
[86] Decool, Maréchal, Portafaix, et al in Fusion Engineering and Design (2011), Detailed design studies at CEA for JT-60SA TF coils -- accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379610005636
[87] Fusion for Energy (2020), Europe and Japan complete JT-60SA, the most powerful tokamak in the world! – accessible via https://fusionforenergy.europa.eu/news/europe-and-japan-complete-jt-60sa-the-most-powerful-tokamak-in-the-world/
[88] Fusion for Energy (2018), JT-60SA TF coils have reached their destination – accessible via https://fusionforenergy.europa.eu/mediacorner/newsview.aspx?content=1209

using built-in adjustment mechanisms, to achieve an error field lower than 10^{-4} metres in coil positioning; this level of precision was essential to ensuring that the tokamak can function as intended. As engineers described, "the high accuracy of the coil positioning achieved during assembly made a significant contribution to keeping the magnetic field errors within acceptable limits, in spite of variations already accumulated due to irreversible manufacturing processes. Besides thorough preparation this is primarily thanks to the adjustable nature of the processes designed."[89] The final, 18th TF coil was inserted into the tokamak in conjunction with the final sections of the vacuum vessel and its thermal shield.[90]

The **equilibrium field coils** as well as the **central solenoid modules** enable wide-ranging and flexible control of the tokamak's plasma shape.[91] EF coils were manufactured on-site in Naka as their larger sizes did not allow for their transport; it was noted during their production that despite their volume, excellent control of deviations was achieved during the winding and stacking of the EF coils.[92] The EF coils were connected to the TF magnet once all TF coils had been installed. The central solenoid modules were simultaneously completed, stacked, and compressed with rods following heat treatment and testing.[93]

Finally, in order to limit heat loads from the magnet system onto the cryogenic system during tokamak operation, 26 High Temperature Superconductive Current Leads (HTS-CLs) were incorporated into the JT-60SA. Their manufacture and successful delivery were overseen by the Karlsruhe Institute of Technology in Germany.[94]

JT-60SA engineers delivered a fully tested, precisely aligned magnet system efficiently and without significant delays.

Vacuum Vessel, Thermal Shield and Cryostat

The JT-60SA's magnetic containment system – its vacuum vessel, thermal shield, and cryostat – were designed to withstand some of the most intense power conditions ever tested, and to shield against the effects of plasmas run at extreme configurations (e.g., longer runtimes, new elongations). Their respective designs incorporated several modifications compared to designs for similar components in existing tokamaks, including modifications to cryostat components for the sake of cost reduction.[95] All containment modules were completed successfully and installed before the tokamak's magnetic system was installed.

The JT-60SA's **vacuum vessel** is double-walled; the space between its two shells is filled with water that provides temperature control and vital shielding to reduce high neutron fluxes during operation. The double-wall structure enhances the stability of the tokamak to withstand severe conditions including high thermal loads and extreme electromagnetic forces during plasma disruptions. The vessel was manufactured and installed in 10 segments, each fabricated in a Japanese factory and transported to the JT-60SA site. A mock-up installation was conducted to allow for predictions of welding

[89] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project
[90] Ciazynski et al in Fusion Design and Engineering (2017), Performance of JT-60SA toroidal field coils in light of strand and conductor test results – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379616307426
[91] Tsuchiya et al in Fusion Engineering and Design (2013), Fabrication and installation of equilibrium field coils for the JT-60SA – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379613002111
[92] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project
[93] Fukui et al in Fusion Design and Engineering (2019), Monitoring and control of the magnet system of JT-60SA – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379618308457
[94] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project
[95] As diiscussed with stakeholders in interviews conducted in March 2020.

distortions during the actual installation of the vessel. The segments were set onto the cryostat base and welded together following precise positioning adjustments. The final segment was installed in conjunction with the final TF coil.[96]

A superconducting tokamak's **thermal shield** is critical to its operation as it limits the amount of radiated heat transferred to its magnet system. The JT-60SA's thermal shield encompasses three sub-shields: a vacuum vessel thermal shield, a cryostat thermal shield, and a port thermal shield. Difficult to manufacture and vital to tokamak assembly, the vacuum vessel thermal shield required several assembly trials and on-site shaping: its thin double wall structure – designed to ensure critical stability of the reactor – proved challenging to install. Nevertheless, engineers successfully completed its installation in 2016.[97]

The **cryostat** of the JT-60SA will provide a vacuum boundary to insulate heat load from external spaces at room temperature to the magnet system Like the thermal shield, the cryostat also comprises three sub-components: a cryostat base and a cryostat vessel body cylindrical section, as well as a cryostat top lid. The cryostat base and vessel body cylindrical section were manufactured, tested and pre-assembled by CIEMAT in Spain before they were shipped to Naka, while the cryostat top lid was procured in Japan.[98] The base was the first component installed in the JT-60SA's torus hall, while the vessel body cylindrical section and the top lid were the last. The cryostat's successful installation represented the successful containment of the tokamak's principal toroidal systems.[99]

Plant systems

Several state-of-the-art systems have been procured for and installed at the JT-60SA site. Its **cryogenic system** supplies supercritical helium to the magnet system, cryopumps, high-temperature superconductor current leads, and the thermal shield. The JT-60SA's cryogenic system is the largest "refrigerator" that will be used at a nuclear fusion facility, though eventually it will be second to ITER's.[100,101]

Its **power system**, designed from scratch to accommodate its new superconducting magnet system, comprises several subsystems:[102]

- The Superconducting Magnet Power Supplies (SCMPS) provides power to the TF coils, EF coils, and CS modules
- The Quench Protection Circuits (QPCs) are designed to protect all elements of the magnet system by dumping magnetic stored energy into external resistors in less than ten seconds when coils transition from their superconducting to a resistive state
- The Switching Network Unit produces high voltage required for the plasma break-down and current ramp-up
- Power systems for the Plasma Control Coils (FPCCs), for the Resistive Wall Mode Control Coils (RWMCCs), and Error Field Control Coils (EFCCs)

[96] Ibidem
[97] Nakamura et al in Fusion Design and Engineering (2019), Design and manufacturing of thermal shield for JT-60SA – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379619305277
[98] CIEMAT (2013), JT-60SA Cryostat – accessible via http://www.fusion.ciemat.es/international-projects/jt-60sa-cryostat-2/
[99] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project
[100] Ibid
[101] Natsume et al in Fusion Engineering and Design (2019), Mechanical design of the JT-60SA cryogenic pipe system
[102] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project

Of the power system components, the QPCs are in particular a novelty in the field of nuclear fusion reactors.[103]

JT-60SA's **plant power and heating systems** have been repurposed from a retired tokamak – the JT-60U.[104] They have been upgraded to accommodate long-pulse plasma operation in the reactor.

Targeted scientific aims of the JT-60SA

The JT-60SA is designed to confine **break-even equivalent high-temperature deuterium plasmas**; that is, it aims to generate a plasma using deuterium fuel at configurations which would, if the reactor were using deuterium-tritium fuel, generate fusion power equal to the heat power put into the reactor. Reaching this break-even point – referred to as $Q = {}^{Power\ from\ plasma}/_{Power\ inputted\ into\ reactorplasma} = 1$ – will be essential for the JT-60SA to act as an effective satellite to ITER, as ITER is intended to operate at 10 times the breakeven point with a deuterium-tritium plasma.[105] Currently the record for break-even is $Q = 0.67$, first achieved by JET in 1997.[106]

Crucially, experiments at the JT-60SA will be able to explore **high beta plasma regimes** better than any existing tokamak. Beta – a measure of kinetic pressure to magnetic pressure, $\beta = \frac{Kinetic\ plasma\ pressure}{Toroidal\ magnetic\ pressure}$ – serves as a proxy for a reactor's efficiency.[107] Any future economically viable fusion power will be generated with high beta plasmas, but their operation using sufficiently large magnetic systems is still insufficiently understood.[108] Beta is partly determined by plasma shaping, which increases stability and suppresses turbulence.[109] It is useful, then, that the JT-60SA is designed to operate a **wider range of plasma shapes** than produced at other big tokamaks – including elongations and triangularities that have not yet been tested at longer pulses. The results of testing different plasma shapings will inform the design of future nuclear reactors so they are optimised for power generation. [110,111]

At the same time, the JT-60SA will allow for testing of plasmas at lower aspect ratios (A) – i.e., the ratio between a torus's outer and inner radius – moving towards $A = 2.5$, the point at which magnetic pressure generated by a torus can be maximised. As ITER is designed to operate at an aspect ratio of 2.5, the results of JT-60SA's tests will help ITER in order to achieve this as well.[112]

Tests at the JT-60SA will explore **high density plasma regimes** that are relevant to ITER, as ITER will aim to confine the highest density plasmas ever run in a tokamak. And a defining feature of the JT-60SA is its capability to maintain plasmas for **longer run times** and with **fully non-inductive currents**, which will enable researchers for the first time to study plasma dynamics and particle handling at runtimes of up to 100s at high power.[113,114]

[103] Takechi, Sakurai, Masaki, Matsunaga, and Sakasai in Fusion Engineering and Design (2019), Disruption simulations for JT-60SA design and construction – accessible via https://www.sciencedirect.com/science/article/abs/pii/S0920379619306507
[104] Barabaschi, Kamada and Shirai on behalf of Fusion for Energy (2019), Progress of the JT-60SA Project
[105] JT-60SA (2015), Project Objectives – accessible via http://www.jt60sa.org/b/index_nav_1.htm?n1/objectives.htm
[106] Windsor in Philosophical Transactions of the Royal Society A (2019), Can the development of fusion energy be accelerated? An introduction to the proceedings – accessible via https://royalsocietypublishing.org/doi/10.1098/rsta.2017.0446#d3e647
[107] Guo et al in Nature (2015), Achieving a long-lived high-beta plasma state by energetic beam injection – accessible via https://www.nature.com/articles/ncomms7897
[108] Corroborated through interviews with experts conducted in March 2020.
[109] Discussed in consultation with expert advisors, March 2020.
[110] Windsor in Philosophical Transactions of the Royal Society A (2019), Can the development of fusion energy be accelerated? An introduction to the proceedings – accessible via https://royalsocietypublishing.org/doi/10.1098/rsta.2017.0446#d3e647
[111] Giruzzi et al in Plasma Physics and Controlled Fusion (2019), Advances in the physics studies for the JT-60SA tokamak exploitation and research plan – accessible via https://iopscience.iop.org/article/10.1088/1361-6587/ab4771/meta
[112] JT-60SA (2015), Project Objectives – accessible via http://www.jt60sa.org/b/index_nav_1.htm?n1/objectives.htm
[113] Ibidem
[114] Los Alamos National Laboratory, Dense Plasma Theory Physical Regimes – accessible via https://www.lanl.gov/projects/dense-plasma-theory/background/physical-regimes.php

Operating the JT-60SA might also enable scientists to observe **plasma disruptions** – instances in which plasmas unexpectedly drop out, losing their thermal and magnetic energy. Causes of plasma disruptions are not always evident to scientists, and the opportunity to observe a plasma disruption especially in a larger reactor could advance physicists' and engineers' understanding of their disruptions and theories on disruption mitigation techniques and technologies.[115,116]

Finally, the JT-60SA will be equipped with a remote handling system to allow maintenance of in-vessel components that become irradiated as they are subjected to high neutron fluxes. This will allow for testing of key technical safety mechanisms at the reactor and would represent a major technological advance in the field of tokamak research.[117]

Advanced systems developed for IFMIF/EVEDA

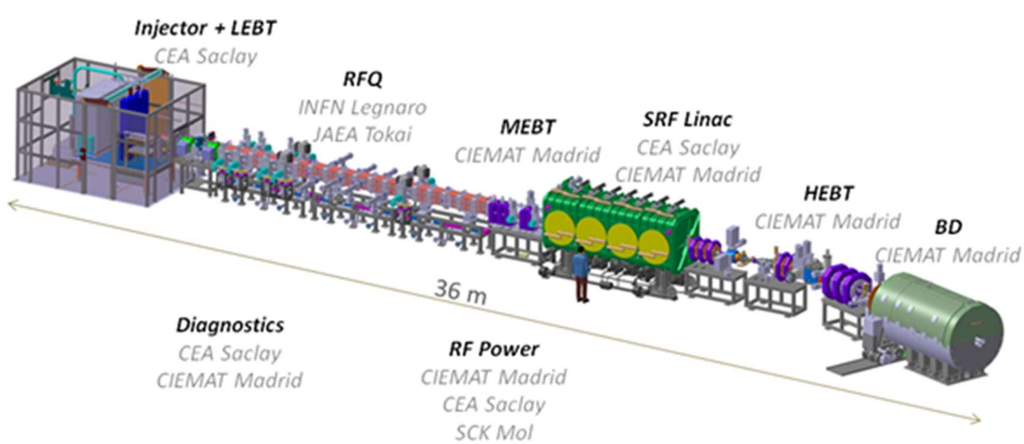
IFMIF-EVEDA's three subsystem prototypes are:[118]

- LIPAc (Linear IFMIF Prototype Accelerator), an accelerator identical in design to IFMIF's up to its first, low energy superconductive accelerating stage
- ELTL (EVEDA Lithium Test Loop), a lithium test loop that contains all key components of the IFMIF target facility
- Test Modules, with prototypes of containment capsules which house materials for testing

LIPAc

IFMIF-EVEDA's linear accelerator prototype was constructed at JAEA's site in Rokkasho, Japan. The institutions CEA, CIEMAT, INFN, and SCK-CEN constructed and tested many of its components in the EU before delivering them to Japan.[119] These components are identified in the figure below, which depicts the structure of the linear accelerator prototype.

Figure A-0-2: Indicative laboratory contributions of LIPAc components[120]



Key: LEBT=Low-energy beam transport; RFQ=Radio Frequency Quadrupole; RF=Radio Frequency; MEBT=Medium-energy beam transport; SRF Linac=Superconducting Radio Frequency Linear Accelerator; HEBT=High-energy beam transport; BD=Beam Dump

115 Lehnen on behalf of ITER (2017), Addressing the challenge of plasma disruptions – accessible via https://www.iter.org/newsline/-/2678
116 Corroborated through interviews with experts conducted in March 2020.
117 JT-60SA (2015), Project Objectives – accessible via http://www.jt60sa.org/b/index_nav_1.htm?n1/objectives.htm
118 Ibidem
119 Ibidem
120 IFMIF/EVEDA (2015), Accelerator facility – accessible via https://www.ifmif.org/?page_id=66

Though the completion of LIPAc was stalled several times by delays in deliveries and manufacturing, it began operating both proton and deuteron beams last year. LIPAc proton and deuteron beams are generated by injectors and focused and filtered in the low-energy beam transport unit. The beams are accelerated initially by the radio frequency quadrupole and then further by eight superconducting resonators in the SRF Linac (the latter to be completed). The beams are measured and controlled before they are stopped at the beam dump. A cryoplant is deployed to cool the SRF Linac to a steady operating temperature.[121]

In successfully developing LIPAc, which began consistent operations in 2019, IFMIF-EVEDA oversaw the construction of a linear hadron accelerator that is now world-leading in power beam range. It will be overtaken only by IFMIF when it is operational.[122]

ELTL

The EVEDA lithium test loop has been operational since 2011. ELTL activities are overseen and implemented jointly by the JAEA (now QST) and by ENEA.[123] Lithium target validation has consisted of constructing and operating a test loop that includes purification systems, analytical diagnostics for the lithium target, conducting erosion and corrosion tests for loop structure materials and testing remote handling apparatus.[124]

Physically, the test loop itself is nearly equivalent to the loop that will be built at IFMIF (though it differs in width and lacks a comparable heat removal system). The main loop includes the target assembly, a quench tank, an electromagnetic pump, an electromagnetic flow meter, a lithium cooler, and a dump tank. Argon gas cylinders and vacuum pumps are used to control the loop’s pressure and vacuum.[125,126]

ELTL is being used to run diagnostics on the surface of a cross-flowing lithium jet in the target assembly, akin to the jet that will absorb deuterium beams in IFMIF. It will be necessary in IFMIF to control the thickness and waviness of the lithium target jet, and researchers at ELTL are developing methodologies to accurately measure and understand jet shape dynamics; contact probe-based and optical mechanisms will be tested at the loop site. Experimenting with these measurement mechanisms will inform how technical operators at IFMIF can accurately control for lithium jet shapes.[127,128]

Simultaneously, a collaborator team of researchers at ENEA in Italy are experimenting with a target assembly mock-up on which they can test remote handling mechanisms that will be required to construct and maintain structures in the lithium target at IFMIF.

Test modules

KIT in Germany, in conjunction with CIEMAT, SCK-CEN, CRPP and the JAEA, are leading the design and validation of materials test facilities. Their research focuses on prototyping high- and medium-flux test modules and developing small-specimen testing techniques. The labs are experimenting with different

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[121] Ibidem
[122] Corroborated through interviews with experts conducted in March 2020.
[123] IFMIF/EVEDA (2015), Target Facility – accessible via https://www.ifmif.org/?page_id=72
[124] Knaster et al in Nuclear Fusion (2017), Overview of the IFMIF/EVEDA project – accessible via https://iopscience.iop.org/article/10.1088/1741-4326/aa6a6a
[125] IFMIF/EVEDA (2015), Target Facility
[126] Knaster et al in Nuclear Fusion (2017), Overview of the IFMIF/EVEDA project
[127] IFMIF/EVEDA (2015), Target Facility
[128] Knaster et al in Nuclear Fusion (2017), Overview of the IFMIF/EVEDA project

designs for high-flux test modules that would allow for irradiation testing at extremely high temperatures, as would be required for certain materials at IFMIF.

Priorities of IFERC's Remote Experimentation Centre

The subsidiary project prioritised the technical development of eight areas that will be essential to remote operation and experimentation within ITER, including:[129]

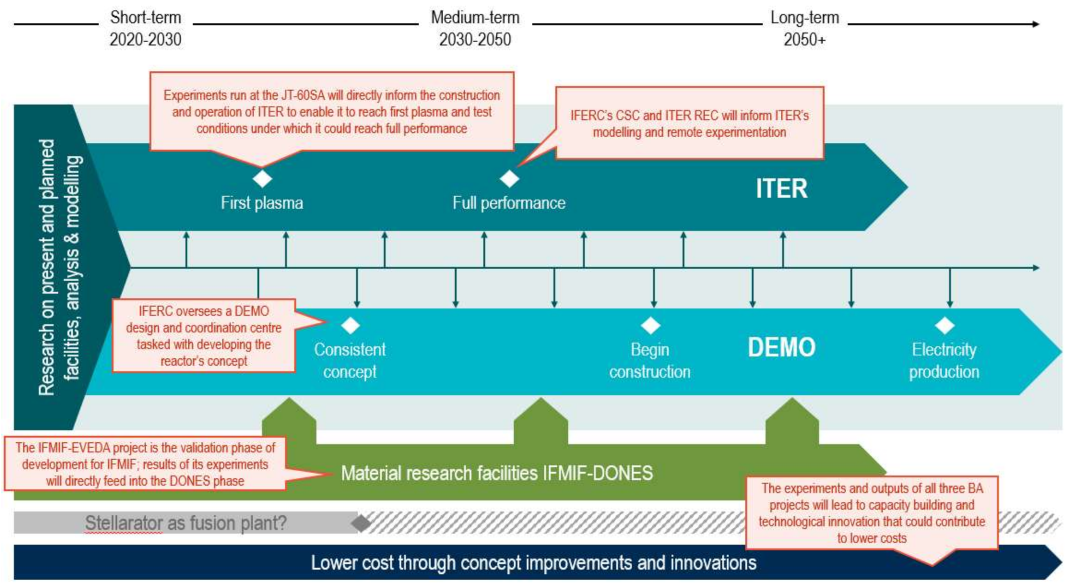
- Surveying and procuring equipment for the REC Room
- Ensuring a reliable REC Network
- Conducting Fast Data Transfer Tests
- Implementing a remote experimentation system for the Satellite Tokamak (SA), i.e. the JT-60SA
- Deploying remote experimentation in EU tokamaks
- Managing data storage
- Developing experimental data analysis software for SA test project
- Developing a remote experimentation simulator for training

BA activity alignment with EUROfusion objectives

EUROfusion has mapped the primary goals in the field of European nuclear fusion research; milestones it hopes to achieve in the short-, medium-, and long-terms. Its roadmap is centred around the construction and operation of ITER and DEMO, as well as the progression of an auxiliary nuclear materials testing facility, IFMIF-DONES.[130] Figure A-0-3 shows how BA project objectives and achievements will enable these targets to be reached. The three projects are slated to achieve their own milestones in the immediate term which will feed directly into project development for ITER and DEMO, and enable those reactors to stay on track for development and operation.

[129] IFERC (2017), REC – accessible via https://www.iferc.org/REC.html#Activities
[130] EUROfusion (2018), European Research Roadmap to the Realisation of Fusion Energy, Long Version – accessible via https://www.euro-fusion.org/fileadmin/user_upload/EUROfusion/Documents/2018_Research_roadmap_long_version_01.pdf

Figure A-0-3: Broader Approach project alignment with EUROfusion's short-, medium-, and long-term experimental plans based on the illustrated EUROfusion roadmap stages[131]



It's clear that achieving EUROfusion's set targets hinges upon the successful completion and deployment of ITER. And indeed, the BA projects were designed as ancillary projects to ITER, given that the European fusion community has centred around ITER for the past two decades. The BA projects have achieved many standalone technical feats, but their most significant achievements will be to directly inform the design and operation of both ITER and DEMO, critical projects to the advancement of nuclear fusion, in order to mitigate risks to their implementation and ensure they can succeed.

Detailed bibliometric analysis methodology and considerations

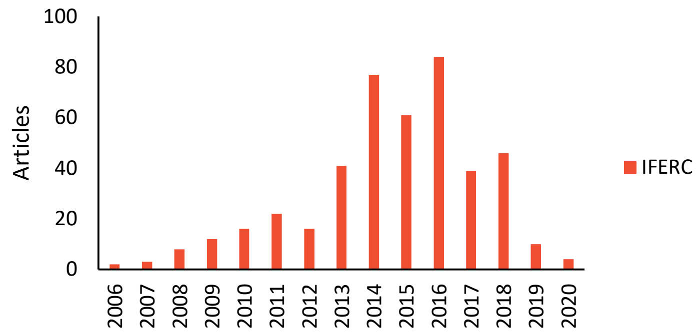
To collect articles relevant to each in-scope nuclear fusion institution, Google scholar was queried using the same set of key words: the lab/institution name followed by nuclear fusion, to focus the results for research institutions with additional mandates outside of the scope of nuclear fusion. Output from Google Scholar included not only articles published by respective institutions, but articles to which institutions had contributed, or in which their research was referenced extensively.

Results from Google Scholar which were not scientific articles – i.e., which were books, citations, or patents – were excluded from the analysis. Additionally, the database was filtered to exclude duplicate results and to filter any articles published in non-roman alphabets, as these articles could not be manually assessed for their relevance to the projects and labs. The database was constructed to include only output published between 2006-2020. In this way, the bibliometric analysis speaks to the scientific relevance of analysed institutions only between this timeframe, which roughly corresponds to the lifetime of the BA agreement until now.

Google Scholar results on the scientific output of IFERC are included in the figure below. The figures contrast with IFERC's own records of its published articles, which speaks to the limitations of using Google Scholar's database as a sole reference source.

[131] Adapted from EUROfusion (2018), European Research Roadmap to the Realisation of Fusion Energy, Long Version

Figure A-0-4 Scientific output of IFERC in the filtered Google Scholar basis



Contributions of the JT-60SA to risk reduction for ITER and DEMO

Figure A-0-5, Figure A-0-6, and Figure A-0-7 depict key design features and target regimes of the JT-60SA contrasted with those of other (existing and future) tokamaks and superconducting tokamaks.

Figure A-0-5 shows that the JT-60SA has the largest major radius and shape parameter of any existing tokamak; its behaviour as such will inform the operation of ITER as a large-radius reactor, but also more particularly, the design of a “SlimCS” compact, low aspect ratio DEMO reactor.
Figure A-0-6 depicts two-dimensional plasma cross-sections of superconducting tokamaks; it makes clear that the JT-60SA represents a significant step between the plasma sizes of existing superconducting tokamaks and the plasma size that will be sustained at ITER. Plasma at the JT-60SA will be studied to better understand and de-risk larger-scale plasma containment at ITER.

Figure A-0-7shows how the JT-60SA will be used to bridge gaps between plasma regimes that have been tested at existing reactors and the targeted plasma regimes of ITER and steady-state DEMO reactors. The JT-60SA will be run to test a new range of break-even conditions at relatively lower temperatures than those tested at e.g., JET and the JT-60U, but at significantly higher thermal energy confinement times per plasma volume. The JT-60SA will not be able to test ignition conditions, which is the core aim of ITER. It will, however, be used to test plasma confinement at long sustainment times necessary for achieving ignition conditions, thereby bridging the substantial divide between sustainment times of ~30 seconds achieved at existing tokamaks and the sustainment time of ~90 seconds necessary for ITER to reach its initial inductive state.

Finally, Figure A-0-8 depicts how JT-60SA experiments and operation has been designed to enable ITER to reach its target performance while generating new knowledge on high-beta, high-density plasma confinement that will be the target of a DEMO reactor. While the JT-60SA will de-risk many technical processes at ITER, it will not act as its direct predecessor and will therefore not be able to de-risk all aspects of ITER operation. Instead it will be run in parallel to ITER in order to test plasma confinements at extreme conditions beyond those of ITER, in order to inform the design and de-risk the eventual operation of a DEMO reactor.

Figure A-0-5 Plasma major radii and shape parameters of global tokamaks[132]

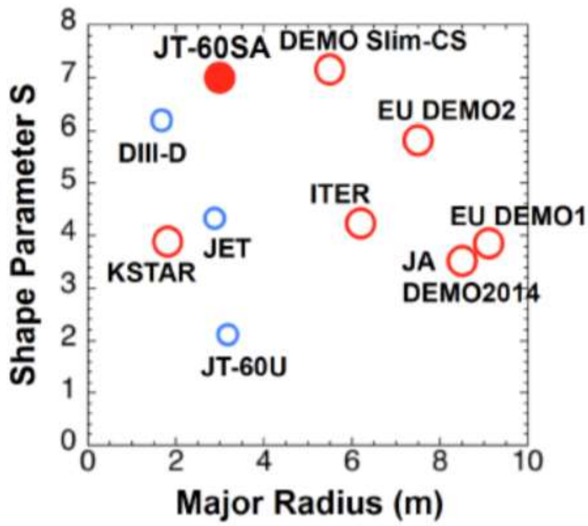
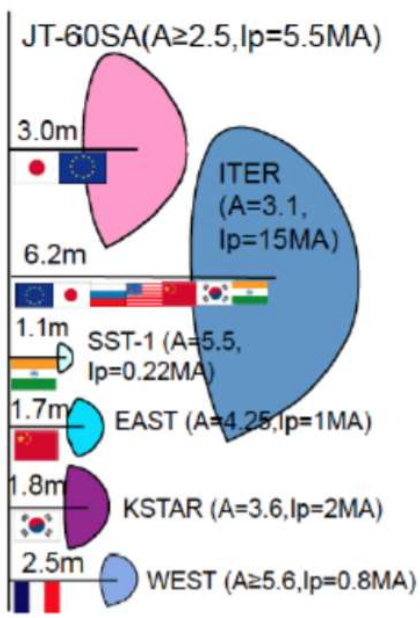


Figure A-0-6 Plasma cross sections of global superconducting tokamaks[133]



[132] JT-60SA Research Unit (2018), Jt-60SA Research objectives and strategy – Version 4.0, Figure 1-3 (b)
[133] JT-60SA Research Unit (2018), Jt-60SA Research objectives and strategy – Version 4.0, Figure 1-3 (c)

Figure A-0-7 Target regimes of the JT-60SA[134]

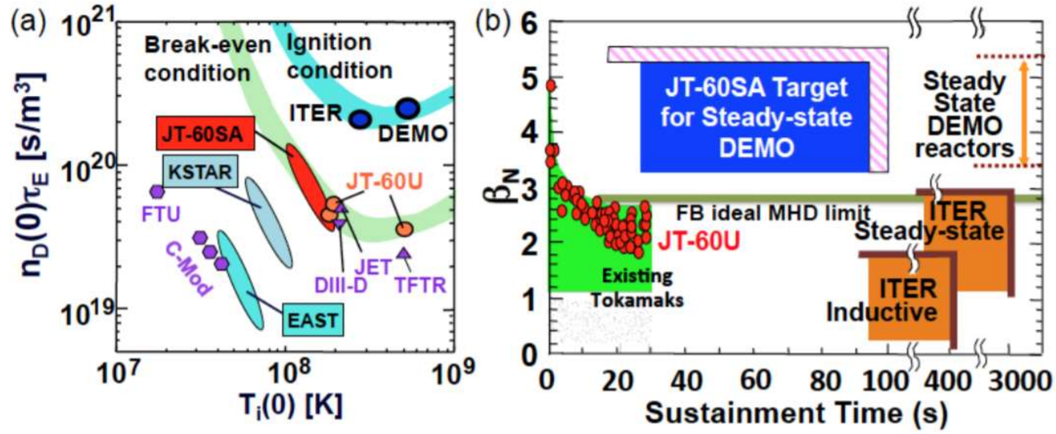
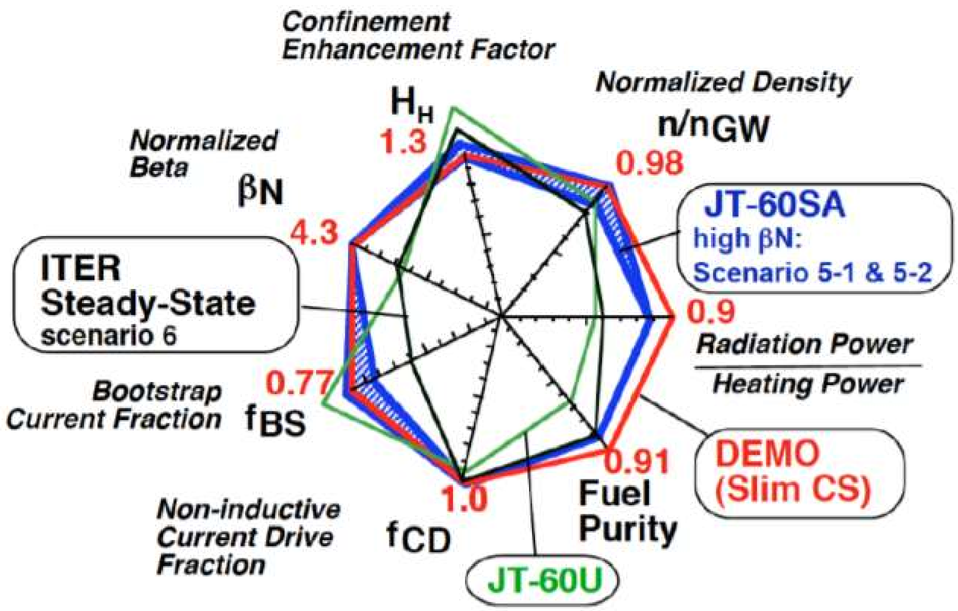


Figure A-0-8 Integrated plasma performance comparison between existing and future superconducting tokamaks



134 JT-60SA Research Unit (2018), Jt-60SA Research objectives and strategy – Version 4.0, Figure 1-2 (a), (b)

Annex B - Additional details on the BA governance, implementation and impacts for participants in Europe

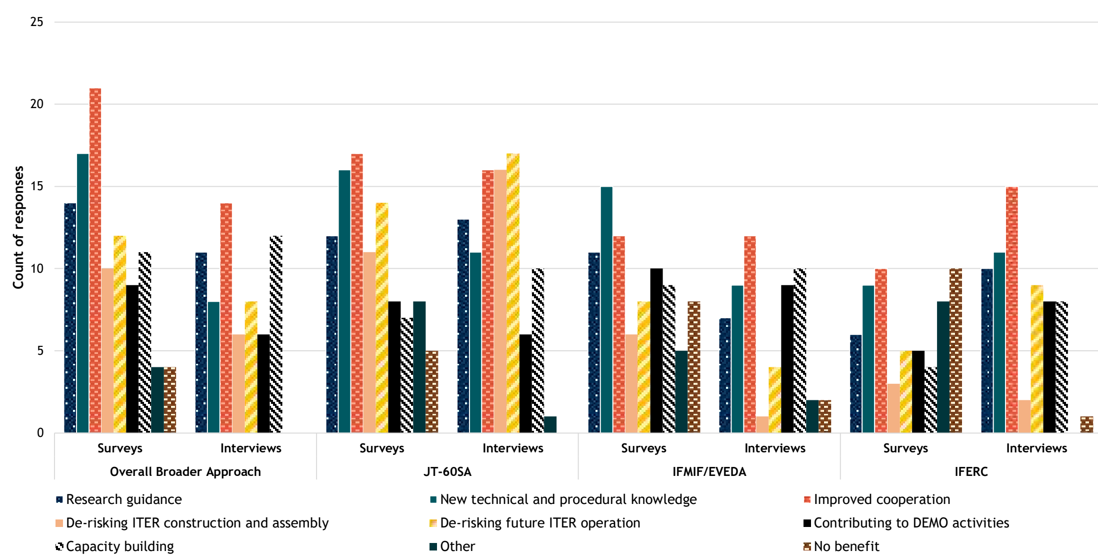
Analysis of survey results on selected topics

Figure B-0-1indicates the perceived benefits of the BA according to the survey respondents and a subset of the interviewees. To all, the BA provides several benefits, as do the individual projects. It must be noted the 'contributing to DEMO activities' was added at a later stage to the survey and interview questionnaires, based on feedback received in the interviews – this is reflected in the lower number of responses highlighting that benefit. Benefits indicated in the "other" category relate to the benefits to DEMO and the applicability of technical and project management skills to large-scale projects in general.

There are contrasting views on the relevance of the IFERC sub-projects, compared to a greater agreement on the positive impact of JT-60SA and IFMIF/EVEDA by stakeholders. 10 survey respondents indicated that they perceived IFERC as providing no benefits, this scale of response is comparable to the number of stakeholders which have assigned some kind of benefit to IFERC. However, 1) 20 other survey respondents have marked IFERC as providing benefits, especially regarding new knowledge and improved cooperation; 2) most interviewees do not support the view IFERC has little or no benefit to ITER and DEMO; 3) one interviewee has indicated many nuclear physicists would strongly support IFERC. The contrasting views on IFERC arise from a number of factors:

- ✓ Being a collection of projects, individual stakeholders are less familiar with the work and objectives of each of the IFERC sub-projects. All of the surveys respondents assigning no benefits to IFERC state that they were not involved with it;
- ✓ All of the IFERC sub-projects could take place under other collaboration initiatives than the BA. There is thus less of a clear reason for their inclusion under the BA to some stakeholders, even when the projects themselves may make clear contribution to IFERC and DEMO.

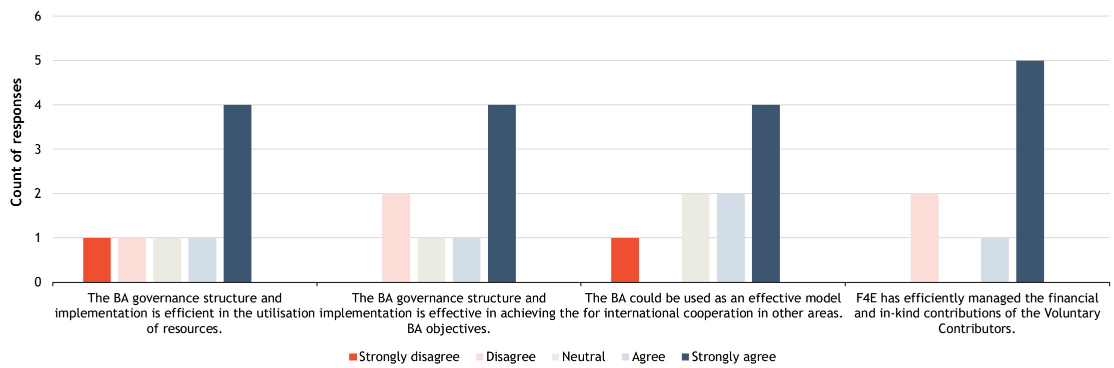
Figure B-0-1 Benefits of the BA and its projects according to survey respondents. $n_{surveys}$ = 24, $n_{interviews}$ =30



The majority of survey respondents have a positive perception of the efficiency and effectiveness of the Broader Approach governance, as well as of the F4E resource management and the applicability of the BA governance structure to other international cooperation activities. Figure B-0-2 presents the responses to statements concerning the overall governance of the BA. However, for each of the statements, up to 2 survey respondents disagree. Explanations of the negative evaluations (given by one stakeholder each) concern:

- ✓ The division of project management responsibilities in IFMIF/EVEDA between the Project Leader, the project team in Rokkasho and the home teams is unclear;
- ✓ F4E has had issues in finding a positive project management role while not overlapping the role of Voluntary Contributor's staff;
- ✓ F4E/EU procurement rules are overly complex for SMEs and require continuous guidance provision during tenders.

Figure B-0-2 Evaluation of the overall Broader Approach governance by survey respondents, n=9



Networking, access to BA knowledge, guidance regarding own research agenda, increased alignment with ITER activities and non-technical competences are the main impacts listed as 'positive' or 'very positive' by survey respondents (see annex B). Figure B-0-3 presents the survey responses on the "impact to your organisation of its participation in the BA overall and its projects". Specific examples of e.g. networking benefits include becoming part of the fusion network for an industrial stakeholder, and positive collaboration with multiple EU and JP laboratories in the case of an EU research organisation, which would help not only on its specific BA project but also on future projects. Details provided on the non-technical competences impacts highlighted the benefits of working in a positive, multi-disciplinary international collaboration environment.

Increased alignment with DEMO activities is indicated as less beneficial – this is likely to be the result of various factors, especially 1) the specific question on DEMO being added at a later stage to the survey, 2) DEMO activities being in the initial R&D and conceptual design phase in the fusion community, and 3) DEMO activities being less relevant to companies. Some stakeholders considered that the BA did not influence their research agenda, with one indicating that in the case of IFMIF/EVEDA the focus should be on implementation and not on re-assessing the research agenda, which could be detrimental to the project. Responses to the 'other' impacts indicate the impact categories of the survey generally covered the potential BA impacts well as respondents did not provide further impacts, except for noting that the BA constituted an important public-private collaboration.

Figure B-0-3 Responses to "Please rate the impact to your organisation of its participation in the BA overall and its projects", n= 24

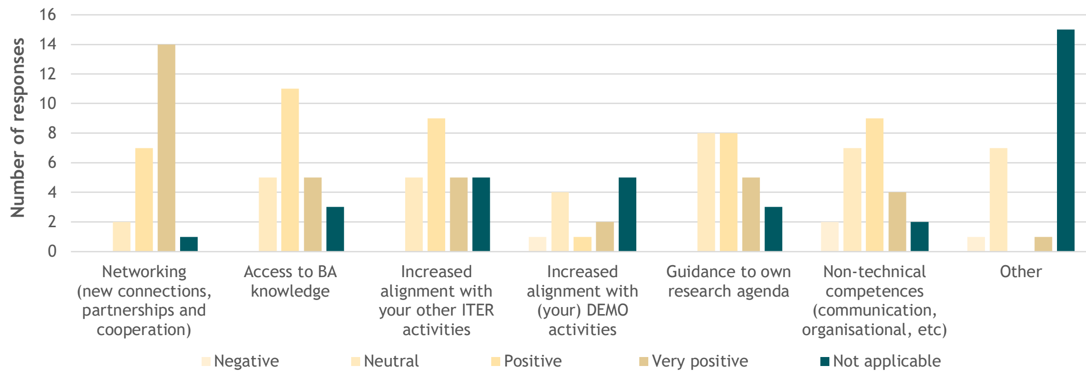
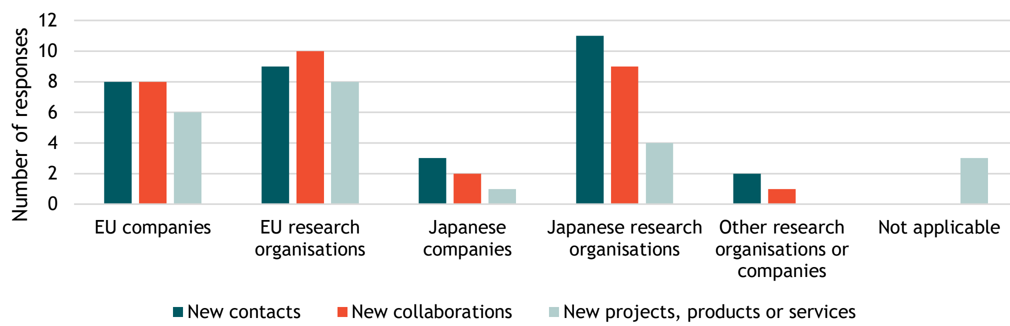


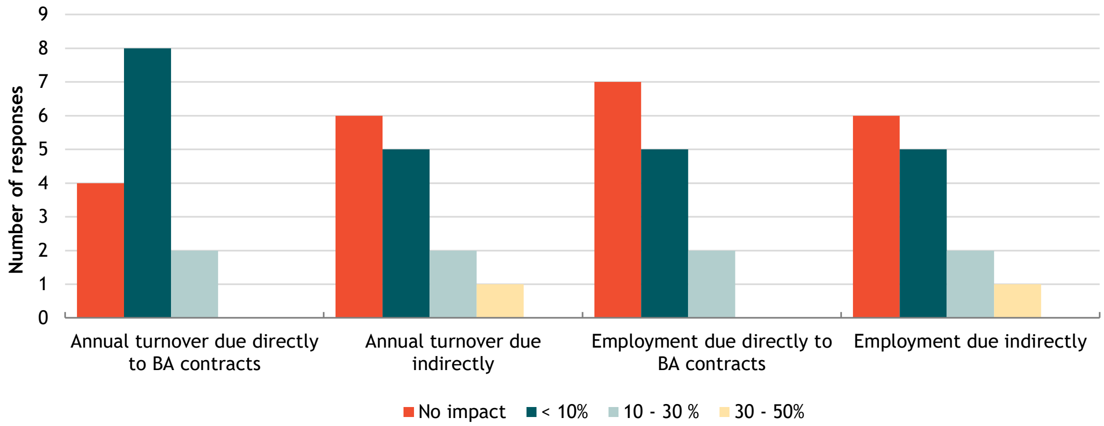
Figure B-0-4 indicates that while the **BA led to new contacts with Japanese research organisations this has not (yet) translated into new projects, products or services for a majority of respondents** – although 4 respondents indicated that it had. In only 2 cases has the BA led to new contacts with Japanese companies. In the EU, less new contacts with research organisations and companies are indicated, which is arguably to be expected as EU research staff would have more contact with fusion-relevant EU organisations. Nonetheless, respondents indicate this has consistently led to new collaborations, products, products or services.

Figure B-0-4 Responses to "Did the collaboration in the BA and its projects lead to new contacts and/or collaboration in new projects/products/services?", $n_{surveys}$ = 13



Survey data on the impact on revenues and employment is presented in Figure B-0-5. This covers 10 companies with a median annual turnover of 32.5 million € (range of 1-375 million €) and employing a median of 107 full-time employees (range of 6-1200 FTEs). Indirect turnover and employment is that arising from new products, services and/or projects developed as a consequence of the BA.

Figure B-0-5 Turnover and employment impact on companies involved in the Broader Approach, n = 14



Spending on BA

Analysing the spending on BA is important to understand the size of any potential impact from the spending. The BA Agreement was signed in 2007 and supported by a 2006 Final Report of Negotiations on the Broader Approach Agreement. The Final Report provided an estimate of the value of the contributions of the European and Japanese Parties to the BA and how these would be split between the projects. In summary, a credit system was employed, using BA Units of Account (BAUA) of which both Parties would provide 500k BAUA. Values for these BAUA were made in both Yen and Euros (in 2005 prices) to reconcile the two, as a result, 1k BAUA would be worth 92m Yen and 678 000 EUR. The BAUAs were split across the 3 projects and then each project also split their allocation further into sub-steps and between the EU and Japanese parties. The BA crediting system is judged as positive on the whole by interviewees.

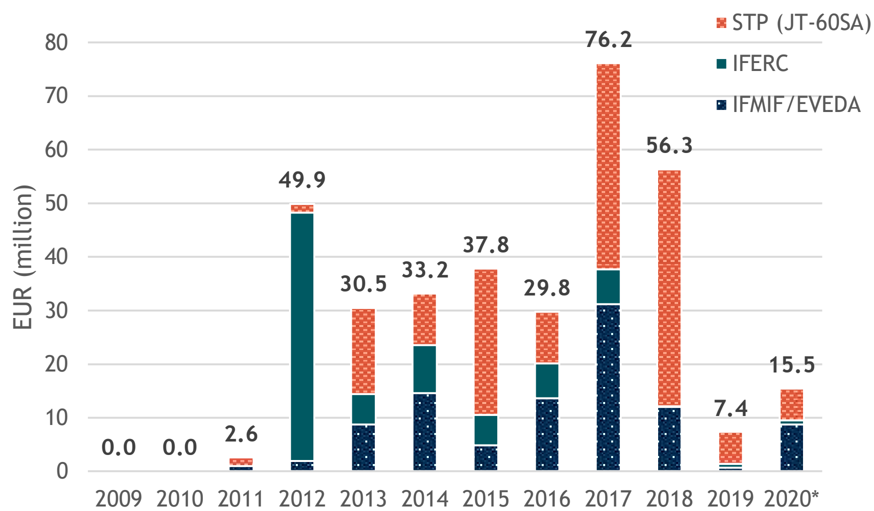
Table B-0-1 presents the key BAUA and EUR value estimates, as presented or derived in the Final Report. These show an EU commitment estimated at EUR 339 million and a comparable nominal commitment from Japan. These also show the EU taking the larger share for IFMIF/EVEDA, but a smaller share than Japan in IFERC. Figure B-0-6, based on the F4E 2018 final accounts, estimates the spending on the projects over time based on credits awarded[135], which shows credit awards resulting from spending being highest from 2012-2017. IFERC awards were already heavily focused on the earlier years, whilst IFMIF/EVEDA was spread more evenly over time and JT-60SA more weighted to the end of the period. As a comparison, the Euratom contribution to ITER in the 2007-2020 period in 2008 EUR is of around EUR 7.2 billion, and in the period 2021-2035 is estimated at EUR 7.1 billion, of which EUR 3.9 billion for the 2021-2025 period to reach first plasma. Hence, EU contributions to the BA phase I amount to around 5% of Euratom contributions to ITER up to 2020, and around 2.5% of the estimated contributions from 2007 to 2035.[136]

[135] In reality there is a time lag between the spending and the (later) award of credits, this should be taken into account.
[136] European Commission (2017) EU contribution to a reformed ITER project. COM(2017) 319 final.

Table B-0-1 BA budgeted values for EU and JP per project, in kBAUA and EUR_{2005}[137]

Project	EU [kBAUA]	JA [kBAUA]	Sum [kBAUA]	EU % of project	EU [2005 mEUR]	JA [2005 mJPY]	JA [2005 mEUR]	Sum [mEUR]
IFMIF/EVEDA	143.75	76.49	**220.24**	65%	97.5	7 037.1	51.4	**148.9**
IFERC	119.84	187.10	**306.94**	39%	81.3	17 213.2	125.8	**207.0**
STP (JT-60SA)	236.41	236.41	**472.82**	50%	160.3	21 749.7	158.9	**319.2**
Total	**500**	**500**	**1000**		**339**	**46 000.0**	**336.1**	**675.1**

Figure B-0-6 Estimated annual spending on BA 2009-2020, EUR_{2005} million[138]



Source: Own elaboration based on F4E (2020) Consolidated Annual Activity Report 2019.

* note that 2020 values are estimates based on allocation of the remaining credits

On the EU side the BAUAs were then allocated to the Voluntary Contributors (the largest part) and F4E. F4E tendering procedures are open to all economic operators established in the F4E countries (namely EU Member States and Switzerland) whereas procurement by VC public organisations need to follow EU public procurement rules. There were cases of companies based on non-VC countries being awarded BA contracts.

In using a crediting system the direct link to EUR amounts was removed, the focus was on delivering the sub-steps rather than on the cost. If sufficient quality could be delivered for a cost less than the estimated ratio then this would be to the benefit of the VC, or, as is more likely, the cost was higher than the estimated EUR cost from the credit:EUR ratio then the VC would need to make up the cost itself. Information on the VC spending is limited, the Final Report estimated a split between VCs of 47% from France, 25% from Italy, 12% from Spain and 4% from Germany, the remaining 13% from F4E, as indicated in the table below. The reality undoubtedly varied from this, with F4E contributions appearing higher in their accounts, and the addition of Belgium as a VC. As noted in the audit report of 2018, no further financial data from the VCs is available to form a clear picture of actual spend by VCs

[137] Values converted from JPY to EUR using ECB annual average exchange rate for 2005 of 1 EUR = 136.87 JPY
[138] Using GDP deflators, these values would be approximately 17% higher in 2019 EUR.

in the course of the work. In 2019 the BA and DEMO activities employed around 7% of F4E's human resources.[139]

Table B-0-2 Estimated contributions of VCs as of 2006 BA negotiations

Voluntary Contributor	Estimated value in EUR million
Belgium	11.0
France	158.9
Germany	13.3
Italy	84.1
Spain	40.3

Source: DG RTD and MEXT (2006) Final Report of Negotiations on the Broader Approach Agreement; for BE, Massaut (2012) Broader Approach for Fusion – Belgian contribution – Progress report 2011

Mapping and description of the BA governance structure

Figure B-0-7 presents the BA governance mapping. The Broader Approach Agreement between Euratom and the Japanese government establishes a governance structure with a BA Steering Committee (BASC), project committees for STP, IFERC and IFMIF/EVEDA, as well as project teams headed by a project leader and a BA secretariat.

The **BASC** is responsible for, amongst other functions, appointing the project leaders and approving multiple project-related elements: the project plans, work programme, annual reports, the structure of the project teams and the annual appointment of experts to the project teams.

The BASC is composed of four members from each party, and meets twice each year. In addition, each side has experts and advisors from e.g. F4E, the European Commission and organisations from the Voluntary Contributors. As of December 2019[140] the EU side was composed of the following members:

- ✓ The Deputy Director-General of the Nuclear Energy, Safety and ITER (ENER.D) and Euratom Safeguards (ENER.E) Directorates of DG Energy;
- ✓ The chair of the Governing Board of F4E;
- ✓ The head of the ITER unit at the European Commission;
- ✓ The director of international affairs and large research infrastructures at CEA (FR).

The **project committees** are responsible for recommending the submission of project plans, work programmes and annual reports to the Steering Committee, monitoring and reporting on project progress, and for other duties. Each project committee has 3 representatives from the EU and Japan, and meets at least twice a year. The composition on the EU side varies, as of December 2019 besides representatives of participating organisations in the Voluntary Contributors, there were also representatives from organisations in other Euratom countries, from the European Commission or from F4E.

The **Integrated Project Teams** are composed of the project leader and its deputy EU and JP project managers, a central project team, as well as EU and JP home teams. The function of (deputy) project leader may be conducted by the project manager of the correspondent party, as is the case of JT-

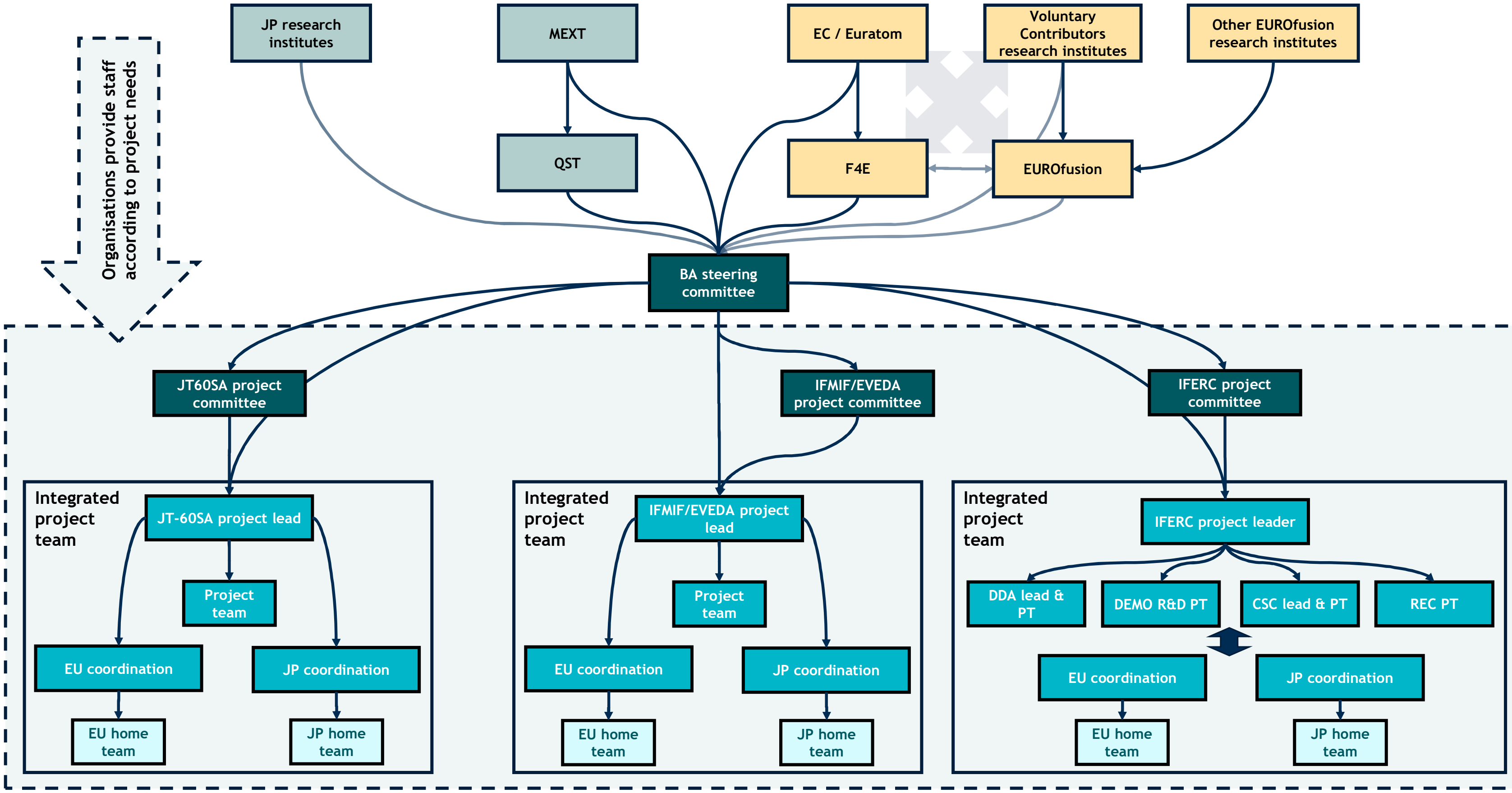
[139] F4E (2020) Consolidated Annual Activity Report 2019
[140] QST (2019) Broader Approach Activities. Available at https://www.qst.go.jp/site/ba/4671.html

60SA.[141] Project leaders are responsible, among other functions, for managing the project team, preparing the documents submitted to the BASC, requesting expenditures from the Japanese Implementing Agency, and accounting for the European and Japanese contributions.

The Japanese Implementing Agency (QST since its creation in 2016, JAEA prior to that) is also responsible for the management of financial contributions from both parties to the operational costs and common expenses of the project teams.

[141] JT-60SA STP project leader (2020), The Satellite Tokamak JT-60SA:BA Phase II – Summary Plan.

Figure B-0-7 Mapping of the BA governance structure and links to other organisations in phase I[142]



Participation of EU and JP research institutes in the BASC indicated in light shade. EUROfusion has coordination meetings with F4E (dashed connections).

Connections of organisations with the project teams not shown for simplicity, staff provided according to project needs.

[142] Own elaboration, with information from among other sources F4E (2018) Audit of Implementation of the Broader Approach Agreement; BA project websites.

Annex C - Stakeholder consultation methodology

This annex describes the two main consultation elements of the study: interviews and an online survey with European and Japanese stakeholders. The interview scripts and survey were tailored to different stakeholder groups were finalised. 32 interviews were conducted between March and July 2020, and 30 complete responses were received for the survey, which was online during the same period as the interviews.

Consultation design

The design of the interviews and the survey consisted of the following steps:

1. Set objectives and overall target audience;
2. Definition of key consultation topics;
3. Definition of stakeholder groups, and approach per group;
4. Identifying and selecting specific stakeholder contacts.

The inception phase further refined these steps, with the inception report providing drafts for the interview scripts and for the survey. Following discussions within the project team and with the EC, these were finalised, and piloted with a first wave of contacts. The final interview script (updated with the insights gained in the pilot) is presented in Annex A. The final, updated online survey is presented in Annex B (a separate pdf file). The interview scripts were sometimes tailored for certain stakeholders, such as interviewees from Japan, the European Commission, the ITER Organisation, and the UK Atomic Energy Authority (UKAEA).

Table C-0-1 presents the various stakeholder types, as well as the most appropriate format (survey or interview) for each of these. In order to simplify the design of the consultation, the same structure of key issues and stakeholder groups were used for both the interviews and the survey. This means that the questions in the interview script and the survey are similar, but adapted to the medium (e.g. the survey makes more extensive use of multiple and single choice questions) and with some additional questions added to the interview.

Along with the refinement of the stakeholder groups with the EC, the final definition of key topics per stakeholder group was also set, as presented in Table C-0-2. The main criteria was the knowledge of the stakeholder group on each topic. Efforts were also made to limit the number of topics per stakeholder, in order to restrict the interview time to around one hour, and the survey completion time to around 30 minutes. Scripts sent to interviewees only contain the questions for the relevant topics, while the online survey automatically presents the relevant questions based on the answer to a stakeholder type question at the start of the survey.

Table C-0-1 Stakeholder groups, methods of contact and specific stakeholders to contact

Stakeholder		Best accessed via		Interview / survey stakeholder group name
		Online survey	Interviews	
Voluntary contributors and companies	• Member state representatives (voluntary contributors, non-contributors)		X	• Voluntary contributor representative / National government
	• Companies (EU beneficiaries, non-beneficiaries)	X		• Industry (EU)
European fusion expert community	• EUROfusion		X	• EUROfusion
	• EU Project experts (working on BA)	X		• BA staff
	• Scientists and academia	X		• Scientific community / research institution
F4E	• BA project managers, other staff		X	• F4E
Euratom	• Management		X	• European Commission / Euratom
ITER organisation	• Management		X	• IO
Broader Approach	• BA management (project managers, steering committee, project committees, project leads / coordinator)		X	• BA management
Other stakeholders	• EC staff (DG ENER and others)		X	• European Commission / Euratom
	• Japanese counterparts (MEXT, QST)		X	• MEXT • QST
	• Companies (Japanese beneficiaries)	X		• Industry (non-EU)

Table C-0-2 Final topic mapping per stakeholder

Key issues to be assessed	BA management	BA project staff	Scientific Community/ Research Institution	Industry (EU)	Industry (non-EU)	F4E	Japan (QST)	EC / EURATOM	National govt. (Vol Con)	IO	EUROfusion (admin)
Benefits to EU scientific community											
Technical achievements/ benefits/ barriers	X	X	X			X	X	X	X	X	
Relevance of participation		X	X	X	X						
EU-Japan networks	X	X	X	X	X						
Benefits to ITER											
Attained and future benefits to ITER	X	X	X	X	X	X	X	X	X	X	X
Economic and technical benefits											
New opportunities and barriers				X	X	X		X	X		X
Economic impact				X	X						
BA 1st phase evaluation											
Overall BA evaluation	X	X				X	X	X	X	X	X
BA projects evaluation	X	X				X	X				
Quality of contributions	X					X	X	X	X	X	
Overall EU-JP cooperation	X					X	X	X	X	X	
Continuation of the BA	X	X	X	X	X	X	X	X	X	X	X

Consultation implementation

Implementation of the interviews

The process to conduct the interviews is:

1. The EC sends an introductory e-mail to the stakeholder;
2. The project team follows up in contacting these stakeholders;
3. The stakeholder fills in the interview script ahead of time;
4. The project team leads the interview and updates the filled interview script;
5. The project team revises the filled interview script and send to the stakeholder for validation;
6. The stakeholder validates the minutes.

The EC provided a list of 44 stakeholders, forming the main group for interviews in the project, as indicated in Table C-0-3. Of this group, 24 were selected for interviews, and an additional 8 interviews were conducted with other stakeholders to complement the original set. Most interviews of the first wave took between 60 and 90 minutes.

Figure A-0-1 Summary of interview progress

Table C-0-3 List of stakeholders for interview

Stakeholder category	Name	Organisation	Country	Interview date
BA management / Voluntary contributors / national government	Alberto Fernandez	SPF Economie	BE	08/05
	Vincent Massaut	SCKEN		
	Radomir Panek	CAS	CZ	11/05
	Joachim Knebel	KIT	DE	13/05
	Dirk Radloff			25/03
	Mario Perez	ESS	ES	20/03
	Joaquin Sanchez	CIEMAT		01/07
	Angel Ibarra			19/03
	Christophe Calvin	CEA	FR	13/05
	Gerardo Giruzzi			19/03
	Bernard Salanon			26/03
	Alberto Facco	INFN	IT	15/05
	Roberto Piovan	CNR		18/03
EUROfusion	Tony Donné	EUROfusion	EU	23/03
	Jerôme Pamela			28/04
	Xavier Litaudon			02/07
European Commission / EURATOM	David Maisonnier	DG RTD	EU	26/03
	Massimo Garribba	DG ENER		07/05
F4E	Philippe Cara	F4E	EU	06/05
	Susana Clement-lorenzo			23/03
	Herve Dzitko			23/04
	Enrico Di Pietro			24/04
	Pietro Barabaschi			30/03
QST/MEXT	Tomohiko Arai	MEXT	JP	17/07
	Taro Matsumoto	QST		20/07
	Kenichi Kurihara			13/08
IO	Alain Becoulet	IO	FR	10/07

Stakeholder category	Name	Organisation	Country	Interview date
	Eisuke Tada		JP	13/07
	Bernard Bigot		FR	02/07
	Tim Luce		US	26/06
Researchers	Marco Wischmeier	Max Planck Institute for Plasma Physics	DE	10/07
	Ian Chapman	UKAEA	UK	16/07
Companies (EU)	Pilar Gil	SevenSolutions	ES	15/07

Further details are provided below the general steps for conducting the interviews.

Based on a draft prepared by the project team, the EC sent an invitation to the first wave of stakeholders. The project team followed up, contacting each stakeholder to present the objectives of the interview, provide the interview script (tailored to the stakeholder category) and suggesting three timeslots for the interview.

Upon our request or on their own initiative, most stakeholders filled in the question script ahead of the interview. This allowed the project team to focus on the most relevant answers and to directly follow-up on the answers provided, asking for more details.

At least two project team experts were present in the interview, one to lead and the other to take minutes. The interview lead introduced Trinomics and the project team, as well as the main objectives of the study. Assurances were given regarding confidentiality of the answers and that the interviewee will be consulted if the team wishes to use any quotes in the study reports. Depending on the section focus, either on technical aspects, or governance of the Broader Approach, the team switched leads during the interview.

In the survey script and at the end of the interview, stakeholders are requested to share the survey link with their contacts which were, or are, involved in the Broader Approach. This has led to several additional respondents to the survey.

Implementation of the online survey

The final survey is presented in Annex B. 30 respondents had completed the survey, out of 60 who started the survey. The average response time was 42 minutes, although this can include time spent on other activities. The distribution of responses by country, stakeholder group and organisation are shown in Table C-0-4. The first response was on March 19th.

Table C-0-4 Organisations which completed the survey

Country / region	Stakeholder group	Organisation	Responses
EU	F4E	Fusion for Energy	2
	EUROfusion	EUROfusion	1
Belgium	Industry (EU)	IBA	1
France	Industry (EU)	TDI	1
	Scientific community / Research institution	CEA	2
	Industry (EU)	RI Research Instruments GmbH	1
		SPINNER GmbH	1
	Scientific community / Research institution	IPP Garching	1
		KIT	1
		Max Planck Institute for Plasma Physics	2
	VC representative / National government	Karlsruhe Institute of Technology	1
Italy	BA project staff	Consorzio RFX	1
	Industry (EU)	OCEM - Energy Technology srl	1
		Walter Tosto S.p.A.	1
	Scientific community / Research institution	Istituto di Scienza e Tecnologia dei Plasmi - Consiglio Nazionale delle Ricerche	1
Spain	BA project staff	CIEMAT	2
	Industry (EU)	AVS Added Value Industrial Engineering Solutions	1
		ALBA synchrotron	1
		Seven Solutions	1
		BROAD TELECOM (BTESA)	1
		ANTEC MAGNETS	1
	Scientific community / Research institution	CIEMAT	1
		ESS-Bilbao	1
United States	Industry (non-EU)	Communications & Power Industries International	1
Portugal	Industry (EU)	A Silva Matos Metalomecanica	1
Hungary	Scientific community / Research institution	EK	1

As indicated, the survey key topics followed the same structure as the interview questions, and the specific questions were largely the same, although adapted to the survey (e.g. increased use of multiple and single choice answers). The survey was implemented in CheckMarket. The extensive use of single/multiple choice matrices for answers in the survey allowed for the graphical analysis of the answers, e.g. regarding the ranking of objectives for a continuation of the Broader Approach. The availability of text fields in the matrices enabled respondents to provide further information, detailing their answers, as illustrated in Figure C-0-2.

Figure C-0-2 Example survey question with single-choice scale and follow-up text field

* 22Do you agree with the following statements regarding the overall Broader Approach? Consider the steering committee, project committees & project leader structures.

	1 Strongly disagree	2	3 Neutral	4	5 Strongly agree	Please elaborate.	Not applicable
The overall BA governance structure and implementation is **efficient in the utilisation of resources.**							
The overall BA governance structure and implementation is **effective in achieving the BA objectives.**							
The BA could be used as an effective **model for international cooperation** in other areas.							
F4E has efficiently managed the financial and in-kind **contributions of the Voluntary Contributors**.							

An issue was identified with the self-identification of the respondents, when the survey link was distributed by a person outside the project team. In this case, respondents do not know their stakeholder group. An explanation was added to the survey introductory page to correct this issue.

Annex D - Interview script

Study on the benefits of current and future Broader Approach activities with Japan

Trinomics is preparing, on behalf of the European Commission, a study on the benefits of current and future Broader Approach (BA) activities with Japan. For this purpose, Trinomics prepares a thorough literature review, has launched a survey, and conducts interviews with a selected group of relevant stakeholders. The focus lies on assessing the technical, organisational and political aspects of the current BA activities, and evaluating potential options to evolve it further in future.

The interview will be conducted via teleconference (skype or GoToMeeting) or phone, and will last not more than one hour. The interview will comprise roughly the following topics and questions. Depending on the specific information already available, Trinomics might decide to skip some topics or ask in more detail about others.

We would appreciate to receive from you more information on the following issues, supported by a qualitative explanation/description, and quantitative information whenever possible. We welcome any documentation that you can share with us concerning any of the mentioned topics.

In addition, we provide at the end of the document inputs on which we would welcome additional comments:

- A framework for assessing the impact of BA continuation options, according to its objectives
- A map of the BA governance

The information shared will be treated confidentially, and will be accessible only to the project team and select European Commission policy officers.

Thank you very much for your time and information provided.

The Trinomics research team.

Interview questions per topic

General

1. Your name and function

2. Your organisation and country

3. What is your involvement in the broader approach? Regarding the overall governance and/or the projects (JT-60SA, IFMIF/EVEDA, IFERC).

Benefits to EU scientific community

Technical achievements/ benefits/ barriers

4. Has there been new knowledge, processes and/or products <u>in fusion</u> technology developed partially or entirely due to your organisation's involvement with the Broader Approach?
Please detail per project (JT60SA/IFMIF/IFERC).

5. Has there been new knowledge, processes and/or products outside of fusion technology developed partially or entirely due to your organisation's involvement with the Broader Approach?
Please detail per project (JT60SA/IFMIF/IFERC).

6. What distinguishes JT60SA/IFMIF/IFERC from comparable fusion projects, and how does this advance the fusion roadmap?

7. Which barriers exist (if any) in the BA for the development of fusion knowledge, processes and/or products?
Please consider: organisational; technical; financial; and others.

Relevance of participation in the Broader Approach

8. Please rate the impact <u>to your organisation</u> of the participation in the BA overall and its projects.
These will be detailed in the interview.

	Very negative		Neutral		Very positive	N/A
Networking (new connections, partnerships and cooperation)	☐	☐	☐	☐	☐	☐
Access to BA knowledge	☐	☐	☐	☐	☐	☐
Increased alignment with ITER activities	☐	☐	☐	☐	☐	☐
Increased alignment with DEMO activities	☐	☐	☐	☐	☐	☐
Guidance to own research agenda	☐	☐	☐	☐	☐	☐
Non-technical competences (communication, organisational, etc)	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

9. Please rate the impact of your organisation's contributions to the overall BA and its projects.
These will be detailed in the interview.

	Very negative		Neutral		Very positive	N/A
Impact of specific products/services contributed	☐	☐	☐	☐	☐	☐
Impact of specific technical knowledge contributed	☐	☐	☐	☐	☐	☐
Impact of contributions and involvement on BA processes and management	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐

EU-Japan Networks

10. Did the collaboration in the BA and its projects lead to new contacts and/or collaboration in new projects/products/services?
Please detail the organisation type (industry/academia) and the location (EU Member State/Japan/other).

Benefits to ITER and DEMO

11. How does the BA and its projects benefit ITER or DEMO?
These will be detailed in the interview.

	Research guidance	New technical and procedural knowledge	Improved cooperation	De-risking ITER construction and assembly	De-risking future ITER operation	Contributing to DEMO activities	Capacity building	Other	No benefit
Overall Broader Approach	☐	☐	☐	☐	☐	☐	☐	☐	☐
JT-60SA	☐	☐	☐	☐	☐	☐	☐	☐	☐
IFMIF/EVEDA	☐	☐	☐	☐	☐	☐	☐	☐	☐
IFERC	☐	☐	☐	☐	☐	☐	☐	☐	☐

12. Which barriers exist (if any) specifically for BA supporting ITER or DEMO?
Please consider: organisational; technical; financial; and others.

13. Has the governance of BA provided lessons which could be applied to the governance of F4E?

Economic and technical benefits for companies and Member States

Products and business opportunities

14. Have there been new opportunities developed (partially) due to the BA projects?
Private actors: Please refer to your organisation's contribution only.
Please consider:

- New products
- New services
- New geographical markets

- New collaborations or partnerships (with other firms or researcher organisations)
- Other

15. Are there other benefits of participation in the BA?

Private actors: Please refer to your organisation's contribution only.

16. Which barriers can you identify in the BA affecting the development of new opportunities?

Economic impact

17. Approximately how many people are employed by your company? (in full time equivalents [FTEs])

18. What is the approximate annual turnover of your company? (in million EUR)

19. Please estimate the following revenue/budget and employment impacts to your organisation due directly or indirectly to the BA.

Indicate the % relative to the total turnover or employment.

	<10%	10-30%	30-50%	> 50%
Annual turnover due directly to BA contracts	☐	☐	☐	☐
Annual turnover due indirectly, through new products, services and/or projects developed	☐	☐	☐	☐
Employment due directly to BA contracts	☐	☐	☐	☐
Employment due indirectly, through new products, services and/or projects developed	☐	☐	☐	☐

BA governance and political impacts

BA Governance

20. Do you agree with the following statements?

Consider the steering committee, project committees & project leader structure.

20.1. The overall BA governance structure and implementation is efficient in the utilisation of resources.

20.2. The overall BA governance structure and implementation is effective in achieving the BA objectives.

20.3. The BA could be used as an effective model for international cooperation in other areas.

20.4. F4E has efficiently managed the financial and in-kind contributions of the Voluntary Contributors.

BA projects governance

Please consider the projects on which you were involved: JT-60SA, IFMIF/EVEDA or IFERC.

For IFERC, consider the Demo Design Activities, DEMO R&D, Computational Simulation Centre (CSC) and the Remote Experimentation Centre (REC) separately.

21. Do you agree with the following statements?

21.1. The governance of this specific BA project is efficient in the utilisation of resources.

21.2. The governance of this specific BA project is effective in achieving the project objectives.

21.3. Post-commissioning access to the (sub-)project for European and Japanese organisations has been clearly and effectively defined.

21.4. There is trust between the European and Japanese counterparts for collaborating and sharing experience in the BA and in this project specifically.

21.5. The (sub-)project (will) make a significant contribution to advancing fusion technology.

Quality of voluntary contributions

22. Do you agree with the following statements?
    - 22.1. The financial contributions of F4E, QST and Voluntary Contributors as well as their audit have been efficiently organised.
    - 22.2. The quality of the in-kind contributions by the Voluntary Contributors to the BA met or exceeded the project's requirements.
    - 22.3. The quality of (any) in-kind contributions by F4E or QST to the BA met or exceeded the project's requirements.

Political impacts

23. Do you agree with the following statements?
    - 23.1. EU-Japan cooperation in the Broader Approach is successful
    - 23.2. The Broader Approach has improved the EU-Japan cooperation in the ITER programme.
    - 23.3. The Broader Approach has improved the EU-Japan cooperation in the field of fusion, beyond ITER (e.g. on DEMO activities).
    - 23.4. The Broader Approach has improved the EU-Japan cooperation outside of the field of fusion.

Continuation of BA

24. Do you support the continuation of the Broader Approach in the coming years, and why? In its current format or a modified one?

25. Please rank and detail the key problems that the BA should address in the coming years.

These will be detailed in the interview.

	Not relevant	Relevant	Very relevant
Economic (avoid wasting previous investments in BA, missed opportunities)	☐	☐	☐
Expertise (EU-based expertise developed may be lost as staff move outside EU or out of sector)	☐	☐	☐
Financial (required changes in funding arrangements)	☐	☐	☐
Political (end of the BA may affect EU-Japan relations and cooperation more broadly)	☐	☐	☐
Timeline for fusion (keeping to ITER and DEMO timetables)	☐	☐	☐

26. Please rank the most important objectives in a continuation of the Broader Approach in the coming years.
    - Improving cooperation and relationship with Japan
    - Guiding fusion research
    - De-risking ITER (construction, assembly and operation)

- Contributing to DEMO development activities
- Technical achievements in fusion technology
- Positive return on investment for EU Member States, academia and industry
- Capacity building
- Other, namely: ____________________

27. Which projects / activities / technical objectives you would see as appropriate to add under the BA umbrella for the post-2025 period - which and why?

Consider the contributions for the EUROfusion roadmap challenges:

- Plasma regimes of operation
- Heat-exhaust systems
- Neutron tolerant materials
- Tritium self-sufficiency
- Implementation of the intrinsic safety features of fusion
- Integrated DEMO design and system development
- Competitive cost of electricity
- Stellarator
- Other – please feel free to suggest something from your ‘wishlist’

28. Would the inclusion of new partner countries be desirable? For which new projects/activities?

29. How would you see the future scope regarding the JT-60SA, IFMIF/EVEDA and IFERC, considering the new projects/activities? *To elaborate details in interview.*

	Stop	Continue	Evolve
JT-60SA	☐	☐	☐
IFMIF/EVEDA	☐	☐	☐
IFERC	☐	☐	☐

30. What other future changes would be desirable in the BA? Consider:

- Overall BA governance structure
- Projects governance
- Funding arrangements
- Access to project facilities & knowledge
- Communication
- Other

Follow-up

Would it be possible for you to share an online survey with relevant staff from your organisation to support the work? In a short form this covers many of the same issues raised in the interview.

The link to the survey is: https://chkmkt.com/broaderapproach

Annex E – Online survey

See separate pdf.

Annex F – Objectives and intervention logic for the BA

The research suggested that the objective of the Broader Approach can and should continue unchanged post-2024. Furthermore, it becomes apparent that significant evolution of the objectives could require revision of the Broader Approach Agreement itself. There is considerable reluctance amongst stakeholders to return to or re-open the Agreement.

As a result we propose that the overarching general objective for the Broader Approach remains aligned with Article 1 of the Agreement namely that:
"The objective of this Agreement is […] joint implementation of broader approach activities […] in support of the ITER Project and an early realisation of fusion energy for peaceful purposes..."

The specific objectives, taken at the level of the three projects of the Broader Approach are also defined in the original Agreement, and remain relevant, namely:

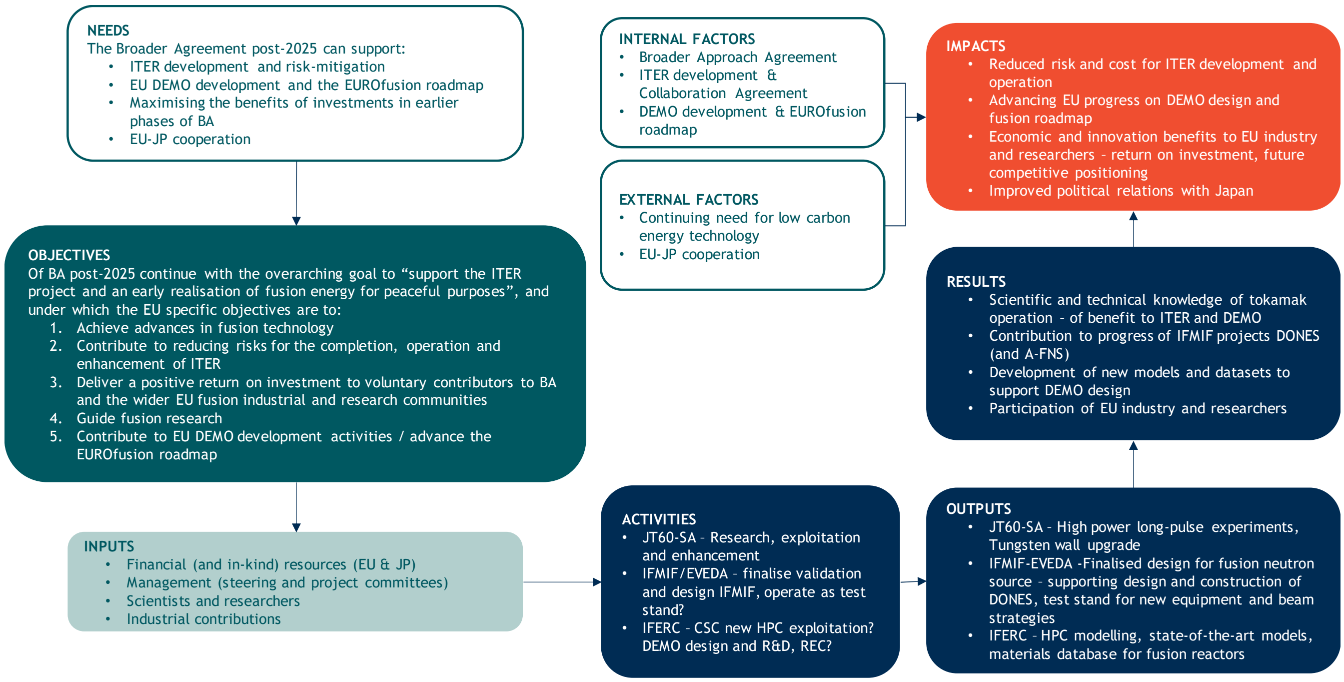
ANNEX III SATELLITE TOKAMAK PROGRAMME (JT-60SA)- Article 1
"Objective
1. *The Parties […] shall conduct the satellite Tokamak programme (STP). This programme includes:*
    (a) *the participation in the upgrade of the Tokamak experimental equipment owned by the Japanese Implementing Agency to an advanced superconducting Tokamak; and*
    (b) *the participation in its exploitation, to support the exploitation of ITER and research towards DEMO by addressing key physics issues for ITER and DEMO.*
2. *The construction and exploitation of the Advanced Superconducting Tokamak shall be conducted under the STP and the Japanese national programme. The exploitation opportunities of the Advanced Superconducting Tokamak shall be equally shared between the national programme and the Satellite Tokamak Programme."*

Annex I IFMIF/EVEDA – Article 1
"1. The Parties […] shall conduct the Engineering Validation and Engineering Design Activities (EVEDA) to produce a detailed, complete and fully integrated engineering design of the International Fusion Materials Irradiation Facility (IFMIF) and all data necessary for future decisions on the construction, operation, exploitation and decommissioning of IFMIF, and to validate continuous and stable operation of each IFMIF subsystem.
2. Such design and data shall then be set out in a final design report to be adopted by the Steering Committee upon proposal by the project leader after consultation with the Project Committee, and be made available for each of the Parties to use either as a part of an international collaborative programme or in its own domestic programme."

Annex II IFERC – Article 1
"The Parties […] shall conduct research and development activities at IFERC aiming at contributing to the ITER Project and at promoting a possible early realisation of a future demonstration power reactor (hereinafter referred to as DEMO)."

These objectives, and those discussed in chapter 4, are represented below in a draft intervention logic for the BA, as shown below in Figure E.

Figure E-0-1 Draft intervention logic for post-2024 BA



Annex G – Background to Broader Approach

ITER and the Broader Approach

The Broader Approach was designed in 2005 as a “privileged partnership” between Europe and Japan, to be enacted in conjunction with the ITER project. Its adoption and signature of the Broader Approach Agreement in 2007 facilitated Japan’s agreement to site ITER at Cadarache in France.

The three projects defined under the Broader Approach agreement are:

1. the Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (IFMIF/EVEDA);
2. the International Fusion Energy Research Centre (IFERC); and,
3. the Satellite Tokamak Programme (STP) Project JT-60SA

These projects are intended to support the development of the ITER project and an early realization of fusion energy for peaceful purposes. Their objectives are to provide information in the fields of physics and technology needed to advance to the next phase of fusion power – the construction of a fusion power plant, DEMO.

The ITER project is now working towards first plasma, planned for December 2025. Following this a Staged Approach has been agreed through to 2041 with different phases of assembly, commissioning, testing and operation. A 2nd major milestone for Deuterium Tritium (DT) experiments is scheduled to begin from 2036. In addition to the scientific work on ITER post-2024 it is also expected that DEMO initiatives will begin to gather pace as ITER participants look to build towards their own prototype fusion reactor. This highlights the continuing scientific and technical work in the area of fusion and to which a continuation of BA could make an important contribution both up to and after 2025.

Broader Approach activities

The Broader Approach projects have operated since 2007; the following sub-sections provide a short summary of activities undertaken since then.

Satellite Tokamak JT-60SA

The JT-60SA is a fully superconducting advanced tokamak, modelled after the most technologically advanced design form for a fusion test reactor that has proven operational so far. The tokamak, based in Naka, Japan, will test proposals for optimizing plasma operation that may support ITER and experimentally explore advanced operating modes to be used in DEMO. JT-60SA, aims to produce and confine its first high-temperature deuterium plasma by 2020, five years before ITER. As a result the ITER Organisation (IO) has concluded a cooperation agreement with the BA with the goal to reduce risks to ITER in its assembly and construction phases. Under the BA agreement, organisations in the Voluntary Contributor (VC) countries in Europe have made major contributions to the JT-60SA including the provision of toroidal field coils, high temperature current leads, superconducting magnet power supplies, switching network units, cryoplant, cryostat and central solenoid.

IFMIF/EVEDA

The International Fusion Materials Irradiation Facility (IFMIF/EVEDA) in Rokkasho, Japan is a step towards a facility that tests advanced materials under conditions analogous to those of a future fusion power plant. The project has focused on producing a prototype neutron source called LIPAc – Linear

IFMIF Prototype Accelerator. The objective of LIPAc is to demonstrate the feasibility of the low energy part (9 MeV) of IFMIF accelerator and consequently to validate the Engineering Design of IFMIF. The LIPAc is a challenging machine considering its average beam power (1.125 MW) and its high deuteron beam current (125 mA). Europe has taken on major responsibility for this project and contributed the prototype accelerator, test facility designs, test module development, and lithium corrosion tests to the project. LIPAc has been successfully tested and entered operation in July 2019. The accelerator, which has the world's highest beam perveance, is the first to deliver a deuterium beam at such high density and energy and the most powerful linear accelerator in the world working in a continuous wave.

International Fusion Energy Research Centre (IFERC)

Three sub-projects comprise the International Fusion Energy Research Centre (IFERC), also based out of Rokkasho:

1. The DEMO Design Research and Development Coordination Centre coordinates R&D technological activities on materials for DEMO and identifies promising research directions and development programmes that will be tested at ITER;
2. The Computational Simulation Centre conducts high performance, large-scale fusion simulations of plasmas and uses experimental results to predict ITER's performance and contribute to DEMO's design – it operates on one of the fastest supercomputers in the world;
3. The Remote Experimentation Centre aims to experiment on ITER at a distance, developing and demonstrating technology that will enable remote data acquisition and control techniques by testing principles on existing tokamaks.

Alignment with EU fusion energy and research policy objectives

The Broader Approach, in supporting and accelerating the progress of ITER and contributing to the planning of DEMO, aligns with the EU's commitment to nuclear fusion research and development as expressed in its **Horizon 2020** programme. The majority of Horizon 2020's EURATOM resources were devoted to ensure that ITER would be built within scope, time and budget, that its operation would be properly prepared, and that a new generation of scientists and engineers would be trained for its deployment. **Horizon Europe**, the successor programme to Horizon 2020 will oversee funding for research and innovation between 2021-2027, affirms the EU's support for fusion energy's development. A policy objective of the programme is to "promote effective and operational synergies" with ITER in order to spur "faster dissemination" and "uptake of research and innovation results." Broader Approach Activities, which also aim to collaborate effectively with and support ITER, distinctly align with current and future EU research policy.

EUROfusion, as a consortium of fusion research bodies from EU member states and Switzerland, has the purpose of supporting and funding fusion research activities on behalf of the EC's Euratom programme. As the Broader Approach has moved away from manufacturing and assembly, and towards operation and exploitation of the equipment the role and contributions of EUROfusion have significantly increased. EUROfusion's Roadmap to the realization of fusion energy charts the EU's objectives to achieve necessary know-how and start the construction of DEMO by 2024, to supply the first fusion-sourced electricity to the grid after 2050, and ultimately to reach the goal of integrating larger-scale fusion electricity in the grid between 2050-2060. The roadmap lays out key short-term, medium-term, and long-term goals, several of which are relevant to Broader Approach projects, indeed the purpose of IFMIF-EVEDA and IFERC is much more geared towards supporting DEMO development than supporting ITER.

Phase II of the Broader Approach

During the early part of this work discussions with Japan have led to a Joint Declaration of a 2nd phase for the work under the Broader Approach Agreement from 2020-2025. Amongst the primary drivers of this were the elapsing of the 10 years originally foreseen in the BA Agreement and also the question of financial contributions now that the originally foreseen contributions from both parties were largely completed.

The major lines of phase II of the BA include:

- The Parties (EU and JP) will provide annual credit contributions, but ensure that these continue to work within an agreed longer term planning and credit total (subject to budget approval), so that for bigger (multi-annual) expenditures such as planned upgrades to the heating system and divertor of the JT-60SA, can still be accommodated.
- The split of contributions will include a host country contribution, the split is 3/8 Europe, 3/8 Japan and 2/8 Host country (Japan), therefore 5/8 in total from Japan.
- An agreement on time-sharing for the Joint Exploitation of JT-60SA, split 60% Japan / 40% Europe.
- Plans for each project in Phase II, including:
    - JT-60SA – (1) to carry out integrated commissioning and first plasma of the tokamak system; (2) to enhance the machine for high-power heating with Deuterium and install additional components; (3) further integrated commissioning and operation of maximum plasma current primarily geared to support ITER; and, (4) plasma experiments to support ITER risk mitigation and steady-state high plasma scenarios for DEMO.
    - IFMIF-EVEDA – the completion, enhancement and experimental validation of the LIPAc facility. Including the demonstration of various operating parameters and continuous high availability operation.
    - IFERC – (1) fostering state-of-the-art modelling tools, providing computer simulation resources and remote experimentation facilities; (2) Supporting the IFMIF validation projects, including LIPAc but also potential DONES or Advanced Fusion Neutron Source (A-FNS); and, (3) To consolidate and further know-how on fusion reactor design (e.g. DEMO).

Within Europe the funding model is also evolving, with Voluntary Contributor Member States no longer expected to be the major contributors, with the main financing and contributions coming directly from F4E and EUROfusion.

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