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Interim Evaluation of indirect actions of the Euratom Research and Training Programme 2014-2018

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Interim Evaluation of indirect actions of the Euratom Research and Training Programme 2014-2018

Report from the Group of Experts

Directorate-General for Research and Innovation
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1. EXECUTIVE SUMMARY

In accordance with Council decision, the European Commission established in 2016 an independent Group of Experts (hereinafter the Panel) to carry out an interim evaluation of the Euratom Research and Training programme (2014-18) (hereinafter Euratom Programme). The purpose of the Interim Evaluation is set out in the terms of reference for the Expert Group namely "*to assess its implementation, to provide an evidence base for preparing future Euratom research programmes and to inform the European Parliament and the Council, Member States, the research community and other stakeholders, and the general public about the progress made by research and training activities funded by the Euratom Programme*."

Panel Findings

The Panel's findings, summarised below, are structured in relation to the tasks as set out in the Panel's Terms of Reference, namely the evaluation of the Euratom Programme in relation to:

- State of Play;
- Relevance;
- Effectiveness;
- Efficiency;
- Internal Coherency; and
- EU Added Value.

The Panel has made a number of recommendations that are aimed at improving the relevance, effectiveness and efficiency of future Euratom research and training programmes. These recommendations are reproduced in this Executive Summary because of their importance.

Evaluation of State of Play

Fusion

Europe currently has a leadership position in fusion research and this has been achieved through the Euratom programmes that have led to a coherent approach in the Member States. The formulation of the European Fusion Roadmap has put Europe in a leading position on the way to the production of fusion electricity. Maintaining such a leadership should be one of the main goals of the Euratom programme.

In passing from Euratom FP7 to the current Euratom Programme, the approach to fusion research has undergone a major transition with the creation of EUROfusion. Research activities are now managed within a single organization. In spite of the initial difficulties EUROfusion is now demonstrating the value of joint programming. The new approach represents a substantial improvement in terms of transparency and effectiveness, and it will strengthen the European leadership in fusion. However, the adaptation to the new approach will require continuous effort by all stakeholders.

Education and training is an important part of the fusion programme and is necessary to attract researchers, engineers and specialists and to ensure that the right competencies are available for the evolving needs of the field. The development of human resources is an important component of the fusion research program that requires training and education to be explicitly recognised through specific support at under-graduate and PhD level.

Fission

The fission part of the Euratom programme is being implemented through three work programmes, 2014/15, 2016/17 and 2018. There was only one call for the first 2 year Work Programme; and a total of 23 grants were awarded with a value of about €90m. The Panel notes that in comparison to other areas of Horizon2020, applications to the fission programme had a very high success rate. The Panel recognises the progress made in the distribution of grants but there is room for improvement. It appears that the larger, more established organisations continue to receive the majority of Euratom funding in the fission area and hence the recommendation made in the ex-post evaluation of Euratom FP7 relating to this issue has not had the desired effect. Accordingly, the Panel believes that this recommendation is also relevant to the current Euratom Programme and repeats it here.

> **Recommendation 1: For future Euratom Programmes the Council should recognise that even if the level of excellence remains the key for applying for research funding, the dominance of the established organisations can lead to the exclusion of emerging contributors who have the potential to provide new ideas and innovation. Hence consideration should be given as to how this source of innovation can be captured rather than lost from European programmes.**

Analysis of the evidence provided to the Panel clearly shows that the aims and intent as set out in the 2014-15 Work Programme have been delivered in both the call and the grants awarded.

In relation to funding, the current rules for participation allow, in some areas, for Euratom to fund up to 100% of a project. It appears that because of this the result has been that less research is being done in some areas because the leverage effect is smaller.

> **Recommendation 2: For future Euratom Programmes the Commission should review the impact of allowing up to 100%-funding has on the level, scope and impact of research being delivered.**

Evaluation of the Relevance of the Euratom Programme

Fusion

The fusion part of the Euratom Programme is clearly relevant as it enables Europe to address the challenge of ensuring an energy production that simultaneously meets the goal of long-term sustainability, security of supply and support to the development of the economy. The important role of fusion laboratories and universities in training and education is recognised by specific support at under-graduate and graduate, specifically PhD level.

Fission

The projects selected in the 2014-17 programme are in the main relevant to the European research needs as set out in the Euratom Work Programmes and the overall Council objectives.

In the area of nuclear safety, the balance of spending between the 21 projects is in general consistent with the challenges as set out in the Work Programme. There is a good balance between the need to support the safety of existing nuclear power plant operations in Europe and the need to focus on the research necessary to underpin the safety of the next generation of nuclear power plants.

The effective management of radioactive waste with the ultimate goal of the delivery of safe and secure deep geological disposal for the higher activity wastes is clearly an important goal for the Euratom Programme. The funded projects are relevant to the needs of the European research community and the citizens of the EU. They are related to furthering understanding of issues that are relevant to the effective management of radioactive waste in the EU and cover issues that are directly related to the safety of a geological disposal facility, the conditioning of radioactive waste, the long-term behaviour of spent fuel in a repository and the clean-up of decommissioned sites.

The importance of supporting the retention and further development of scientific competence and human capacity including education and training activities in order to guarantee the availability of suitably qualified researchers, engineers and employees in the nuclear sector is a long term priority in past and future Euratom programmes. The Panel found that the projects are in line with the objective of the Euratom Programme to develop knowledge to improve scientific and technical competences.

CONCERT is an example of a European Joint Programming (EJP) and the radiation research programme is directly relevant to the understanding of the risks from low dose of radiation. The funded projects are expected to lead to better integration of the radiation protection scientific community at EU level, leading to a better coordination of research efforts and the provision of more consolidated and robust science-based policy recommendations to decision makers in this area. In the long term, these efforts will translate into additional or improved practical measures for the effective protection of people and the environment.

In terms of relevance of CONCERT to the research needs of the European Community, the call priorities of the 1st open CONCERT call have been established by taking into account the Strategic Research Agendas (SRAs), of the European radiation protection platforms MELODI, ALLIANCE, NERIS and EURADOS.

The funded projects relating to Innovation and Industrial Competitiveness in both the 2014-15 and 2016-17 calls are generally relevant to the wider EU goals.

The three Pan-European Research Infrastructure projects are consistent with the aims and objectives of the Euratom Work Programmes and as such are relevant.

The aims and objectives of the three projects selected in the Social Aspects and Networking area, HoNEST, NUCL-EU2020 and SPRINT are consistent with the Work Programme but the extent to which they meet the needs of European citizens is less clear. The funding balance for the NUCL-EU 2020 and SPRINT projects is in line with their importance and priority but the funding level for the HoNEST project seems excessive.

Evaluation of the Effectiveness of the Euratom Programme

Fusion

Europe has a long-standing leadership in fusion with the largest magnetic confinement fusion device in operation (JET), the most advanced technology programme and the largest share of the ITER construction. JET has unique features: it is the experiment closest to ITER, the only one that can use tritium as fuel and beryllium as plasma facing component. The successful operation in JET of the ITER-like Wall (ILW) led to the ITER decision in 2013 to adopt this combination of materials also in the pre-nuclear phase, with a substantial saving in costs and a more robust strategy for the development of the ITER regimes of operation. This is one of the best examples of the role JET can play in ITER risk mitigation.

It is important to acknowledge that JET is the only fusion device with the closest possible conditions to ITER that is available to address urgent R&D needs that may arise in the period leading up to the first ITER plasma. Therefore, JET is the last opportunity to address in advance of the ITER first plasma the main risks to the successful operation of ITER.

> **Recommendation 3: In view of the importance of JET for ITER the JET campaigns should be extended up to 2024.**

The launch of an ambitious DEMO Conceptual Design Activity (CDA) is one of the distinctive features of the fusion part of the Euratom Programme. The proposal to align the DEMO construction decision to the new date for the Q=10 milestone on ITER is sensible. However, because of the importance of aligning the start of the DEMO Engineering Design Activity (EDA) with the completion of the main ITER machine components, the Panel believes that the DEMO EDA should start around 2025.

Recommendation 4: EUROfusion should not delay the DEMO CDA and should start the DEMO EDA around 2025 in order to maintain the industrial know-how generated by the ITER construction.

At the present stage of development of fusion research, setting the commercial fusion power plant as the target for the research effort to be carried out over the next two decades may be overambitious. It would defocus the activities and would increase substantially the time of the delivery of fusion power for electricity production.

Recommendation 5: EUROfusion to maintain the original Roadmap focus on DEMO as an ITER-like tokamak to be built as soon as ITER achieves the Q=10 target.

Regarding education EUROfusion recognises the need to continue the previous PhD support activities. However, the Panel believes that there is a need for EUROfusion to focus more attention on fusion technology and engineering skills.

Recommendation 6: EUROfusion should use its educational resources to promote educational programmes that will deliver the nuclear engineers and technologists as foreseen in the Roadmap.

There are difficulties with both short-term and long-term mobility of researchers that seem to result from the application of the Unit Cost regulation. This appears to be inhibiting movement of staff.

Recommendation 7: EUROfusion and the Commission should review the impact of Unit Costs on mobility and make any necessary changes.

Overall the fusion part of the Euratom Programme is effective as the amount of resources allocated to the various activities reflects the priorities of the Roadmap and the programme is pursuing the activities with the highest impact in the realization of the Roadmap.

Fission

In the fission area, the use of the instrument of European Joint Programme (programme co-fund action) is in its infancy and hence it is too early to see definitive evidence one way or the other. However there are signs that it is not always beneficial to use this instrument.

The availability of some preliminary reports and website information has enabled assessment of progress in the delivery of projects selected following the 2014-15 call for proposals.

In the area of nuclear safety, all of the projects in the 2014-15 call indicate that progress is generally as planned with most deliverables and milestones being achieved.

In relation to radioactive waste, the JOPRAD project, which is aimed at exploring the feasibility of establishing a European Joint Programme (EJP) in this area, is not progressing as expected with only 15 of the 25 deliverables being delivered. Of the outstanding deliverables some were nine months late. In all of the other projects good progress is reported.

Given the level of progress that had been made by the end of Dec 2016 it is difficult to see how EJP could go ahead in this area. The Panel believes that in principle a EJP in waste management has some potential advantage however, to be able to judge the benefits at this point in time it needs to be demonstrated that it is sufficiently developed.

Recommendation 8: For WP2018 or the extension of Euratom 2014-18 the Commission and Members States should carefully

consider if there is sufficient evidence to demonstrate that the EJP instrument can be applied to research on geological disposal of radioactive waste at this point in time.

More recent information on JOPRAD suggests that things have improved, however the Panel believes the above recommendation remains valid in view of the importance of the topic.

The regulation for education and training is rather general and there are no specific objectives in work packages. However, better specification of goals in the Euratom Work Programme may facilitate the implementation of an education and training in the programme.

Recommendation 9: For the implementation of future research Programmes the Commission should ensure that there are specific objectives for the delivery of education and training in the Work Programme.

Output from previously funded radiation protection programmes suggests that the Euratom Programme is delivering results. However, in relation to the effectiveness of the programme, delays were sometimes encountered mainly because of the nature and unpredictability of scientific research and also because of administrative delays. The CONCERT project was cited as an example where such delays were encountered, however, in terms of progress to date on the deliverables identified from the beginning of CONCERT until the end of 2016, nearly all have been completed.

Whilst the Euratom projects relating to radiation protection in the medical exposure area have been successful and have contributed to increased knowledge, it is recognised that further benefit would be gained by establishing better links between programmes funded by Euratom and other EU health-related programmes.

Recommendation 10: The Commission and the Member States should make continued efforts to link future Euratom research programmes in radiation protection associated with medical exposure with other EU medical research programmes.

There have been initial "teething" difficulties in the operation of CONCERT but it is too early to judge whether these are of concern. Given that it is the first time the EJP instrument has been applied in the Euratom Programme outside of fusion, the Panel believes that there would be benefit of a review of the working of CONCERT in advance of the development of future Euratom programmes, so that the Commission can be satisfied that its aims and objectives, and benefits of using the EJP approach in the field of radiation protection, have been delivered.

Recommendation 11: The Commission should carry out a review of how CONCERT is working, to satisfy itself that the aims of the European Joint Programme (programme co-fund action) in relation to the effective and efficient management of research in the field of radiation protection are being delivered.

In relation to the other nuclear fission areas, namely Innovation and Industrial Competitiveness, Pan-European Research Infrastructure and Social Aspects and Networking, the information that is available suggests that progress in general is on track.

Evaluation of the Efficiency of the Euratom Programme

Fusion

The bodies that play a role in the EUROfusion governance are the General Assembly (GA), Scientific and Technical Advisory Committee (STAC) and the Programme Manager (PM) and the Programme Management Unit (PMU). The multiple roles of the Consortium members (supervisory, executive and operator) make the risk of conflict of interest possible. The Panel believes that the EUROfusion structure should be capable of dealing successfully with this risk. A possible way of minimising the risks associated with conflict of interest could be avoiding the presence of those responsible for the implementation of the programme on the supervisory committees (no Project Leaders in the GA or STAC, no Task Leader in the Project Board of the same project).

Recommendation 12: EUROfusion should put in place explicit provisions to manage conflicts of interest.

A strong approach to project management within EUROfusion is essential for the efficient delivery of the programme. Good progress is being made in this area but some improvement is still required.

Recommendation 13: EUROfusion should continue to strengthen its project management arrangements and ensure that the Programme Manager is responsible for the implementation strategy.

The EY report has also pointed out the lack of a design authority for DEMO. In the next Euratom programme, progress should be made towards a strong central coordination of the DEMO Engineering Design Activity.

Recommendation 14: EUROfusion should as a matter of urgency set up the design authority for DEMO.

The core function of STAC is to monitor the implementation of the Roadmap and advise the General Assembly on the decisions to take. At the moment, the selection of 'Enabling Research' projects is entirely a STAC responsibility. The selection procedure ensures the goal of promoting excellence and innovation. However, this places a significant burden on the STAC which limits its ability to focus on its core function. The Panel suggest that EUROfusion should find an approach (e.g. by involving further external reviewers with modest financial support) that does not compress the role of STAC in monitoring the implementation of the Roadmap

Recommendation 15: EUROfusion should look at ways of reducing the burden on STAC from its role in the project selection process for Enabling Research.

Fission

The nuclear safety related projects selected in both the 2014-15 and 2016-17 calls are all in line with the Euratom Work Programmes and therefore have been judged to be suitable. However, it is difficult at this stage to comment upon the extent to which the outcomes that are claimed will be generated, will deliver the project aims in a cost effective way.

Projects relating to radioactive waste management in each of the 2014-15 and 2016-17 calls are consistent with Council objective (b). Projects from the 2014-15 call appear to be on track to deliver their aims and if this proves to be the case the Euratom investment in these research projects should make a substantial contribution to the delivery of safe and secure disposal of Europe's radioactive waste. However, the funding of these projects should be reviewed because as it is the producer of the waste that should pay for its disposal it is hard to see why Euratom should fund 73% of the cost for 2014-15 projects and 95% of the cost in the 2016-17 projects.

Regarding education and training, the Council should consider creating fellowships for early stage researchers, incorporating a scheme similar to the Marie Skłodowska-Curie Early Stage Research Training, and the Marie Skłodowska-Curie Conferences and Training Courses.

Recommendation 16: The Council should consider extending the Marie Skłodowska-Curie scheme to Euratom's Fission Research Programmes.

The use of European Joint Programme (programme co-funded action) in the area of radiation protection has presented a few challenges, especially as low dose research is mostly done in universities that are third parties for CONCERT. There are problems with the national co-funding that may disadvantage universities/third parties.

The innovation and industrial competitiveness projects are relevant but in the case of the ESSANUF project the 100% funding seems difficult to justify.

The three projects in the Pan-European Research Infrastructure are consistent with the Council objectives. However, in the case of the HERACLES and FOREvER projects, the 100% and 95% Euratom funding is hard to justify and hence it is debatable that these projects will be cost effective.

Evaluation of the Internal Coherency of the Euratom Programme

Fusion

The success of the fusion part of the Euratom Programme requires effective and efficient co-operation between the main fusion delivery organisations especially at the top management level. The strategic coordination of the programme is left entirely to the European Commission, now requiring the close interaction between two different Directorates-General (DG). Under these conditions coordination between the top-level management of F4E and EUROfusion must be ensured.

> **Recommendation 17: To improve the coherence of the research needs of the Roadmap the coordination between the top level management of F4E and EUROfusion should be strengthened**

The Fusion Roadmap has been instrumental not only in relation to the success of the research programme but also delivering European leadership. The Roadmap is a European Union vision and not a EUROfusion Consortium document. The formal procedure for the approval of Roadmap revisions should be clarified in advance of any proposed revisions. The Panel believes that any revision procedure should involve a body like the former Consultative Committee for Fusion (CCE-FU) which played a role in the endorsement of the original Roadmap. The CCE-FU discussed strategic issues relating to fusion at Member State level with EFDA and F4E leadership present as standing experts.

The Panel understands that, while periodic reviews of the Roadmap are part of the project management process, a Roadmap revision should be undertaken only when there are fundamental technical or budgetary reasons that make the implementation no longer possible.

> **Recommendation 18: The Commission should introduce a formal Fusion Roadmap revision procedure to ensure that any revision to the original Fusion Roadmap is owned by all relevant stakeholders.**

Fission

The overall aims and intentions of the Euratom Programme to support the safe operation of nuclear systems represent a coherent approach to research and innovation that is needed to sustain nuclear safety within the EU. The 2014-15 projects are, in general, aligned to and consistent with the overall goals of the EU's nuclear safety policies. The 2016-17 projects present a more coherent approach to the delivery of the overall EU nuclear safety goals.

In the field of radioactive waste management the 2014-15 and 2015-16 research projects represent a coherent programme. All of the projects address topics that are relevant to the delivery of safe and secure geological disposal of radioactive waste.

CONCERT is considered to be a coherent programme in the context of support for research and innovation in general in Europe. The platforms for programming research in radiation protection (e.g. MELODI, NERIS) are relatively recent and therefore the research is more fragmented. Thus the complementarity between projects (in particular in radiobiology) does not always appear very clearly. But this should change in the coming years.

Other projects in the Fission area generally present a coherent programme of nuclear research actions in the context of support for research and innovation in general in Europe. They are also consistent with EU policies in general.

Evaluation of The EU Added Value of the Euratom Programme

The Projects selected so far in the 2014-18 Euratom Programme in the main have European Added Value (EAV). However, more clarity of the concept of EAV would be helpful to support the evaluation of European Added Value.

Fusion

The fusion part of the Euratom Programme clearly demonstrates European Added Value. It is essential for the successful completion of the ITER project, the delivery of the Fusion Roadmap and the ultimate goal of commercially viable fusion-generated electricity.

The Euratom fusion programme gives Europe leadership in this very important field. No single EU Member state would be able to provide a fusion research programme on the scale necessary to achieve this. The European fusion community and the fusion facilities located in the EU are key assets and as such offer a key European added value.

JET is a unique European fusion asset and it is a fundamental part of the ITER project. JET is a clear example of European Added Value.

Fission

Euratom fission research is more than just research to support fission for energy production; it also supports research into radiation protection, the impact of radiation on human health and medical applications of ionising radiation.

In the field of nuclear safety it is the operator/ licensee that is responsible for the safe operation of nuclear installations. The European Added Value from the fission part of the Euratom Programme comes from the benefit to all Member States that results from the contribution projects are making to improve our knowledge in the science and technology that underpins nuclear safety. The projects in the 2016-17 Work Programme relating to Generation- IV reactors provide a clear European Added Value because of their generic focus. European Added Value is also gained through the development of skills and capabilities in the smaller Member States through their participation in the projects.

In the area of radioactive waste management, it is possible that individual Member States could undertake much of the work that is necessary to demonstrate the concept of geological disposal for radioactive waste. However, sharing knowledge and developing skills in geological disposal safety case development is of value to all Member States wishing to deliver safe geological disposal for their radioactive wastes.

Research projects that support nuclear training and the development of expertise in nuclear related areas are of key importance to Europe. The projects selected in this area in general provide European Added Value.

The Euratom radiation protection research programme provides significant European Added Value through its flexibility and focus.

Conclusions

Overall it is the Panel's view that in both the fusion and fission areas the 2014-17 research and training activities funded by the Euratom Programme are relevant to the aims of the Council Regulations and are delivering progress in line with expectations.

Fusion

The fusion part of the Euratom Programme is playing a crucial role in the development of Europe's long-term sustainable energy supplies as suggested in the Fusion Roadmap. The

Euratom fusion programme, together with the activities under F4E responsibility, is implementing the Fusion Roadmap.

The efficiency of the implementation of the research programme needs to be improved. The transition between the EFDA/CoA system and the current Euratom Programme took place very rapidly and the new system under EUROfusion is slowly adapting. The governance of EUROfusion is progressing but improvements are necessary to strengthen the approach to project management. The Programme Manager should exercise leadership to ensure the prevention of potential conflicts of interest due to the multiple roles of the beneficiaries.

JET is the closest experiment to ITER and plays a central role in Europe's fusion strategy. The execution of the programme in support of ITER will require JET campaigns extending up to 2024. An earlier closure of JET would significantly increase the risk of possible delays in the ITER exploitation up to Q=10.

The Fusion Roadmap is a vitally important document but there is a lack of clarity over who actually "owns it" and who has the authority to change it. There does not appear to be any compelling technical argument that justifies a revision of the Roadmap, at the present moment, instead of an update of the implementation plan to adapt for the new ITER schedule. The focus of the Roadmap should remain on an ITER-like DEMO to be constructed as soon as ITER achieves the Q=10 milestone.

Fission

The nuclear fission part of the Euratom Programme is more diverse than the fusion part, but a number of common observations can be made. Overall, the selected projects in the 2014-15 and 16-17 calls are in line with the goals of the Council objectives. The funding of the calls could be improved in the future Euratom programme by reducing the number of calls to ensure a more coordinated approach over the whole period.

The rules of participation, common for Horizon 2020 and the Euratom Programme, allowing for up to 100% funding have distorted the balance of funding between Euratom and the beneficiaries to the extent that the current Euratom Programme is providing 73% of the total project cost compared to 53% in Euratom FP7. In effect this means that less research is being done for the same level of Euratom funding because the beneficiaries are seeking to limit their contributions.

The projects funded during 2014-17 are in the main relevant to the European research needs as set out in the Euratom Work Programmes and the overall Council objectives. The projects are in general achieving their milestones but there are some examples of milestones being missed. In general, the projects present, where possible, a coherent research approach. European Added Value is a consistent theme in the vast majority of the projects.

2. 1. Introduction

One of the key goals of the European Atomic Energy Community (Euratom) is to promote nuclear research and to complement nuclear research conducted in Member States by carrying out a Euratom Research and Training Programme.

Since 1984 the Euratom research activities have been channelled through multiannual framework programmes addressing nuclear research and training activities. The seventh Euratom framework programme (FP7) ran from 2007-2011; it was succeeded by a two-year Euratom framework programme 2012-2013 (FP7+2).

The current Research and Training Programme of the European Atomic Energy Community covers the period from 1 January 2014 to 31 December 2018 and complements the Horizon 2020 Framework Programme for Research and Innovation. In this report it is referred to as "Euratom Programme".

In its decision launching the Euratom 2014-2018 programme *[Ref 1]* the Council set the broad objectives and the funding envelope for the research programme distinguishing between direct and indirect actions. Direct actions are carried out exclusively by the European Commission's Joint Research Centre (JRC) and are not part of this evaluation. In this report reference to the Euratom Programme refers to the indirect actions only, unless stated otherwise. This interim evaluation covers the research activities under Euratom 2014-2018 up to February 2017.

2.1. 1.1 Objectives of the Evaluation

The purpose of this interim evaluation of the Euratom Research and Training Programme (2014-2018) is set out in the terms of reference (Annex 1) for the Expert Group (Annex 2) namely "*to assess its implementation, to provide an evidence base for preparing future Euratom research programmes and to inform the European Parliament and the Council, Member States, the research community and other stakeholders, and the general public about the progress made by research and training activities funded by the Euratom Programme*".

The Expert Group (the Panel) was asked to address the following questions and where appropriate provide recommendations for the current Euratom Programme 2014-2018 and for the Commission's proposals for future Euratom Programmes. The questions were grouped under six main themes:

State of play

Q1 How has the Euratom Programme been implemented during 2014-2016?

Q2 What conclusions can be drawn from the participation patterns and trends?

Relevance of the Euratom Programme

Q3 To what extent do the objectives of the Euratom Programme still correspond to the needs of research stakeholders and to EU citizens?

Q4 Does the Programme offer the right balance between the various areas of nuclear research?

Effectiveness of the Euratom Programme

Q5 What is the progress made towards the objectives of the Euratom Programme?

Q6 What are the factors driving or hindering progress and how they are linked (or not) to the Euratom Programme?

Q7 How effective are new measures (European Joint Programmes, prizes) introduced by the Euratom Programme?

Q8 What are the main long-term impacts of the previous Euratom Framework Programme?

Q9 How is the Euratom research programme contributing to the EU strategic objectives and policies?

Efficiency of the Euratom Programme

Q10 To what extent are the inputs provided to Euratom Programme reasonable (i.e. cost-effective) in light of the outcomes that have been generated or are likely to be generated?

Q11 Is there scope for further simplification?

Internal coherency of the Euratom Programme and consistency with EU policies

Q12 To what extent can the Euratom Programme, as part of Horizon 2020, be considered a coherent programme of nuclear research actions in the context of support for research and innovation in general in Europe?

Q13 To what extent is the Euratom Programme consistent with EU policies in general (including other EU funding programmes)? To what extent is the intervention coherent with EU's international obligations?

EU added value of the Euratom Programme

Q14 What is the added value resulting from the Euratom Programme, compared to what could be achieved by Member States acting alone or at regional level?

Q15 To what extent do the issues addressed by the Euratom Programme continue to require action at EU level?

Q16 What would be the most likely consequences of discontinuing the Euratom Programme?

2.2. 1.2 Evaluation Methodology

The Panel carried out its task via a combination of meetings with the Commission, interviews with research stakeholders, and evaluation of documents provided by the Commission. The evaluation report represents the consensus view of the Panel.

The meeting schedule is shown in Annex 3. Prior to each meeting the Panel prepared a list of questions in order to elicit the necessary information and evidence regarding the relevance, effectiveness and efficiency of the relevant research activities. Follow up questions were also sent to key stakeholders to elicit further information on key topics. These questions are listed in Annex 4.

2.3. 1.3 Structure of the Report

This report has been structured in line with the Panel’s Terms of Reference (TOR). In relation to the fusion research programme the evaluation has focussed on the impact of the major changes in governance with the creation of EUROfusion and the extent to which the programme is consistent with the Fusion Roadmap. For the fission research programme the Panel’s focus has been on the seven research themes, namely:

- Safe operation of nuclear systems;
- Management of ultimate radioactive waste;
- Nuclear expertise and excellence;
- Radiation protection and medical applications of radiation;
- Innovation and industry competitiveness;

- Pan-European research infrastructure; and
- Social aspects and networking.

For the sake of clarity, this report evaluates the fusion and fission programmes against the following six factors as required by the TOR:

- State of Play;
- Relevance;
- Effectiveness;
- Efficiency;
- Internal coherence; and
- European Added Value.

Chapter 2 provides the background to the fusion and fission programmes and describes the aim and objectives of the biennial Euratom Work Programmes and of the selected projects in each call. The projects are described in detail in order to provide the reader with sufficient information to be able to put the comments made by the Panel into context.

Chapter 3 addresses the state of play of the Euratom Programme and provides comments on how the Euratom Programme has been implemented to date (2014-17); and it aims to draw conclusions on the participation patterns and trends.

Chapter 4 examines the relevance of the Euratom Programme. Here the Panel comments upon the extent to which the objectives of the Euratom Programme correspond to the needs of research stakeholders and to EU citizens in general. The chapter also addresses the extent to which the fusion and fission programmes provide the right balance between the various areas of nuclear research.

Chapter 5 addresses the effectiveness of the Euratom Programme. The focus in this chapter is to evaluate the progress being made towards the delivery of the objectives of the Euratom Programme and identify any factors that are driving or hindering progress. The chapter also examines the impact of the new measures that have been introduced such as the European Joint Programme (programme co-fund action). Effectiveness also includes the evaluation of the main long-term impacts of the previous Euratom Framework Programme, and the extent to which the Euratom Research Programme is contributing to the wider EU strategic objectives and policies.

Chapter 6 provides an evaluation of the efficiency of the Euratom Programme and addresses the extent to which the inputs provided to the Euratom Programme are reasonable (i.e. cost-effective) in light of the outcomes that have been generated or are likely to be generated. The chapter also addresses the scope for further simplification.

Chapter 7 addresses internal coherency of the Euratom Programme and the extent to which the Euratom Programme, as part of Horizon 2020, can be considered a coherent programme of nuclear research in the context of support for research and innovation in general in Europe, with EU policies in general, and with the EU's international obligations.

Chapter 8 provides the evaluation of the European added value of the Euratom Programme, in particular the added value compared to what could be achieved by Member States acting alone or at regional level and the most likely consequences of discontinuing the Euratom Programme.

Chapter 9 provides the detailed conclusions of the Panel.

Where the Panel believes recommendations can be instrumental to improve the programmes, these are brought out in the body of the report and for completeness summarised at the end of the report.

3. 2. Background to the Euratom Research and Training Programme 2014-18

This chapter provides the background to the fusion and fission parts of the Euratom Programmes and describes the aim and objectives of the biennial Euratom Work Programmes and of the selected projects in each call. The projects are described in detail in order to provide the reader with sufficient information to be able to put the comments made by the Panel into context.

3.1. 2.1 Nuclear Fusion

Council Objectives

In its regulation establishing the Euratom 2014-2018 Programme *[Ref 1]* the Council defines its objectives for the indirect actions in the area of fusion and describes the activities necessary to achieve the programme objectives in Annex 1 to the regulation.

The fusion programme is covered by three objectives and related necessary activities:

- Council objective (e): Moving towards demonstration of feasibility of fusion as a power source by exploiting existing and future fusion facilities.
  Supporting common research activities undertaken by members of the European Fusion Development Agreement and any of the entities referred to under paragraph (i) to ensure the swift start of high performance operation of ITER including the use of relevant facilities (including JET, the Joint European Torus), of integrated modelling using, among others, high performance computers, and training activities to prepare the next generation of researchers and engineers.

- Council objective (f): Laying the foundations for future fusion power plants by developing materials, technologies and conceptual design
  Supporting joint activities undertaken by members of the European Fusion Development Agreement and any of the entities referred to under paragraph (i) to develop and qualify materials for a demonstration power plant requiring, inter alia, preparatory work for an appropriate material test facility and negotiations for the Union's participation in a suitable international framework for that facility. Such development and qualifications are to make use of all possible levels of the experimental, computational and theoretical capacities available.

  Supporting joint research activities undertaken by members of the European Fusion Development Agreement and any of the entities referred to under paragraph (i) that will address reactor operation issues and will develop and demonstrate all relevant technologies for a fusion demonstration power plant. Those activities include the preparation of complete demonstration power plant conceptual designs and exploration of the potential of stellarators as a power plant technology.

- Council objective (i): European Fusion Programme
  A grant (Programme co-fund action) is to be awarded to the legal entities established or designated by Member States and any third country associated to the Euratom Programme and that will develop a joint programme of activities implementing the roadmap towards the goal of electricity production by 2050. That grant may include resources in kind from the Community, such as scientific and technical exploitation of the JET facility in accordance with Article 10 of the Treaty, or the secondment of Commission staff.

Key Activities

Activities in Fusion research are carried out through a grant with the EUROfusion Consortium and through a contract for the operation of JET with the United Kingdom Atomic Energy Authority (UKAEA).

The EUROfusion Consortium involves all institutions working in fusion within the Euratom Member States and associated countries. The formal interfaces between EUROfusion and the individual research units are the 30 institutions that are members of the Consortium.

The reference document for the programmatic aspects is the Roadmap to Fusion Electricity *[Ref 2]* elaborated by the European Fusion Development Agreement (EFDA) in 2012. The Roadmap articulates in eight Missions the R&D effort to be carried out in order to exploit ITER and to design and build a demonstration fusion power plant DEMO.

A comprehensive European effort is necessary to assess the need for developing, training and maintaining adequate human resources for the fusion programme. A coherent policy that will meet the future needs not only of the EUROfusion programme but that also takes into account the industrial aspect is of strategic value.

The initial Euratom grant to EUROfusion is €425m, contributing to a total funding for EUROfusion of €857m over five years. In addition, there is the New JET Operation Contract (NJOC) with a Euratom contribution of €283m that represents 87.5% of the cost of operating JET (12.5% is funded by the United Kingdom).

3.2. 2.2 Nuclear Fission

To achieve the high-level goals set out in the Council's objectives for the nuclear fission and radiation protection area (Council objectives a-d, g, h) two Work Programmes (WP) have been released during the period covered by this interim evaluation: The Work Programme 2014-2015 (WP2014-15) *[Ref 3]* and the Work Programme 2016-2017 (WP2016-17) *[Ref 4]*. The Work Programmes defined topics (NFRP) for the call for proposals, an indicative budget for each NFRP and the conditions for the call.

For WP2014-15, proposals were invited against each of 16 topics (NFRPs). The 62 proposals received were evaluated individually against criteria of excellence, impact and implementation. Out of 52 proposals above the threshold, 23 projects were selected for funding.

WP2016-17 defined 14 NFRPs structured in six main areas to address the Council objectives for Euratom 2014-2018. Proposals were invited against each of the 14 NFRPs. The 70 eligible proposals received were evaluated individually against criteria of excellence, impact and implementation. Out of 59 proposals above the threshold 25 projects were selected for funding. Unlike the previous Work Programme, the selection process was based on six areas of NFRPs and not on the individual 14 NFRPs. Due to the lack of sufficiently good proposals two of the topics (NFRP 8 and NFRP 10) were not addressed.

The information presented to the Panel suggests that the Euratom funding for fission research during 2014-2017 is comparable to that for the FP7/FP7+2 programme as shown in *Table 1*.

Table 1

Funding for fission and radiation protection research under the Euratom 2014-2018 Programme (first 4 years) and previous Framework Programmes in fission and radiation protection (indirect actions; note that 25 projects from 2016-17 call are still in the 'grant preparation' phase)

	No of projects funded	**EC Contribution (€m)**	**Total costs of projects (€m)**	**No of participants**	**No of partici-pations**
Euratom FP6 (2002-2006)	110	189	355	444	1218
Euratom FP7/7+2 (2007-2013)	135	354	661	225	2106

Euratom Programme 14-18 (first 4 years)	48	199	272	455	853

To structure the research topics, the Work Programmes defined five (WP2014-15) and six (WP2016-17) "main sections" combining several topics. However, in this interim evaluation the Panel reports its findings for the fission and radiation protection activities in relation to the areas covered by the Council objectives, namely:

- Safety of Nuclear Systems;
- Management of Ultimate Nuclear Waste;
- Nuclear Expertise and Excellence;
- Radiation Protection and Medical Applications of Radiation;
- Innovation and Industrial Competitiveness;
- Pan-European Infrastructures;

and an area of:

- Social Aspects and Networking.

In this section of the report, italic text within quotation marks represents direct quotes from the Commission's 2014-15 or 2016-17 Work Programmes *[Ref 3] [Ref 4]*.

3.2.1. 2.2.1 Safety of Nuclear Systems

The Council regulation *[Ref 1]* states the objective and related implementation activities for this area as follows:

- Council objective (a): Supporting safety of nuclear systems.
  In line with the general objective, support to joint research activities concerning the safe operation and decommissioning of reactor systems (including fuel cycle facilities) in use in the Union or, to the extent necessary in order to maintain broad nuclear safety expertise in the Union, those reactor types which may be used in the future, focusing exclusively on safety aspects, including all aspects of the fuel cycle such as partitioning and transmutation.

In **WP2014-15** three topics (NFRP 1-3) are focused on the area of safety of nuclear systems. The key challenges for each topic and the scope and expected impact of projects are described below**.** *Table 2* lists the projects selected for funding in WP2014-15 in this area.

NFRP 1 – 2014: Improved safety design and operation of fission reactors

For this topic the Euratom Work Programme for 2014-15 *[Ref 3]* sets out the key challenge as being the need for the European Union (EU) to maintain its tradition of strong leadership in reactor design and operation within stringent safety requirements. The Work Programme sees the main research challenge as the need to reinforce research cooperation on reactor safety at EU level and worldwide.

The Euratom funding is "*devoted to supporting the continuous improvement of nuclear safety of the existing reactor fleet and to optimising the safety characteristics in the design of future reactors e.g. by implementation of passive safety features and by increasing the redundancy and diversity or by performing experimental tests and developing advanced simulation tools."*

The Euratom focus is on actions that will "*increase the knowledge basis on reactor life-time management issues relevant to safety (e.g. integrity of structural components, containment, irradiation and corrosion issues, …), as well as on those promoting safety culture and providing guidance for severe accident management (especially on issues* *arising after the Fukushima accident e.g. safety of fuel storage, hydrogen explosion, containment behaviour, corium/debris coolability and interactions, …)"*

In addition, the Euratom Work Programme makes it clear that funding will be dedicated to "topics where national programme priorities converge and where European added value is obvious and maximised".

The impact of the Euratom Programme in the area of reactor safety is expected, *"in the short term, to provide the knowledge basis for developing robust national and EU policies in the field of nuclear reactor safety, while also helping interacting with stakeholders and civil society on nuclear reactor safety."* The medium term impact is expected to "*further improve the safety of nuclear reactors in Europe and worldwide through increased resistance of safety relevant equipment and better safety culture*".

NFRP 2 – 2014: Tool for the fast and reliable prediction of severe accident progression and anticipation of the source term of a nuclear accident

For this topic the Euratom Work Programme for 2014-15 *[Ref 3]* sets out the key challenge as being the need for *"fast and reliable prediction of severe accident progression and the anticipation of the source term in case of severe accident …. for the protection of people in triggering the appropriate response to a nuclear emergency."* Another priority is seen as the *"need to improve the tools for predicting the plant status and the source term"*.

This research is intended to support emergency operation centres. The tool should be capable of being adapted to "*all types of reactors in operation or foreseeable in the EU*." Also it should "*be able to predict the different possible accidental scenarios and provide results in a fast and user-friendly way*." It should also "*rely on state of the art knowledge on severe accident phenomenology and mitigation measures in order to give results with enough accuracy, confidence and reduced uncertainties*".

The impact of this work is expected to *"lead to reinforcing nuclear safety through improved accident management procedures that will ensure a faster and site specific response to nuclear emergencies". "It will improve the availability and reliability of dose projection caused by atmospheric releases following a nuclear accident and respond to the need identified as a priority following the Fukushima accident."*

NFRP 3 – 2014: New innovative approaches to reactor safety

For this topic the Euratom Work Programme for 2014-15 *[Ref 3]* sees the challenge as being *"innovative reactor safety concepts …. which could become breakthrough options if their scientific and practical maturity is demonstrated."* The Euratom research in this area is intended to focus on *"safety and reliability and optimal waste management".*

The intended aim of this research will be to allow promising designs to move from the Technology Readiness Level (TRL) 1 to TRL 3, or from TRL 2 to TRL 3. The focus will be on "*the proof of concept regarding safety (e.g. passive safety systems and new approaches to severe accidents management), reliability and quality assurance (e.g. industrial standards)*". The Work Programme requires that the work should be "*undertaken in close cooperation with industry and regulators whose involvement is indispensable at an early stage of design*".

The impact of this research is expected to *"offer top-level scientists a level playing field for highly innovative ideas enabling them to demonstrate the feasibility of advanced safety concepts. It will open-up new avenues towards reactor safety design. In the medium / long term, this action should lead to new orientation and breakthrough in nuclear safety."*

Seven projects were selected in the area of these NFRPs (see Table 2).

The **WP2016-17** part of the programme covers five topics relating to the safety of nuclear systems. The key challenges for each topic, the scope and expected impact of projects are described below.

Table 2: Projects funded in WP2014-15 in the area of nuclear safety

Project	Description	Euratom contribution (€)
FASTNET	Tool for the fast and reliable prediction of severe accident progression and anticipation of the source term of a nuclear accident.	2,831,910
INCEFA-PLUS	Increasing safety in NPP's by covering gaps in environmental fatigue assessment	2,550,128
IVMR	In vessel melt retention severe accident management strategy for existing and future NPPs	4,831,454
SAMOFAR	A paradigm shift in reactor safety with molten salt fast reactor	3,466,896
sCO2-HeRo	A supercritical CO2 heat removal system	2,791,561
SESAME	Thermal hydraulic simulations and experiments for the safety assessment of metal cooled reactors	5,200,000
SOTERIA	Safe long-term operation of light water reactors based on improved understanding of radiation effects in nuclear materials	4,971,297

NFRP 1 (2016/17): Continually improving safety and reliability of Generation II and III reactors

Within the EU, Generation II and III reactors will continue operating for many years. The scope of this work will cover the safety and reliability improvements. "*The action should address the remaining technology gaps and encompass experiments as well as numerical simulations. It should focus on the integrity of structural components in ageing reactors, the knowledge basis for lifetime management of the reactor islands and the management of severe accidents*."

The expected impact will be to "*help industrial stakeholders to develop efficient solutions in response to the new requirements of the amended Nuclear Safety Directive"*. It will result in the "*reinforcement of the safety features of the Generation-II and -III EU nuclear reactor fleet."* It should also "*improve the market profile of EU-based reactor designs and strengthen the competitiveness of the EU nuclear sector through promoting an excellent level of safety in response to market requirements and trends".*

NFRP 2 (2016/17): Research on safety of fast neutron Generation-IV reactors

It is expected that the first Generation-IV reactors be fully operational in the next 25-30 years in various places around the world. However, Generation-IV concepts and designs currently under development, both in Europe and worldwide, will need to meet appropriate safety requirements. In addition whilst offering major advantages in uranium utilisation, they could also offer potentially increased proliferation resistance. The scope of this work is aimed at the "*development of the technical assessment of safety improvements of critical fast neutron Generation-IV systems and their supporting reactor islands, as identified by ESNII in the SET Plan Integrated Roadmap".* The expected impact will be "*to draw on the unique expertise and operational experience feedback gained by the EU in Generation-IV technology in order to place the EU at the forefront of the development of safety standards for this new generation of reactors*".

NFRP 3 (2016/17): Investigating the safety of closed nuclear fuel cycle options and fuel developments

The open fuel cycle uses only a few percent of the energy contained in uranium. Uranium utilisation can be greatly improved through the recycling of spent fuel. Furthermore, closed fuel cycles could facilitate the management of ultimate radioactive waste by reducing its volume and radiotoxicity through such things as partitioning and transmutation. The scope of this work will include "*research and innovation in fuel cycle chemistry and physics for the optimisation of fuel design in line with the strategic research and innovation agenda and deployment strategy of SNETP*". The focus will "*be on reprocessing and fuel manufacture, including MOX, with the objective of increasing the safety of installations for interim storage during normal operation and hypothetical accident scenarios*". This work "*should aim at further integrating EU activities on partitioning and fuel fabrication and foster the participation of the chemical separation community from European research institutions and educational establishments*".

The impact is expected to *"lead to the provision of more science-based strategies for nuclear fuel management in the EU. It will reinforce the EU leadership in this domain and open up new avenues towards the EU energy security of supply and increased competitiveness. It will allow nuclear energy to contribute significantly to EU energy independence. In the longer term, it will facilitate the management of ultimate radioactive waste by reducing its volume and radiotoxicity."*

NFRP 4 (2016/17): Research on the safety of small modular reactors

Small Modular Reactors (SMRs) offer different options to the current Generation-II and -III reactors. They are in principle easier to build and could have significant export potential. The scope of this work will be to "*investigate safety features of SMRs, notably passive ones, and provide a set of essential technical specifications, against which compliance of SMRs with the amended Euratom Safety Directive could be tested.*" The research should "*also propose the methodology for the performing of these tests, including the experimental validation of essential items of the proposed models of safety demonstration as well as their effects on the SMR licensing process under various typical fields of application*." *The expected impact will be to "allow the EU to establish standards for compliance of SMR to the requirements of the revised Euratom Safety Directive. … In the longer term, it will also improve the flexibility of nuclear power generation regarding power output and adaptation to local grid and siting conditions, while taking into account the highest safety standards. Ultimately, it will reinforce EU's commercial prospects and competitiveness in this field."*

NFRP 5 (2016/17): Materials research for Generation-IV reactors

Materials research and innovation is essential in the field of nuclear energy, where technical qualification and certification of materials and components are subject to stringent safety criteria. Materials research aimed at resolving key issues relating to structural and fuel materials to be used in Generation-IV reactor concepts is important to the success of these technologies. The scope of this work will focus on "*the changes in properties of materials and joints under fast neutron irradiation and/or high temperature of the coolant, as well as to the compatibility between structural materials, the coolant and advanced fuel*". It will "*include the refinement of physical models and/or modelling-oriented experiments aimed at the validation of models of microstructural change and the resulting effects on material properties, as well as advanced micro-structural characterisation techniques*." The work is expected to result in "*significant progress regarding the predictive capability of changes in material properties and behaviour and subsequent refinement of Generation-IV reactor design codes".* It should also help to *"overcome the bottlenecks in the certification of materials and hence in the development of safety demonstration for Generation-IV reactor technologies".*

14 projects were selected in the area of these NFRPs (see *Table 3*).

Table 3: Projects selected in WP2016-17 in the area of nuclear safety

Project	Description	Euratom contribution (€)

IL TROVATORE	Innovative cladding materials for advanced accident-tolerant energy systems. • Improved nuclear safety ensured by accident-tolerant fuels (ATFs) • Improved fuel performance in response to the requirements of the amended Nuclear Safety Directive	4,999,999
CORTEX	Core monitoring techniques and experimental validation and demonstration • Development of an innovative core-monitoring technique for early-stage operational anomalies detection and characterisation • Deepened understanding on physical processes involved in NPPs operational anomalies	5,092,627
ATLASplus	Advanced Structural Integrity Assessment Tools for Safe Long Term Operation • Systematic ageing management justifying NPPs Long Term Operation (LTO) • Improved engineering and probabilistic assessment of NPPs components under LTO • Demonstration and quantification of components integrity and NPPs inherent safety margins	5,092,627
McSAFE	High-Performance Monte Carlo Methods for SAFEty Demonstration- From Proof of Concept to realistic Safety Analysis and Industry-like Applications • Less conservative prediction of important core safety parameters • Improvement of nuclear reactors performance and operational flexibility • Ensuring the adaptability of codes and methods to future Gen-III and Gen-IV reactors	2,981,592
MEACTOS	Mitigating Environmentally Assisted Cracking Through Optimisation of Surface Condition • Address Environmentally-Assisted Cracking (EAC) as one of the major failure modes occurring in light water reactors (LWRs) • Enhanced safety and reliability of Gen-II and Gen-III NPPs through improved critical parts resistance	2,550,798
TeaM Cables	European Tools and Methodologies for an efficient ageing management of nuclear power plant Cables	4,179,344

	• Address NPPs cables ageing management under both operational and accidental conditions • Analysis of Irradiation and temperatures effects on cables	
NOMAD	Nondestructive Evaluation (NDE) System for the Inspection of Operation-Induced Material Degradation in Nuclear Power Plants • Development, demonstration and validation of a non-Destructive Evaluation (NDE) tool for Reactor Pressure Vessels (RPVs) • Extension of the existing database of RPV materials degradation, including reliability and uncertainty quantification	4,881,169
NARSIS	New Approach to Reactor Safety Improvements • Updated NPPs Probabilistic Safety Assessment (PSA) focusing on exceptional natural events like earthquake, tsunami, flooding, strong winds, etc. • Natural hazards characterisation * Assessment of NPPs' elements fragility and functionality • Integration of expert-based information within PSA	4,965,481
ADVISE	ADVanced Inspection of Complex Structures • Advance ultrasonic inspection of complex structured materials, for which conventional ultrasonic techniques suffer from severe performance limitations • Step change inspections in terms of depth, defect detection, characterisation accuracy, etc. • Confidence to safety decisions based on inspections results	4,168,855
ESFR-SMART	European Sodium Fast Reactor Safety Measures Assessment and Research Tools • Enhancing safety of Gen-IV reactors, in particular of European Sodium Fast Reactor (ESFR) in accordance with ESNII roadmap • Produce experimental data and perform calibration and validation of computational tools to support safety assessments • Selection, implementation and assessment of safety measures	5,000,000
GENIORS	GEN IV Integrated Oxide fuels recycling strategies	4,999,700

	• Efficient use of nuclear fuel developing techniques for dissolution, reprocessing and manufacturing • Reduced volume and radio-toxicity of radioactive waste • Better understanding of a spent nuclear properties and behaviour, improving the safety of interim storage installations	
GEMINI Plus	Research and Development in support of the GEMINI Initiative • Provide a conceptual design (including SMRs) for a High Temperature Nuclear Cogeneration (HTGR) system • Outline a licensing framework and a business plan for a full scale demonstration for HTGR systems • Further development of HTGR technology to provide higher temperature process heat	3,960,582
INSPYRE	Investigations Supporting MOX Fuel Licensing in ESNII Prototype Reactors • Enable a timely, facilitated and cost-effective licensing of MOX fast reactor fuels • Accurate description of basic phenomena occurring in the fuel • Characterisation of key irradiated fuel samples • Increased reliability of empirical performance laws governing nuclear fuels under irradiation	4,043,479
GEMMA	GEneration iv Materials MAturity • Qualification and codification of selected structural materials of Gen-IV reactors, as envisaged within the European Sustainable Nuclear Industrial Initiative (ESNII) • Generation of experimental data to be transformed to useful rules for system and component designers	3,999,182

3.2.2. 2.2.2 Management of Ultimate Radioactive Waste

The Council regulation *[Ref 1]* states the objective and related implementation activities for this area as follows:

- Council objective (b): Contributing to the development of safe, longer term solutions for the management of ultimate nuclear waste, including final geological disposal as well as partitioning and transmutation

  Joint and/or coordinated research activities on remaining key aspects of geological disposal of spent fuel and long- lived radioactive waste with, as appropriate, demonstration of technologies and safety. Those activities are to promote the

> *development of a common Union view on the main issues related to waste management from discharge of fuel to disposal.*
>
> *Research activities related to management of other radioactive waste streams for which industrially mature processes currently do not exist.*

In **WP2014-15** three topics (NFRP 4-6) are focused on the area of management of ultimate radioactive waste. The key challenges for each topic and the scope and expected impact of projects are described below. *Table 4* lists the projects selected for funding in WP2014-15 in this area.

NFRP 4 – 2014: EU concerted development of Member State research on radioactive waste management

The Euratom work programme identifies the immediate challenge as the need to address uncertainties about the safety of geological disposal facilities and the need "*to build a sound safety case, special attention being paid to stakeholders' concerns regarding all ultimate radioactive waste materials to be disposed of*".

The main aim of the research is "*to develop synergies and increase coordination of national research programmes in the field of the management of spent fuel and radioactive waste*". The aim also includes "*the reviewing of all strategic aspects linked to a stepwise move to joint programming in this field. For this purpose it should seek to involve as many entities as possible that are active in the management and disposal of radioactive waste, notably most relevant public or industry funded research programmes, industry, implementers, TSOs and policy makers while not confusing their respective roles*."

NFRP 5 – 2015: Supporting the licensing of geological repositories

The challenge here is the need to explore the "*interaction between regulatory authorities, their TSO and national radioactive waste management organisations is essential in the context of the licensing process of underground repositories*". The main aim is to develop a common understanding on reviews of licence applications and the identification of the necessary scientific competence of the people that will be needed to undertake these activities.

Another key issue is the need to identify research priorities. This should "*include exchange on criteria and guidance on the review of licence application and the interpretation of standards. Due account should be taken of existing and planned initiatives at international level. Outreach activities of main findings should also be part of the activity*".

The expected impact of this work will be the *"exchange of regulatory review methods and competence in regulatory functions, thereby easing and accelerating the licensing process. This work will also help consolidating the knowledge base and stimulate its sharing amongst all stakeholders including the public at large, which is central to the implementing of solutions for the long-term safety of geological repositories".*

NFRP 6 – 2014: Supporting the implementation of the first-of-the-kind geological repositories

The Euratom Work Programme envisaged the main challenge in this area to be the research needed to *"improve the knowledge base for the safety case including the development of monitoring strategies, also taking into account stakeholder's concerns"*.

The Work Programme suggests that the *"priority topics of IGD-TP should be considered as well as those of public waste management oriented research programmes. EU funding will be dedicated to topics where national programme priorities converge and where European added value is obvious and maximised".* The aim of the joint implementation of this research at pan-European level is to help develop and maintain the necessary competences.

The expected impact of this research and development work is the resolution of *"the key remaining technical issues for the actual implementation of the planned geological disposal projects in the EU"*. It is also hoped that it *"will demonstrate the EU leadership in this domain"*.

Five projects were selected in the area of these NFRPs (see *Table 4*).

Table 4

Projects funded in WP2014-15 in the area of radioactive waste management

Project	Description	Euratom contribution (€)
Cebama	Cement-based materials, properties, evolution, barrier functions	3,868,607
JOPRAD	Towards a joint programme on radioactive waste management	1,000,000
MIND	Development of a safety case knowledge base about the influence of microbial processes on geological disposal of radioactive waste	4,160,234
Modern2020	Development and demonstration of monitoring strategies and technologies for geological disposal	5,997,143
SITEX-II	Sustainable network for independent technical expertise of radioactive waste disposal – interactions and implementation – supporting the licensing of geological repositories	1,777,182

The **WP2016-17** covers three topics relating to the management of ultimate radioactive waste. The key challenges for each topic, the scope and expected impact of projects are described below.

NFRP 6 (2016/17): Addressing key priority R&I issues for the first-of-the-kind geological repositories

Deep geological disposal is regarded as the safest practical solution for the final disposal of high- and intermediate-level long-lived radioactive waste. "*Thanks to a concerted and long-term strategy, Europe has acquired a clear leadership in this domain and will host the world's first such repositories, which are expected to become operational around 2020-2025*." The scope of this work will include addressing the key R&I issues associated with the construction and operation in the EU of the first Deep Geological Repository (DGR), "*notably with respect to validating data and performance". The focus will be on topics "of high priority and European added value that were raised in safety reviews and identified in the SRA of IGD-TP. These concern notably the disposal of new and unconventional fuels, the validation of the properties of engineered barrier materials and the confirmation of the integrated performance of engineered barrier systems*." The expected impact of this work will be its contribution "*to further progress in resolving remaining technological innovation issues important in the actual implementation of the planned DGRs in the EU, thereby consolidating the EU leadership in this domain*".

NFRP 7 (2016/17): Research and innovation on the overall management of radioactive waste other than geological disposal.

The interim storage of radioactive waste destined for geological disposal, and the management of other, especially non-standard, radioactive waste types present specific challenges. The scope of this work is aimed at "*further improving the management of radioactive waste generated by the nuclear industry. This includes all management steps, up to and including disposal*". It will include for example, "*unconventional or legacy waste, operational wastes, waste arising from repair or maintenance and decommissioning/dismantling waste, and could also include the interim storage and other* *pre-disposal management steps in the case of spent fuels and other wastes destined for geological disposal*". The expected impact "*will lead to the further refinement of the EU policy on radioactive waste management. It will help develop new or improved solutions for the management of radioactive waste, including waste destined for geological disposal, whilst further improving safety aspects and possibly realising economy and efficiency gains, for example in the dismantling of nuclear installations*."

NFRP 8 (2016/17): Pan-European knowledge sharing and development of competence in radioactive waste management.

The Radioactive Waste Management Directive (2011/70/Euratom) *[Ref 5]* requires each Member State to, *inter alia,* establish a national programme for the management of radioactive waste, including the carrying out of the necessary research. It is important for the Euratom research and training programme to contribute to the wider development of R&D and managerial competences in the field of radioactive waste management at EU level with particular attention being paid to the needs of Member States and associated countries with little or no practical experience in this area. The scope of this work will include the further development of "*scientific, technical and managerial knowledge and competences in the area of radioactive waste management at pan-European level, encompassing the whole range of waste types and forms and origins*" and "*the development and transfer of knowledge and competence rather than the actual elaboration and harmonisation of national strategies and programmes".* The expected impact of the work will be to "*help to consolidate and extend the knowledge base and competences at pan-European level in the area of radioactive waste management. This in turn will help Member States and associated countries developing their national programme for radioactive waste management including the supporting research and development actions, which is central to the implementing of the Radioactive Waste Management Directive."*

Five projects were selected in this area (see *Table 5*).

Table 5: Projects selected in WP2016-17 in radioactive waste management

Project	Description	Euratom contribution (€)
Beacon	Bentonite mechanical evolution • Developing and testing tools for the assessment of the bentonite barriers hydro-mechanical evolution • Assessment of evolution from an installed engineered system to a fully functioning barrier • Better understanding of material properties, scale effects, homogenisation processes, etc.	3,804,206
DISCO	Modern spent fuel dissolution and chemistry in failed container conditions • Improve understanding on the dissolution of new types of fuels with additives ("doped fuels") in a repository environment • Better understanding of the spent fuel dissolution process and the conditions inside a failed waste container	3,987,676

	• Expansion of the spent fuel dissolution database4	
CHANCE	Characterization of conditioned nuclear waste for its safe disposal in Europe • Comprehensive understanding of characterization methods and quality control schemes for CRW (Conditioned Radioactive Waste) • Development, testing and validation of novel techniques to improve CRW characterization • Identification of links and overlaps between acceptance criteria and CRW characterization	3,982,604
THERAMIN	Thermal treatment for radioactive waste minimisation and hazard reduction • Deployment of thermal treatment towards an optimised RWM lifecycle providing volume reduction, waste passivation, organics destruction, etc. • Provide an EU-wide strategic review and assessment of the value of thermal treatment technologies	3,899,940
INSIDER	Improved Nuclear SIte characterization for waste minimization in DD operations under constrained EnviRonment • Addressing technical, financial and societal challenges on Decommissioning and Dismantling (D&D) • Provide better estimation of contaminated materials, waste volumes and timely planning • Combine statistical processing and modelling with innovative measurement methods	3,781,065

3.2.3. 2.2.3 *Nuclear Expertise and Excellence*

The Council regulation *[Ref 1]* states the objective and related implementation activities for this area as follows:

- Council objective (c): Supporting the development and sustainability of nuclear expertise and excellence in the Union
  Promoting joint training and mobility activities between research centres and industry, and between different Member and Associated States, as well as support for maintaining multi-disciplinary nuclear competences in order to guarantee the availability of suitably qualified researchers, engineers and employees in the nuclear sector in the Union in the long term.

In **WP2014-15** two topics (NFRP 10, 14) are focused on the area of nuclear expertise and excellence. The key challenges for each topic and the scope and expected impact of projects are described below. *Table 6* lists the projects selected for funding in WP2014-15 in this area.

The human resources needs of the Euratom fission actions strongly depend on the evolution of the programme and the need to guarantee the availability of suitably qualified researchers, engineers and employees in the nuclear sector over the longer term. A key concern of industry and policy makers is that human resources could be at risk, especially because of retirement expectations and low renewal rates in countries with nuclear installations. The JRC's Human Resources Observatory plays an important role in monitoring the needs. Euratom has worked to strengthen education and training in all sectors of nuclear fission and radiation protection. The scope of the activities considered in nuclear fission education and training includes cross-cutting areas of nuclear safety, reactor systems, waste management and radiation protection, as well as research infrastructure. The objective is to establish a single mutual-recognition system across the EU, using the European Credit Transfer and Accumulation System (ECTS).

NFRP 10 – 2014: Education and training (Bologna and Copenhagen processes)

The education and training is an integral and significant part of Euratom program. This segment is fundamental for human resources (HR) policies and is essential to train, attract, and retain not only qualified researchers, but also engineers and technicians in order to maintain top-level research, technological development and high levels of safety. Thus expedient measures in the Euratom Programme are necessary in support of training and education to ensure the coaching of the next generation of nuclear specialists through collaboration between educational organizations and also with private companies in nuclear industry. The human resources needs of the programme strongly depend on the evolution of the programme and should be permanently monitored.

The Euratom Work Programme identifies that "*one of the main goals of Euratom from its inception in developing research and training programmes is to maintain nuclear expertise by generating knowledge (research) and developing competences (training)*". One of the main challenges is the maintenance of skilled people to support the design, operation and regulation of the nuclear industry. "*More specifically, within the EU, the nuclear education and training community is faced with the challenges of lifelong learning and cross border mobility.*"

The aim of this research is to focus on the "*further implementation, in the nuclear and relevant medical and industrial sectors, of the EU policies stemming from the Bologna and Copenhagen processes. Education and training organisations (notably at university or equivalent level) are invited to submit proposals in close collaboration with the 'end–users', i.e. industry, research and regulatory organisations. A special effort should be devoted to the development of European Masters and summer schools for the continuous professional development of researchers and other private/public actors*."

The expected impact will "*accelerate and optimise the development of competences in the nuclear area with a special focus on nuclear safety culture and radioactive waste management. It will contribute to the creation and transfer not only of knowledge but also of skills and competences in a well-focused and practical manner. In the long term, it will contribute to improving the safety and radiation protection culture and hence, the safety of nuclear installations in the EU*."

NFRP 14 – 2014: Regional initiative aiming at nuclear research and training capacity building

The challenge here is again to maintain competence in fission safety in a number of Member States especially in the Baltic and Eastern European region.

The aim of this research is to "*support the exchange of scientific staff and the sharing of equipment, knowledge and competences between private and/or public research laboratories within the region and with similar organisations in other EU Member States. This action should take advantage of and develop synergies with on-going and future Euratom projects in particular those offering access to research infrastructures in conjunction with education and training*."

The expected impact will be that "*capacity building at regional level for nuclear research and training through cooperation and networking will reduce regional disparity in the European Union. Such effort will reinforce the EU excellence in fission relevant applications and in particular in nuclear safety and radioactive waste management.*"

Four projects were selected in this area (see *Table 6*).

Table 6

Projects funded in WP2014-15 in the area of nuclear expertise and excellence

Project	Description	Euratom contribution (€)
ANNETTE	Advanced network for nuclear education and training and transfer of expertise	2,517,399
BRILLIANT	Baltic regional initiative for long-lasting innovative nuclear technologies nuclear research and training capacity building	1,197,345
CORONA II	Enhancement of training capabilities in VVER technology through the establishment od a VVER training academy	1,017,605
VINCO	Visegrad initiative for nuclear cooperation – regional initiative aimed at nuclear research and training capacity building	1,091,324

For **WP2016-17** there is only one topic relating to nuclear expertise and excellence. The key challenges, the scope and expected impact of projects are described below.

NFRP 12 (2016/17): Support for careers in the nuclear field

The work here is to address "*the difficulties encountered with maintaining and renewing an adequate number of well-educated and trained nuclear researchers and professionals, especially in view of expected high retirement and low renewal rates in countries with a strong nuclear tradition and of the growing need for further specialised training in emerging nuclear energy countries. The aim is to respond to the needs of the nuclear industry, regulatory bodies and TSOs."* The scope includes the "*further implementation, in the nuclear and relevant medical and industrial sectors*". It also includes "*initiatives to attract new talent in the nuclear field and develop competences and expertise beyond the academic curricula*". The scope is intended to include activities associated with medical applications, the relevant non-nuclear industrial applications and the transport of radioactive materials. The expected impact will be a revival in the "interest of the young generation for careers in the nuclear sector (in particular, reactor safety, geological disposal, radiation protection)".

Two projects were selected in this area (see *Table 7*).

Table 7

Projects selected in WP2016-17 in the area of nuclear expertise and excellence

Project	Description	Euratom contribution (€)
MEET-CINCH	A Modular European Education and Training Concept In Nuclear and RadioCHemistry • Development of a teaching package for high schools and a MOOC on Nuclear and Radio-Chemistry (NRC) for public use • Development of new education and training approaches based on remote teaching and the flipped classroom concept • Provide ECVET course modules adapted to end-users needs	2,110,051
ENENplus	Attract, Retain and Develop New Nuclear Talents Beyond Academic Curricula • Revival of the young generations' interest in nuclear sector careers • Establishment of a mobility fund for European students researchers and learners	2,986,188

3.2.4. 2.2.4 *Radiation Protection and Medical Applications of Radiation*

The Council regulation *[Ref 1]* states the objective and related implementation activities for this area as follows:

- Council objective (d): Supporting radiation protection and development of medical applications of radiation, including, inter alia, the secure and safe supply and use of radioisotopes

  Joint and/or coordinated research activities, in particular those regarding the risks from low doses from industrial, medical or environmental exposure, on emergency management in relation to accidents involving radiation, and on radioecology, to provide a pan-European scientific and technological basis for a robust, equitable and socially acceptable system of protection.

  Research activities on medical applications of ionising radiation and addressing the operational safety aspects of radiation protection and their utilisation.

In **WP2014-15** one topic (NFRP 7) is focused on the area of radiation protection and medical applications. The key challenges for this topic and the scope and expected impact of projects are described below. *Table 8* lists the project selected for funding in WP2014-15 in this area.

NFRP 7 – 2015: Integrating radiation research in the European Union

The Euratom Work Programme recognizes the importance of research in the field of radiation protection and identifies the key challenges as the need for a deep understanding of the effects of ionising radiations, and the poorly understood risks from low doses of radiation. It is considered that a "*reinforced multidisciplinary approach to research and innovation is essential to further develop the knowledge base in this field*".

The scope of research in this area is expected to "*build on the Strategic Research Agendas of MELODI, NERIS and ALLIANCE, while also making use of other existing expertise in Europe, notably regarding dosimetry (EURADOS) and the medical use of ionising radiation*".

EU funding will specifically be devoted to "*supporting the further integration, at EU level, of radiation protection research, with due attention to the interaction and synergies to be established between the various areas of expertise, in particular biology, biophysics, epidemiology, dosimetry and modelling. These disciplines are pivotal for research on medical exposures and the optimisation of the use of, and protection from ionising radiation in this field*."

It is also expected that *"attention should also be paid to the development of advanced knowledge on the biology and bio-kinetics of medical radioisotopes and to the understanding of the effects of naturally occurring radiation (and the optimisation of the protection thereof), which also contribute to radiation protection basic science. This activity will also address the improvement of knowledge on the effects of ionising radiation on living beings (radioecology) both during the normal operation of nuclear installations and after an accident, which would be needed to further develop mutually compatible European tools and innovative approaches on nuclear emergency management and environmental remediation."*

The research and innovation in this area should also support the *"successful transposition and implementation of the revised European Basic Safety Standards, which will require changes in national regulations and practices that should be done in a co-ordinated manner in order to optimise protection and avoid duplication"*.

An additional aim of this research activity will be to accelerate and improve the development of *"competences in radiation protection with a special focus on radiation protection culture and at addressing the challenge of communicating results in radiation protection to non-specialist audiences such as policy decision makers and the public at large"*.

The expected impact of this research will be a better integration of the *"radiation protection scientific community at EU level, leading to a better coordination of research efforts and the provision of more consolidated and robust science-based policy recommendations to decision makers in this area. In the long term, these efforts will translate into additional or improved practical measures in view of the effective protection of people and the environment."*

A multidisciplinary approach to research and innovation is considered as essential to further develop the knowledge base in this field. Within the Euratom Work Programme 2014-2015, NFRP 7 – 2015, had the high level objective of integrating radiation research in the European Union.

The type of action chosen for this call was a 'Programme Co-fund Action (European Joint Programme)' with a contribution from the Euratom programme of between €18.5m and €19.5m envisaged.

Table 8

Project funded in WP2014-15 in the area of radiation protection and medical applications of radiation

Project	Description	Euratom contribution (€)
CONCERT	European joint programme for the integration of radiation protection research	19,822,787

One project was selected in this area (see *Table 8*).

To foster radiation protection and to gain a better understanding of the effects of low-dose ionising radiation on humans, one topic (NFRP 9) was identified in the **WP2016-17**:

NFRP 9 (2016/17): Impacts of low dose radiation exposure

The foreseen challenge in this area is the need to reinforce the cooperation between the medical and nuclear sectors. The work "*will allow the formulation of science-based recommendations to decision-makers and practitioners in the respective sectors in view of the effective protection of patients, workers and the general public, and the fine-tuning of the necessary precautionary measures*". Research into "*innovative and updated radiation protection tools and methods will allow the formulating of practical recommendations and improved protection of patients and staff in everyday medical practices*".

Table 9

Project selected in WP2016-17 in the area of radiation protection and medical applications

Project	Description	Euratom contribution (€)
MEDIRAD	Implications of Medical Low Dose Radiation Exposure • Enhance the scientific basis and clinical practice of radiation protection in the medical field • Better understanding of health effects due to low dose ionising radiation exposure	9,995,146

	• Formulation of science-based policy recommendations for the protection of patients, workers and the general public	

The scope of this work "*should allow significant progress to be made in the understanding of radiation effects and underlying mechanisms, notably by performing radiation molecular epidemiology studies of people who have undergone radiology procedures (i.e. looking at side-effects from radiotherapy on healthy surrounding tissues and tissues exposed during radiology diagnosis)*". It action should also consider "*creating a networked and structured repository for patient dosimetry, imaging meta-data and bio-banking, the latter being integrated with health databases*". The overall aim of this work "*is to further improve the science base for recommendations to decision-makers and practitioners in the respective sectors, including for optimisation of radiation protection in medical imaging*". The expected impact is the achievement of significant progress "*in the interaction between the radiation protection and medical scientific communities at EU level, leading to cross-fertilisation of research efforts and the provision of more consolidated and robust science-based policy recommendations to decision makers in the respective sectors. Ultimately, the risks from radiation will be better evaluated and the necessary precautionary measures better quantified, leading to a more robust system of protection of patients, workers and the general public, whilst not unduly penalising activities through unnecessary and costly measures. This could also lead to some revision of the relevant regulatory frameworks."*

One project was selected in this area (see *Table 9*).

3.2.5. 2.2.5 Innovation and Industrial Competitiveness

The Council regulation *[Ref 1]* states the objective and related implementation activities for this area as follows:

- Council objective (g): Promoting innovation and industry competitiveness
  Implementing or supporting knowledge management and technology transfer from the research co-funded by the Euratom Programme to industry exploiting all innovative aspects of the research.

  Promoting innovation through, inter alia, open access to scientific publications, a database for knowledge management and dissemination and promoting technology topics in educational programmes.

  In the long term, the Euratom Programme is to support the preparation and development of a competitive nuclear fusion industrial sector facilitating the involvement of the private sector as well as SMEs where appropriate, in particular through the implementation of a technology road map to a fusion power plant with active industrial involvement in the design and development projects.

In **WP2014-15** one topic (NFRP 16) is focused on the area of innovation and industrial competitiveness. The key challenges for this topic and the scope and expected impact of projects are described below. *Table 10* lists the project selected for funding in WP2014-15 in this area.

NFRP 16 – 2015: Supporting the licensing of Western nuclear fuel for reactors of VVER design operating in the EU.

The challenge here is the need to diversify the nuclear fuel supply for Russian pressurized water reactors (VVER) as there are as many as 16 VVERs operating in the EU. "*The diversification of fuel supply in EU VVER plants would be relevant for greater security of energy supply. However, the licensing in the EU of VVER reactor fuel assemblies manufactured by a new supplier requires a full range of safety evaluations for which R&D is to be carried out at EU level, involving industrial and regulatory (or TSO) experts*."

The aim of this work is to "*build on the experience gained in different VVER plants in the EU and on well-documented irradiation campaign results (either past or on-going). It should aim at establishing all necessary safety analyses, tests and procedures in view of the further licensing of VVER fuel manufactured by Western suppliers, with due*

Table 10

Project funded in WP2014-15 in the area of innovation and industrial competitiveness

Project	Description	Euratom contribution (€)
ESSANUF	European supply of safe nuclear fuel – supporting the licensing of western companies to supply nuclear fuel for VVER's operating in the EU	2,053,913

consideration to international safety standards."

It is expected that this work will contribute to the security of supply of nuclear fuel for VVER reactors operating in the EU.

One project was selected in this area (see *Table 10*).

WP2016-17 identified the following two topics in the area of innovation and industrial competitiveness. The key challenges, the scope and the expected impact of projects are described below.

NFRP 13 (2016/17): Fission/fusion cross-cutting research in the area of multi-scale materials modelling.

There are increasing opportunities for synergies in the fission and fusion research areas especially in the areas of materials modelling. The work here is to encourage closer integration of research between the fission and fusion research communities in the area of multi-scale modelling of material properties and the development of new materials. The scope includes research on ferritic-martensitic (F/M) steels for use in both fusion and fission installations. "*The predictive capability of models is of paramount importance and should be aimed at supporting the elaboration of design rules. Proposed modelling approaches would need to be supported by robust validation means, including where necessary testing of environmental degradation and appropriate irradiation campaigns ranging from neutrons to ions. Contributions to benchmarking, the development of codes and standards as well as to small specimen test technology is also encouraged.*" The aim is for this work to demonstrate substantial benefit for both fission and fusion, and to complement the existing research efforts in both domains. The expected impact is to help the "*cross-fertilisation in nuclear materials research between the two main fields of activity represented by fission and fusion*" and to "*result in a better general understanding and critical mass in the discipline as a whole. In turn, it will help overcome bottlenecks that are limiting developments in fission and fusion, including in technology areas with safety relevance*".

NFRP 14 (2016/17): Cross-cutting support to improved knowledge on tritium management in fission and fusion facilities

The discharges of tritium are *"increasing owing to new nuclear fuel management modes and the lack of detritiation capability. Discharges are also anticipated from fusion installations once they start operating as nuclear facilities"*. As a result of this challenge *"further research is needed to assess and mitigate impacts of discharges and potentially to limit them"*. The scope of this work will include *"assessing technologies to minimise tritium* *permeation at source and to capture and store tritium from treatment of metallic waste and liquid and gaseous effluents, e.g. using photo-synthesised polymers"*. It should also include *"(i) an assessment of the tritium inventory in both fission and fusion systems using state-of-the-art modelling tools for tritium migration studies, e.g. from primary to secondary systems between which tritium may pass, (ii) refinement of the knowledge on outgassing and release mechanisms, radiotoxicity, radioecology, radiobiology, dosimetry and metrology of tritium, (iii) engineering solutions for detritiation techniques (metals, liquids and gasses) and waste management to meet the stringent regulations in force in the EU, and (iv) tritium permeation"*. The expected impact will be to contribute to the *"solution of a number of key issues in the management of tritium in fission and fusion facilities that will satisfy regulatory requirements and thus minimise environmental and possible subsequent health effects. It will pave the way for robust science-based policy recommendations to decision makers in this area at EU level."*

Two projects were selected in this area (see *Table 11*).

Table 11

Projects selected in WP2016-17 in the area of innovation and industrial competitiveness

Project	Description	Euratom contribution (€)
M4F	MULTISCALE MODELLING FOR FUSION AND FISSION MATERIALS • Foster the understanding of phenomena associated to formation and evolution of irradiation induced defects and their role on deformation behaviour • Reduce the gap between the materials science activities as model and experiments	4,000,000
TRANSAT	TRANSversal Actions for Tritium • Improve knowledge on tritium management in both fission and fusion facilities • Refinement of the knowledge on radiotoxicity, radiobiology, and dosimetry • Address radiotoxicity, radioecology, radiobiology and dosimetry on tritiated particles produced during dismantling	3,999,260

3.2.6. 2.2.6 Pan-European Research Infrastructures

The Council regulation *[Ref 1]* states the objective and related implementation activities for this area as follows:

- Council objective (h): Ensuring availability and use of research infrastructures of pan-European relevance

  Activities supporting the construction, refurbishment, use and continued availability of key research infrastructures under the Euratom Programme, as well as appropriate access to those infrastructures and cooperation between them.

In **WP2014-15** two topics (NFRP 8, 9) were focused on the area pan-European infrastructures. The key challenges for these topics and the scope and expected impact of projects are described below. *Table 12* lists the project selected for funding in WP2014-15 in this area.

NFRP 8 – 2015: High density uranium fuel and targets for the production of medical radioisotopes

The challenge here results from the shortage of Molybdenum-99 as a result of the low availability of specific research reactor facilities and the extensive replacement of highly enriched uranium fuel by low enriched fuel to address nuclear proliferation concerns.

The aim of this research and innovation is to "*support the replacement of highly enriched uranium fuel and targets by low enriched and high density ones."* The issue for the fuel surrounds the maintenance of reactor performance and safety. For the targets, the issue is to achieve a sufficient number of fission reactions to produce Molybdenum-99 and to get a high quality pharmaceutical product.

The focus of this work will be on "*developing new kinds of high density uranium fuel and targets bearing in mind their thermal, mechanical and chemical behaviour and their suitability for use in different research reactors*".

The expected impact will be a "*cost effective supply of high density and low enriched uranium fuel and targets will allow the more efficient use of research reactors in Europe for the purpose of energy research and the production of medical radioisotopes like Molybdenum-99. This will contribute to the addressing of key challenges of Horizon 2020 in the sectors of energy and health. The principal impact of this action will be the prevention of future crises in the supply of Molybdenum-99*."

NFRP 9 – 2015: Transmutation of minor actinides (Towards industrial application)

The challenge in this area arises from the need to eliminate or transmute the minor actinides in order to sustain the back-end of the fuel cycle. The Euratom Work Programme suggests that *"further research is needed in order to demonstrate the feasibility of transmutation of high-level waste at industrial scale. Advanced experimental tests as well as numerical simulation tools will be required to conduct this interdisciplinary research encompassing basic as well as applied sciences. The technological and economic performance of transmutation in a fast neutron facility should also take into account the other possible uses of the equipment, e.g. for the production of radioisotopes or material testing for nuclear fission and fusion applications."*

The scope of this research will be to "*contribute to the further development of state-of-the-art critical or sub-critical fast neutron installations for transmutation. Due consideration should be given to the actual effectiveness of the transmutation process, as for example by using accelerator driven systems, as well as the safety and reliability of the facility and the demonstration of the industrial feasibility of the process. The development of innovative fuel and targets for the transmutation of minor actinides should also be considered in this proposal, as well as the development of advanced experiments and numerical simulation tools.*"

The expected impact of this work will be on the reduction of the radioactive waste burden of a geological disposal facility. "*This research will allow pursuing this objective by using state-of-the-art technology, notably in terms of efficiency and safety of the process.*"

Two projects were selected in this area (see *Table 12*).

Table 12

Projects funded in WP2014-15 in the area of pan-European infrastructures

Project	Description	Euratom contribution (€)
HERACLES-CP	Towards the conversion of high performance research reactors in Europe – high density uranium fuel and targets for the production of medical radioisotopes	6,387,960
MYRTE	MYRRHA research and transmutation endeavour – transmutation of the minor actinides –towards industrial application	8,995,962

WP2016-17 identified the following two topics in the area of pan-European research infrastructures. The key challenges, the scope and the expected impact of projects are described below.

NFRP 10 (2016/17): Support for the optimised use of European research reactors

The key challenge here is to further the *"coordination of the exploitation of available research reactors in Europe in order to help resolve the recurrent shortage of medical radioisotopes and optimise the use of irradiation time in the available reactors thereby reducing disruptions and delays occurring in many experiments"*. The scope of the work includes *"networking the largest possible number of research reactor operators at EU level in order to further the exchange of information on the availability of research reactors against research needs across the EU"*. It will also identify *"key parameters that are influencing reactor availability and derive an overall strategy for research reactors in Europe"*. The expected impact will be to *"allow the more efficient use of research reactors in Europe for the purpose of energy research and training and the production of medical radioisotopes like Molybdenum-99"* and the *"prevention of future crises in the supply of Molybdenum-99 and the more effective planning of research reactor needs in the EU"*.

NFRP 11 (2016/17): Support for the EU security of supply of nuclear fuel for research reactors.

The challenge identified here is the security of supply of nuclear fuel for research reactors and hence the *"availability of such reactors in the EU, which are essential for, notably, materials research, isotope production, silicon doping, nuclear science and engineering and related education and training purposes"*. The scope of this action should involve the creation of a *"multidisciplinary research consortium able to tackle technical as well as economical and legal aspects, and should include EU-based RR fuel manufacturers alongside a fully representative number of EU RR operators. It will investigate future needs in terms of volume and fuel design requirements for each reactor for which European operators do not possess relevant data, as well as the safety-related technical requirements of RR fuel manufacturing, storage, transport, and reprocessing, and can include possible pilot scale experiments."* The aim is also to *"address the regulatory context and the legal and economic conditions for the long-term sustainability of EU-based RR fuel manufacturing and long-term supply of LEU (low-enriched uranium)"*. The expected impact will be to help to *"secure the supply of nuclear fuel for research reactors in Europe"* and to *"reinforce the security of supply of medical radioisotopes like Molybdenum-99 and the availability, in the EU, of an adequate neutron irradiation capability for materials testing and other applications"*.

Only one project was selected in this area (see Table 13*).*

Table 13

Project selected in WP2016-17 in the area of pan-European infrastructures

Project	Description	Euratom contribution (€)
FOREvER	Fuel fOR REsEarch Reactors • Securing the nuclear fuel supply for European research reactors • Fuel shortage risk analysis • optimisation of manufacturing process (up to the design of pilot equipment) and modelling of the fuels' in-pile behaviour	6,598,148

3.2.7. 2.2.7 Social Aspects and Networking

In **WP2014-15**, there were three topics (NFRP 12, 13, 15) focused on social aspects and networking. As such they were related to more than one specific Council objective. The key challenges for these topics and the scope and expected impact of projects are described below. *Table 14* lists the projects selected for funding in WP2014-15 in these three topics.

NFRP 12 – 2014: Nuclear developments and interaction with society

The challenge here is the communication and engagement with the public regarding the use of nuclear energy. There is a *"large body of knowledge of past successes and failures in interacting with civil society in the implementing of nuclear projects exist in the form of books and studies, press articles, government reports, radio and TV broadcasts, the memory of projects stakeholders, etc."* The main aim of this research is to *"exploit to the best extent this information in view of shedding light on the last sixty years of developments of nuclear in Europe and a number of other major nuclear stakeholder countries, clarifying the context within which certain decisions were made, identifying the factors which influenced projects' success or failure in gaining engagement of the civil society and ultimately, help improving communication and interaction with civil society for the benefit of all public and private stakeholders concerned."*

The research will cover *"nuclear developments and projects, over the last sixty years, in the EU and abroad (USA, Russia, Ukraine, Japan) and related international cooperation where appropriate. These cases shall be examined also taking account of the broader context (economic, political, institutional…) within which decisions were taken regarding the main energy sources for electricity production"*.

The work will be carried out in three phases. *"In a first phase, historians shall provide the core facts and figures, based on available documents and other sources of information, complemented as appropriate by field investigations, notably interviews of major players with regard to the selected developments and projects. This should result in a well-organised and documented database and historical record. The second phase shall bring-in additional experts, i.e. communication specialists, sociologists or psychologists of organisations, philosophers and other such specialists in order to analyse and interpret this information from the perspective of furthering the understanding of the mechanisms for effective interaction with civil society regarding nuclear applications and projects, including the factors underlying perception, participation and engagement. In the third and last phase, the results shall be presented and discussed with industry, associations, policy makers and representatives of the civil society."*

It is expected that the research *"should contribute to the understanding of factors triggering the societal engagement with nuclear energy and other nuclear applications and provide insights to decision makers and other stakeholders regarding interaction with civil society"*.

NFRP 13 – 2015: Fostering the network of National Contact Points

The aim here is to *"facilitate trans-national co-operation between National Contact Points (NCPs) on Nuclear Fission and Radiation Protection with a view to identifying and sharing good practices and raising the general standard of support to programme applicants, taking into account the diversity of actors that make up the constituency of this Programme"*.

The focus will be on issues *"specific to Nuclear fission and radiation protection, and should not duplicate actions foreseen in the NCP network for quality standards and horizontal issues under 'Science with and for Society'"*.

The expected impact will be an *"improved and professionalised NCP service across Europe, thereby helping simplify access to Euratom fission 2014-2018 calls, lowering the entry barriers for newcomers, and raising the average quality of proposals submitted"*. An additional outcome will be a more consistent level of NCP support services across Europe.

NFRP 15 – 2015: Specific support to the work of the Sustainable Nuclear Energy Technology Platform

The Sustainable Nuclear Energy Technology Platform (SNETP) rests on three main pillars: (i) the NUGENIA association addressing the safety of existing light-water reactors; (ii) ESNII (European Sustainable Nuclear Industrial Initiative) dealing with the safety of fast reactors with associated strategies of spent nuclear fuel management and waste minimization, and (iii) nuclear safety of plants not restricted to electricity production. *"The major challenge of SNETP is to continue to integrate the R&I in nuclear safety at European Level in the global context taking due account of the various stakeholders' concerns."* The scope of this work includes such things as *"specific studies, data collection and analysis activities and workshops for the further development of technology roadmaps, implementation plans and deployment strategies as well as to the dissemination of the platform activities to the various stakeholders"*. It also includes the *"recent SET Plan initiatives for integrating the different energy roadmaps (nuclear and non-nuclear)"*. The aim is to "*foster collaboration between ETPs to address cross-sectorial challenges between fission, fusion and non-nuclear energy sources as put forward at SET Plan level, notably on materials and education and training. Euratom will not cover secretariat and other running costs of the platform as it should be self-financed for these needs*". The expected impact will be "*to help SNETP to further structure – content-wise - its activities. It will also help better situating the development of nuclear energy in the broader context of the relevant Horizon 2020 societal challenges, and hence help disseminating the platform's activities to the policy-makers and stakeholders.*"

Three projects were selected in this area (see *Table 14*).

Table 14

Projects funded in WP2014-15 in the area of societal aspects and networking

Project	Description	Euratom contribution (€)
HoNEST	History of nuclear energy and society - nuclear development and interaction with society	3,052,269
NUCL-EU 2020	Connecting Euratom national contact points in a pro-active network under Euratom programme HORIZON 2020	500,000
SPRINT	SNETP programming for research and innovation in nuclear technology – specific	599,550

	support to the network	

No topics were defined in this area in **WP2016-17**.

4. 3. EVALUATION OF STATE OF PLAY

This chapter addresses the "State of Play" of the programme and provides comments on how the Euratom Programme has been implemented to date (2014-17); and it aims to draw conclusions on the participation patterns and trends.

4.1. 3.1 Nuclear Fusion

The goal of fusion research is the realization of nuclear fusion as an energy source. Fusion has made enormous progress since 1958 with controlled thermonuclear reactions obtained in JET in 1997 in conditions close to breakeven. With the start of the ITER construction, magnetic fusion research is now focussed on demonstrating the production of fusion power at reactor level (500MW) with a fusion amplification factor Q=10 (Q=Fusion power/auxiliary power injected in the reaction chamber).

ITER construction started in 2007 after the establishment of the international ITER Organisation (ITER IO) by seven parties (Euratom, Japan, United States of America, Russian Federation, Korea, China, India). The Euratom contribution to the ITER construction (as well as the activities that are part of the so-called Broader Approach) is under the responsibility of Fusion for Energy (F4E), which since the start of the present MFF (Multiannual Financial Framework) reports to DG Energy of the European Commission. These activities are not part of the Euratom research programme, and therefore are mentioned in this document only for their relation to the research activities.

Europe currently has a leadership position in fusion research: the largest fusion device in operation (JET), the more advanced technology programmes and the largest share of the ITER construction. This leadership has been achieved thanks to the Euratom Programme that has led to a coherent approach in fusion energy research in the Member States.

The definition of the Fusion Roadmap has further strengthened this position since it has translated the goal of fusion electricity into a detailed programme for the DEMO design and R&D that is now implemented by EUROfusion.

The Panel believes that maintaining such a leadership should be one of the main goals of the Euratom Programme.

4.1.1. 3.1.1 The Fusion Roadmap

In 2012 a Roadmap to Fusion Electricity *[Ref 2]* was developed by the European Fusion Development Agreement (EFDA), in collaboration with F4E, adopted by all fusion research stakeholders and endorsed by the Member States represented in the Consultative Committee for Fusion Research (CCE-FU). The Fusion Roadmap defines the R&D priorities to achieve the production of fusion electricity by 2050 in a demonstration fusion power plant (DEMO). DEMO will not only produce fusion power at reactor level, it will also convert efficiently fusion power into electricity, and will be self sufficient in terms of tritium production to fuel the fusion reactions.

ITER is the key facility of the Roadmap: it will demonstrate the production of fusion energy in a controlled way at the level of a medium size reactor and most of the technologies needed to build DEMO.

The formulation of the European Fusion Roadmap has put Europe in a leading position on the way to the production of fusion electricity. In the following, the Roadmap approach that is at the basis of the EUROfusion programme, is briefly outlined.

The target of the Roadmap is to demonstrate electricity production from fusion energy at the earliest possible time. Thus the Roadmap target translates into two objectives:

- The successful completion of the construction and a swift scientific exploitation of ITER;

- The design and R&D for an ITER-like DEMO to be built as soon as ITER achieves the Q=10 target "as a credible prototype for a power-producing fusion reactor, although in itself not fully technically or economically optimized" *[Ref 2] [Ref 6].*

Once DEMO has achieved its goal, industry will have to take over the exploitation of fusion for electricity production. In this sense DEMO will be the last step before the development of a commercial fusion power plant.

The technical challenges to achieve fusion electricity have been known for many years. The main novelty of the Fusion Roadmap has been to put these challenges into the perspective of a pragmatic approach to fusion. In order to minimize the risks of a delay in the demonstration of fusion electricity production, the pragmatic approach advocates for the use in DEMO of established technologies and well-characterized regimes of operation such as those that have been chosen by ITER to achieve its Q=10 target, rather than pursuing more innovative but less mature options. More innovative solutions may lead in due time to a more attractive option for a commercial fusion power plant than an ITER-like DEMO but these have not been sufficiently qualified yet to be the basis for a DEMO design (although prototypes of innovative components could be tested on DEMO).

Although the pragmatic approach of the Fusion Roadmap calls for a prudent choice of the scientific-technical basis for the ITER-like DEMO, further innovation into fusion energy is being pursued through different paths:

- Research on "optimized configurations", such as the advanced tokamak regimes and the stellarator line, or on alternative solutions for the heat exhaust through specific upgrades of existing facilities or a dedicated diverter tokamak test facility.
- The participation of industry, now heavily involved in the ITER construction, in DEMO through an early start of a DEMO Engineering Design Activity (EDA) to make the best use of the lesson learned in the ITER construction and of the expertise generated in industry by the construction of ITER.

In the Euratom Programme, curiosity driven research (Enabling Research) to foster new ideas is supported through specific projects selected on the basis of the excellence of the proposal.

Finally the role given in the Fusion Roadmap to international collaborations in order to gain from the intellectual diversity of the rest of the fusion community and from the sharing of resources should be stressed. As also noted in the recent midterm review of EUROfusion *[Ref 7],* the Roadmap implementation may be more efficient if interested international partners can take charge of some of the work.

4.1.2. 3.1.2 The transition from EFDA/CoA to EUROfusion

In passing from FP7/FP7+2 to the current Euratom Programme the approach to fusion research has undergone a major transition to adapt to the implementation of the Roadmap as a project-oriented activity.

In Euratom FP7/FP7+2 (and in the previous FPs) the approach to fusion research (other than the part related to the ITER construction and the Broader Approach activities) was organized on the basis of bilateral Contracts of Association (CoA) between Euratom and individual laboratories and of the European Fusion Development Agreement (EFDA) that was in charge of operating and exploiting JET, of coordinated activities in physics and technologies, of training and of the international collaborations other than those related to ITER. The allocation of funds through the CoAs was made on the basis of the programmatic priorities of each laboratory with Euratom supervising the overall coherence of the programme through the European Commission services. A few goal-oriented activities were carried out through specific tools like the JET Implementing Agreement under EFDA (and the JET Joint Undertaking before 2000), the NET project and the technology programme under EFDA mainly for the R&D needs of ITER.

Although the system of the CoAs had been instrumental for the development of fusion activities in all Euratom Member States, with the start of the ITER construction in 2007 a change was deemed necessary. To this end, the Fusion Roadmap was elaborated and approved in 2012, and by the end of 2013 the structure of the new EUROfusion Consortium was in place. Thus, in Euratom 2014-2018 and in line with Horizon 2020 the fusion programme has strongly reduced the fragmentation inherent in about 30 CoAs. All the activities are now managed within a single consortium. The structure of the EUROfusion grant has been one of the first examples of a European Joint Programme based on the Programme Co-fund instrument.

The allocation of funds by EUROfusion is made on the basis of the programmatic priorities, on a competitive basis and with the goal of pursuing excellence. A restricted number of facilities have their operation supported by Euratom resources: JET through the NJOC and a few national facilities (for the part of operation related with the joint programme) through EUROfusion. These facilities have been selected in 2008 by an external review *[Ref 8]* on the basis of their relevance to the fusion programme.

The Panel considers the new approach a substantial improvement in terms of transparency and effectiveness.

The competitive approach to funds allocation may sometime conflict with the aspiration to a broad participation in the programme but there is a clear evidence of an increased participation of the smaller institutions that have aligned their scientific strategy to the Roadmap priorities.

The Panel is convinced that the transition from CoAs to EUROfusion will strengthen the European leadership in fusion. The transition, however, took place in a very short time scale (with all the difficulties that this implies) and the adaptation to the new approach still requires continuous effort of all stakeholders.

4.1.3. 3.1.3 Education and Training in the Fusion Programme

Education and training in the domain of fusion research in Europe is necessary to attract researchers, engineers and specialists and to ensure that the right competencies are available for the evolving needs of the field. The biennial Euratom Work Programmes, adopted by the Commission after obtaining the opinion of Member States, do not detail the goals for education and training in fusion; however, these goals are addressed in the Roadmap and implemented in the EUROfusion grant.

The recent 2016 survey on human resources in fusion *[Ref 9]* analysed the evolution of the fusion workforce during the last decade and the future need for scientists and engineers in the programme. A first estimate of the number of researchers and professional engineers that need to enter the programme in the future can be made based on the available data about people retiring in the next five years. This is in the range of 100-150 professional engineers and 200-250 physicists, i.e. a minimum input of about 50 engineers and physicists per year is required to replenish vacancies in the research laboratories. Taking into account the needs of industry and fluctuations, and assuming that the fusion programme will become gradually more technology-oriented, twice the number is a fair estimate of the actual overall needs. To this should be added the need for technical support staff, most with an engineering background, that is estimated to be well over 20 people per year *[Ref 9]*.

Following the previous 2007 human resources survey *[Ref 10]* many initiatives have been started to address the identified gaps with some success. There are specific funds in EUROfusion for education and for training with a budget of *ca.* €8m/year for education (PhD students) and €4.7m/year for training (post-doc level engineering and research grants).

The Panel considers the development of human resources an important component of the fusion part of the Euratom Programme that requires training and education to be explicitly addressed through specific support at under-graduate and PhD level.

EUROfusion should ensure the development of competences in areas that are pivotal in the Roadmap, with particular reference to engineering, technology and nuclear skills. Training in critical qualifications should be reviewed and the existing training schemes should involve industry through in-company training of engineers bringing together fusion and fission specialists. EUROfusion should, in the long term, aim to support around 600 PhD students and the accreditation of PhD programmes with an increased coverage of topics in fusion engineering.

4.2. 3.2 Nuclear Fission

In relation to the call for proposals of the 2014-15 Work Programme the Panel received a comprehensive presentation from the Commission services' staff *[Ref 11]* on the key elements of the fission part of Euratom Programme, the clustering of the topics and the allocation of funds, and the budget and grant distribution over the cluster. The Commission also provided the panel with a detailed summary of the objectives, funding and participation of each of the 23 grants.

In the Euratom 2014-15 Work Programme, there was only one call; a total of 23 grants have been awarded with a value of about €90m. The Panel notes that some projects have a longer duration (e.g. CONCERT runs for five years). In comparison to other thematic areas of Horizon2020, applications to the Euratom fission programme had a higher success rate.

The Panel notes that some of the recommendations in the Euratom FP7/FP7+2 ex-post evaluation *[Ref 12]* have been addressed, notably recommendation 10 of the FP7/7+2 ex-post evaluation about the contribution of projects to the objectives of the Euratom Programme, i.e. "In future Euratom research programmes, each research proposal/project should show how it will contribute to the delivery of the high-level aims and objectives of the programme".

However, further effort is required in future calls to broaden the participation in the programme, maintaining the focus on excellence. The first call 2014-15 shows that the trend of the distribution of grant amount *[Ref 11]* has not changed since FP7/FP7+2.

The Panel therefore believes that Recommendation 9 of the ex-post evaluation of Euratom FP7/FP7+2 is also relevant to the current Euratom Programme and hence it is reproduced here:

> **Recommendation 1: For future Euratom Programmes the Council should recognise that even if the level of excellence remains the key for applying for research funding, the dominance of the established organisations can lead to the exclusion of emerging contributors who have the potential to provide new ideas and innovation. Hence consideration should be given as to how this source of innovation can be captured rather than lost from European programmes.**

The distribution of the grant amount per cluster *[Ref 11]* would appear to be in line with the intent of the Work Programme with the majority of the funding going to the key areas of reactor safety, radiation protection and radioactive waste management respectively.

Analysis of the evidence given in the interviews, presentations and in the documentation provided by the Commission clearly shows that the aims and intent as set out in the 2014-15 Work Programme have been delivered in both the call and the grants awarded.

The Commission provided further information on the outcome of the call launched on the basis of the 2016-17 Work Programme *[Ref 13]***.** A total of 25 proposals have been selected in six areas with a total funding of €109m.

The total Euratom funding for the 2014-17 fission projects is €199m and the total project cost is €272m. This means that the Euratom Programme in its first four years is providing

73% of the total project cost compared to 53% in the FP7/FP7+2 programme. The total funding from Euratom for the years 2014-2017 is comparable to the FP7/FP7+2 funding (scaled to a four years programme), i.e. €199m compared with €231m, but the fact that Programme's rules allows for up to 100% Euratom funding means that less research is being done for the same amount of funding.

Recommendation 2: For future Euratom Programmes the Commission should review the impact of allowing up to 100%-funding has on the level, scope and impact of research being delivered.

4.2.1. 3.2.1 Safety of Nuclear Systems

It is clear from the information that was provided to the Panel for the 2014-15 programme that the range of the 7 projects that were selected was consistent with the intent of the Euratom Programme in this area. The range of topics is in general relevant to the goals of maintaining Europe's leadership in the delivery of nuclear safety within the nuclear industry.

In relation to participation patterns and trends it is encouraging that there is diverse participation in the projects but there remains a dominance of the larger more established organizations; this results in the majority of funding going to a small number of the traditionally strong nuclear countries.

The 14 projects in the 2016-17 Work Programme are consistent with the Council objective for nuclear safety of current and future reactor systems. The information provided by the Commission on the outcome of the call for the 2016-17 part of the programme *[Ref 13]* shows a reasonable balance between research to support the safety of operation of the current fleet of reactors in the EU and the need to support the safety of future Generation-IV reactor systems. There are nine projects related to the continued operation and safety of the Generation II and Generation III nuclear power plants. Four projects are directly related to the design, development and safety of Generation-IV reactor systems and one project on advanced nuclear fuel cycle for future reactor systems. The split of €33.5m / €17.5m / €5m for Gen-II/III, Gen-IV and fuel cycle projects, respectively, seems reasonable and in line with both the Council objectives *[Ref 1]* and the Euratom Work Programmes *[Ref 3] [Ref 4].*

4.2.2. 3.2.2 Management of Ultimate Radioactive Waste

The effective management of radioactive waste is a central part of the Euratom Programme and Member States are at various stages of development in the delivery of a sustainable long-term management strategy. The Euratom work programme identifies the immediate challenge as the need to address uncertainties surrounding the safety of geological disposal facilities.

The projects selected in the first call (2014-15) demonstrate that the intent of the Euratom Programme has been implemented with three of the five projects focussed on geological disposal challenges and the other two associated with looking into the development of a European Joint Programme for radioactive waste research and networking. The total Euratom funding in this area is €16.2m which is 72% of the total project funding. One project (MIND) has 90% Euratom funding. The participation pattern reflects a good spread of the areas of expertise within the EU radioactive waste community.

The analysis of the funding for the five projects in the 2016-17 programme shows that all projects are related to waste characterisation and conditioning in preparation for geological disposal and geological disposal challenges. In this call the Euratom funding of €19.5m represent 95 % of the total project funding. Looking at the projects it is difficult to see the justification of such a large Euratom contribution.

The Panel notes that there is consideration of applying EJP to this area (JOPRAD). In principle EJP should deliver a greater contribution from beneficiaries. However the case for joint programming remains to be made (see Chapter 5).

4.2.3. 3.2.3. Nuclear Expertise and Excellence

In the 2014-15 Work Programme there were four projects relating to education and training. The total EU funding of €5.8m represents 77% of the total project funding.

The 69-member-strong European Nuclear Education Network (ENEN), a non-profit association was formed in 2003 to integrate master-level education and training in nuclear programmes throughout Europe. ENEN is central to the strategy of the Euratom Programme. Subsequently Euratom Fission Training Schemes (EFTS) were launched in 2009 to help structure research training and researcher career development across the EU focusing on advanced reactor designs, radiation protection and radioactive waste management. EFTS go beyond training and mobility: a typical scheme may receive up to EUR 1 million to be used over the course of three years. In the implementation of the 2016-17 Work Programme's ENENplus project of ca. €3m was launched to attract and retain new nuclear talents. Research institutions, industry and EU organisations formed the European Sustainable Nuclear Energy Technology Platform Education (SNETP) *[Ref 14]* in collaboration with ENEN to secure an adequate resource of well-educated and trained young professionals to support the research recommended in the SRA and to meet the demand of industry.

4.2.4. 3.2.4 Radiation Protection and Medical Applications of Radiation

In the 2014-15 Work Programme there was one proposal (CONCERT) submitted under topic NFRP7-2015. Following evaluation by independent experts appointed by the Commission, a Euratom contribution of €19.8m was allocated. This represents 68% of the total project funding.

In the 2016-17 programme only one project was proposed, MEDIRAD, with the EuratomU providing €10m which represented 100% of the total project funding.

The CONCERT consortium brought forward a proposal that aimed to build on the results achieved through projects developed in the sixth and seventh Euratom Framework Programmes, such as the DoReMi Network of Excellence, and the OPERRA project in the field of radiation effects on humans, and on similar projects in other fields of radiation protection such as emergency preparedness and response (NERIS-TP and PREPARE) and in the field of radioecology (STAR NoE and COMET).

The DoReMi and OPERRA projects had originated from a policy review prompted in 2008 by the European Commission which had initiated a review by a European High Level and Expert Group (HLEG) of the state of knowledge and the major elements of scientific uncertainty in the context of radiation risk assessment and protection policies. The HLEG recommended the establishment of mechanisms and structures for specification and periodic updating of priorities in radiation protection research, to ensure the provision of long-term funding for focused research projects, to integrate education and training in state of the art research in radiation protection, and to ensure the availability of key infrastructures.

Based on the recommendations of the HLEG, national radiation protection organizations together with research centres and university institutes founded MELODI as a European platform to promote research in effects and risks associated with low-dose radiation exposures. In parallel to MELODI, the platforms ALLIANCE and NERIS were initiated in the fields of radioecology and nuclear emergency preparedness, respectively. To promote integration in the entire field of radiation protection research, MELODI, ALLIANCE, NERIS and EURADOS, an existing platform to foster promoting research and development as well as European cooperation in the field of the dosimetry of ionizing radiation, joined forces and signed a Memorandum of Understanding (MoU). CONCERT operates as an umbrella structure for the research initiatives jointly launched by the radiation protection research platforms MELODI, ALLIANCE, NERIS and EURADOS.

CONCERT aims to contribute to the sustainable integration of European and national research programmes in radiation protection by focussing resources and efforts in five key directions:

- Bring together the elements of the European scientific communities in the fields of radiation effects and risks, radioecology, nuclear emergency preparedness, dosimetry and medical radiation protection, whose joint expertise is essential to continue the development of radiation protection knowledge in a multidisciplinary mode to reduce further the uncertainties in radiation protection.
- Strengthen integrative activities between the various areas of expertise, in particular biology, biophysics, epidemiology, dosimetry and modelling as well as fostering the use of existing infrastructures and education and training activities in radiation protection.
- Stimulate and foster scientific excellence, by setting up and co-funding advanced research programmes with the potential to enhance current knowledge and the scientific evidence base for radiation protection.
- Exchange and communicate with all stakeholders, including the professional organizations concerned with radiation protection, the regulatory organizations across Europe, the public and media where necessary, and the international community of scientific, technical, legal and other professional experts in radiation protection.
- Foster the harmonious application of available scientific basis for radiation protection practices across Europe, by bringing together scientific and technical expertise in radiation protection issues, standard setting know how, particularly with respect to the implementation of the Euratom Basic Safety Standards (BSS) at the legal, administrative and operational level.

4.2.5. 3.2.5 Innovation and Industrial Competitiveness

Under the theme of innovation and industrial competitiveness there was one project in the 2014-15 Work Programme. The ESSANUF project received €2m of Euratom funding which represent 100% of the total project cost. Given that this project is to support the security of supply for utilities operating VVER nuclear power plants in the EU it is difficult to understand why this has no funding contribution from those utilities.

In the 2016-17 Work Programme there were two projects in this area. TRANSAT is a four years multidisciplinary project built to contribute to research and innovation on "cross-cutting activities" needed to "improve knowledge on tritium management in fission and fusion facilities". As such it is in line with the broader aims and objectives of the Euratom Work Programme. The M4F project aims to bring together the fusion and fission materials communities working on the prediction of microstructural-induced irradiation damage and deformation mechanisms of irradiated ferritic/martensitic steels. M4F is a multidisciplinary project, were both modelling and experiments at different scales will be integrated to foster the understanding of complex phenomena associated to the formation and evolution of irradiation induced defects and their role on the deformation behaviour. These two projects received €8m (69%) out of a total funding of €11.6m.

4.2.6. 3.2.6 Pan-European Research Infrastructures

In the 2014-15 programme there were two projects, HERACLES-CP and MYRTE. Both projects are relevant to the Council objectives and to the wider Euratom nuclear research needs as set out in the WP2014-15**.** Each project subject area is important to the long-term goals of the programme. It is also clear that there is a good level of participation, but in relation to the MYRTE project, perhaps understandably, there is a limited participation.

HERACLES–CP received €6.4m from the Euratom Programme which is 100% of the total project funding. Given the objective of this project it is again hard to see why the Euratom should fund 100%.

The 2016-17 Work Programme had one project, FOREvER. This project is focussed on securing the nuclear fuel supply for European research reactors. The EU is providing €6.6m out of a project total of €6.9m which means the EU is funding 95% of the project costs. It is hard to see how this can be justified given the nature of the expected outcome of the project.

4.2.7. 3.2.7. Social Aspects and Networking

The 2014-15 Work Programme selected one project related to social aspects, HoNEST, and two projects to promote networking, NUCL-EU2020 and SPRINT. All three projects cover areas addressed in the Work Programme. The projects are very different in nature and application. Implementation is underway and there is a good measure of Member States participation.

The total Euratom funding of €4m represent 100% of the total cost.

Two projects primarily addressing issues of expertise (VINCO and BRILLIANT), also contribute to this area.

No projects in this area were funded in the 2016-17 Work Programme.

4.3. 3.3 State of Play - Summary

The Panel was asked two questions on the state of play, namely: "How has the Euratom Programme been implemented during 2014-2016?" and "What conclusions can be drawn from the participation patterns and trends?" The above analysis shows that the Panel believes that in the aims of the Euratom Programme in both fusion and fission are being implemented but there are areas where improvements can be made as shown above in relation to participation of smaller organisations. Further effort is required in future calls to broaden the participation in the programme, maintaining the focus on excellence. Also, the fact that the rules for participation allow for up to 100% Euratom funding means that less research is being done for the same amount of funding.

5. 4. Evaluation of the Relevance of the Euratom Programme

This chapter examines the “Relevance” of the Euratom Programme. Here the Panel comments upon the extent to which the objectives of the Euratom Programme correspond to the needs of research stakeholders and to EU citizens in general. The chapter also addresses the extent to which the fusion and fission programmes provide the right balance between the various areas of nuclear research.

5.1. 4.1 Nuclear Fusion

Fusion offers a number of advantages for the long-term delivery of clean, secure and sustainable energy supplies for Europe. Fusion offers also the opportunity to foster innovation through the participation of industry in ITER and to the DEMO design.

The success of fusion requires educating and training a new generation of scientists and engineers, a significant component of the EUROfusion programme.

5.1.1. 4.1.1 Relevance of the Fusion Research Programme

Europe faces the challenge of ensuring an energy production that simultaneously meets the goal of long-term sustainability, security of supply and support to the development of the economy.

The advantages of fusion are such that its exploitation fits well in the EU strategy in response to those challenges. The fuel used in a fusion power plant (deuterium and lithium) is diffuse in seawater and in the Earth crust. No greenhouse gases are produced. Fusion does not produce nuclear wastes that require a long-term geological repository. With a proper choice of materials the components that are radioactive at the end of the reactor life cycle can be recycled after 100 years in a new reactor. The Fusion Roadmap has set the goal of demonstrating the production of fusion electricity around 2050 in order for Europe to achieve the goal of commercial fusion power for electricity production in the latter part of this century. It also defines the research priorities to achieve such a goal. These are now being pursued in the EUROfusion programme.

The large involvement of the European industry in the ITER construction is providing an opportunity for fostering innovation. It is of utmost importance that the expertise developed by industry in the ITER construction be retained for the further development of fusion as a commercial energy source through the construction of a DEMO plant.

5.1.2. 4.1.2 Relevance of Education and Training for Fusion

The leading research teams and laboratories in fusion science and technology play an indispensable role in training and education. The role of fusion laboratories and universities in training and education is recognised by specific support at under-graduate and graduate, specifically PhD level.

In addition, training in critical qualifications should be reviewed with industry, ITER and F4E, and should be encouraged. As recommended in the Fusion Roadmap, the existing training schemes would be enhanced by the involvement of industry through in-company training of engineers involved in fusion-related tasks and specific training of professionals and technicians, already specialised in fusion, for future technologies and standards.

5.2. 4.2 Nuclear Fission

The distribution of funding in the 2014-15 Work Programme *[Ref 13]* demonstrates that a good balance has been achieved between the various topics in the fission and radiation protection research areas. The focus of the selected projects is in line with the Euratom Work Programme and the overall Council objectives. The research is relevant but as discussed in section 3 above, the balance between Euratom and beneficiary spending is not always justified.

The projects in the 2016-17 Work Programme are again focussed on the key nuclear fission and radiation protection issues of interest. The range of projects in this Programme are generally balanced with the majority of the funding going to nuclear safety and radioactive waste management which are the key areas of importance for Euratom fission research today.

5.2.1. 4.2.1 *Safety of Nuclear Systems*

Evaluation of the grants awarded in the 2014-15 Work Programme in the area of nuclear safety clearly demonstrated that the aims and objectives that were set out in the Euratom Work Programme have been met and the research being undertaken is relevant to the research stakeholders and to the wider needs of the citizens of the EU. The balance of spending between the seven projects is in general consistent with the challenges as set out in the Work Programme.

The grants awarded in the 2016-17 programme are all relevant to the research needs set out in the Euratom Work Programme. There is a good balance between the need to support the safety of existing nuclear power plant operations in Europe and the need to focus on the research necessary to underpin the safety of the next generation of nuclear power plants.

5.2.2. 4.2.2 *Management of Ultimate Radioactive Waste*

The effective management of radioactive waste with the ultimate goal of the delivery of safe and secure deep geological disposal for the higher activity wastes is clearly an important goal for the Euratom Programme. The balance of spending on the projects in both the 2014-15 and 2016-17 Programmes is consistent with the challenges and aims of the radioactive waste research programme.

The five selected projects are consistent with the goals of the Euratom Work Programme 2014-15 and hence are relevant to the needs of the European research community and the citizens of the EU. All the projects selected in the 2016-17 programme are related to furthering understanding of issues that are relevant to the effective management of radioactive waste in the EU. They cover issues that are directly related to the safety of a geological disposal facility, the conditioning of radioactive waste, the long-term behaviour of spent fuel in a repository and the clean-up of decommissioned sites.

5.2.3. 4.2.3 *Nuclear Expertise and Excellence*

The importance of supporting the retention and further development of scientific competence and human capacity including education and training activities in order to guarantee the availability of suitably qualified researchers, engineers and employees in the nuclear sector is a long term priority in past and current Euratom Programmes. Euratom Projects facilitate the coordination of scientific research at the EU level, associating different competences and laboratories available in Europe in a multidisciplinary approach necessary for development of competences.

The Panel found that the results achieved are in line with the objective of the Euratom Programme to develop and assemble knowledge to improve scientific and technical competences, and know-how. One key aspect of added value with projects intended to produce guidelines and policy recommendations is the inherent ability of EU-level projects to ensure widespread dissemination of results through their international dimension and large number of project partners.

5.2.4. 4.2.4 *Radiation Protection and Medical Applications of Radiation*

Contrary to high dose, the risks from low dose of radiation, including its interaction with other risk factors, are poorly understood. In order to optimise the use of ionising radiation in medical and other applications, a deeper understanding of the associated effects is required including developing understanding of dependencies such as gender, age and individual radiosensitivity. A fundamental question in radiation protection is whether the LNT (Linear No Threshold) concept is still valid at very low doses. While this question is embedded in current research activities, it has been suggested that future calls should have more specific goals to address open research challenges, like the issue that DNA damage from radiation is mostly linear, but the efficiency of repair mechanisms is not; or specific issues raised by individual and non-linear factors that need to be explored *[Ref 15]*.

To achieve this, it is necessary to harness co-operation within the research community at a European level and to draw on expertise within other scientific disciplines. An integrated approach to radiation protection research, exploiting synergies between the various areas of expertise is required to fully realise maximum benefits and outcomes. This action should lead to better integration of the radiation protection scientific community at EU level, leading to a better coordination of research efforts and the provision of more consolidated and robust science-based policy recommendations to decision makers in this area. In the long term, these efforts will translate into additional or improved practical measures in view of the effective protection of people and the environment.

The EY review *[Ref 16]* looked at projects funded under Euratom FP7 and as such projects funded between 2014 and 2016 were not the primary focus of this study. However, the review looked at the impact and usefulness of Euratom research in a more general sense, at the mobility of researchers within the Euratom programme and drew some conclusions for all areas of the Euratom programme. As CONCERT draws heavily on the output of previous research programmes, some of the findings of the review are directly relevant. In addition, the EY review also conducted a survey to assess satisfaction and opinion for all Euratom FP7 and 2014-18 projects and carried out the first of a series of qualitative interviews to assess end user views on the programme. CONCERT and other recent Euratom projects were included in the survey.

In terms of relevance of CONCERT to the needs of the European research community, the call priorities of the first open CONCERT call have been established by taking into account the Strategic Research Agendas (SRAs) of the European radiation protection platforms MELODI, ALLIANCE, NERIS and EURADOS.

5.2.5. 4.2.5 Innovation and Industrial Competitiveness

In the 2015-16 programme ESSANUF is an unusual research project and it is debatable whether it fits into the Euratom programme given the obvious commercial nature. However, given the vulnerability of the nuclear fuel supply to Russian VVER reactors in the EU, it is understandable that some funding of this work is justifiable. The objectives of the project *[Ref 13]* are comprehensive and relevant to the need to reinforce European capabilities for nuclear fuel supply for reactors of VVER-440 design and expedite the process of strengthening such capabilities.

The project clearly is in line with the need to support the needs of EU citizens. However, as discussed in Section 3 above, the 100% Euratom funding for the project is debatable.

The 2016-17 Work Programme has two projects in this area. The TRANSAT project is aimed a furthering understanding of the issues surrounding the management of tritium. As such it is relevant to both fission and fusion technologies. The M4F project aims to bring together the fusion and fission materials communities working on the prediction of microstructural-induced irradiation damage and deformation mechanisms of irradiated ferritic/martensitic steels. It is a multidisciplinary project, where both modelling and experiments at different scales will be integrated to foster the understanding of complex phenomena associated to the formation and evolution of irradiation induced defects and their role on the deformation behaviour. Both Projects are judged to be relevant and clearly consistent with the Euratom Work Programme and the needs of EU citizens.

5.2.6. 4.2.6 Pan-European Research Infrastructures

In the 2014-15 programme the two projects, HERACLES-CP and MYRTE, are relevant to the wider EU nuclear research needs as set out in WP2014-15.

The 2016-17 Programme had one project FOREvER. This project, which is aimed at the security of supply for research reactor fuel is very relevant to the delivery of the Work Programme.

5.2.7. 4.2.7 Social Aspects and Networking

In the 2014-15 Programme three projects were selected, HoNEST, NUCL-EU2020 and SPRINT. All three are very different from each other but the projects aims and objectives are consistent with the Work Programme. The extent to which they meet the needs of European citizens is less clear. The HoNEST project should provide information to enable the public to have a better understanding of the history and social impacts of nuclear power in Europe. However, the €3m allocated to this seems excessive. The funding balance for the NUCL-EU 2020 and SPRINT projects is in line with their importance and priority.

The 2016-17 programme does not include any projects in this area.

5.3. 4.3 Relevance - Summary

The Panel was asked two questions on the relevance of the Euratom Programme, namely: "To what extent do the objectives of the Euratom Programme still correspond to the needs of research stakeholders and to EU citizens?" and "Does the Programme offer the right balance between the various areas of nuclear research?" The Panel believes that the above analysis shows that the research being done in both the fusion and fission areas is relevant and does correspond to the needs of both the research stakeholders and the wider EU citizens. There is also a balanced programme that reflects the needs of both the fusion and fission communities.

6. 5. Evaluation of the Effectiveness of the Euratom Programme

This chapter addresses the "Effectiveness" of the Euratom Programme. The focus in this chapter is to evaluate the progress being made towards the delivery of the objectives of the Euratom Programme and to identify any factors that are driving or hindering progress. The chapter also examines the impact of the new measures that have been introduced such as the 'European Joint Programme'. Effectiveness also includes the evaluation of the main long-term impacts of the previous Euratom Framework Programme, and the extent to which the Euratom research programme is contributing to the wider EU strategic objectives and policies.

6.1. 5.1 Nuclear Fusion

Europe has a long-standing leadership in fusion with the largest magnetic confinement fusion device in operation (JET), the most advanced technology programme and the largest share of the ITER construction. This leadership has been achieved thanks to the Euratom programmes that have led to a coherent approach in the Member States and facilitated the emergence of excellence.

The major factor driving the progress in fusion is ITER. Following the definition of the Roadmap in 2012, the Euratom programme has made substantial progress to secure the success of ITER and lay the foundation for a demonstration fusion power plant (DEMO).

The test on JET of the ITER plasma facing materials (the ITER-like wall) has progressed and now awaits experiments with tritium. Tests are on-going of ITER systems that are critical for the authorization to progress from the pre-nuclear to the nuclear phase. The JET tritium experiment will also provide the best opportunity to train the ITER staff. JET will provide the largest impact for a successful ITER start, provided operation is extended up to 2024.

The DEMO design activity has started in a professional manner. A substantial effort in the critical areas of materials and tritium breeding has been started. The original Roadmap approach, for the achievement of fusion electricity at the earliest possible time, should be maintained. This requires a focused approach to the R&D on DEMO and starting the DEMO Engineering Design Activity at the earliest possible time to make full advantage of the know-how generated in industry through the ITER construction.

The stellarator research line has achieved an important milestone in the reporting period with the start of W7X.

Progress have been achieved also thanks to a new organizational structure of fusion research that supports, through joint programming, a transparent allocation of funds and facilitates the emergence of excellence.

The Fusion Roadmap is articulated in eight Missions. In the Annex 5 a list of technical achievements during the period 2014-2016 in each Mission is presented. A midterm review of the EUROfusion programme has been carried out in 2016 and made available to the Panel *[Ref 7].*

In order to evaluate the impact of the activities implemented by EUROfusion so far, the results are grouped under the following areas: the preparation for ITER exploitation, the design and R&D for DEMO, the stellarator line and training and mobility.

6.1.1. 5.1.1 Preparation For ITER Exploitation

The main goal of the ITER preparation is to address (in conditions as close as possible to those of ITER) the main challenges that ITER will face in the first part of its exploitation. The impact on the programme of this approach is made clear by noting that if an issue is found now, remedial actions can be put in place in a timely manner to ensure a swift progress of ITER. If the same issue is found during the ITER exploitation, a significant delay and cost increase can ensue. For this reason, the preparation for the ITER exploitation is the main risk mitigation element in the Fusion Roadmap.

The ITER schedule has been recently revised and it now foresees first plasma in 2025 (five years behind the original scheduled time) and the start of deuterium-tritium operation in 2037 (a delay of nine years). The ITER delay with respect to what was assumed in the Fusion Roadmap makes even more necessary an adequate preparation to avoid the risk of further delays in achieving the Q=10 milestone on ITER.

The Euratom 2014-2018 activities in fusion (the EUROfusion grant and the NJOC) devoted to the ITER preparation include the operation and exploitation of JET and other medium size tokamaks (MSTs) and the preparation for the exploitation of JT-60SA.

6.1.1.1.5.1.1.1 JET

JET is the largest tokamak experiment in operation, the only one that can use tritium as fuel and that has beryllium as the plasma facing component. JET has been instrumental in achieving the European leadership in fusion. Thanks to the flexibility of its design it has been possible to adapt the facility to the changing needs in fusion research.

During FP7 all the JET components inside the reaction chamber were replaced with the same combination of materials foreseen in ITER for the nuclear phase (beryllium for the main wall and tungsten for the divertor) - a combination never tested before. The successful operation on JET of the ITER-like wall (ILW) led to the ITER decision in 2013 to adopt this combination of materials also in the pre-nuclear phase, with a substantial saving in cost and a more robust strategy for the development of the ITER regimes of operation.

The Panel considers this is one of the best examples of successful ITER risk mitigation.

The exploitation of the ITER-like wall has been progressed further by EUROfusion (see Annex 5). JET experienced some operational difficulty at the beginning of the current Euratom Programme but is now operating well and the Panel expects that it can fulfil its tasks without any major issues related to machine reliability provided the ongoing refurbishment programme is completed.

JET continues to play the crucial role for such a risk mitigation strategy for ITER. A detailed list of tasks that could be successfully carried out by JET has been produced by the ITER Organization following a request of this Panel and summarised below. Some of these tasks are already being implemented and some are new, following the evolution of the ITER Research Plan. Schematically, the goal of the tasks is to address on JET the following areas:

- Development of ITER-relevant regimes of operation at high plasma current with tolerable stationary and transient heat loads on the plasma-facing components. This is particularly relevant as JET has the same plasma facing materials as ITER and can investigate deuterium-tritium plasmas.
- Characterization of hydrogen and helium plasmas to be used in ITER during the pre-nuclear phase.
- Test of reliable systems to mitigate off-normal events (disruptions and runaway generation) utilizing massive material injection, in particular via a so-called "shattered pellet injector" foreseen for application to ITER.
- Test and extensive use of the ITER Integrated Modelling Analysis Suite (IMAS). IMAS will be a key tool for the implementation of the ITER scientific programme, allowing the validation of plasma regimes of operation in advance of their exploitation in ITER and the analysis of experimental data resulting from the ITER operations programme.

- Development of methods that impact on the nuclear safety of ITER such as dust and tritium inventory control, validation of the calculations of neutron streaming in the ITER biological shield, characterization of collective dose distribution, validation of models for the production and transport of activated cooling water and activated corrosion products.
- Characterization of effects of fusion generated neutrons on essential ITER diagnostics.
- Training of personnel in the execution of tokamak operating sessions; operational experience with tritium for the ITER fuel cycle team and experience with beryllium handling.

Some of these tasks must be completed by JET in order to facilitate the authorization process for ITER to progress from the pre-nuclear to the nuclear phase, others will allow to prepare in advance all the possible strategies during the nuclear phase to achieve the Q=10 milestone in the shortest possible time. Training of ITER personnel has an obvious impact in reducing the risks of ITER delays by transferring all the possible know-how and best practices to the ITER staff.

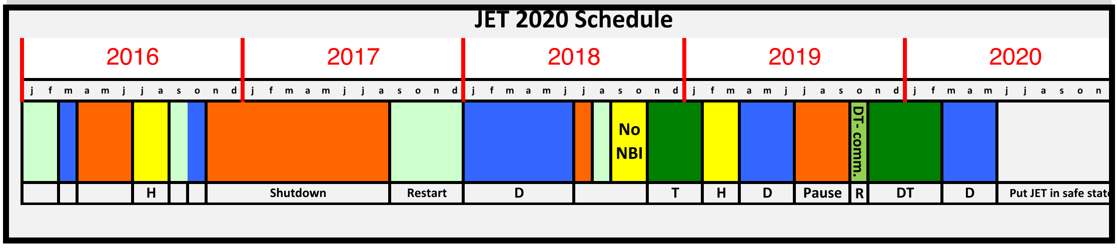
The Panel has also examined the implications of different dates for the closure of JET on the basis of the schedule provided by EUROfusion *[Ref 17]*.

In the event of a closure of JET in 2018 (end of the current Euratom Programme) only seven months of operation would be available for the programme. No deuterium-tritium experiment would be carried out and no input on the nuclear safety of ITER would be generated. The development of ITER relevant regimes of operation would be heavily constrained, the test of the disruption mitigation tools could be performed but no possibility of follow-up would be possible and training opportunities for the ITER team would be almost entirely lost.

In case of closure in 2020, about 24 months of operation would be available and many of the above tasks could be partially addressed. A limited (four months) deuterium-tritium experiment could be executed. However, the helium campaign (a relevant test for the preparation of the ITER non-active phase) would not be carried out. This schedule (see *Figure 1*) would also force a "once through" approach that would preclude the possibility of returning to areas where the analysis would require a second iteration to complete the database, with the risk of leaving significant uncertainties in extrapolation to ITER. In addition, a closure in 2020 would heavily limit the training of ITER operational staff which is planned to be built up from 2020 onwards. Although in preparing this schedule reasonable assumptions for contingency have been made, any unforeseen event (e.g. a small delay in one of the scheduled shut-downs) could significantly impact on the amount of experimental time - from January 2018 to May 2020 the machine should be available 24 months over 29 months.

Figure 1

JET 2020 schedule (Orange=shut-down, Pale green=Restart, Blue=deuterium operation, Yellow=hydrogen/helium operation, Green=tritium operation)

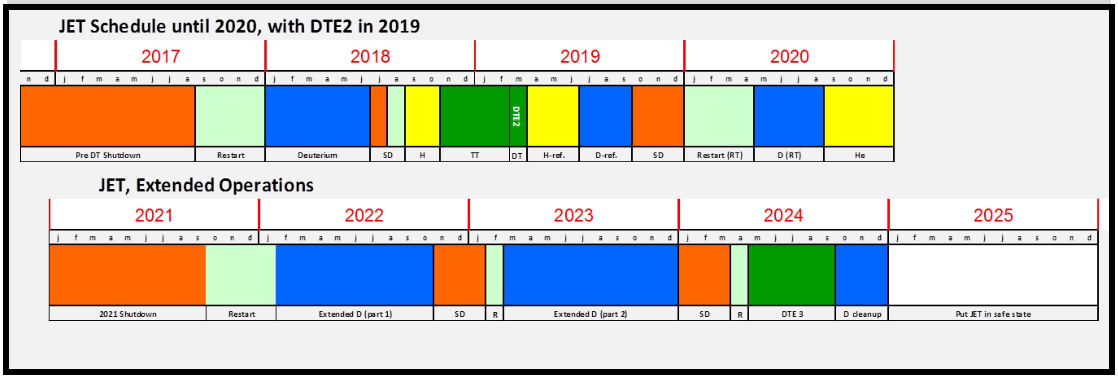


The JET Team has also produced a tentative schedule to fully address all the ITER tasks (see *Figure 2*). This schedule foresees operation up to the end of 2024 with JET put in a safe state in 2025, with 54 months of operation over a total amount of 84 months including a 4-month full-tritium campaign and a 6-month deuterium-tritium campaign. This schedule also includes a four-month helium campaign. This option would allow addressing all the urgent ITER R&D needs listed above with a sufficient contingency margin and sufficient flexibility to adapt the programme on the basis of the indications emerging from the results obtained early in the experimental campaigns. Results would arrive in time to be incorporated in the ITER Research Plan in advance of the first ITER plasma in 2025. Furthermore, it would allow an optimal training of the ITER operational personnel.

The Panel makes the following observations on the impact of the closure of JET on the following dates:

Figure 2

JET schedule with DTE2 in 2019 (Orange=shut-down, Pale green=Restart, Blue=deuterium operation, Yellow=hydrogen/helium operation, Green=tritium operation)



- **2018** - most of the tasks requested by ITER could not be executed and no training of ITER staff would be possible. The scientific return out of the investments made in JET in 2004-2011 would be severely reduced.
- **2020** - most of the tasks could be preliminarily addressed but it would be impossible to have any follow-up on the findings. The availability requested of JET during this period appears to be challenging and the risk that the program could not be completed seems high. No substantial training of the ITER staff would be possible.
- **2024** - all the ITER tasks could be completed with sufficient depth to inform the ITER Research Plan and the training of ITER staff would be possible. This is also the option proposed by the international ITER Organisation (ITER IO) [Ref 18].

It is important to acknowledge that JET is the only fusion device with the closest possible conditions to ITER that is available to address urgent R&D needs that may arise in the period leading up to the first ITER plasma. Therefore, JET provides the last opportunity to address in advance of the ITER first plasma the main risks to the successful operation of ITER in ITER-relevant conditions.

Recommendation 3: In view of the importance of JET for ITER the JET campaigns should be extended up to 2024.

6.1.1.2.5.1.1.2 Medium size tokamaks and PWI devices

In the current Euratom Programme the ITER preparation activities have been significantly improved through the joint exploitation through a campaign-oriented approach of the medium size tokamaks (ASDEX-U, MAST-U and TCV) that have emerged from the 2008 Facility Review *[Ref 8]* as those having features relevant for ITER. Linear plasma devices

(MAGNUM-PSI, Pilot-PSI, etc.) and the WEST tokamak are also used collectively for plasma-wall interaction studies in support of ITER. This programme also investigates alternative solutions for the heat exhaust in DEMO at a proof-of-principle level.

Until FP7, the exploitation of these devices, although supported by Euratom, was under the responsibility of their home laboratories. Bilateral collaborations were in place and exchange of personnel was supported through the Euratom mobility funds. In some cases, the EFDA Leader was involved in an advisory role.

From 2014With Horizon 2020 a substantial part of the experimental programme is now carried out under the EUROfusion responsibility, in a way similar to the exploitation of JET. The experimental programme is discussed collectively and implemented under the responsibility of the relevant EUROfusion Task Force Leaders and Project Leaders.

The main advantage of the new system is the integration among the experimental programmes of the various facilities. This allows an optimal allocation of tasks to the various European facilities (JET, MSTs and plasma-wall interaction devices) through the selection of the facility best suited for the execution each task. The execution of the programmes has been harmonized to allow the participation of the key scientists to each task. The Panel is convinced that this approach has substantially increased the added value of the Euratom contribution.

6.1.1.3.5.1.1.3 JT-60SA

JT-60SA is a superconducting tokamak built within the Broader Approach activities in collaboration with Japan. It is expected that the construction of JT-60SA will be completed by the end of 2019. JT-60SA has a plasma current similar to that of JET but thanks to the use of superconductors is particularly suited for the development of advanced tokamak regimes of operation in preparation of the second phase of the ITER exploitation. Thus, in the next decade as soon as the commissioning of the device has been completed and a substantial amount of heating power is available, JT-60SA will play an important role in support of the preparation for the ITER exploitation.

The activities for the preparation of the JT-60SA exploitation are progressing well in collaboration between EUROfusion, F4E and Japan. Specifically, the JT-60SA Research Plan has been revised in order to incorporate the input of the European scientists.

6.1.2. 5.1.2 DEMO Conceptual Design and R&D

The launch of an ambitious DEMO Conceptual Design Activity (CDA) and R&D is one of the distinctive features of the Euratom Programme fusion activities, with an increase by about an order of magnitude in the budget in this area with respect to Euratom FP7. The main goal is to complete the Conceptual Design and the associated R&D by 2020.

The Panel notes that the DEMO design activity has started in a professional manner with a thorough examination of system integration aspects supported by a systems engineering approach. The Panel encourages the continuation of this work.

A baseline architecture has been established that integrates all the major DEMO sub-systems into a coherent plant concept. This approach is necessary in order for the plant design to drive R&D and not the other way round. A stakeholder group has been also set up in order to gather the view of industry and utilities on the mission of DEMO.

Different projects have been set up to implement the R&D effort on all the main DEMO technologies: breeding blanket, balance-of-plant, diagnostic and control, divertor, superconducting magnets, heating and current drive, material, remote maintenance, safety and fuelling. The allocation of resources privileges those areas not covered by the ITER R&D, namely tritium breeding and materials, or that require a substantial change in approach with respect to ITER such as remote maintenance.

The focus of the activities in the Breeding Blanket Project is on strengthening the technical basis and resolving all the main technical issues associated with the four breeding blanket concepts that have been selected in 2012 as promising candidates for this programme. The present schedule foresees the selection of one concept completed by 2024 (rather than by 2020 as in the original programme). The possibility of realigning the ITER Test Blanket Module (TBM) and EUROfusion Breeding Blanket programmes is also being discussed with F4E.

The Panel supports a realignment of the TBM programme to the priorities of the Fusion Roadmap.

In the area of materials, different options are being investigated for reduced activation steels with the goal of increasing the operational window in temperature. The programme experienced some delay as specific financial provisions had to be put in place to support irradiation campaigns in material test facilities. First results from neutron irradiation in material testing reactors are expected by 2020.

As to the schedule for the completion of the DEMO design activity, the Panel notes that the timing of the decision on the DEMO construction is determined in the Fusion Roadmap by the following elements:

- The time at which ITER will confirm the viability for DEMO of the plasma regimes of operation. This is conventionally identified with the achievement of the Q=10 milestone.
- The need to exploit the know-how and experience gained in industry during the ITER construction by launching at an early stage the DEMO Engineering Design Activity (EDA).

As to the first point, the ITER schedule, at the time of the preparation of the Fusion Roadmap, foresaw the Q=10 milestone achieved in 2030. In the revised ITER schedule there is a nine year delay in the achievement of the Q=10 milestone.

As to the second point, at the time of the preparation of the Roadmap the first assembly phase of the main machine components (magnets, vacuum vessel, cryostat - internal components will be installed in two successive phases) was expected to be completed at the beginning of 2020 whereas the revised schedule foresees now the end of 2024. This date is important as the components involved in the first assembly phase are the components that mostly impact the cost of the fusion power plant core and on which the industrial expertise will be crucial in finding more innovative and less expensive solutions for DEMO. Hence, the need for a start of the DEMO EDA not much later than the end of the first ITER assembly phase.

In dealing with the impact of the change in the ITER schedule EUROfusion is proposing:

- To align the DEMO decision of construction to the new date for the Q=10 milestone on ITER;
- To postpone the start of the DEMO EDA to 2030. The time up to 2030 would be devoted to a pre-conceptual design activity for the period 2014-2020 followed by a true CDA in the period 2020-2030.

The Panel supports the proposal of aligning the decision of DEMO construction to the new date for the Q=10 milestone on ITER.

However, because of the importance of aligning the start of the DEMO EDA with the completion of the main ITER machine components, the Panel believes that the DEMO CDA should not be delayed in order for the DEMO EDA to start around 2025, as explained above.

Recommendation 4: EUROfusion should not delay the DEMO CDA and should start the DEMO EDA around 2025 in order to maintain the industrial know-how generated by the ITER construction.

The new schedule of the DEMO CDA/EDA is indeed motivated not only by the delay in the ITER schedule but also by the goal of redefining the DEMO concept as close as possible to that of a commercial fusion power plant. For this reason a number of different options are presently being explored ranging from limited modifications of the magnetic configuration (e.g. going from the ITER single-null to a double-null magnetic equilibrium) to configurations capable of incorporating very different features (e.g. advanced divertor configurations) and presently tested only at a proof-of-principle level.

The focus of the DEMO programme should be maintained on an ITER-like DEMO design because fusion will become a credible energy source only when it will demonstrate the production of net electricity in large-scale plant with a reasonable amount of availability in an integrated way including tritium breeding, nuclear safety and electricity conversion in one facility. Thus, an approach should be taken that prioritises a rapid build-up of the know-how in the nuclear aspects of fusion, rather than trying to figure out at this stage the layout of a commercial power plant.

Studies of advanced fusion power demonstration concepts have certainly a value but the timescale for the validation of their underlying assumptions makes it likely that such advanced demonstration concepts, if feasible at all, will demonstrate electricity production at a much later stage. These investigations can be pursued with limited resources but should not interfere with DEMO design work and its goal of early electricity production while more innovative solutions are developed and qualified in parallel.

At the present stage of development of fusion research, setting the commercial fusion power plant as the target for the research effort to be carried out over the next two decades may be overambitious. It would defocus the activities and increase the time of the realization of fusion even beyond what is presently foreseen by the Roadmap revision under discussion.

Recommendation 5: EUROfusion to maintain the original Roadmap focus on DEMO as an ITER-like tokamak to be built as soon as ITER achieves the Q=10 target.

6.1.3. 5.1.3 Stellarator

The stellarator line is a potential alternative to the tokamak line with intrinsic advantages since the confining magnetic field can be generated by external coil only and the configuration is not prone to the problem of disruptions. A new large facility (W7X) has started in 2016 and the operation and its exploitation is involving all the EUROfusion laboratories. The main objective of the first campaign was the integral commissioning of plasma start-up and operation using an electron cyclotron resonance heating (ECRH) system and an extensive set of plasma diagnostics.

6.1.4. 5.1.4 Training and Mobility

Past training programmes under EFDA such as the European Fusion Research Fellowship and the Goal-Oriented Training programmes have been effective, as shown by the selection of high-quality students and research proposals and by the large fraction of the participants staying in fusion research.

Regarding education, EUROfusion recognises the need to continue the previous PhD support activities. However, the Panel believes that there is a need for EUROfusion to focus more attention on fusion technology and engineering skills.

Recommendation 6: EUROfusion should use its educational resources to promote educational programmes that will deliver the nuclear engineers and technologists as foreseen in the Roadmap.

Mobility in fusion research is important to underpinning the successful transition to a more integrated and results focused way of working within the framework of increasingly complex pan-European projects. The mobility support covers three elements (all on unit-cost scheme): funding for visiting scientists, secondees, and fellowships. With EUROfusion, mobility now has to be justified by the needs of the programme and is directly integrated into the programme budget and managed within each project and taskforce. Research grants were awarded by a panel based on the quality of the proposal. Engineering grants were given for individual proposals attached to projects and not given to the Research Units.

Some of the stakeholders interviewed by the Panel suggested that mobility support needs increased attention as it appears to be more restrictive in EUROfusion than it has been under the previous system. This has created discontent *[Ref 16]* that chiefly stems from the "unit cost" Commission Decision *[Ref 19],* a system whereby travel costs are reimbursed by a lump sum based on rates defined in the Decision. According to Art 2.1.1 of the Decision the unit cost scheme does apply to secondments, both short-term such as for JET campaigns and long-term such as to the PMU. However, the interpretation of Art. 2.1.1 is quite broad, meaning that short 'missions' such as to attend the General Assembly or to support networking among the labs can also be covered. The system has tended to create additional administrative burden for some Research Units, particularly larger ones that are used to applying national cost-based reimbursement schemes. The unit cost scheme also seems to penalise secondments to the PMU.

While available statistical data do not point towards a negative impact on mobility, the PMU could address these issues by proposing, for example, that application of unit costs is restricted to true secondments for the purposes of actual research activities.

Table 15 provides a good estimate of the number of researchers receiving mobility support (in comparison with FP7).

The short-term mobility has become more clearly focused on the implementation of the Roadmap. However, the support for mobility appears to be overwhelmingly

Table 15
Number of researchers receiving mobility support (data from EUROfusion)

Year	Researchers supported	Mission days	Researchers supported accessing infrastructure
2014	839	10 572	872
2015	842	10 860	958

concentrated on the physics side of EUROfusion activity (e.g., experimental campaigns at JET and the medium-sized tokamaks). It should be noted that developing a higher level of mobility is also important for creating scientific networks between the different Research Units involved, particularly within the context of fragmented and geographically dispersed project teams.

Issues with long-term mobility of the Programme are quite different. The unit cost decision provides the basis for the supplemental remuneration of secondees to the Programme Management Unit (PMU).

Recommendation 7: EUROfusion and the Commission should review the impact of Unit Costs on mobility and make any necessary changes.

6.2. 5.2 Nuclear Fission

Most projects selected after the first call (WP2014-15) of the Euratom Programme started in 2015 with duration of usually four years for Research and Innovation Action (RIA) projects. Therefore the Panel has only seen a limited number of periodic progress reports that in many cases focus on the administrative aspects and project implementation issues.

There is even less information available to judge the progress of the projects in the 2016-17 Programme.

In the Fission area the concept of joint programming (European Joint Programme / Programme Co-fund Action) is in its infancy and hence it is too early to see definitive evidence one-way or the other. However there are signs that it is not always beneficial to adopt a joint programming approach and it should only be used when it can offer clear benefits to research coordination.

It is difficult to define what the long-term impacts of the previous Euratom Programmes have been other than to say that research activities have generally been focused on providing support to the delivery of a safe and secure nuclear energy programme in the EU and on understanding the effects of ionizing radiation on human health.

The impact of the previous Euratom Framework Programme FP7/FP7+2 is effectively summarized in the EY report *[Ref 16]* and in the ex-post evaluation *[Ref 12]*. Both these reports conclude that in general the research has contributed to the EU's strategic objectives and policies.

6.2.1. 5.2.1 Safety of Nuclear Systems

Not all of the seven projects in this area of the 2014-15 Programme have detailed documentation showing progress against the required deliverables. The following summarises the progress to date of these projects based upon the available reports supplied by the Commission and information obtained from the project websites.

FASTNET

The main objective of this project is to set up a severe accident scenarios database *[Ref 20].* The project implementation is over a 4-year period Oct 2015-September 2019. There are five work packages (WP): WP1 Development of a Scenarios Database; WP2 Emergency Preparedness; WP3 Emergency Response, WP4 Benchmarking and WP5 Dissemination. To date progress on WP1 has been reported on the successful completion of the first FASTNET workshop in November 2016 in Bologna *[Ref 21].* Further workshops in Stockholm in January 2017 discussed progress on WP1 and WP2.

INCEFA-PLUS

The objective of this project is to develop new guidelines for assessment of environmental fatigue damage susceptibility for nuclear power plant (NPP) components *[Ref 22].* The project has two main parts:

- The characterization of a limited selection of typical austenitic stainless steel alloys employed in NPPs; and
- The development of a modified procedure for estimating the fatigue degradation of the materials.

The main deliverable of the project *[Ref 23]* is a new or modified fatigue analysis procedure. Besides a new/revised fatigue analysis procedure the project will also establish a new fatigue data format standard.

In the first 18 months of the project, progress has been made on all four Work Packages (WP). In WP1 (Project Management) an advisory board has been established, terms of reference agreed and a number of project meetings convened. In WP2 (Test Programme) the test programme for phase I has been agreed but commencement of testing was delayed due to a combination of specimens not being available and some laboratories not being ready. WP3 (Development of a fatigue analysis procedure) is progressing: A workshop has been delivered along with a full day web meeting to develop ideas for data analysis. In WP4 (Development of INCEFA-PLUS website, training seminars and workshops) the project was presented at several international conferences, and also to the World Nuclear Association CORDEL project. At one of the conferences the presentation was included in a session co-organized by the INCEFA-PLUS project.

Overall the project appears to be progressing and the agreement of a testing protocol that is being adhered to by 16 partners from across Europe is a major development.

IVMR

The IVMR (In-Vessel Melt Retention) project *[Ref 24]* aims at providing new knowledge (experimental, theoretical and technical) and a new methodology able to provide a best-estimate evaluation of In-Vessel Retention (IVR) strategy for large power reactors. The project has six work packages (WP). WP1 (Project Management) appears to have delivered most of the expected deliverables to date. In WP2 (Methodology and Modelling Activities) a considerable amount of work has been reported in this area with extensive modelling work being completed. WP3 (Experimental study of heat and mass transfer in stratified molten pool within RPV lower head) is showing that a considerable amount of work has gone into planning experiments and constructing suitable facilities but no experiments have take place so far. In WP4 (Experimental assessment of vessel external cooling and long term stabilization), in the case of the small-scale experimental activities, work is on schedule as is the construction of the large-scale test facility. For WP5 (Review of innovation and technical engineering applicable to IVMR – New ideas for the efficiency and optimal management of IVMR) again a considerable amount of work has been reported in this area. In WP6 (Dissemination and use of results) to date there have been a few publications but there are activities such as conferences planned to further disseminate results.

Overall reasonable progress is being made with the first year being mostly dedicated to analytical work and the development of "*benchmark exercises which should lead to a common understanding and evaluation of the IVR strategy and, later, to a harmonization of the methodology at the European level (or even at the international level if connections can be established with external countries)*."

SAMOFAR

The objective of SAMOFAR is to prove the innovative safety concepts of the Molten Salt Fast Reactor (MSFR) by advanced experimental and numerical techniques, to deliver a breakthrough in nuclear safety and optimal waste management, and to create a consortium of stakeholders to demonstrate the MSFR beyond SAMOFAR *[Ref 25].* A "Kick Off" meeting was held at Delft University on 15 August 2015 and to date the Project has produced 25 publications. Another deliverable has been the "Description of initial reference design and identification of safety aspects" *[Ref 26].* Deliverable 1.1 presents the initial reference design and operation procedures of the MSFR proposed by CNRS and the other partners of WP1 at the beginning of the project.

SOTERIA

The aim of this project is to improve understanding of the ageing effects in reactor pressure vessel steels in order to ensure the safe long-term operation of Europe's nuclear power plants. The aims and objectives of the project *[Ref 27]* are impressive but all key deliverables are not due until the end of the project mid 2019. Of the short-term deliverables the "Kick-Off" meeting was held within the first month of the project start date as required *[Ref 28]* and the website is up and running *[Ref 29]***.**

sCO2-HeRo

The objective of this project is to show the proof of the concept of the supercritical CO_2 heat removal (sCO2-HeRo) system. The project has five work packages: WP1 System Integration and Simulation; WP2 Heat Exchanger; WP3 Turbo Machine Set; WP4 integration in the Glass Model; and WP5 Exploitation and Dissemination. The Project deliverables are given at the Project website *[Ref 30]* but it is not clear if the deliverables were delivered on time. Some of the project meetings have taken place, a 3D-printed model of the turbomachine has been delivered as well as the 1st European Seminar on "Supercritical CO2 Power Systems", TU Vienna, 29-30 Sep 2016. All this indicates that progress is being made.

SESAME

SESAME is a coordinated R&D programme for nuclear thermal-hydraulics reactor safety to support both future reactors and the continued safe operation of existing nuclear plants

[Ref 31]. It aims to maintain and develop the necessary supporting research infrastructures, such as experimental facilities and numerical tools. It will use available liquid metal laboratories and facilities in Europe, such as the existing facilities from KALLA, KASOLA, CIRCE, TALL, NACIE, and the Phénix sodium fast reactor.

In the short term, SESAME will improve the thermal hydraulics knowledge base for liquid metal fast reactors and for contemporary light water reactors. The new experimental data and the advanced simulation approaches to be developed within SESAME will support interactions with stakeholders at large and the civil society on nuclear reactor safety. In the medium term, the project will improve the safety of liquid metal fast reactors and contemporary light water reactors in Europe, and in a second step globally, by making available new safety related experimental results and improved numerical approaches.

The publishable summary for this project *[Ref 32]* and the Technical Report *[Ref 33]* provide details of the progress that has been made so far. Information on the project milestones *[Ref 34]* and deliverables *[Ref 35]* show that for all the milestones most of the deliverables have been achieved, to the extent that reports have been submitted.

6.2.2. 5.2.2 Management of Ultimate Radioactive Waste

There are five projects the 2014-15 Programme: CEBAMA, JOPRAD, MIND, Modern2020 and SITEX-II.

Cebama

Cebama is a 4-year project that started 1st of June 2015. The consortium has 27 members including some from Switzerland and Japan. The main objective of Cebama is to support the implementation of geological disposal by significantly improving the knowledge base for the Safety Case for European repository concepts.

The project has five work packages: WP1- Experiments on interface processes and the impact on physical properties; WP2 - Radionuclide retention; WP3 - Interpretation and modelling; WP4 - Documentation, knowledge management, dissemination and training; WP5 - Management. Progress in each of deliverables in each of the work packages is encouraging *[Ref 36] [Ref 37]* with a number of workshops being delivered and experimental programmes started.

JOPRAD

The overall aim of the JOPRAD project is to assess the feasibility and prepare for the setting-up for a RD&D European Joint Programme (EJP) that would bring together all R&D activities in the field of geological disposal of spent fuel and other higher activity radioactive waste. The Joint Programme would also include pre-disposal activities such as treatment, characterization and conditioning of radioactive waste and the accompanying key horizontal activities of knowledge management and training.

JOPRAD has six work packages: Management (WP1); Engagement and Commitment of Member States (WP2); Basis of the "Programme Document" (WP3); Production of the "Programme Document" (WP4); Preparation for Implementation (WP5); and Dissemination of the Project outcomes (WP6). A number of events took place in 2016 to discuss the order to inform on, engage and involve countries in the process of European Joint Programming (EJP) and its preparation within the JOPRAD project *[Ref 38].* Various newsletters have been published *[Ref 39] [Ref 40]* which illustrate progress being made. The report on the project milestones *[Ref 41]* shows that all the milestones up to August 2016 have been achieved. However out of some 25 planned deliverables only 15 have been delivered on time *[Ref 42].* Of the outstanding deliverables some were nine months late.

Given the level of progress that had been made by the end of Dec 2016 it is difficult to see how EJP could go ahead in this area. The Panel believes that in principle EJP in waste management has some potential advantage but more work is needed to demonstrate that it is sufficiently developed to be able to judge the benefits at this point in time.

Recommendation 8: For WP2018 or the extension of Euratom 2014-18 the Commission and Members States should carefully consider if there is sufficient evidence to demonstrate that the EJP instrument can be applied to research on geological disposal of radioactive waste at this point in time.

More recent information suggests that things have improved, however the Panel believes the above recommendation remains valid in view of the importance of the topic.

MIND

The Microbiology In Nuclear Waste Disposal (MIND) programme is a unique multidisciplinary project that brings together a broad range of leading research institutions and stakeholders in the field of radioactive waste disposal. Its main objective is to address the key technical issues, involving microbial processes that could affect the safety case for geological disposal facilities. The project has a website *[Ref 43].* There are four work packages: WP1 Improving the geological safety case knowledge of the behaviour of organic containing long-lived ILW; WP2 Improving the safety case knowledge base of HLW; WP3 Integration, communication and dissemination of experimental and computational output and WP4 Project management. The Project Publishable Summary *[Ref 44]* shows that the "Kick Off" meeting took place in September 2015 and that good progress is being made in the delivery of the work packages. Progress against the project milestones *[Ref 45]* and deliverables *[Ref 46]* shows that all milestones up to December 2016 have been achieved and all the required reports have been delivered.

Modern 2020

The objective of this project is to develop and implement an effective and efficient repository operational monitoring programme for radioactive waste geological disposal facilities. The project has six work packages. WP1 deals with management and administration. WP2 Strategy: addresses the development of detailed methodologies for screening safety cases to identify needs-driven repository monitoring strategies and to develop operational approaches for responding to monitoring information. WP3 Technology: is aimed at carrying out research and development (R&D) to solve outstanding technical issues in repository monitoring, which are related with wireless data transmission technologies, alternative long term power supplies, new sensors, geophysics, reliability and qualification of components. WP4 Demonstration and Practical Implementation: aims to enhance knowledge on the operational implementation and demonstrate the performance of state-of-the-art and innovative techniques by running full-scale and in-situ experiments. WP5 Societal concerns and Stakeholder Involvement: Develop and evaluate ways for integrating public stakeholders concerns and societal expectations into repository monitoring programmes. WP6 Dissemination: addresses the distribution of knowledge gained from the project including the provision of a project website *[Ref 47].*

The Publishable Summary of the project *[Ref 48]* gives a review of progress against the work packages. Progress against project milestones *[Ref 49]* indicates that 17 out of the 18 Milestones up to January 2017 had been achieved.

In addition out of the 9 required deliverables 8 had been submitted *[Ref 50].*

SITEX-II

This project aims at further developing the independent Expertise Function network in the field of deep geological disposal safety *[Ref 51].* The project has six work packages: WP1 covers Programming R&D; WP2 aims at developing a joint review framework; WP3 covers training and tutoring for reviewing the safety case; WP4 deals with interactions with civil society; and WP5 covers management and coordination.

The Publishable Summary *[Ref 52]* shows the progress being made in the early stages of the project, such as the development of a strategic research agenda, consideration of the implications of Joint Programming and the initial steps for developing guidance on reviewing safety cases for a geological disposal facility. Progress against the achievement of the project milestones *[Ref 53]* suggests that all milestones up to the end of November

2016 have been achieved. Of the eight deliverables for the project up to the 1 February 2017, seven have been submitted on time *[Ref 54].*

6.2.3. 5.2.3 Nuclear Expertise and Excellence

The fission programme ensures the availability of required competences through education and training. Though the provision of the Programme's regulation for education and training are rather general and there are no specific objectives in Project's work packages, the programme goals are realized. However, better specification of goals in Euratom Work Programme may facilitate the implementation of education and training in the Euratom Programme. In general it is recognised that about 5% of every project in fission programme should be spent on education and training.

Recommendation 9: For the implementation of future research Programmes the Commission should ensure that there are specific objectives for the delivery of education and training in the Work Programme.

A number of topics concerning education and training actions was launched under WP2014-15.

One of the main goals of the project Advanced Networking for Nuclear Education and Training and Transfer of Expertise (ANNETTE) *[Ref 56]* is developing research and training programmes to maintain nuclear expertise by generating research and training competences. It is dealing with the further implementation, in the nuclear and relevant medical and industrial sectors, of the EU policies stemming from the Bologna and Copenhagen processes. Education organisations participate in collaboration with the industry, research and regulatory organisations. A special effort is devoted to the development of European Masters curricula and summer schools for the continuous professional development of researchers and other private/public actors.

The CORONA II project aims at continuation of the European cooperation and support in the area for preservation and further development of expertise in the nuclear field by improvement of higher education and training through networking between universities, regulatory bodies, industry and any other organisations involved in the application of nuclear science, ionising radiation and nuclear safety *[Ref 57].* A specific objective of the CORONA II project is to proceed with the development of a state-of-the-art regional training centre for VVER competence (called CORONA II Academy), whose pilot implementation through the (2011-2014) CORONA project proved to be a viable solution for supporting transnational mobility and lifelong learning amongst VVER operating countries. The selected form of the CORONA II Academy, together with the online availability of the training opportunities allows trainees from different locations to access the necessary knowledge on demand. The available set of courses covers the whole range of training of VVER specialists from the university until reaching high professional skills and competences in the area.

Further to the projects ANNETTE and CORONA II launched under the topic of nuclear expertise and excellence, the projects CONCERT and MYRTE have important education and training work packages.

In CONCERT (European Joint Programme for the Integration of Radiation Protection Research), a special budget of about €6.5m Euro *[Ref 55]* is allocated to education and training (70% EC and 30% national funding). In the work packages, education and training courses and travel grants are funded. Proposals for open calls have to show how education and training is integrated. Training courses are funded via open calls, in the 2015-2016 call eight courses have been funded, and fourteen in the next call. They are mainly in the range of €20-30k. Training courses developed and training materials are made available openly.

MYRTE has an education and training work package in addition to five technical work packages. The work package on training has three dedicated tasks: (a) Course on accelerators and accelerator-driven systems (ADS systems) and lecture notes; (b) lecture series on thermohydraulics and chemistry; and (c) a workshop at the end of project *[Ref 58].* This includes also education and training of young scientists, master and PhD students in the scientific and technologies challenges related to all work packages of MYRTE. Communication and dissemination of the latest results will be achieved through an international workshop open to the whole scientific community.

Communication with the public and technological awareness are important aspects since civic society's interaction with nuclear developments changes over time, and is locally, nationally and transnationally specific. Project HoNESt (History of Nuclear Energy and Society) *[Ref 59]* involves an interdisciplinary team of 24 high profile research institutions to cover the complexity of political, technological and economic challenges; safety; risk perception and communication, public engagement, media framing, social movements, etc. Research on these interactions has thus far been mostly fragmented. Extensive historical data from different countries are analysed through the lens of an integrated approach, in order to improve our understanding of the mechanisms underlying decision-making and associated citizen engagement with nuclear power.

The concept of fission mobility has been presented in Annex 1 of the Council Regulation *[Ref 1]* of Euratom 2014-2018. One of the activities identified as necessary to achieve the Council objective of *"Supporting the development and sustainability of nuclear expertise and excellence in the Union*" was defined as "*promoting joint training and mobility activities between research centres and industry and between different Member States and Associated States*" *[Ref 1].* The objective is to facilitate the mobility of teachers and students, in particular through support from public-private partnerships. Such mobility is essential for a research community allowing for cross-pollination of ideas between both cultures and disciplines. Mobility is encouraged for scientists through grants and fellowships that help them move between universities and research institutes within and outside the EU.

The 2014-2015 Euratom Work Programme identified in topic NFRP 10 a particular challenge for the nuclear education and training community in relation to cross-border mobility. However, no reference is made to mobility within the 2016-2017 Work Programme.

6.2.4. 5.2.4 Radiation Protection and Medical Applications of Radiation

The FP7/FP7+2 Activity 'Radiation Protection' was aimed at providing a scientific basis for a robust, equitable and socially acceptable system of protection that would not unduly limit the beneficial and widespread uses of radiation in medicine and industry in particular with regards to low dose exposure. The Activity was divided into four areas: 'Quantification of risks for low and protracted exposures', 'Medical uses of radiation', 'Emergency management and rehabilitation' and 'Other topics: national research activities in other areas'. The expected impact was to understand the medical mechanisms linked with radiation and to establish a clear link between exposure level and radiation effects. The objectives and strategies of the projects in this Activity were further informed by the 2009 report published by the High Level Expert Group on European Low Dose Risk Research.

In the area of risk quantification for low and protracted exposures, a total of €86.7m was provided to support 12 projects over the period 2007 to 2013. A number of projects were focused on the integration and coordination of radioprotection research in Europe including the DoReMi project which supported the development of the Multidisciplinary European Low Dose Risk Re-search Initiative - MELODI. The on-going OPERRA project established a mechanism for joint programming and implementation of radiation protection research, organising two rounds of competitive calls to date, and began preparation of an education and training strategy.

In the area of medical uses of radiation, six projects were funded over the period 2007 to 2010 for a total cost of €23.1m.

For both of these areas (risk quantification and medical uses), the EY review *[Ref 16]* concluded that the projects funded under FP7 were implemented in line with the objectives set out in the work programmes and produced expected outputs with few deviations.

Output from previously funded programmes suggests that the Euratom programme is delivering results. For example in DoReMi, most of the funding was for integration, only a small amount for research and studies and yet more than 100 publications have been produced; much of this research was done by labs alone, but the programme brought them together. OPERRA had more funds for direct support of research, but results are still awaited. The lesson from DoReMi is that forcing collective work on consortia is productive *[Ref 60]* and results in higher output.

MELODI showed that epidemiological research alone cannot resolve the questions of low dose research; only multidisciplinary R&D can do that *[Ref 60].*

The views expressed above are corroborated by the EY review *[Ref 16].* EY conducted 47 case studies of FP7 fission projects with 10 of these funded under the Activity radiation protection. The report considers the projects under the headings Effectiveness, Coherence and Complementarity, Impact and EU Added Value of the Euratom programme. In terms of effectiveness, they concluded that all of the projects reviewed produced the expected outputs and results with no issues identified that would impact on effectiveness. The reviewers highlighted two of the projects (DoReMi & OPERRA) as playing an important role in supporting the coordination of radiation protection research in Europe. DoReMi (funding in excess of €20m) supported the structuring and management of a network of excellence involving a large number of labs (36 labs) to support European and international research on low dose effects of ionizing radiation. OPERRA contributed to structuring the national and European research and training programmes in radiation protection, including the medical use of radiation, low dose effects, radioecology and nuclear emergency management. Of note, EY observed that OPERRA also laid the ground work for an integrated platform for managing competitive calls with a significant involvement of stakeholders to define research priorities in radiation protection. The reviewers also commented that the DoReMi and OPERRA projects both contributed to better structuring and coordinating radiation protection research in Europe.

The EY survey to assess satisfaction and opinion for all FP7 and H2020 projects generally found satisfaction among respondents with the Euratom programme. Of note in relation to the effectiveness of the programme however, were indications that delays were sometimes encountered mainly because of the nature and unpredictability of scientific research, but also because of administrative delays. The CONCERT project was cited as an example where such delays were encountered.

The scope of the Activity within NFRP7-2015 was such that it was intended to build on the work of previous research platforms such as MELODI, NERIS, ALLIANCE and EURADOS. More recently, a new platform EURAMED has been established. CONCERT is committed to the vision of a strong science based roadmap in radiation protection research, tailored to the protection needs of society, stakeholders and authorities, that will serve the radiation protection community beyond the actual project. A first joint roadmap draft of all platforms is foreseen and work is in progress (CONCERT deliverable D3.4 mid 2017). The long-term research roadmap that will be jointly produced, could build the basis for future research Programmes in Europe.

The 2014-2015 Work Programme's topic NFRP7-2015 identified the need for a reinforced multidisciplinary approach to research and innovation and considers it to be essential to further develop the knowledge base in this field. CONCERT considers that integration of a) research activities in the field of medical applications of ionising radiation and b) of research in social sciences and humanities (SSH) related to radiation protection should be taken into account in future open calls. Part of the scope of Activity envisaged under NFRP7-2015 was to address the challenge of communicating results in radiation protection to non-specialist audiences such as policy decision makers and the public at large.

To reach its goals CONCERT has seven work packages within which these high level objectives are to be explored and developed:

- WP 1 deals with the management of CONCERT
- WP 2 on integration in radiation protection research
- WP 3 on joint research programming,
- WP 4 on administration of the CONCERT open research calls,
- WP 5 on stakeholder involvement,
- WP 6 on access to infrastructures, and
- WP 7 for education and training.

In terms of progress to date on the deliverables identified in the CONCERT proposal, 28 deliverables were scheduled across the seven different Work Packages from the beginning of CONCERT until the end of 2016. Nearly all have been completed. Three deliverables had to be postponed to the end of May 2017; however, the consortium believe that this will have no major impact on the progress of other deliverables. In addition, they believe that this delay will not jeopardise the overall planning of CONCERT.

In addition, call priorities have been established taking into account input from National programme owners participating in CONCERT and from stakeholders, through open web and workshop consultations. Call priorities were identified to address radiation protection challenges in Europe and Member States with targeted radiation protection research.

The total budget for the first call issued by CONCERT was €10.5m. This budget allowed the funding of the first three projects from the ranking list (see *Table 16)*. This ranking list was established by an independent peer review panel. Three projects were selected, one from Topic 1 and two from Topic 2.

Table 16

Projects funded in the first call issued by CONCERT ('Budget' gives total funding of projects; the contribution from CONCERT for the first call was €10.5m)

Topic	Project Name	Project Description	Budget (€)
1. Improvement of health risk assessment associated with low dose/dose rate radiation.			
	LDLensRad	Towards a full mechanistic understanding of low dose radiation induced cataracts	2.5m
2. Reducing uncertainties in human and ecosystem radiological risk assessment and management in nuclear emergencies and existing exposure situations, including NORM.			
	CONFIDENCE	COping with uNcertainties For Improved modelling and DEcision making in Nuclear emergenCiEs	6.2m
	TERRITORIES	To Enhance unceRtainties Reduction and stakeholders Involvement TOwards integrated and graded Risk management of humans and wildlife In long-lasting radiological Exposure Situations	4.2m

CONCERT actively supported the establishment of a new Research Platform in the field of Radiation Protection in Medicine – EURAMED (European Alliance for Medical Radiation Protection Research). As the most recently established platform (launched in September 2016), EURAMED will lead European research activities in medical radiation protection and harmonise clinical practice to advance European radiation safety culture in medicine.

EURAMED aims to initiate and facilitate research on medical radiation protection issues in Europe, to bring together researchers in the field, cooperate with stakeholders, facilitate training of researchers, integrate into radiation protection communities in Europe, work on communication issues and regularly update the newly developed EURAMED Strategic Research Agenda (SRA). While CONCERT does not directly address the therapeutic use of radiation, it recognises that there is learning from medically exposed cohorts.

Radiation Protection is very much about risk communication and societal issues. CONCERT supported the development of a strategic research agenda in social sciences and humanities in relation to radiation protection by initiating workshops and meetings of scientists and stakeholders in these fields together with scientists and stakeholders in the wider field of radiation protection.

Consideration has been given to the establishment of a platform to address these issues or alternately ensuring that they are adequately integrated into other activities; however, caution must be exercised to avoid creating new silos.

Closer co-operation of these social science activities with those going on in other nuclear areas, e.g. reactor safety, is difficult and could potentially endanger the perception of RP research being independent. For the same reason CONCERT platforms are cautious to have industrial partners in their membership.

EURAMED and social sciences and humanities related research topics will be included as an integral part in the second open CONCERT call in early 2017 and should be included in future research projects funded by Euratom. As this was very much part of the scope of the Activity envisaged under NFRP7-2015, notwithstanding the inherent challenges, it would be important that appropriate emphasis be given to this area.

The ex-post evaluation of the FP7 and FP7+2 programme concluded that “whilst the Euratom programmes relating to radiation protection in the medical exposure area have been successful and have contributed to increased knowledge, it is recognised that further benefit would be gained by establishing better links between programmes funded by Euratom and other EU health-related programmes”. The Panel believes that this conclusion remains relevant and hence repeats recommendation 27 of the FP7/7+2 ex-post evaluation.

Recommendation 10: The Commission and the Member States should make continued efforts to link future Euratom research programmes in radiation protection associated with medical exposure with other EU medical research programmes.

There have been initial “teething” difficulties in the operation of CONCERT but it is too early to judge whether these are of concern. Given that it is the first time the EJP instrument has been applied in the Euratom Programme outside of fusion, the Panel believes that there would be benefit of a review of the working of CONCERT in advance of the development of future Euratom programmes. This review would allow the Commission to be satisfied that its aims and objectives, and the benefits of using the EJP approach in the field of radiation protection, have been delivered.

Recommendation 11: The Commission should carry out a review of how CONCERT is working, to satisfy itself that the aims of the European Joint Programme (programme co-fund action) in relation to the effective and efficient management of research in the field of radiation protection are being delivered.

6.2.5. 5.2.5 Innovation and Industrial Competitiveness

ESSANUF

The Panel heard evidence that the project is underway and that there is a reasonable level of Member States participation. Information made available to the Panel *[Ref 61]* shows that five reports in WP1, seven reports in WP2, one report in WP3, three reports in WP4, two reports in WP5, two reports in WP6, three reports in WP7, two reports in WP8, one report in WP 9 and one report in WP10 have been submitted. The detailed adequacy and value of the reports submitted to date need detailed evaluation in relation to the project and programme objectives but the scope of the work covered looks comprehensive *[Ref 62].* Progress to date suggests that the project is on track to deliver its objectives *[Ref 63].* The project has a website that provides further information *[Ref 64].*

The project, when completed, will clearly contribute to the wider EU strategic objectives in this area.

The 2016-17 Work Programme has two projects in this area, TRANSAT and M4F. These have only recently been launched and it is too early to comment on progress.

6.2.6. 5.2.6 Pan-European Research Infrastructures

HERACLES-CP

This project's main objective is "the provision of the technical and scientific foundations for the successful qualification of UMo fuel" *[Ref 65].* The project has six work packages. WP1 focuses on management. WP2 (Dispersed fuel comprehension) looks at improved understanding of swelling behaviour in fuels. WP3 (Production Technology) is aimed at improved understanding of production technologies for dispersed and monolithic fuels. WP4 (Powder and Plate Manufacturing) aims to establish new knowledge for high density UMo fuel plate manufacturing. WP5 (Heavy Ion Irradiations) aims to carry out several irradiations to plug the current gaps in knowledge. WP6's (SEMPER FIDELIS in-pile irradiation) objective is to test by irradiation in a test reactor the advanced fuel produced according to the design proposed in WP2 with the advanced manufacturing technology defined in WP3, and implemented in the plates produced in WP4. WP7 (PERSEUS device) focuses on the examination of fuel.

Progress has been made in a number of areas, including management arrangements, irradiation experiments, manufacturing and measurement technology *[Ref 66].* Of the 9 milestones due to be achieved by the end of December 2016 only 6 had been achieved *[Ref 67].* A report on deliverables *[Ref 68]* shows that out of the 22 identified deliverables 4 had not been delivered on time.

MYRTE

MYRTE is a project to demonstrate the feasibility of transmutation of high-level waste on an industrial scale, through the development of the MYRRHA (Multi-Purpose Hybrid Research Reactor for High-Tech Applications) research facility *[Ref 69].* The Project has 7 work packages: WP1 Project management; WP2 Accelerator R&D for ADS/MYRRHA; WP3 Thermal Hydraulics; WP4 Chemistry of volatile radionuclides; WP5 Experiments in support of the MYRRHA design evolution; WP6 Actinide fuel; and WP7 Dissemination and communication. The MYRTE publishable summary *[Ref 70]* shows that this is a complex project but one that is in line with the long-term energy needs of Europe. *[Ref 71]* shows that most of the project milestones to date have been achieved. Of the 11 project deliverables planned to be delivered by November 2016, 10 have been delivered *[Ref 72].*

There are no results available to judge the progress of the project in the 2016-17 Work Programme, FOREvER.

6.2.7. 5.2.7 Social Aspects and Networking

HoNEST

The main objective of this project is to provide a practically useful analytical framework that allows for the identification of key factors influencing the interaction of nuclear technology with civil society *[Ref 73].* The project has six work packages: WP1 Management and coordination; WP2 History of the civilian production and use of nuclear energy in Europe, 1945-2013; WP3 Translating, linking and bridging, Phase 1 (History) and Phase 2 (Social Sciences); WP4 Understanding perceptions and mechanisms for social engagement; WP5 Backcasting ideal futures; and WP6 Dissemination and engagement.

In the 12 months since the start of the project the consortium has produced over one thousand pages of academic research on the interactions of nuclear power with civil society across most of Europe and beyond *[Ref 74].* Of the 10 planned milestones only 5 have been achieved and of the 27 deliverables 23 were delivered *[Ref 75].*

NUCL-EU 2020

The objective of this project is to enhance the competence of National Contact Points (NCPs), raise the level of know-how of the Euratom network in particular helping less experienced NCPs rapidly acquire the experiences accumulated in other countries and to consolidate the network of Euratom NCPs *[Ref 76].* The project has four work packages: WP1 Management; WP2 Capacity building for NCPs; WP3 Dialogue with energy participants; and WP4 Communication and dissemination.

There is not much information on progress with the delivery of the objectives or work package milestones or deliverables, but the first NCP Assessment Report *[Ref 77]* in WP 2 suggests that the project is up and running and progress is being made.

SPRINT

This project has four objectives: (1) Ensure an inclusive and efficient process for producing strategic roadmaps; (2) Improve the ‘value proposal’ of SNETP for the fission R&D community in Europe; (3) Confirm SNETP as a key player within the international energy technology landscape; and (4) Enhance the visibility and dialogue of SNETP towards a wider audience. The project has six work packages: WP1 Strategic Roadmapping; WP2 Enhancing SNETP’s added value for the community; WP3 Interaction with SNETP’s technology environment; WP4 Communicating SNETP; WP5 Event Management; and WP6 Consortium Management.

The Periodic Technical Report (Part B) *[Ref 78]* gives a report on progress. Analysis shows that the aims of the project are being delivered but some of the planned milestones and deliverables have been delayed.

6.3. 5.3 Effectiveness - Summary

The Panel was asked five questions in relation to evaluating the effectiveness of the Euratom Programme, namely: “What is the progress made towards the objectives of the Euratom Programme?”; “What are the factors driving or hindering progress and how they are linked (or not) to the Euratom Programme?”; “How effective are new measures (European Joint Programmes, prizes) introduced by the Euratom Programme?”; “What are the main long-term impacts of the previous Euratom Framework Programme?”; and “How is the Euratom research programme contributing to the EU strategic objectives and policies?”.

The Panel believes that the above evaluation shows that in general good progress is being made in both the fusions and fission parts of the Euratom Programme. However, there are some areas where improvements can be made in future programmes. An instrument of the European Joint Programme (programme co-fund action) is proving to be effective in the fusion area but more work is required to assess its effectiveness in the radiation protection area (CONCERT) and in the field of radioactive waste management (JOPRAD). It is still too early to say what the long-term impact of the previous programmes will be. However, both the EY report *[Ref 16]* and the FP7/FP7+2 *[Ref 12]* ex-post evaluation conclude that in general the research has contributed to the EU’s strategic objectives and policies. The Panel finds that both the fusion and fission Euratom research actions are in the main contributing to the wider EU strategic objectives and policies.

7. 6. EVALUATION OF THE EFFICIENCY OF THE EURATOM PROGRAMME

This chapter provides an evaluation of the efficiency of the Euratom Programme and addresses the extent to which the inputs provided to Euratom Programme are reasonable (i.e. cost-effective) in light of the outcomes that have been generated or are likely to be generated. The chapter also addresses the scope for further simplification.

7.1. 6.1 Nuclear Fusion

A comprehensive assessment of the management and governance of EUROfusion has been carried out by EY *[Ref 79]* and provided as input to the Panel. The Panel has further discussed some of the conclusions of the report with the fusion stakeholders.

Fusion research underwent a major reorganization in passing from FP7/FP7+2 to Euratom 2014-2018 in order to change from a broad programmatic approach to a project-oriented approach. This change was made in a very short time and the transition is still ongoing. Specifically, EUROfusion needs to further strengthen the project management structure (with the Programme Manger fully in charge of the implementation strategy) and to put in place specific provisions to deal with conflict of interest. The lack of a design authority for DEMO is an issue to be tackled urgently.

The level of industrial involvement in fusion research has increased. In order to make best use of the competences gained by industry with the ITER construction, it is necessary to maintain an approach to DEMO that will involve industry in the DEMO EDA at the earliest possible time.

The Enabling Research programme, modelled along the experience of the ERC projects, appears to be successful in fostering innovation and promoting excellence. However the selection process should not impact too heavily on STAC, to preserve its role in monitoring the implementation of the Roadmap.

7.1.1. 6.1.1 Governance

The bodies that play a role in the EUROfusion governance are the General Assembly (GA), Scientific and Technical Advisory Committee (STAC) and the Programme Manager (PM) / Project management Unit (PMU).

The General Assembly is the ultimate decision-making body responsible for defining and reviewing the overarching strategy and the annual work plan. It is composed of one representative for each Consortium member.

STAC advises the General Assembly on strategic and implementation issues related to the Consortium work programme, and its coherence with respect to the Roadmap. STAC members are selected *ad personam*.

The Programme Manager is responsible to the General Assembly for the overall top-level planning, coordination and implementation of the programme, including the allocation of tasks to the various beneficiaries.

The change from a broad programmatic approach to a project-oriented approach requires a substantial change in the role of the Consortium members. As the members have signed up to the implementation of the Roadmap, the Consortium governance should ensure that the common goal takes the precedence over the scientific strategy/interest of individual members. This requires a clear distinction of responsibility between the General Assembly and the Programme Manager with the latter having the full leadership of the implementation strategy.

Although the multiple roles of the Consortium members (supervisory, executive and operator) makes the risk of conflict of interest possible, the Panel considers that the EUROfusion structure is capable of dealing successfully with this risk provided that the

Programme Manager has the ownership of implementation and his responsibility for the implementation strategy is fully preserved and exercised.

A possible way of minimising the risk of conflict of interest could be to avoid the presence in the supervisory committees of those responsible for the implementation of the programme (no Project Leaders in the GA or STAC, no Task Leader in the Project Board of the same project).

Recommendation 12: EUROfusion should put in place explicit provisions to manage conflicts of interest.

In view of the STAC role, the management of conflict of interest is a delicate matter. As the fusion community is a limited-size, strongly interacting community, removal of all formal conflicts of interest can also lead to removal of competence. The approach adopted by STAC is one of transparency and peer example, and an atmosphere where prejudice and bias is noticed and remarked upon, and thereby largely eliminated. The Panel supports this approach.

7.1.2. 6.1.2 Project Management

Fusion is changing from a broad programmatic research activity to a project-oriented activity structured to achieve results on the programmatic priorities defined in the Roadmap. The largest part of the EUROfusion budget is therefore committed for work carried out either in task forces (for the exploitation of JET and the MSTs under a campaign-oriented approach) or projects.

The transition is still on-going and to be successful needs the active role of the Programme Manager in matching the programmatic priorities of the Roadmap and the scientific interest of the consortium members. The experience of EFDA shows that this approach can be successful especially with small and medium size Research Units that generally performed well already in the first call for participation in the EUROfusion projects.

The Project Leader is assisted by a Project Board (with a representative of each of the members participating in the project) that deals with the practical issues of the implementation. The scope, resources, organization, planning, work breakdown structure, risks and risk mitigation actions are described in a single document for each project, the Project Management Plan (PMP) prepared by the Project Leader.

There are a few issues that have been identified in the EY report *[Ref. 79]:*

- The need to internalize the project management process in all the projects.
- There remains a "culture of inclusiveness" that leads several EUROfusion members to spread their participation in EUROfusion activities over several projects, so increasing fragmentation and decreasing efficiency;
- The tendency of the beneficiaries to shift the scope of tasks to follow their scientific interest rather than the project needs - this can end in a problem of conflict of interest if it occurs at Project Board level.
- The project management approach in EUROfusion, whilst appropriate, needs to improve, especially in relation to the role of the Programme Manager. The Programme Manager needs to exercise close oversight of the process. The Project Leader should have adequate delegations to take decisions without any interference of policy considerations by the beneficiaries. In general, projects can work well if the number of participants is limited and the participation of each member achieves a critical mass. Representatives in the Project Boards should not be primarily concerned with protecting the interests (and resources) of their institutions but rather with steering the project in an objective way based on purely technical criteria.

The Panel believes that measures like having the PL/TFL reporting to the Programme Manager and having the Project Boards assisting the PLs in the execution of the project rather than in the definition of the scope, will help in strengthening project management.

> **Recommendation 13: EUROfusion should continue to strengthen its project management arrangements and ensure that the Programme Manager is responsible for the implementation strategy.**

The EY report has also pointed out the lack of a design authority for DEMO. To address this issue EUROfusion proposes (a) strengthening the project management and technical capabilities of the PMU and (b) reinforcing the budgetary and technical authority of the PMU. These actions would be gradually implemented over the next Euratom Programme, aiming towards a strong central coordination of the DEMO Engineering Design Activity.

> **Recommendation 14: EUROfusion should as a matter of urgency set up the design authority for DEMO.**

7.1.3. 6.1.3 Programming and Planning

One of the main advantages made with the formulation of the Roadmap and the award of the EUROfusion grant has been the possibility of having a multi-annual programme. The detailed technical deliverables are included in the Project Management Plans (PMP) and updated there on a regular basis.

However, the annual life-cycle of the Commission budget requires the preparation of an Annual Monitoring Report (AMR) and of an Annual Work Plan (AWP). The preparation of Annual Reports has been described by many stakeholders as "unduly long and tedious". The Panel believes that it is important to strike a reasonable compromise between the level of detail needed for the AMR/AWP approval by the Commission and the need to avoid unnecessary paperwork. The AMR/AWP should be light documents that should be based on the updated PMPs and should not need an extensive mobilization of human resources.

7.1.4. 6.1.4 Industrial Involvement

The involvement of industry in fusion research has a long history and specific measures for the high-level industrial involvement were taken at the time of the Engineering Design Activity for ITER. However, it is with the Roadmap and the EUROfusion grant that the industrial involvement has been put as one of the central elements to be actively pursued in the strategy to DEMO. In line with that, EUROfusion has set up a few provisions to facilitate the involvement of industry in the programme such as secondment of industry personnel (one of the Project Leaders comes from industry), the formation of a Stakeholder Group to define the high-level DEMO requirements, and the supply of contracts for design and hardware. At the moment, the level of industrial personnel involvement is about 10% of the total.

The EY report points out that the need for a transition from science-driven and laboratory-based research to an industry and technology driven activity, advocated by the Roadmap, is shared by the EUROfusion members but there is currently no consensus on when this should take place. The Panel believes that following the approach outlined in the original Roadmap for the DEMO strategy will facilitate the industrial involvement. In particular, a critical issue for industrial participation is the need to maintain the competences that have been generated through the ITER construction by having a reasonable continuity between the end of the ITER construction and the start of the DEMO EDA (see Recommendation 14).

7.1.5. 6.1.5 Enabling Research

To foster innovation and promote excellence there are yearly calls for proposals evaluated in way similar to the ERC projects. About 100 proposals have been selected with a rejection rate around about 66%. A number of successful projects have been launched in this way in the areas of core and edge turbulence modelling, fast-particle collective effects, modelling of disruptions and runaway behaviour, material science and high temperature superconductors.

The selection of fusion research projects is entirely a STAC responsibility. Specific provisions to deal with conflicts of interest are in place.

The selection procedure ensures the goal of promoting excellence and innovation. However, this procedure places a significant burden on the STAC and this limits its ability to focus on its core function. The Panel believes that STAC must retain its focus on its core function and hence EUROfusion should find an approach (e.g. by involving external reviewers) that will allow STAC to concentrate on monitoring the implementation of the Roadmap and providing advice to the General Assembly.

Recommendation 15: EUROfusion should look at ways of reducing the burden on STAC from its role in the project selection process for Enabling Research.

7.1.6. 6.1.6 Administrative Costs

The amount of resources devoted to administrative functions include those of the PMU, the support provided by the coordinator (IPP) and those of the EUROfusion members for administrative managing the various tasks.

The figures provided by EUROfusion show a level of administrative expenses in the range 6-7% *[Ref 80].* The Panel considers this to be a reasonable level for administrative costs**.** However, Consortium Members have expressed a number of concerns about the administrative burden. While this is understandable as the CoA system gave a large freedom to the Head of Laboratories with a minimal administrative burden, a project-oriented approach necessarily requires a more complex system. The Panel believes that by keeping the number of laboratories in a project to a manageable level the administrative burden could be minimized and work fragmentation avoided.

7.2. 6.2 Nuclear Fission

7.2.1. 6.2.1 Safety of Nuclear Systems

The projects selected following the 2014-15 call for proposals are all in line with the Euratom Work Programme *[Ref 3]* and therefore have been judged to be suitable. However, it is difficult at this stage to comment upon the extent to which the outcomes that are claimed will be generated and will deliver the project aims in a cost effective way. Progress, as discussed in chapter 5 of this report, suggests that most projects are on target to deliver their objectives.

In relation to research into molten salt fast reactor it is difficult to see how cost effectiveness can be evaluated at this stage given the novelty of the project and the likely use of this technology for commercial electricity generation.

The projects selected following the 2016-17 call for proposals again are all relevant to the Euratom Work Programme *[Ref 4].*

Evaluating cost effectiveness in relation to specific projects aimed at improving nuclear safety will be difficult. This is because nuclear safety is delivered through a combination of high quality engineering; defence in depth against internal plant malfunctions (faults), external hazards and human error; the use of suitably qualified and experienced people and a strong nuclear safety culture. This combination ensures that faults that can result in the uncontrolled release of radioactivity have a very low frequency of occurrence, typically 10^{-7} per year. Hence, to demonstrate cost effectiveness of research activities it would be necessary to show how the research contributed directly to the factors that influence the safety case and then evaluate the value of any improvement gained against the cost of the research.

7.2.2. 6.2.2 *Management of Ultimate Radioactive Waste*

The projects chosen in both the 2014-15 and 2016-17 calls are consistent with Council objective (b) i.e. "Contributing to the development of safe, longer term solutions for the management of ultimate nuclear waste, including final geological disposal as well as partitioning and transmutation". Progress on the projects in launched in 2015 reported above suggests that the aims are on track to be delivered and if this proves to be the case the Euratom investment in these research projects should make a substantial contribution to the delivery of safe and secure disposal of Europe's radioactive waste.

The funding of these projects should be reviewed because as it is the producer of the waste that should pay for its disposal it is hard to see why Euratom should fund 73% of the cost for 2014-15 projects and 95% of the cost in the 2016-17 projects.

7.2.3. 6.2.3. *Nuclear Expertise and Excellence*

In the fission area there is a need to improve the approach to early stage training (PhD, post-doc). The Panel believes that opening up the Euratom fellowships to early stage researchers, incorporating a scheme similar to the Marie Skłodowska-Curie Early Stage Research Training, and the Marie Skłodowska-Curie Conferences and Training Courses, should ensure high quality training at the post doc stage. Moreover, industrial doctorates, combining academic research with work in companies, and other innovative training that enhances employability is very important for the Euratom programme.

Legal interpretation has so far prevented Marie Skłodowska-Curie (MSC) grants implementation in the nuclear research. The Panel believes that Council should consider the extension of MSC to Euratom research programmes and, if this is not possible, consideration should be given to the creation of a 'Pierre Curie' Euratom fellowship and training scheme to support researchers at all stages of their careers. Thus this initiative should be considered in a preparation for future Euratom programmes.

Recommendation 16: The Council should consider extending the Marie Skłodowska-Curie scheme to Euratom's Fission Research Programmes.

7.2.4. 6.2.4 *Radiation Protection and Medical Applications of Radiation*

NFRP7-2015 envisaged that proposals under this Activity would aim at accelerating and improving the development of competences in radiation protection with a special focus on radiation protection culture. The CONCERT proposal recognises the decline in Radiation Protection competences / expertise / activity across Europe and identifies this as an area that should be addressed. CONCERT dedicates a whole work package (WP) to education and training (E&T) for the development and maintenance of the expertise and competence of the community of research scientists working in the area of radiation protection research. The specific activities organised by the work package, and funded as integration activities, included: (1) Setting up a programme of student travel grants to allow students to attend relevant training courses at other institutions, or attend conferences to present their work; (2) Launching calls for short courses in topics important for radiation protection research, aimed particularly at students entering the field or young researchers and (3) Encouraging the career development of new scientists entering the field through interaction with the European Radiation Research Association for Young Scientists (EURAYS).

The use of EJP in the area of radiation protection presents a particular challenge as low dose research is mostly done in universities that are third parties for CONCERT (CONCERT has Beneficiaries and Linked Third Parties). Beneficiaries have ways to access complementary national funding and third parties have contractual links with beneficiaries and can contribute in-kind, but national co-funding is more difficult to obtain for universities. This can make the use of this type of instrument more challenging. Raising the cap for third party funding took some time to negotiate and delayed the first open call.

The medical area was not included in the first CONCERT call because at that time, the SRA had just been set up; it will be a priority in the second call.

Early experience suggests that administrative costs will be below 10%.

For maximum efficiency and effectiveness there needs to be a strong link between knowledge generation and RP governance. However, there is still a gap (and not only in radiation protection) in relation to a review mechanism evaluating what should be done with the knowledge created through the research projects. Progress in the application of results is slow and the time from research results to application is too long. Integration needs to encompass the general issue of consolidation of scientific results into (governance) application *[Ref 60].*

The EY survey *[Ref 16]* to assess satisfaction and opinion for all FP7 and Euratom 2014-18 projects looked at efficiency in terms of the relationship between the financial and administrative resources used to implement the projects and the achievements of the project (outputs and results). While the responses were mainly positive in relation to efficiency, a small number of projects drew negative comments on this aspect of their management and one of these was CONCERT. The EY report cautions that the large number of participants in some of the projects, including CONCERT, might contribute to this negative perception.

7.2.5. 6.2.5 Innovation and Industrial Competitiveness

In the 2014-15 Work Programme the ESSANUF project, whilst consistent with the intent of Council objective (g), Promoting innovation and industry competitiveness - "*Implementing or supporting knowledge management and technology transfer from the research co-funded by the Euratom Programme to industry exploiting all innovative aspects of the research,"* is an unusual research project and relates to the needs of security of supply. The inputs are well defined and the outputs that are being generated are relevant to the key safety and licensing issues.

In the 2016-17 Work Programme the TRANSAT project is no doubt of interest but it is not novel. It will provide some useful information but the 80% of the Euratom funding needs justification. The M4F project is 60% funded Euratom and whilst this is reasonable given the crosscutting nature of the work, it is too early to comment on its cost effectiveness.

7.2.6. 6.2.6 Pan-European Research Infrastructures

In the 2014-15 Programme the two projects MYRTE and HERACLES-CP are consistent with the Council objective (h)-Ensuring availability and use of research infrastructures of pan-European relevance.

The MYRTE project on partitioning and transmutation is a long-term challenge. Success will depend upon the industrialization of the process and in the long-term this should be funded by the nuclear industry. The potential benefits of the successful industrialization of transmutation to the long-term management of radioactive waste are such that the level of funding by Euratom of 75% is appropriate.

The HERACLES-CP project on the conversion of research reactor fuel and targets from HEU to LEU is clearly important to ensure the continued supply of technetium isotopes (Tc99) for medical purposes. The reduction of HEU fuel is also important to deliver the EU non-proliferation goals. However, it could be argued that that this is a commercial / industrial issue and that funding should come from the nuclear or medical industries.

The FOREvER project in the 2016-17 Work Programme is again consistent with Council objective (h), but given its purpose in relation to the supply of fuel for research reactors, the 95% EU funding for the project needs justification.

7.2.7. 6.2.7 Social Aspects and Networking

It is recognised that enhancing the public's understanding of nuclear technologies is important and appropriate to be covered in the Euratom research programme. However, in view of the high level (€3m) funding for the HoNEST project it is important that the expected outcomes are delivered. The other two projects have relatively modest funding. In relation to the NUCL-EU 2020 it is important that the goals relating to the improvements in the effectiveness of the NCPs are realised.

7.3. 6.3 Efficiency - Summary

The Panel was asked to answer two questions on the efficiency of the Euratom Research Programme, namely: "To what extent are the inputs provided to Euratom Programme reasonable (i.e. cost-effective) in light of the outcomes that have been generated or are likely to be generated?' and "Is there scope for further simplification?".

In the fusion part of the Euratom Programme the Panel believes that EUROfusion has improved the cost effectiveness of the programme. However, the preparation of the annual reports has been described by many stakeholders as "unduly long and tedious". The Panel believes that it is important to strike a reasonable compromise between the level of detail needed for the AMR/AWP approval by the Commission and the need to avoid unnecessary paperwork. Further simplifications can result from ensuring that the number of laboratories in a project is kept to a manageable level and work fragmentation is avoided. The Panel makes a number of recommendations to improve efficiency in relation to potential conflicts of interest, strengthening project management, reducing the burden on the STAC and considering the extension of the Marie Skłodowska-Curie programme to Euratom.

In the fission area, the cost effectiveness of the research is not always easy to evaluate. The Euratom funding levels of some of the research projects is high and needs justification. This suggests that the cost effectiveness is debatable in some cases.

8. 7. Evaluation of the Internal Coherency of the Euratom Programme

This chapter addresses internal coherency of the Euratom Programme and the extent to which the Euratom Programme, as part of Horizon 2020, can be considered a coherent programme of nuclear research in the context of support for research and innovation in general in Europe, with EU policies in general, and with the EU's international obligations.

8.1. 7.1 Nuclear Fusion

Fusion research is pursued by different players: F4E for the ITER construction and the Broader Approach (now under DG Energy of the European Commission), EUROfusion for the fusion part of the Euratom Programme, with JET operation managed through the JET Operation Contract between Euratom and UKAEA.

In principle the Euratom Programme is internally coherent as the missions of the various organizations do not overlap and all the Roadmap scope is covered. A co-operation between F4E and EUROfusion exists in some areas (especially within the Broader Approach activities and possibly in the TBM programme), however, the strategic coordination of the Programme is left entirely to the European Commission now requiring the close interaction between two different Directorates-General (DG). Under these conditions coordination between the top-level management of F4E and EUROfusion must be ensured.

> **Recommendation 17: To improve the coherence of the research needs of the Roadmap the coordination between the top level management of F4E and EUROfusion should be strengthened.**

This is particularly important should a Roadmap revision be necessary at some stage. As the Roadmap is a European Union vision and not only a EUROfusion Consortium document, the formal procedure for the approval of Roadmap revisions should be clarified in advance and should involve a body like the former Consultative Committee for Fusion (CCE-FU), a body in which strategic issues related to fusion were discussed at Member State level with EFDA and F4E leadership present as standing experts, as it has been for the endorsement of the original Roadmap.

The Panel understands that, while periodic reviews of the Roadmap are part of the project management process, a Roadmap revision should be undertaken only when there are fundamental technical or budgetary reasons that make the implementation no longer possible.

> **Recommendation 18: The Commission should introduce a formal Fusion Roadmap revision procedure to ensure that any revision to the original Fusion Roadmap is owned by all relevant stakeholders.**

Within the Euratom Programme activities, the separation between JET operation and JET scientific exploitation may require at some point a revision. The close link between the operational and scientific aspects of a fusion device makes such a separation artificial - fusion experiments are not facilities in the same way as neutron or synchrotron radiation sources. This may require a suitable solution for a future JET Operation Contract.

8.2. 7.2 Nuclear Fission

8.2.1. 7.2.1 Safety of Nuclear Systems

The overall aims and intentions of the Euratom Programme in this area represent a coherent approach to the research and innovation that is needed to support nuclear safety within the EU. However, there is a range of topics that are covered in the 2014-15 Programme. Given this range of topics it is difficult to see how this part of the research programme could be considered to be coherent except at the highest level.

The 2014-15 Work Programme in general is aligned to and consistent with the overall goals of the EU's nuclear safety policies. It is difficult to relate the research projects in this area with the EU's international obligations. It is clear that Member States have an obligation to maintain a structure to ensure the safe and secure use of nuclear energy and the research activities in this area should, if successful, provide information that will be useful to support these obligations.

The projects in the 2016-17 Work Programme present a more coherent approach to the delivery of the overall EU nuclear safety goals.

8.2.2. 7.2.2 *Management of Ultimate Radioactive Waste*

The research projects in both the 2014-15 and the 2015-16 Work Programme represent a coherent approach. The projects all address topics that are relevant to the delivery of safe and secure geological disposal of radioactive waste.

8.2.3. 7.2.3 *Nuclear Expertise and Excellence*

As well as the projects having their main objectives focused on education and training, the CONCERT project also provides a coherent approach to nuclear expertise and training. CONCERT intends to hold an annual Forum in association with the MELODI Workshop, to strengthen the integration of education and training institutions within radiation protection, and to promote the integration of education and training into research projects funding under the CONCERT calls.

8.2.4. 7.2.4 *Radiation Protection and Medical Applications of Radiation*

NFRP7-2015 envisaged that successful proposals would address the need for research and innovation required to support the successful transposition and implementation of the revised European Basic Safety Standards (BSS). While CONCERT plans to start vocational training for Experts foreseen in the new Euratom BSS, this has not yet started. Given that the transposition date is February 2018, it might have been expected that this would have started by now.

In the EY case study of FP7 fission projects *[Ref 16]*, the reviewers noted that the platforms for programming the research in radiation protection (e.g. MELODI, NERIS) are relatively recent and therefore the research is more fragmented. Thus the coherence between projects (in particular in radiobiology) does not always appear very clearly. But they noted, this should rapidly change in the coming years.

There is a need to allow for stability of the current approach before any further changes are made. The continued support of platforms as a way to integrate the European research community is an appropriate use of European research funds.

The current system is open to new members and platforms bring in new people who have not been involved in Euratom before. For example DoReMi expanded from 12 to 24 members now; OPERRA from 14 to 49 members with the majority of them not having been involved in Euratom research programmes before. Platforms also bring in different disciplines and encourage participation from outside Euratom which is very often of high quality *[Ref 60].* Thus the RP platforms and CONCERT as umbrella project are coherent with the overarching goal of promoting the concept of European Research Area (ERA).

R&D in health research is primarily focussed on therapeutic objectives; Radiation protection has been seen as a secondary consideration, however, it's now recognised as a major issue. There is a growing integration of medical doctors and RP specialists in some projects, but it has been slow to happen.

8.2.5. 7.2.5 Innovation and Industrial Competitiveness

The ESSANUF project is unique and not part of a coherent Euratom research programme. However, it is consistent with the wider EU policy of having security of supply in nuclear electricity generation. The TRANSAT and M4F projects are stand-alone projects that support the wider nuclear fission and Fusion research programmes. They are also consistent with the wider EU nuclear energy policies.

8.2.6. 7.2.6 Pan-European Research Infrastructures

The two projects in the 2014-15 Work Programme are relevant to the delivery of Council objective (h) and are consistent with the EU’s nuclear energy policies. The FOREvER project in the 2016-17 Work Programme is also aligned to the delivery of the Council objective in this area and provides a coherency with the wider EU nuclear research programme.

8.2.7. 7.2.7 Social Aspects and Networking

The HoNEST project will add to the EU nuclear knowledge base but it is difficult to see where it fits in the wider EU nuclear energy goals. However, if the two projects NUCL-EU 2020 and SPRINT are successfully delivered, the outcomes should support the delivery of coherency in the wider Euratom research programme.

8.3. 7.3 Coherence - Summary

The Panel was asked to address three questions relating to the coherence of the Euratom Research Programme, namely: “To what extent can the Euratom Programme, as part of Horizon 2020, be considered a coherent programme of nuclear research actions in the context of support for research and innovation in general in Europe?”; “To what extent is the Euratom Programme consistent with EU policies in general (including other EU funding programmes)?”; and “To what extent is the intervention coherent with EU's international obligations?”. The Panel believes that the above evaluation shows that the fusion research programme can be said to be a coherent programme. Similarly in the fission area the various projects in general represent a coherent programme. Both the fusion and fission parts of the Euratom Programme are consistent with the EU policies in general. However it is difficult to comment on the extent to which the fission research projects are consistent with the EU’s international obligations.

9. 8. Evaluation of the EU Added Value of the Euratom Programme

This chapter provides the evaluation of the European Added Value of the Euratom Research Programmes, in particular the added value compared to what could be achieved by Member States acting alone or at regional level and the most likely consequences of discontinuing the Euratom Programme.

The Commission noted that European Added Value (EAV) "is best defined as the value resulting from an EU intervention which is additional to the value that would have been otherwise created by Member States action alone" *[Ref 81].*

Today EAV is used to generate focus, synergies, cooperation, and ultimately more results from the limited available financial resources.

The European Added Value definition will be further developed and adapted by the researchers and research communities. It will be used to define and evaluate programmes as well as to build citizens' trust and commitment.

For the next Multiannual Financial Framework (MFF) period (after 2020) the result oriented approach remains and will further evolve. The Panel notes that the "Budget for Result" (BFOR) concept *[Ref 82]* is nearing completion and that it goes far beyond EAV, developing Key Performance Indicators (KPI) to measure the success.

The Panel used the slightly modified EAV criteria *[Ref 83]* applicable to all parts of the Euratom Programme to check their added value for all programmes: Fusion, Fission, Radiation Protection and Training (see Annex 6).

Euratom Research and Training Programmes have additional common added value elements by sustaining safe use of nuclear activities, trust of society via transparency, and the worldwide leadership in the global race; promoting global mobility, building competitive advantage in research and connected industries, and increasing scientific output and access to data.

The Panel notes that EAV is implicitly part of the DNA of the Euratom research programme. However, the Panel believes that recognition of the value of this research would be enhanced if both the fusion and fission communities communicated the EAV of their projects.

9.1. 8.1 Nuclear Fusion

The ITER project has an enormous impact on Europe's and the world's scientific and political progress, being the first scientific programme initiated at the edge of the Reykjavik Summit (11-12 October 1986) during an era determined by the Cold War.

ITER is a global research project, and the European Union and all its 28 Member States are key global partners in the project to build the ITER facility in Cadarache, France. The Euratom fusion research programme has and is making a significant contribution to the success of ITER.

The Panel believes that the Euratom fusion research programme clearly demonstrates European Added Value and is essential for the successful completion of the ITER project, the delivery of the Fusion Roadmap and the ultimate goal of commercially viable fusion-generated electricity.

9.1.1. 8.1.1. European competitiveness in the global race

The Euratom fusion programme gives Europe leadership in this very important field. No single EU Member state would be able to provide a fusion research programme on the scale necessary to achieve this. It is important to keep European leadership and hence

European added value in the fusion area, in the short, medium and long-term. Fusion research must therefore play a key role in the future Euratom research programme.

The European fusion community and the fusion facilities located in the EU are key assets and as such offer a key European added value. To maximize European added value and exploit all potential benefits it is important to offer existing EU assets to international fusion and material science communities and therefore is the suggested way forward.

9.1.2. 8.1.2 Scientific Cooperation

The creation of EUROfusion is recognised as being a positive achievement at both the European and international level. The focus on scientific cooperation and networking has not only been successful but has clearly demonstrated European added value. The EUROfusion management should continue efforts to encourage inclusion and increase awareness of the vision, mission and achieved results of the programme.

JET is a unique European fusion asset and it is a fundamental part of the ITER project. JET is a clear example of European Added Value. If Europe is committed to remain a global player in fusion research, the Panel believes that JET with its unique European Added Value has great benefit for the international fusion community.

9.2. 8.2 Nuclear Fission

The nuclear fission research includes nuclear safety, radioactive waste management, radiation protection and medical applications of ionising radiation. Fission research has seven major streams with significant added value for all Europe.

9.2.1. 8.2.1 Safety of Nuclear Systems

In the field of nuclear safety it is the operator/ licensee that is responsible for the safe operation of nuclear installations. The European Added Value from the fission part of the Euratom Programme comes from the benefit to all MS that results from the contribution projects are making to improve our knowledge in the science and technology that underpins nuclear safety. The projects in the 2016-17 Work Programme relating to Generation- IV reactors provide a clear European Added Value because of their generic focus. European Added Value is also gained through the development of skills and capabilities in the smaller Member States through their participation in the projects.

9.2.2. 8.2.2 Management of Ultimate Radioactive Waste

Given that there is a clear EU need to provide a solution to the management of radioactive waste in general and the demonstration of the viability of deep geological disposal in particular there is a considerable EU added value to these projects. It is possible that individual Member States could undertake all the work that is necessary to demonstrate the concept and provide the detailed safety substantiation to satisfy regulatory requirements. However, sharing knowledge and developing skills in geological disposal safety case development is of value to all Member States wishing to deliver safe geological disposal for their radioactive wastes.

9.2.3. 8.2.3 Nuclear Expertise and Excellence

Use of nuclear energy (especially fission energy) to produce electricity, is a choice of individual Member States. To keep the state of art, understanding in the field of nuclear research is and will remain of common interest to all European citizens. Nuclear training and the development of expertise in all related nuclear research is a key European added value.

Added value has also been demonstrated in sharing knowledge and developing common training and research projects in areas such as: radiation protection, materials research and geological disposal of radioactive waste.

9.2.4. 8.2.4 Radiation Protection and Medical Applications of Radiation

In the EY review *[Ref 16],* it was noted that many different types of EU added value were identified through the case study analysis. The most frequent were related to creating platforms for research coordination and cooperation (either around a specific project or more durable platforms), bringing together different, complementary actors to achieve the necessary multidisciplinary approach, achieving the necessary scale inherently necessary for some types of research and the EU approach allows to build large cohorts and harmonize the methods more rigorously), providing access to infrastructures, enabling actors to compare and benchmark research results, avoiding duplications and fragmentation, disseminating results, etc.

The Euratom radiation protection research programme provides significant European Added Value through its flexibility and focus. While international organisations like ICRP, UNSCEAR do address these issues, the progress can be slow. For example, in radiation protection of the lens of the eye, many years elapsed between the first publication of findings to the publishing of recommendations and later implementation in regulations or guidance. The process can take 15 years or even more. The structure of research platforms and the CONCERT European Joint Programme created by the Euratom Programme is unique in radiation protection research worldwide and should shorten the time from research output to regulation *[Ref 60].*

9.2.5. 8.2.5 Innovation and Industrial Competitiveness

The ESSANUF project could have been undertaken at the Member State level and hence the EU added value is limited. However, given that there is a concern surrounding the security of the supply of nuclear fuel for utilities operating VVER reactors it is not unreasonable for the Euratom programme to continue to support this work. The project has shown that organisations in Member States working together to address this issue has brought benefits from the sharing of knowledge and experience. If the programme were discontinued it would be for the utilities to support the project.

The TRANSAT and M4F projects in the 2016-17 Work Programme are generic and hence they do provide some European Added Value.

9.2.6. 8.2.6 Pan-European Research Infrastructures

The HERACLES-CP, MYRTE and FOREvER projects are addressing areas that will potentially benefit the wider EU. Each in their own way provides European Added Value because of the long-term generic research applications. MYRTE is a good example of a project that creates a particularly high European Added Value.

9.2.7. 8.2.7. Social Aspects and Networking

The NUCL-EU 2020 and the SPRINT projects clearly have an EU added value because no single MS could deliver the goals of these projects. If these projects were to be discontinued the impact would be to undermine the SNETP and the efficiency and effectiveness of the wider H2020-Euratom nuclear research programme.

9.3. 8.3 European Added Value – Summary

The Panel was asked three questions relating to the European added value of the Euratom Programme, namely: "What is the added value resulting from the Euratom Programme, compared to what could be achieved by Member States acting alone or at regional level?"; "To what extent do the issues addressed by the Euratom Programme continue to require action at EU level?"; and "What would be the most likely consequences of discontinuing the Euratom Programme?". The above evaluation shows that nuclear fusion is a clear example of European Added Value. The Panel believes that the nuclear fission part of the Euratom Programme also demonstrated a high level of European Added Value. To be successful, both the fusion and fission programmes will continue to require action at the

EU level. It is clear to the Panel that if the Euratom Programme were discontinued there would be a significant adverse impact on nuclear fusion, nuclear fission and radiation protection research in Europe.

10. 9. CONCLUSIONS

Overall, it is the Panel's view that in both the fusion and fission areas the research and training indirect actions funded up to February 2017 by the Euratom 2014-2018 Research and Training Programme are relevant to the aims of the Council Regulation and are delivering progress in line with expectations.

10.1. 9.1 Nuclear Fusion

The fusion part of the Euratom Programme is playing an important role for securing in the long term a sustainable energy supply for Europe.

The formulation of the European Fusion Roadmap in 2012 has been crucial to focus the commitment of the fusion research community towards the goal of the exploitation of fusion energy and has put Europe in a leading position on the way to the production of fusion electricity.

The Euratom Programme (together with the activities under F4E responsibility) is implementing the Fusion Roadmap. The Panel is pleased to see the increased level of transparency in the allocation of funds and an approach that promotes competition and excellence.

The Panel considers that to date the Euratom Programme in fusion has been effective as the various activities reflect the priorities of the Roadmap and that the programme is pursuing the activities with the highest impact in the realization of the Roadmap.

The efficiency of the implementation of fusion research needs to be improved. The transition between the EFDA/CoA system and the Euratom Programme 2014-18 took place very rapidly and the new system under EUROfusion is slowly adapting. Progresses in the governance are being made. However rigorous project management rules should be systematically implemented and the Programme Manager should fully exercise his/her leadership on the implementation strategy to prevent potential conflicts of interest due to the multiple roles of the beneficiaries.

A proper preparation to the ITER exploitation is needed to minimize the risks of further delays in the achievement of the Q=10 milestone. JET is the experimental device closest to ITER and plays a central role in this strategy. The execution of the programme in support of ITER will require JET campaigns extending into future Euratom Programmes up to 2024. An earlier closure of JET would significantly increase the risk of possible delays in the ITER exploitation up to Q=10.

The industrial involvement in the DEMO definition and design, advocated by the Roadmap, is being pursued but it should be strengthened further. The competences that have been formed in industry during the ITER construction phase should be exploited for the DEMO Engineering Design Activity.

The Panel has not found any compelling technical argument that justify at the present moment a revision of the Roadmap, rather than an update of the implementation plan to adapt for the new ITER schedule.

The Panel believes that the focus of the Roadmap should remain on an ITER-like DEMO to be constructed as soon as ITER achieves the Q=10 milestone. Priority should be given to the challenges of: integrating technologies related to tritium breeding; developing materials capable of withstanding neutron damage; and building nuclear safety into a consistent design of an ITER-like DEMO to demonstrate the production of a net fusion electricity output. Once DEMO has achieved its target, industry will have to take over the exploitation of fusion for electricity production. In this sense DEMO will be the last step to a commercial fusion power plant.

10.2. 9.2 Nuclear Fission

The nuclear fission research programme is more diverse than the fusion research programme, but a number of common observations can be made. Overall, the selected projects in the 2014-15 and 16-17 calls are in line with the goals of the Council objectives. The funding of the calls could be improved in future Euratom programmes in order to reduce the number of calls thus ensuring a more coordinated approach over the whole period.

The Euratom Programme arrangements that are common with those of Horizon 2020 (Rules of Participation) allow for up to 100% Euratom funding of projects. This appears to have distorted the balance of funding between Euratom and the beneficiaries to the extent that the Euratom is now providing around 73% of the project costs compared to 53% in the FP7/FP7+2 programme. This suggests that less research is being done for the same level of EU funding because the beneficiaries are seeking to limit their contributions.

The projects selected during 2014-17 are in the main relevant to the European research needs as set out in the Euratom Work Programmes and the overall Council objectives. The projects are in general delivering their milestones but there are some examples of milestones being missed. In general, they present, where possible, a coherent research approach. European Added Value is a consistent theme in the vast majority of the projects.

In the fission area the use of the instrument of European Joint Programme (Programme Co-fund Action) is in its infancy and hence it is too early to see definitive evidence one-way or the other. However, it may not always beneficial to adopt such an approach and it should only be used when it can offer clear benefits to research coordination.

10.2.1. 9.2.1 Safety of Nuclear Systems

In the area of nuclear safety, the range of topics is in general relevant to the goals of maintaining Europe’s leadership in the delivery of nuclear safety within the nuclear industry. Projects supported by the fission part of the Euratom Programme are consistent with the Council objective for nuclear safety of current and future reactor systems. It is encouraging that there is diverse participation in the projects but there remains a dominance of the larger more established organizations; this results in the funding going to a small number of the traditionally strong nuclear countries.

The balance of spending between the projects is in general consistent with the challenges as set out in the Work Programme. There is a good balance between the need to support the safety of existing nuclear power plant operations in Europe and the need to focus on the research necessary to underpin the safety of the next generation of nuclear power plants.

All of the nuclear safety related projects in the 2014-15 call indicate that progress is generally as planned with most deliverables and milestones being achieved. However, it is difficult at this stage to comment upon the extent to which the outcomes that are claimed will be generated will deliver the project aims in a cost effective way. The 2014-15 programme in general is aligned to and consistent with the overall goals of the EU’s nuclear safety policies but projects in the 2016-17 Work Programme present a more coherent approach to the delivery of the overall EU nuclear safety goals.

In the field of nuclear safety it is the operator/ licensee that is responsible for the safe operation of nuclear installations. The European Added Value from the fission part of the Euratom Programme comes from the benefit to all MS that results from the contribution projects are making to improve our knowledge in the science and technology that underpins nuclear safety. The projects in the 2016-17 Work Programme relating to Generation- IV reactors provide a clear opportunity for European Added Value to be delivered.

10.2.2. 9.2.2 Management of Ultimate Radioactive Waste

Radioactive waste management is an important component of the use of nuclear energy in Europe. The projects selected in the first call (2014-15) demonstrate that the intent of the Euratom Programme has been implemented. The five projects in the 2016-17 Work Programme are all related to waste characterisation and conditioning in preparation for geological disposal and geological disposal challenges. In this call the Euratom funding of €19.5m represents 95 % of the total project funding and it is difficult to see the justification for such a large Euratom contribution.

The funded projects are relevant to the needs of the European research community and the citizens of the EU. The JOPRAD project, which is aimed at exploring the feasibility of a European Joint Programme approach, has some difficulties and at the end of 2016 it was not progressing as expected. Since this time improvements have been made but the panel remains of the view that the Commission should satisfy itself that the there is sufficient evidence to support the case for proceeding with application of EJP to radioactive waste management research. The projects in both the 2014-15 and 2016-17 parts of the programme are consistent with Council objective (b). Progress in the 2014-15 projects suggests that the aims are on track. However, the funding of these projects should be reviewed because as it is the producer of the waste that should pay for its disposal it is hard to see why Euratom should fund 73% of the cost for 2014-15 projects and 95% of the cost in the 2016-17 projects.

10.2.3. 9.2.3 Nuclear Expertise and Excellence

The importance of supporting the retention and further development of scientific competence and human capacity including education and training activities in order to guarantee the availability of suitably qualified researchers, engineers and employees in the nuclear sector is a long term priority in both past and future Euratom programmes. The projects are in line with the objective of the Euratom Programme to develop knowledge and to improve scientific and technical competences.

The Council Regulation’s objective for education and training is rather general and there are no specific objectives in the biennial Work Programmes. Better specification of goals in the Euratom Work Programmes may facilitate the implementation of education and training in the programme.

Euratom should consider creating fellowships for early stage researchers, incorporating a scheme similar to the Marie Skłodowska-Curie Early Stage Researcher fellowship, and the Marie Skłodowska-Curie Conferences and Training Courses.

Research projects that support nuclear training and the development of expertise in nuclear related areas are of key importance to Europe. The projects selected in this area in general provide a European Added Value.

10.2.4. 9.2.4 Radiation Protection and Medical Applications of Radiation

There remains a need to seek closer cooperation between the Euratom radiation protection programme and the wider EU health research programme in order to maximise the European added value of the Euratom research to health within the EU.

CONCERT is an example of a European Joint Programme (Programme Co-fund Action) and the radiation research programme is directly relevant to the understanding of the risks from low dose of radiation. The funded projects are expected to lead to better integration of the radiation protection scientific community at EU level, leading to a better coordination of research efforts and the provision of more consolidated and robust science-based policy recommendations to decision makers in this area. In the long term, these efforts will translate into additional or improved practical measures for the effective protection of people and the environment.

The use of the European Joint Programme instrument in the area of radiation protection has presented a few challenges, especially as low dose research is mostly done in universities that are third parties for CONCERT. There are problems with the national co-funding that disadvantages universities/third parties. The Panel believes that it would be beneficial for the Commission to carry out a review to satisfy itself that its aims and objectives, and the benefits of using the EJP approach in the field of radiation protection, have been delivered.

10.2.5. 9.2.5 Innovation and Industrial Competitiveness

The selected projects relating to innovation and industrial competitiveness in both the 2014-15 and 2016-17 calls are generally relevant to the wider EU goals. The information that is available suggests that the projects are in general on track. The innovation and industrial competitiveness projects are relevant but in the case of the ESSANUF project the 100% funding seems difficult to justify.

10.2.6. 9.2.6 Pan-European Research Infrastructures

Both projects in the 2014-15 Work Programme are relevant to the Council objectives and to the wider EU nuclear research needs. In the case of the HERACLES-CP and the FOREvER project (2016-17 programme) it is hard to see why the EU should be funding 100% and 95% respectively of the research costs.

The three pan-European research infrastructure projects are consistent with the aims and objectives of the Euratom Work Programmes and as such are relevant and consistent with the Council objectives. The information that is available suggests that progress is generally on track.

10.2.7. 9.2.7 Social Aspects and Networking

The aims and objectives of the three projects selected in the Social Aspects and Networking area, HoNEST, NUCL-EU2020 and SPRINT are consistent with the Work Programme but the extent to which they meet the needs of European citizens is less clear. The funding balance for the NUCL-EU 2020 and SPRINT projects is in line with their importance and priority, but the funding level for the HoNEST project seems excessive. The information that is available suggests that progress is generally on track.

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12. LIST OF RECOMMENDATIONS

Recommendation 1: For future Euratom Programmes the Council should recognise that even if the level of excellence remains the key for applying for research funding, the dominance of the established organisations can lead to the exclusion of emerging contributors who have the potential to provide new ideas and innovation. Hence consideration should be given as to how this source of innovation can be captured rather than lost from European programmes.

Recommendation 2: For future Euratom Programmes the Commission should review the impact of allowing up to 100%-funding has on the level, scope and impact of research being delivered.

Recommendation 3: In view of the importance of JET for ITER the JET campaigns should be extended up to 2024.

Recommendation 4: EUROfusion should not delay the DEMO CDA and should start the DEMO EDA around 2025 in order to maintain the industrial know-how generated by the ITER construction.

Recommendation 5: EUROfusion to maintain the original Roadmap focus on DEMO as an ITER-like tokamak to be built as soon as ITER achieves the Q=10 target.

Recommendation 6: EUROfusion should use its educational resources to promote educational programmes that will deliver the nuclear engineers and technologists as foreseen in the Roadmap.

Recommendation 7: EUROfusion and the Commission should review the impact of Unit Costs on mobility and make any necessary changes.

Recommendation 8: For WP2018 or the extension of Euratom 2014-18 the Commission and Members States should carefully consider if there is sufficient evidence to demonstrate that the EJP instrument can be applied to research on geological disposal of radioactive waste at this point in time.

Recommendation 9: For the implementation of future research Programmes the Commission should ensure that there are specific objectives for the delivery of education and training in the Work Programme.

Recommendation 10: The Commission and the Member States should make continued efforts to link future Euratom research programmes in radiation protection associated with medical exposure with other EU medical research programmes.

Recommendation 11: The Commission should carry out a review of how CONCERT is working, to satisfy itself that the aims of the European Joint Programme (programme co-fund action) in relation to the effective and efficient management of research in the field of radiation protection are being delivered.

Recommendation 12: EUROfusion should put in place explicit provisions to manage conflicts of interest.

Recommendation 13: EUROfusion should continue to strengthen its project management arrangements and ensure that the Programme Manager is responsible for the implementation strategy.

Recommendation 14: EUROfusion should as a matter of urgency set up the design authority for DEMO.

Recommendation 15: EUROfusion should look at ways of reducing the burden on STAC from its role in the project selection process for Enabling Research.

Recommendation 16: The Council should consider extending the Marie Skłodowska-Curie scheme to Euratom's Fission Research Programmes.

Recommendation 17: To improve the coherence of the research needs of the Roadmap the coordination between the top level management of F4E and EUROfusion should be strengthened

Recommendation 18: The Commission should introduce a formal Fusion Roadmap revision procedure to ensure that any revision to the original Fusion Roadmap is owned by all relevant stakeholders.

13. Glossary

ALLIANCE	Research Platform to coordinate and promote European research on Radioecology (http://www.er-alliance.org/)
AMR	Annual Monitoring Report
ASDEX-U	ASDEX Upgrade (Medium-sized tokamak at Garching, Germany)
AWP	Annual Work Programme
BFOR	Budget for results; Commission initiative to demonstrate the value added for the EU budget
Breeding Blanket	The DEMO component that absorbs the neutrons produced in fusion reactions. Its main role is to breed the tritium needed to fuel the reactor and to transform the neutron energy in thermal energy to be used for electricity production.
BSS	(European) Basic Safety Standard
CCE-FU	Consultative Committee for the Euratom specific research and training programme in the field of nuclear energy (FUsion)
CDA	Concept Design Activity
CIRCE	CIRColazione Eutettico (facility to simulate thermo-hydraulic behaviour of heavy liquid metal cooled reactor)
CNRS	Centre National de la Recherche Scientifique
CoA	Contract of Association
COMET	COordination and iMplementation of a pan-European instrumenT for radioecology (www.comet-radioecology.org)
CORDEL	Cooperation in Reactor Design Evaluation and Licensing
COUNCIL Objectives	Objectives as described in the Council regulation establishing the Euratom 2014-2018 Programme
DEMO	DEMOnstration fusion power plant
DGR	Deep Geological Repository
EAV	European Added Value
ECTS	European Credit Transfer and Accumulation System
ECVET	European Credit system for Vocational Education and Training
EDA	Engineering Design Activity
EFDA	European Fusion Development Agreement
EJP	European Joint Programme/co-fund action
ENEN	European Nuclear Education Network
ERC	European Research Council
ESNII	European Sustainable Nuclear Industrial Initiative
ETP	European Training Programme
EURAMED	European Alliance for Medical Radiation Protection Research
EURADOS	European Radiation Dosimetry Group
EURAYS	European Radiation Research Association for Young Scientists (http://www.eurays.eu/)
EUROfusion	European Consortium implementing a comprehensive joint programme in line with the fusion roadmap
EY	Ernest & Young group
F4E	Fusion For Energy
FP6	6th Euratom Framework Programme 2002-2006
FP7, FP7+2	7th Euratom Framework Programme 2007-2011 and Euratom Framework Programme 2012-13; FP7/FP7+2 refers to the combined 2007-2013 Programme
FP9	Euratom Framework Programme 2021-2025 (to be decided)

FUSENET	European FUSion Education NETwork
GA	EUROfusion General Assembly
Generation- II/-III	Current generations of nuclear power plants
Generation- IV	Generation IV (advanced fission nuclear systems)
HEU	High Enriched Uranium fuel
HLEG	High Level and Expert Group on European Low Dose Risk Research
HLW	High-Level (radioactive) Waste
ICRP	International Commission on Radiological Protection
IGDTP	Implementing Geological Disposal Technological Platform
ILW	Intermediate-Level (radioactive) Waste
ILW	ITER-like wall
IMAS	ITER Integrated Modelling & Analysis Suite
IPP	Institute of Plasma Physics, Garching, Germany
ITER	International Thermonuclear Experimental Reactor
ITER IO	ITER International Organization
ITER Research Plan	The document that outlines the research to be carried out on ITER throughout the various phases of the ITER exploitation.
JET	Joint European Torus
JET DTE2	The experimental campaign to be carried out on JET using deuterium and tritium at the end of Horizon 2020.
JRC	Joint Research Centre
JT-60SA	Joint Torus 60 Super Advanced, Tokamak in Japan
KALLA	KArlsruhe Liquid metal LAboratory
KASOLA	KArlsruhe Sodium LAboratory
KPI	Key Performance Indicators
LEU	Low Enriched Uranium
LNT	Linear No Threshold
Magnum-PSI	Linear plasma facility at Foundation for Fundamental research On Matter (FOM), Netherlands
MAST-U	Mega Ampere Spherical Tokamak at Culham, UK
MELODI	Multidisciplinary European Low-Dose Initiative (http://www.melodi-online.eu/)
MFF	Multiannual Financial Framework
Mission (Roadmap)	See Annex 5
MOOC	Massive Open Online Courses
MOX	Mixed Oxyde reactor fuel
MS	EU Member States
MSC	Marie Skłodowska-Curie
MSFR	Molten Salt Fast Reactor
MST	Medium-Sized Tokamak
MYRRHA	Project of ADS nuclear system demonstrator
NACIE	NAtural Circulation Experiment
NCP	National Contact Point
NERIS	European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recover (http://www.eu-neris.net))
NERIS-TP	Technology Platform on Preparedness for nuclear and radiological emergency response and recovery

NET project	Next European Torus. Project established in Garching by EURATOM at the end of the '80 to design an experiment to produce fusion power at a reactor level.
NFRP	Topics for calls in the Nuclear Fission Radiation Protection area
NJOC	New JET Operation Contract
NUGENIA	NUclear GEneration II & III Association
OPERRA	Open Project for the European Radiation Research Area (http://www.melodi-online.eu/operra.html)
Pilot-PSI	Linear plasma facility at Foundation for Fundamental research On Matter (FOM), Netherlands
PL	Project Leader
PMP	Project Management Plan
PM	EUROfusion Programme Manager
PMU	EUROfusion Programme Management Unit
PREPARE	FP7/7+2 project on Innovative Integrated Tools and Platforms for Radiological Emergency Preparedness and Post-Accident Response in Europe (http://www.eu-neris.net/index.php/projects/prepare.html)
Q=10	Performance of ITER, yielding a fusion power of 10 times the auxiliary power injected in the reaction chamber
R&I	Research and Innovation
RIA	Research and Innovation Action
Roadmap	Fusion Energy Research Roadmap
RP	Radiation Protection
RR	Research Reactor
RU	Research Unit
SET-Plan	Strategic Energy Technology Plan
SMR	Small Modular Reactor
SNE	Seconded National Expert
SNETP	Sustainable Nuclear Energy Technology Platform
SRA	Strategic Research Agenda
SSH	Social Sciences and Humanities
STAC	Science and Technology Advisory Committee
STAR NoE	STrategy for Allied Radioecology (STAR) network of excellence (NoE) (http://www.radioecology-exchange.org)
Stellerator	Magnetic configuration that produces the confining magnetic field entirely with external coils, without a current flowing in the plasma. It is an intrinsically steady state configuration.
TALL	Thermal-hydraulic ADS Lead-bismuth Loop
TBM	Test Blanket Module
TCV	Tokamak à Configuration Variable at Lausanne, Switzerland
TFL	Task Force Leader
TRL	Technology Readiness Level
TSO	Technical Support Organisation
UKAEA	United Kingdom Atomic Energy Authority
UMo	Uranium-Molybdenum nuclear fuel
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VVER	Vodo-Vodianoï Energetitcheski Reaktor / Pressurized-Water Reactor of Russian design

W7-X	Wendelstein7-X, large advanced superconducting Stellerator at Greifswald, Germany
WEST	'W' Environment in a Steady-state Tokamak (W is the chemical symbol for tungsten), Cadarache, France
WP	Work Programme
WP2014-15	1st biennial Work Programme of Euratom 2014-2018
WP2016-17	2nd biennial Work Programme of Euratom 2014-2018
WP2018	3rd and last Work Programme of Euratom 2014-2018 (to be decided)

14. ANNEX 1 TERMS OF REFERENCE

TERMS OF REFERENCE OF THE GROUP OF EXPERTS ON THE INTERIM EVALUATION OF INDIRECT ACTIONS OF THE EURATOM RESEARCH AND TRAINING PROGRAMME (2014-18)

1. NAME OF THE EXPERT GROUP

The Group of Experts on the interim evaluation of indirect actions of the Euratom Research and Training Programme (2014-2018), hereinafter referred to as 'Interim Evaluation of Euratom Programme'.

2. CONTEXT AND BACKGROUND INFORMATION

According to Article 22(1) of the Council Regulation (Euratom) 1314/2013, by 31 May 2017, and taking into account the ex-post evaluation of the Seventh Euratom Framework Programme established by Decision 2006/970/Euratom and of the Euratom Framework Programme (2012-2013) established by Decision 2012/93/Euratom to be completed by the end of 2015, the Commission shall carry out, with the assistance of independent experts selected on the basis of a transparent process, an interim evaluation of the Euratom Programme.

Evaluations are an essential step to manage and revise the existing body of EU legislation and policy and should precede impact assessment for proposals for new legislation. The Commission is committed to evaluate in a proportionate way all EU spending and non-spending activities intended to have an impact on society or the economy. The Interim Evaluation of Euratom Programme will be based on the evaluation principles established by the Better Regulation Guidelines1.

3. PURPOSE, OBJECTIVES AND SCOPE

The purpose of the Interim Evaluation of the Euratom Research and Training Programme (2014-2018) (hereinafter Euratom Programme) is to assess its implementation, to provide an evidence base for preparing future Euratom research programmes and to inform the European Parliament and the Council, Member States, the research community and other stakeholders, and the general public about the progress made by research and training activities funded by the Euratom Programme.

In line with Article 22(2) of the Council Regulation (Euratom) 1314/2013, direct and indirect actions are subject to separate evaluations. These terms of reference concern indirect actions i.e. research funded through competitive calls for proposals managed by the Commission's Directorate-General for Research & Innovation.

Main evaluation questions are defined by Article 22(1) of the Council Regulation (Euratom) 1314/2013 and further elaborated in these terms of reference. Evaluation shall cover the Programme's achievements, at the level of results and progress towards impacts, continued relevance of all the measures, the efficiency and use of resources, the scope for further simplification, and European added value. The evaluation shall also take into account the contribution of the measures to the Union priorities of smart, sustainable and inclusive growth, results on the long-term impact of the predecessor measures and the degree of synergy and interaction with other Union funding programmes, including the Structural Funds.

Regarding scope, the interim evaluation will cover the implementation and results of indirect actions funded under the Euratom Programme between January 2014 and June 2016. It will cover all steps of the Euratom Programme's implementation, from the defining of Work Programmes, through implementation of calls for proposals and monitoring of projects.

Particular attention should be paid to the evaluation of the new measures introduced by the Euratom Programme: European Joint Programmes in fusion research and in radiation protection, and prizes. In this context the group might be requested to examine the outcome of the mid-term review of EUROfusion and of the fusion research roadmap.

The group of experts shall answer the following questions and formulate recommendations for the Euratom Programme 2014-2018 and for the Commission's proposals for the future Euratom Programmes:

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[1] http://ec.europa.eu/smart-regulation/guidelines/ug_chap6_en.htm

3.1. State of play

- How has the Euratom Programme been implemented during 2014-2016?
- What conclusions can be drawn from the participation patterns and trends?

3.2. Relevance of the Euratom Programme

- To what extent do the objectives of the Euratom Programme still correspond to the needs of research stakeholders and to EU citizens?
- Does the Programme offer the right balance between the various areas of nuclear research?

3.3. Effectiveness of the Euratom Programme

- What is the progress made towards the objectives of the Euratom Programme?
- What are the factors driving or hindering progress and how they are linked (or not) to the Euratom Programme?
- How effective are new measures (European Joint Programmes, prizes) introduced by the Euratom Programme?
- What are the main long-term impacts of the previous Euratom Framework Programme?
- How is the Euratom research programme contributing to the EU strategic objectives and policies?

3.4. Efficiency of the Euratom Programme

- To what extent are the inputs provided to Euratom Programme reasonable (i.e. cost-effective) in light of the outcomes that have been generated or are likely to be generated?
- Is there scope for further simplification?

3.5. Internal coherency of the Euratom Programme and consistency with EU policies

- To what extent can the Euratom Programme, as part of Horizon 2020, be considered a coherent programme of nuclear research actions in the context of support for research and innovation in general in Europe?
- To what extent is the Euratom Programme consistent with EU policies in general (including other EU funding programmes)? To what extent is the intervention coherent with EU's international obligations?

3.6. EU added value of the Euratom Programme

- What is the added value resulting from the Euratom Programme, compared to what could be achieved by Member States acting alone or at regional level?
- To what extent do the issues addressed by the Euratom Programme continue to require action at EU level?
- What would be the most likely consequences of discontinuing the Euratom Programme?

4. WORKING APPROACH AND METHODOLOGY

4.1. Working method

The experts shall carry out an independent and robust evaluation built on a solid evidence base. The experts shall prepare a report via a combination of collective and individual work carried out remotely and structured around regular meetings.

The Chairperson shall specify the working method of the panel and ensure that the capacities of the experts are best utilised in order to carry out this evaluation.

The group shall include a Rapporteur who shall prepare the final report. The Rapporteur shall draft summaries of the discussions held at meetings. Commission staff shall support the production of the report, notably by making available relevant evidence base and by providing relevant feedback.
The evaluation shall be designed and carried out in line with the Better Regulation guidelines[2].

4.2. Support and evidence base

A comprehensive set of relevant data, reports and studies allowing the carrying out of the evaluation shall be delivered by the Commission to the experts as their work evolves:

a) statistical information on the implementation of the Euratom indirect actions;
b) targeted studies carried out for the purpose of this evaluation;
c) report from the ex-post evaluation of the Euratom FP7;
d) report from mid-term review of EUROfusion consortium;
e) relevant policy documents concerning Euratom research;
f) scientific publications and other sources of evidence at the level of the programme and projects.

The members may invite, as appropriate, representatives of the Commission services, beneficiaries of the Euratom Programme and end-users, independent experts and stakeholders in fission and fusion research to give written or oral evidence.

5. Distribution of the work among the members of the expert group

The group is composed of a Chairperson, a Rapporteur and four experts. The Chairperson shall specify the distribution of the work among members of the expert group in order to carry out this evaluation.
The experts will be asked by the Commission to devote up to 28 working days (including meetings and remote work) to these tasks. In the case of the Chairperson and the Rapporteur, the maximum number is 32 and 35 working days respectively.

6. Meetings, reporting and deadlines

The group shall prepare a report in English. The report shall include:

a) an executive summary of maximum 4 pages in English;
b) the following standard disclaimer: "The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein."
c) The experts shall start their work in June 2016. A draft report shall be made available to the Commission by end of November 2016 and the final report shall be addressed to the Commission by end of January 2017. The Commission shall make the report publicly available.

The Chairperson and/or Rapporteur may be invited in the future by the Commission to present the report.

7. Experts profiles

The experts shall have the relevant expertise to ensure evaluation in all of the areas covered by the indirect actions of the Euratom Programme. Experts shall be appointed on the basis of high level of skills, experience and knowledge in the relevant areas, in particular:

[2] http://ec.europa.eu/smart-regulation/guidelines/index_en.htm

a) in the fields of research and technological development, as attested by higher education qualifications of at least doctoral level and/or proven by having won prizes and awards at national, European and international level and/or as evidenced by experience, research outputs, publications and skills that are widely recognised;

b) an appropriate range of skills in different aspects of the Euratom Programme, including knowledge on nuclear systems, radiation protection, radioactive waste management, cross-cutting issues as well as education & training in the nuclear field, energy policy, social and economic aspects of nuclear energy, combined with the ability to examine related questions and analyse the general context into which they fall;

c) appropriate language skills.

The following criteria shall also be taken into consideration when appointing the members of the group:

d) geographical diversity and gender balance;

e) where appropriate, the balance between academic and industry expertise;

f) ability to assess the societal dimension and strategic relevance of the Euratom Programme;

g) knowledge about evaluations of previous Euratom Programmes;

h) absence of conflict of interest.

8. EXPERTS SHORT BIOGRAPHIES

[Experts short biographies will be added after appointment of the experts by the Director-General.]

15. ANNEX 2 EVALUATION EXPERT GROUP

The evaluation Panel comprised the following independent members:

Professor Laurence G Williams FREng (UK) - Chairman

Senior Research Investigator in the Centre for Nuclear Engineering at Imperial College London; Emeritus Professor of Nuclear Safety and Regulation at the University of Central Lancashire; Former HM Chief Inspector of Nuclear Installations (1998-2005) and Director for Nuclear Safety in the UK Health and Safety Executive; Chief Engineer and Director for Nuclear Safety, Security and Environment at the UK Nuclear Decommissioning Authority. Chair of UK Committee on Radioactive Waste Management (CoRWM); Chair IAEA Commission on Safety Standards (2000-2005); Chair Ex-post evaluation of indirect actions of Euratom FP7 and FP7+2 Programmes.

Professor Eugenijus Butkus (LT)

Eugenijus Butkus, Head of the Life Sciences Center of Vilnius University, Professor. Eugenijus Butkus previously served as the Chairman of the Research Council of Lithuania during 2003-2013, Vice-Rector for research of Vilnius University in 2013-2015 and Vice President of the European Science Foundation (ESF) in 2012-13. He has also been the Chair of the BONUS program steering committee (2013-14). He was a HLEG member of Ex-Post-Evaluation of the 7th EU Framework Programme (2007-2013). He has coordinated the FP7 collaborative project Servicing Policy for Resource Efficient Economy. In 2014 he has been awarded the National Science Prize. Eugenijus Butkus is a full member of the Lithuanian Academy of Sciences.

Edit Herczog (HU)

Edit Herczog, managing director of the company called Vision & Values, specialised on Strategic Marketing, Brussels. She is a former MEP served ten years in the European Parliament Committee for Industry Technology and Research, Committee for Internal Market, Committees for Budget and Budget Control. She worked as rapporteur or shadow rapporteur for several energy and nuclear energy related legislation. She was chairman for the Forum for the future of the nuclear energy in Europe, and vice president of the European Energy Forum. Before EP Edit was a manager for ten years responsible for Central Easter Europe at Company called National Starch and Chemical (member of ICI group) in the field of Specialised Chemicals. She is a lecturer at HEC University in Liege.

Dr. Geraldine O’Reilly (IE)

Geraldine O'Reilly is Chief Physicist and Head of the Medical Physics and Bioengineering Department in St.James's Hospital, Dublin. She acts as Radiation Protection Adviser to St.James's and to a number of other hospitals in the region. She is a member of the Article 31 Group of Experts, an advisory group to the European Commission on matters relating to radiation safety and has acted as a consultant to the International Atomic Energy Agency. She lectures on a number of post-graduate programmes in Trinity College Dublin and also in the Royal College of Surgeons of Ireland. She has acted as a reviewer for a number of journals in the field of Radiology and Radiation Protection, including the BJR. She served two terms as a Board Member on the Radiological Protection Institute of Ireland and served on both their environmental and medical radiation advisory committees. She is a member of the National Radiology Steering Group.

Professor Francesco Romanelli (IT)

Francesco Romanelli is professor of Physics of Nuclear Energy in the Department of Industrial Engineering of the University of Rome "Tor Vergata". He has been Leader of the European Fusion Development Agreement (EFDA) from 2010 to 2014 and Leader of the Joint European Torus (JET) from 2006 to 2014. He has directed the activities in Physics of Magnetic Confinement Fusion at ENEA from 1996 to 2006. From 2003 and 2006 he has been Chairman of the EFDA Science and Technology Advisory Committee.

Dr. Hans G Riotte (DE) - Rapporteur

Hans Riotte is former Head of the Radiation Protection and Radioactive Waste Management Division at the OECD Nuclear Energy Agency. He is a retired official of the German Federal Ministry of Research and Education where he was in charge of technology foresight and strategic research policy issues. Hans was the rapporteur of the panel for the ex-post evaluation of indirect actions of Euratom FP7 and FP7+2 Programmes.

The Panel was assisted by the following representatives of the European Commission Directorate-General for Research & Innovation:

- Frederick Mariën – Coordinator for Euratom R&I Horizontal Activities
- Tomasz Sliwinski – Policy Officer

16. ANNEX 3 MEETINGS SCHEDULE

The Panel met ten times between June 2016 and March 2017 at the Commission premises in Brussels (BE), in London (UK), and at the CCFE (Culham, UK) and IPP (Garching, DE) research centres:

- 27 June 2016 Brussels (Meeting with Commission stakeholders)
- 18 July 2016 Brussels (Meeting with EY and Cesarski-Panel representatives)
- 08 August 2016 Brussels (Meeting with fission stakeholders)
- 21-22 September 2016 Culham, UK (Meeting with fusion stakeholders)
- 27-28 October 2016 Brussels
- 23-25 November 2016 Garching, DE (Meeting with fusion stakeholders)
- 29-30 November 2016 Brussels
- 26-27 January 2017 London
- 21-22 February 2017 Brussels
- 16-17 March 2017 Brussels
- 20 April 2017 Brussels

17. ANNEX 4 QUESTIONS PUT TO THE FUSION AND FISSION STAKEHOLDERS

17.1. Annex 4.1 Questions to Fusion Stakeholders

Topics of the meetings with fusion stakeholders on 21-22 September and 23-25 November 2016

- The impact of the transition from EFDA to EUROfusion.
- The relevance of the Euratom Fusion research and training programme.
- The effectiveness and efficiency of EUROfusion in the delivery of the Euratom fusion research and training programme.
- The EU added value of the Euratom fusion research programme.
- The extent to which the EUROfusion programme in delivering the intent of the Fusion Roadmap.
- The revision of the Fusion Roadmap.
- The role of JET in the delivery of the 2014-18 Programme
- The role of JET in future fusion research
- The role of JET in support of ITER
- JET upgrade requirements
- The implications of the closure of JET on Euratom Fusion research in FP 9
- Experience of small research units in EUROfusion.
- Status of the Roadmap implementation
- Summary of the status of the Roadmap implementation in terms of standard indicators (e.g. deliverables, milestones, budget committed by the beneficiaries for the capital investments, etc.)
    a. Schedule of the main decision points
    b. JET internationalisation
    c. Divertor Tokamak Test facility (DTT)
    d. Early Neutron Source
    e. JT60-SA exploitation post Broader Approach
- EUROfusion achievements on the Roadmap Missions 1 (Plasma regimes of operation), Mission 2 (Heat and particle exhaust) and Mission 8 (Stellarators)
- Evolution of the JT60-SA research plan and opportunities for implementing part of the ITER/DEMO preparation there (e.g. test of tungsten plasma facing components)
- Possible role of EU Medium Size Tokamaks in FP9 in support of ITER/DEMO.
- Status of the DTT discussion
- The main achievements so far (STAC).
- The role and effectiveness of STAC
- The management of conflicts of interest in STAC
- The extent to which the EUROfusion programme is delivering the intent of the Fusion Roadmap in relation to the objectives of increasing competence in engineering and technology .
- The ability of EUROfusion to measure the quality of the information provided by each of the participating institutions.

- Areas where improvements can be made in education and training aspects of the Euratom Programme
- The Countries that are benefitting from the E&T programme
- The role of FUSENET.
- The achievements in terms of better return for EURATOM from the IC in the first two years of EUROfusion
- International participation in JET.
- EUROfusion participation in the design of the Chinese Fusion Engineering Test Reactor.
- Progress in the possibility of making material irradiation in fission reactors of international collaborators.
- Collaboration on the non EU stellarators
- Status of JET upgrade/ refurbishment programme
- JET lifetime – status of lifetime usage of main components
- JET availability / reliability over the past 15 years
- Experience with the first 3 years of EUROfusion as a participant in the projects and member of the GA
- Role of the UK fusion programme in the Roadmap implementation (MAST-U, etc.)
- Management of the transition between JET and ITER after JET era.

(Written) Questions on fusion research for fusion R&D stakeholders

Role of JET and consequences of closure at the end of the present Euratom programme.

Q1 With realistic assumptions of JET reliability, how much experimental time is needed for JET to complete the original EP2 programme (including the tritium campaigns) and execute the additional tasks outlined by ITER during the JET internationalization workshop?

Q2 The schedule presented in Fig.3 of the Addendum foresees almost 3 years of operation in 2018-2020 with limited time for interventions. Is this realistic in view of the need to have most of the systems operating at their top performance?

Q3 What role can JET play in order to mitigate the risks to the success of ITER (in the areas of preparation of ITER operation, consolidation of ITER design choices, training of ITER personnel, etc.) and in which time frame?

Q4 What would be the consequences of the closure of JET in 2018 or 2020, respectively on the risk mitigation strategy for ITER?

Q5 A main difference between EFDA and EUROfusion is the separation between the direction of JET operation and that of JET scientific exploitation. How is this impacting on the preparation, selection, and review of the individual experimental proposals for JET?

Q6 What would be the consequences of managing the JOC through EUROfusion?

Fusion Roadmap

Q7 No input from ITER operation is expected during the CDA both in the 2012 Roadmap and in the revised Roadmap. What is to be gained by postponing the start of the Engineering Design Activity (EDA)?

Q8 One of the motivations behind the start of the DEMO EDA in the 2020s advocated by the 2012 Roadmap was to avoid dispersing the know-how acquired by industry from the ITER design and construction. What plans have been made by EUROfusion to cope with the problem caused by delaying the start of EDA by ten years?

Q9 Taking into account the aggressive schedule of China for the CFETR construction, how can the present leadership position of Europe in Fusion be maintained in the revised Roadmap?

Q10 What is the schedule presently envisaged for narrowing down the blanket concepts?

Q11 Which steps is EUROfusion taking to orient the Test Blanket Module program in ITER to provide additional input for the DEMO design finalization?

Q12 The Roadmap advocated for the development of FM steels for DEMO out of the High-Temperature steels developed within the fission research. How is this development progressing?

Q13 The E&Y review pointed out the lack of a design authority for the DEMO CDA. How is this compatible with the implementation of a project oriented activity? In the comments to E&Y EUROfusion mention the experience of GenIV with a strong team of 500 people on site. Is EUROfusion considering to put together a similar effort on the Garching site? (see also Q13 below on lack of PMU leadership of the implementation strategy)

Q14 In relation with the choice of investigating different Power Plant layouts, what resources are planned to be devoted to this activity in H2020 and does this compare with those planned in the grant for the DEMO design?

Q15 Following the PEX assessment on mid October 2016, what is the strategy of EUROfusion with regard to the risk-mitigation strategy on Mission 2?

Transition from EFDA to EUROfusion

Q16 The review made by E&Y has pointed out the lack of PMU leadership of the implementation strategy and, more generally, an attitude to see the PMU/Task Force leader/Project leader role as that of referee or back-office. How is this compatible with the implementation of a project oriented activity such as that envisaged in the Roadmap?

Q17 Is the EUROfusion organization capable of steering the effort of the European fusion laboratories on the DEMO R&D activities?

Q18 Who do Project Leaders/Task Force Leaders respond to?

Q19 What were the administrative costs in FP7 including those of the EFDA system (CSU)?

Q20 What are the current and projected administrative costs in the H2020 for the monitoring of the EUROfusion grant.

Q21 What are the current PMU costs, the coordinator costs and those recognized as administrative costs of the beneficiaries?

Q22 What were your administration costs of the EFDA/CoA programme and how do these compare with the current and projected administration costs associated with EUROFUSION? Are there specific administrative barriers that can be overcome?

Q23 What are the steps to prepare the annual Work Programme?

Q24 What are the quantitative indicators that have been used to show how this change has impacted on the quality and quantity of the scientific production?

Q25 What quantitative indicators have been used to measure the increased focalization of the Medium Size Tokamak experimental programme around the most urgent ITER R&D needs in going from EFDA?

Q26 What, broken down by Work Package, is the budget committed up to the end of 2018 and the amount of that has not yet been committed?

Q27 How does this compare with the budget breakdown foreseen in the grant proposal?

Q28 How is the balance struck between the desire to get the maximum participation of Member States, the delivery of excellence and the need for effective and efficient use of research funding to deliver the goals of the roadmap?

Q29 What analysis has been done to assess the costs on Beneficiaries to administer the need to have the widest possible collaboration across Member States, and what are the implications for the large and small fusion research labs.

STAC and Enabling Research

Q30 What is the rejection rate of the Enabling Research projects?

Q31 How does STAC assess the achievements of the Enabling Research projects and the effectiveness of this programme to promote excellence and innovation?

Q32 What are the main conclusions that can be drawn for the projects that are coming to an end now?

Q33 What is the distribution among the EUROfusion members of:

- number of principal investigators,
- manpower resources (ppy), and
- hardware (euros).

Q34 Are the new Member States benefitting from the Enabling Research process?

Q35 How does STAC deal with conflict of interest both for its internal work and the ER assessment?

Q36 Is a declaration for conflict of interest requested from each STAC member?

Q37 Have you made a comparison between the ER selection process and the similar processes managed by ERC in terms of success rate, complexity of the process and referee's effort (average per proposal)?

Education and training.

Q38 How is this being implemented? Do you have indicators that show that this programme is indeed promoting the Universities to adapt their curricola.

Q39 How many PhD students have been supported since the start of EUROfusion and how is the number is evolving with time?

Q40 How is the fusion relevance of individual PhD project assessed to check that the link with fusion is not "marginal"?

Q41 Do you rank a PhD proposals e.g. according to quality or to relevance for the Roadmap?

EUROfusion added value

Q42 What is the European added value of the EUROfusion programme? Can you compare it with EFDA/CoA?

Governance

Q43 Do you think that the present system is missing a body like the old CCE-FU in which strategic issues related to fusion were discussed at Member State level with EFDA and F4E Leadership present as standing experts? What system would you suggest for a better coordination within the existing fusion governance?

17.2. Annex 4.2 Questions to Fission Stakeholders

Questions to Ernst&Young (EY)

- Questions with particular focus on the relevance, effectiveness, efficiency and EU added value of the fission part of the Euratom Programme

Questions to Commission services

- Response to the recommendations of the FP7 & FP7+2 ex-post evaluation

- The relevance of the Euratom funded fission research to the delivery of the objectives of the Euratom Programme 2014-18.
- The effectiveness of the Euratom funded fission research in meeting the objectives of the Euratom Programme 2014-18.
- The efficiency of the fission part of Euratom Research and Training Programme 2014-2018
- The EU added value of the fission part of the Euratom Research and Training Programme 2014-18.

Questions to fission project stakeholders (Heracles/ CONCERT/ MELODI/ MYRTE/ ESSANUF/ CORONA-II/ JOPRAD/ ANNETTE/ SNETP)

a) General questions

- The relevance of the *[PROJECT]* to the delivery of the nuclear safety/radiation protection objectives of the Euratom Programme
- The effectiveness of the *[PROJECT]* in meeting the nuclear safety/radiation protection objectives of the Euratom Programme
- The EU added value of the *[PROJECT]*
- Training activities within the *[PROJECT]*
- Progress to date in the delivery of the *[PROJECT]* objectives

b) Project-specific questions to MYRTE

- The Efficiency of the MYRTE project

c) Project-specific questions to MELODI:

- How has the 2014-2016 Euratom project "CONCERT - Integrating radiation research in the European Union" impacted on MELODI?
- Has this project led to a better integration of the radiation protection scientific community in the EU?
- What achievements have been delivered so far and what are likely to be delivered over the course of the 2014-18 programme?
- Do you think these achievements, with a total expenditure of €27m, represent value for money and if so, why?
- How do you think this work will improve our understanding of the impact of exposure to low doses of radiation so that realistic risk assessments can be made in the analysis of nuclear reactor or nuclear fuel cycle facility safety?
- How will this work impact on radiation protection regulatory requirements / standards?

18. ANNEX 5 FUSION ROADMAP TECHNICAL ACHIEVEMENTS

The Fusion Roadmap is articulated in eight Missions. In the following the main progress is summarized. The results involve the combination of experimental effort, theoretical simulation and modelling, and design work.

Mission 1. Development and qualification of **plasma regimes of operation** for ITER and DEMO.

Performance optimization with metallic wall has been progressed closer to ITER conditions. Stationary operation that avoids tungsten accumulation in the plasma core - a potential problem for ITER - has been established both in JET and ASDEX-U. Energy confinement quality relevant for ITER has been achieved on JET both for the baseline H-mode regime of operation (up to 3.0 MA) and the hybrid regime at higher normalised plasma pressure.

Identical discharges with metallic walls have shown a 25%-30% reduction of the L to H power threshold, P_{L-H}, in ASDEX Upgrade and in JET - if confirmed on ITER this result would significantly increase its margin of success.

Mitigation and control of disruption and runaway electrons. Mitigation of disruptions is a requirement for safe ITER operation. The use of Massive Gas Injection (MGI) for disruption mitigation became mandatory on JET for operations with metallic walls and is integrated in the scenario development. Using the JET disruption mitigation system, the vessel forces during vertical displacement of disruptions could be reduced by 40% and the asymmetric forces fully mitigated.

Control of edge instabilities. Substantial mitigation of Edge Localized Modes (ELMs) is required on ITER to avoid damage of the plasma facing components. Full ELM suppression has now been demonstrated in low collisionality discharges at higher triangularity on ASDEX Upgrade as part of a joint experiment with researchers on DIII-D (GA, US).

Analysis of the transient heat loads during mitigated and non-mitigated ELMs in JET, ASDEX-U and MAST have allowed a quantification of the analogous loads in ITER.

Preparation of the ITER non-active phase. A dedicated helium discharge campaign was carried out in ASDEX Upgrade in 2015 to investigate the suitability of He for non-nuclear plasma operations in ITER.

Plasma operations with high radiated power. ITER and DEMO need to radiate between 70% and 90% of the heating power in order to reduce the heat load on the divertor to tolerable levels. Regimes of operation with high radiated power have been established both on JET (75%) and ASDEX-U (90%) through impurity seeding. However plasma confinement is still below the ITER requirements.

Preparation for the EU participation in JT-60SA. Feasibility studies of JT-60SA transition to tungsten PFCs, with simulations in the presence of a W divertor and tests of PFC coatings on EU high heat flux facilities have been performed. As a result, a DEMO-relevant test on JT-60 SA of the compatibility of plasma operation with a full tungsten wall is now being considered in the JT-60SA baseline research plan around 2027.

Mission 2. Development of **heat exhaust systems** capable of withstanding the high thermal and particle loads of the plasma facing components of ITER and DEMO.

Tritium retention with the ITER plasma facing materials. Both post-mortem analysis of retrieved plasma facing components and gas balance studies in ASDEX-Upgrade and JET have demonstrated a significant reduction (by factor of 10-15) of the deuterium fuel retention with metallic first walls as compared to the previously used carbon based first walls.

Operation with molten tungsten in ITER. Deliberate shallow tungsten melting has been produced on JET using protruding lamellae. The experiment has shown that the consequence of melting can be tolerated for JET operation and that the JET results indicate tolerable consequences also for ITER operation.

Preliminary design of the DEMO divertor. The design and technology development of the DEMO divertor based on the same engineering approach as the ITER divertor has been started in a specific project. A required margin against heat load excursions limits the water coolant temperature of the plasma facing components to 150°C or lower. Although, the neutron damage in DEMO is higher than in ITER, the effects on the CuCrZr properties is not expected to be a limiting factor for the design in the temperature range of interest. Alternative technology solutions of the divertor target PFC are being investigated to further improve the heat flux performance such as advanced heat-sink materials (e.g. Cu-W composite). The first batch of mock-ups has been successfully fabricated and is being tested where the results achieved so far demonstrate the high fabrication quality and the envisaged performance. Extensive neutronic, electromagnetic, thermal and mechanical analyses have been carried out for both the divertor cassette and the plasma facing components.

Definition of the scope and feasibility of a divertor tokamak test facility. Work has progressed in this area to assess the DEMO relevance of divertor configurations presently investigated at proof-of-principle level on existing tokamaks. However, a decision on the scope and feasibility of a divertor tokamak test facility is still pending.

Mission 3. Development of **neutron resistant materials** capable of withstanding the 14MeV neutron damage.

The qualification of the main candidates as DEMO structural materials - the ferritic-martensitic steel EUROFER, CuCrZr as heat sink and tungsten as plasma facing materials - has been started.

Irradiation campaigns are underway to fill the database of irradiated materials. Post-irradiation examination data shall be available latest 2020 for EUROFER97 (the version of EUROFER produced in 1997) irradiated up to 20dpa, CuCrZr up to 5 dpa, both at various temperatures, complemented by irradiation of tungsten options at 1dpa. Data will feed into the Material Property Handbook, where updates of engineering data are regularly released.

The goal of increasing the working temperature window of EUROFER is also being pursued - reducing the low temperature boundary is crucial to make it possible the use of water as blanket coolant. Approximately three dozens of new alloys have been produced at industrial scale. The results so far demonstrate that the development of improved 9Cr steels for high temperature applications is a realistic goal: a significant improvement of EUROFER-HT mechanical properties can be obtained at the expense of the degradation of fracture properties at the lower temperature end with either of the following options: (i) modified heat treatments (compared to standard EUROFER97), (ii) optimized chemical compositions or (iii) by thermo-mechanical treatments. The development of 9Cr steels for low temperature applications with improved (fracture) properties, turned out to be really challenging. Some improvement of (impact) properties have been obtained and new treatments on optimized compositions may yield more significant gains, all to be confirmed und irradiation conditions. It was found that double austenitization at 1020°C was the optimum treatment in terms of grain size reduction, which resulted in a reduction of the ductile-to-brittle transition temperature of some 10 K (up to ~30 K at the best).

After a first down-selection, ion irradiation in JANNuS and neutron irradiation experiments up to 2.5 dpa, where results are expected by 2020, have been launched.

In the frame of the development of advanced High Heat-Flux Materials there has been significant progress in various areas, including:

Particle reinforced W composites via powder injection molding.

Short and long fiber reinforced W materials with optimized fiber/matrix interface.

W-particle and fiber reinforced Cu-based alloys as well as quarternary CuCrZr-(V,Ta) alloys.

Multi-metal W-laminates (W/Cu, W/Ti and W/V – the two latter with implemented interlayers acting as diffusion barriers) and the newly set-up W/W laminate option.

Thermal barrier layers with a wide range of available thermal conductivity and W/Cu-Functional Graded Materials.

The amount of available data from detailed mechanical, thermo-physical and high heat flux characterization is steadily increasing and transferred to the newly established material database as basis for the Material Property Handbook.

Mission 4. Development of components to ensure **tritium self-sufficiency** of DEMO.

The design of the four breeding blanket concepts selected as promising candidates for this program is in progress and the supporting technical documentation is almost completed, including the definition of all the interfaces with other DEMO blanket-interdependent systems (i.e. remote handling, balance-of-plant and tritium systems). The conceptual design of the associated tritium extraction and removal systems and of the largest ancillary systems (e.g., the PbLi loop for the liquid blanket concepts), including the preliminary layout and space allocation, are available and are being used to perform the required studies. The associated R&D programme has progressed especially in the following areas: production and characterization of tritium permeation and corrosion barriers and of suitable tritium extraction technologies, manufacturing and welding of EUROFER sub-components, characterization of double-wall pipes for water cooled concepts, fabrication and characterization of functional gradient tungsten layers for the first-wall, fabrication of advanced functional material for solid breeder blankets.

A strategy for realigning the ITER Test Blanket Programme and the EUROfusion Breeding Blanket Programme is being elaborated by a Working Group composed of representatives of key EU laboratories involved, EUROfusion and F4E and an independent Review Panel of external experts is addressing, in support to the Working Group activities, a specific list of technical points.

A preliminary design layout and performance analysis of the DEMO balance-of-plant (primary heat transfer system (PHTS), energy storage system (ESS) and power conversion system) based on the use of either helium or water as coolant for the breeding blanket has been performed. The He-PHTS design has been integrated into an initial design of the DEMO tokamak building together with a few other large systems and plants (some already designed for DEMO, some others extrapolated from ITER, such as NBI, Magnet Feeders, Cryoplant and cryodistribution lines etc. A similar, layout is being developed for a water cooled blanket PHTS and both will be used to conduct initial design integration studies, safety, technology feasibility, and cost analyses

Mission 5. Implementation of the **intrinsic safety features of fusion** into the DEMO design.

Work in this area involves the definition of the design and licensing requirements, the integrated safety analysis/source terms/models and codes, and the analysis of radioactive waste management. The relevant documents defining the *General Safety Principles* and the *Plant Safety Requirements Document* have been released. The UK and French nuclear regulators have been approached to define a possible strategy for the licensing of DEMO. In radioactive waste management the main issue is the detritiation of solid materials. A number of possible technologies has been identified.

Mission 6&7. **Integrated DEMO design** and system development and **competitive cost of electricity**.

The DEMO design activity has started in a professional manner with a thorough examination of system integration aspects supported by a systems engineering approach. Systems codes that model the interplay of key systems and subsystems of a fusion plant have been further improved and benchmarked with similar tools developed in Japan and realistic plasma physics and engineering assumptions have been used to derive the reactor design parameters of various DEMO design options. A baseline architecture has been established that integrates all the major DEMO sub-systems into a coherent plant concept, Establishing system requirements and a baseline concept is mandatory, as this should drive R&D - not the other way round. A stakeholder group has also been set up in order to gather the view of industry and utilities on the mission of DEMO, and to establish the high level requirements and constraints. Their involvement culminated in the definition of the Stakeholder and Plant Requirements Document.

In the area of DEMO superconducting magnets, three toroidal field coil winding pack designs were studied, each with various pros and cons (cost, integration, manufacture methods, etc.). All the WP designs have opted to depart from the radial plates approach adopted by ITER- a significant simplification that offers the possibility of cost reduction for one of the largest DEMO component. Mechanical studies have so far shown that this is possible. Two DEMO-relevant TF conductor samples were fabricated (React & Wind + Wind & React routes) and one tested in the EDIPO facility, and one tested in the SULTAN facility. These tests demonstrated that these conductors do not show degradation with EM cycles and have a lower level of strain than in ITER – which will lead to more robust and efficient winding pack designs.

Several studies were carried out on high temperature superconductors, from tapes (transport critical properties, sustainment to irradiation, and mechanical properties) to cables (four types of cable concept evaluated) including tests and analyses.

In the area of Remote Maintenance, significant progress has been made on the maintenance of the blanket segments, the most critical element to ensure high-availability of a fusion power plant. The vertical-large sector maintenance scheme has been selected from different options as the most appropriate to meet the high-level requirements. The different challenges of this scheme have been identified. These are related to the large size/weight of the components to manipulate, the presence of a large number of high-pressure service connections and the extreme conditions due to the nuclear environment. The project aims at defining the remote maintenance strategy by 2018.

A specific project for the DEMO H&CD systems has been launched. The R&D activity focuses on the critical components of each of the DEMO systems under consideration.

Mission 8. Stellarator development.

The W7X facility has started in 2015. Its operation and its exploitation involves many of the EUROfusion laboratories. The main objective of the first campaign was the integral commissioning of plasma start-up and operation using an electron cyclotron resonance heating system and an extensive set of plasma diagnostics. The performance of W7-X and the science output during the first campaign exceeded all expectations.

19. Annex 6 European Added Value

European Added Value Criteria (modified from *[Ref 81]*)	
Criterion	**Applicable to Fusion, Fission, RP and E&T**
Scale too big for Member States to handle alone	yes
Financial benefits: a joint approach would be advantageous	yes
Combines complementary MS efforts to tackle European problems	yes
Cohesion of European markets	yes
Unification of European S&T across borders	yes
Promotes uniform laws and standards	yes
Mobilising EU potential at European and global level by coordinating national and EU programmes	yes
Contributes to implementing EURATOM policy	yes
Contributes to societal objectives (later 'grand challenges')	yes
Exploits opportunities for the development of European science, technology and industry	yes
Structures the EU R&D community and 'fabric'	yes
Improves quality through exposure to EU-wide competition	yes (n/a to E&T)

A more recent source defines EAV more relevant to research and research infrastructure:

Critical mass

Research activities are often of such a scale and complexity that no single Member State or company can provide the necessary financial or personnel resources, and hence need to be carried out at a EU level in order to achieve the required "critical mass". This occurs where a large research capacity is needed, resources and expertise must be pooled to be effective (e.g. for areas such as rare diseases) or where there is a strong requirement for complementary knowledge and skills (e.g. in highly inter-disciplinary fields).

More efficient use of scarce resources

Large scale demonstration projects and major research infrastructures are better planned and funded at European level. Instead of supporting multiple national flagship demonstrators and infrastructures, planning and competitive selection of projects and better sharing of these infrastructures and demonstration plants at EU level are a more cost efficient use and provide better value for money. Alignment of research agendas at EU level can also help to increase impact of scarce resources.

Reducing financial risks

EU funding can support entrepreneurs to undertake risky projects in R&I through financial incentives;

Increase competition in research

EU funding helps to promote more intense competition in research leading to higher quality proposals and excellence.

Improving S&T capabilities

EU funding contributes to access to knowledge, to training, cross border mobility and international research careers. Research teams wishing to develop their S&T capabilities in specific fields can participate in top trans-national teams, benefit from learning and synergies, and so become recognised world centres of excellence;

Improving industrial productivity and competitiveness

EU funding leads to a better exploitation of S&T capabilities within industry, including in SMEs, by addressing significant industrial challenges, by integrating technologies, and by enhancing the access of SMEs to new markets and users,

Promote human capital and high skills availability

By generating new knowledge and international mobility, human capital can contribute directly to innovation through the spillovers produced by skilled workers who diffuse their knowledge throughout their workplace and the wider environment.

Leverage on private investment

Through EU research schemes, private companies can collaborate with foreign partners at a scale not possible at national level, which encourages them to invest more of their own funds than they would under national funding schemes;

International attractiveness

International attractiveness of the European Research Area and international breath of European research.

Boost EU competitiveness in markets outside Europe

More openness to the world also implies more opportunities for entry in foreign markets, including young firms having a comparative advantage in market-creating innovation;

Assistance in scaling up

Internationally oriented start-ups and SMEs with great breakthrough innovation potential are most effectively and efficiently identified and supported at EU level.

EU scale dissemination of results

It is more efficient to disseminate the results of research and innovation at an EU level - to users, industries, firms (SMEs in particular), citizens, etc. – leading to a better exploitation of research and innovation results, and giving a larger impact than would be possible only at Member State level.

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