Priorities for European nuclear research and training

An STC Opinion

Euratom Scientific and Technical Committee

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FOREWORD

The Euratom Scientific and Technical Committee (STC), together with the European Economic and Social Committee and the Committee of the Regions, is an advisory body established by the European Treaties. Since 1958, it has delivered opinions on relevant scientific and technical issues, in particular, in relation to the Euratom research and training programme.

The members of the STC are the highest-level nuclear experts, appointed in a personal capacity by the Council of the European Union. They serve a five-year term with the last completed mandate of the Committee running from November 2018 to November 2023.

This document is divided in two parts. Part A is the Key Messages addressed to policy- and decision-makers. Part B is the Legacy Document addressed to a more specialist audience. The document was adopted at the STC plenary meeting of 12 October 2023. The members of the STC at the time of its adoption were:

Carlos Varandas (Chair),
Michel Bourguignon (Vice-Chair),
William D'haeseleer (Rapporteur on this document)

and

Evgenia Benova
Daniela Diaconu
James Drake
Michel Feider
János Gadó
José Marques
Carlos Hidalgo Vera
Kyriakos Hizanidis
Petri Kinnunen
Marco Kirm
Jan-Leen Kloosterman
Wolfgang Liebert
Macarena Liniers-Vázquez
Jens Peter Lynov
Gabriel Marbach
Peter Ian Mitchell
Thomas Mull
Antonio Naviglio
Thomas Pardoen
Milan Patrik
Pavol Pavlo
Aldo Pizzuto
Eric Proust
Demetrios Sakkas
Emmanuel Sinagra
Borut Smodiš
Józef Sobolewski
Uwe Stoll
Thomas Sunn Pedersen
Tonči Tadić
Alexandru Toma
Beata Tyburska-Pueschel
Egidijus Urbonavičius
Ioan Ursu
Pavel Veis
Roman Zagórski
Roberto Zanino
Sándor Zoletnik

The preparation of this document was facilitated by the STC Secretary, Frederick Mariën, and his team, Franklin Mamo and Tomasz Sliwinski from the Euratom Research Unit of DG RTD in the European Commission.

Part A

Key Messages for policy- and decision-makers

1. This opinion of the Euratom Scientific and Technical Committee (STC) is the 'legacy' document of the current mandate of the STC (2018-2023) addressed to the next mandate, the Council and Member States, as well as the European Commission as it prepares its proposal for a Euratom Research and Training Programme 2026-2027. This document brings together reflections of the current STC mandate and indicates where action could be required in the future for better developing research and education and training in the interest of all Member States.

2. The new geopolitical and energy realities call for a degree of 'strategic autonomy' for the EU when it comes to different energy technologies and non-energy applications using ionising radiation. The STC is convinced that Europe has lost its leading competence in the field of nuclear fission. This may affect the development, engineering, operation and maintenance of nuclear facilities. This leadership is also needed to ensure Europe's continued global influence on nuclear matters and to maintain the EU's position as the international reference for nuclear safety and radiation protection standards.

3. Developing strategic autonomy requires, first and foremost, a close European collaboration to increase education and training measures to reinforce the workforce and competence in the nuclear field. A sustained effort is essential for the next generation of scientists and engineers needed to continue safely operating infrastructures, in the fission and fusion areas as well as in non-energy fields (e.g. medical).

4. The STC recommends that the education and training challenge should be treated by the Commission holistically, trying to bring together the different threads (fission, fusion and non-energy) towards the development of a comprehensive European Nuclear Competence Area. For this to happen, there is the need for a strategic plan and a roadmap with clear milestones and outcomes to implement that plan.

5. The Commission is invited to carefully reflect on nuclear fuel autonomy in the EU. Euratom should explore secure ways to assure guaranteed nuclear fuel delivery both for existing and future fission reactors which is not the case today in terms of uranium sources. Euratom should also investigate the merits of developing and deploying facilities to ensure own production and manufacturing capability of standard as well as innovative advanced fuel assemblies. This applies to fission-dedicated fuels as well as to future fusion-fuel resources.

6. Lack of strategic autonomy is also a consequence of the reduction of the Euratom Programme's budget in real terms over the past decades. While the budget for the EU Framework Programme has nominally increased by 490% since 1998, the budget for fission research grew only by a mere 39% over the same period. Even more worrying, the budget for the present fission programme (2021-2025) was reduced by 30% compared to its immediate predecessor when, during the same period, Horizon Europe's was increased by 22%. Member States should consider a substantial increase to the budget of the Euratom Programme to bring it in line with the trend of EU Framework Programmes and ambitious climate policy targets.

7. The STC underlines that for the safety of existing and future nuclear systems, a broad range of Euratom-funded safety research must be implemented as a priority for the continued operation and the eventual decommissioning of existing reactors but also for the licensing of their replacements. Euratom-funded research is needed not only for issues such as ageing processes and material integrity but also for the development of new accident-tolerant fuels and safety-related modelling.

8. More attention needs to be directed to small modular reactors (SMRs), with a priority on European designs, to regain leadership and some degree of strategic autonomy. Euratom's role should primarily concentrate on the development of the scientific basis for safety

assessment and alignment of regulators' views on these new technologies. Interested Member States and industry should focus their resources on research on the development of those designs which could be deployed in the shorter term with the objective of streamlining their licensing based on the best regulatory and institutional standards.

9. A continued but more result-oriented administrative effort must be pursued by Euratom to establish better-aligned regulatory-safety and radiation-protection standards and rules within the EU. The extra effort must include a timely initiative to start common training and knowledge transfer to nuclear regulators on the science and technology of new systems. The STC invites the Commission to intensify the dialogue with ENSREG, WENRA and HERCA for this purpose.

10. The 2022 landmark achievement from EUROfusion at the Joint European Torus (JET) facility is a clear demonstration of the sound scientific fundamentals of magnetic confinement fusion and, therefore, the potential for fusion to deliver low-carbon energy.

11. The STC underlines that the current European fusion roadmap will not lead to commercial electricity generation in the short term. The STC recommends restructuring the fusion part of the Euratom Programme, considering various paths with differentiated risks, for a much faster development of fusion energy. European actors must update the fusion roadmap and identify the critical bottlenecks requiring an increased and sustained effort involving industry, especially in the design and safety and licensing activities. Industry should be entrusted with the practical organisation and management of construction activities and with helping to address and resolve the critical issues and risks in building the first fusion power plant. Industry's leading role in key aspects of the development of fusion power will help focus the research community on results, costs and schedule.

12. The STC recommends investigating how a Public-Private Partnership (PPP) should be embedded in EUROfusion's holistic approach to address the remaining fusion technological challenges. The STC notes that boosting the commercial development of fusion energy using a PPP would imply new challenges for the organisation and governance of the fusion part of the Euratom Programme. The implementation of this transition should begin with the extension of the Programme (2026-2027).

13. We are on the cusp of a global race for fusion energy development and the EU shares with the world, in line with the ITER agreement, most of the relevant Intellectual Property (IP) developed for the ITER facility. It is crucial that IP for key technologies is not only developed but also protected and held in Europe.

14. For radiation protection, the STC recommends more multidisciplinary and integrative research, possibly under the PIANOFORTE Partnership, on the basic mechanisms of the biological effects of radiation. This would study DNA damage response and risk evaluation applicable to all situations of exposure. Notably, the distinct individual response of humans to a variety of so-called genotoxins, such as ionising radiation and numerous chemicals, merits much more research attention.

15. The STC asks the Commission to launch, in the next three years, a concrete collaborative research action on cancer and degenerative diseases between the Euratom Programme and the Health Cluster of Horizon Europe. These diseases are the two main causes of human morbidity and mortality due to repeated exposures at low doses to a variety of genotoxic compounds. A close cooperation in this area between the Euratom Programme and Horizon Europe would be very relevant to scrutinise the mechanisms of these diseases, to develop specific prevention measures and treatments and to treat cancer through radiotherapy (external or internal) alone or in combination with chemotherapy or labelled antibodies. Such collaboration

should receive appropriate combined funding from Euratom and Horizon Europe.

16. The next STC should pay closer attention to developments in the safe management of radioactive waste and spent fuel under the Euratom Joint Programme on radioactive waste management, EURAD. Support should be provided to Member States in the design and implementation of their national programmes for waste management as required by the Euratom Nuclear Waste Directive. The Euratom Programme plays a strategic role in delivering research and tools needed for implementation of deep geological repositories, addressing, at the same time, important safety concerns.

17. As part of satisfactorily resolving the nuclear waste challenge, the next mandate is invited to revisit and re-examine the value of partitioning and transmutation, be it on its own right through autonomous self-standing facilities or as part of the advanced (Generation-IV type) nuclear fission facilities with fast neutron spectrum.

Part B

Legacy Document of the 2018-2023 STC

ACRONYMS AND SPECIFIC TERMINOLOGY USED

ACER	Agency for the Cooperation of Energy Regulators (for electricity & gas markets)
ATF	Accident-Tolerant Fuel
Council of the EU	EU Decision body – National Government Ministers per Policy Area
ENEN	European Nuclear Education Network
ENSREG	European Nuclear Safety Regulators' Group
ENTSO-E	European Network Transmission System Operators - Electricity
E&T	Education and Training
Euratom	European Atomic Energy Community
EUROfusion	European Consortium for the Development of Fusion Energy (research bodies)
European Council	EU Decision body – Heads of State and Governments
F4E	Fusion for Energy – engaged in delivering Europe's contribution in the various projects involved (including ITER)
GHG	Greenhouse gas(es)
HERCA	Heads of the European Radiological Protection Competent Authorities
IAEA	International Atomic Energy Agency
IP	Intellectual Property
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
JRC	Joint Research Centre
LLNL	Lawrence Livermore National Laboratory
LTO	Long-Term Operation
MEMS	Micro-electro-mechanical systems
MIT	Massachusetts Institute of Technology
MSCA	Marie Skłodowska-Curie Actions
NEA	Nuclear Energy Agency (part of the OECD)
NORM	Naturally-occurring radioactive material
OECD	Organisation for Economic Cooperation and Development
PPP	Public-Private Partnership
RD&I	Research, Development and Innovation
SCHEER	Scientific Committee on Health, Environmental and Emerging Risks
SMR	Small modular reactor
STC	Scientific and Technical Committee (defined in the Euratom Treaty)
TRL	Technology Readiness Level
TSO	Technical Support Organisation (Nuclear Regulators)
WENRA	Western European Nuclear Regulators' Association
WG	Working Group

1. AIM OF THE LEGACY DOCUMENT

This **'Legacy' document** is issued by the current **Scientific and Technical Committee (STC)** with a mandate covering the period 2018-2023. The audience to which it is addressed consists, first and foremost, of the new and reappointed members of the incoming STC (with a mandate from November 2023 to November 2028). However, this document furthermore targets a broader audience within the EU Institutions and the EU Member States. More specifically, these messages are also intended for the Commission to prepare the proposal for the Euratom Research and Training Programme 2026-2027, as required by Article 7 of the Euratom Treaty. At the same time, the document serves as an **opinion** of the STC's thoughts to the Member States and the Council of the EU. For those familiar with the latest activities of the 2018-2023 STC, the document is a refresher/reminder and a starting point for the new mandate. For the newcomers and other interested parties, these legacy messages recall the specific tasks and role of the STC as well as its aspirations and explains the context in which it is supposed to operate.

2. SETTING THE SCENE – THE ROLE OF THE STC, ITS IMPORTANCE AND RELEVANCE

At the beginning of the 2020s, **nuclear energy applications** are back on the overall global agenda and unquestionably also in Europe. The ever-more alarming messages on anthropogenic climate change, as expressed by the latest three-volume IPCC Sixth Assessment Report (AR6), call for urgent action to mitigate greenhouse gas (GHG) emissions worldwide.[1] To complicate matters further, as triggered by geopolitical tensions, the recent re-discovery and recognition of security of energy supply as a basic necessity has awakened Europe from its energy-related hibernation. Moreover, the broader notion seems to be gaining ground that in the real competitive world some degree of strategic resource and technological autonomy is called for. As a result of these pressing circumstances, European policy makers and public opinion seem to realise that **all necessary trustworthy means** must be allowed and even stimulated/encouraged to contribute towards clean, reliable/secure and affordable energy provision, **without a priori exclusion of any technology.**

There are also the **non-energy nuclear applications,** especially in the **medical and health** context where the applications of **radioisotopes and radiopharmaceuticals** are of vital importance for diagnostic and therapy purposes. However, scrupulous attention is to be paid to the **radioprotection aspects** of these rapidly growing medical applications, whereby a proper **risk assessment** is needed for optimising a judicious use of radiological medical diagnostics and treatments; especially for diagnostics, a proper genuine balance between the actual medical necessity to 'know' and the radiological burden due to overconsumption must be sought. Furthermore, and equally crucial, **timely supply of the required radioisotopes** is essential to match the growing global demand for the isotopes.

To better understand and address the challenges, European policy- and decision-makers, their advisors and relevant stakeholders at the EU institutional level and in the Member States, including the EU citizens, not only 'deserve', but 'require', solid i**mpartial scientific-evidence-based information on nuclear- and ionising-radiation related subjects.** Facts and figures, properly specified application boundaries, constraints and conditions, hypotheses and caveats are to be made explicit and where relevant put into perspective.

Hence the importance of the STC, as being the sole scientific and technical advisory body explicitly defined (i.e., formally enshrined) in a European treaty, specifically the **Euratom Treaty** of 1957 and its later revisions.[2] Interestingly, although in a different context but also facing daunting challenges in those times, the relevance and applicability of **a trustworthy consultative committee** as originally envisaged by the founders of Euratom in 1957 remains more pertinent than ever. The actual role of the STC is defined in the Treaty[3] and importantly, it is to be consulted by the Commission on its proposal for **'research and training' programmes in the nuclear fields** defined in Annex I of the Treaty, after which the Council decides by unanimity.

Furthermore, the Treaty entrusts the **STC** with appointing two groups of experts for establishing the basic standards for *'the protection of the health of workers and the general public against the dangers from ionising radiation'* (**Article 31 Group of Experts**), and for advising the Commission on *'any plan for the disposal of radioactive waste'* in the Member States *[including the assessment of the health impact of radioactive release from nuclear facilities]* (**Article 37 Group of Experts**).[4]

1 https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/; https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/; https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/;

2 See the consolidated version of the Treaty dd 2016, doi:10.2860/865952

3 The role of the STC is specified explicitly in Articles 4, 7, 8, 31 and implicitly in Article 13. It is defined in Article 134.

4 To be formally correct, the Treaty only requests the appointment of one Group of Experts (as defined in Article 31), since Article 37 refers to the same Group of Experts. However, right from the start, the STC soon realised that the group of experts appointed under the article 31 could not cover all the tasks in particular those under article 37. Therefore, at its meeting in October 1959, the STC established the Article 37 group of Experts, with also a broader scope as given in the square brackets above.

Having been defined in the original Euratom Treaty, the STC has executed its **advisory role for 65 years now**, since 1958.[5] It has assumed its role in accordance with the provisions of the Euratom Treaty and is expected to comply with those stipulations in the future.

It is important to recall the essential and unique role that the STC is to play in advising and informing not only the European Commission (to which it is formally 'attached' and which assures the Secretariat) but also the Council of the EU, the European Parliament and the Economic and Social Committee on nuclear-related matters. Obviously, the content-related **quality** and **substance** of the STC advice are the prime objectives but the **visibility** and **influence** of the STC should be enhanced considerably, requiring sufficiently broad **dissemination** of its opinions. In that respect, the STC itself should make every effort to **write valuable authoritative opinions to increase its appeal for the Commission services as their preferred/favourite 'advisory body' to be consulted** on all nuclear matters.

Notwithstanding the liberty provided by the Treaty in its Article 135 (following the article defining the STC) stating that 'The Commission may undertake any consultation and establish any study groups necessary to the performance of its tasks',[6] the Commission is strongly advised **not to bypass the STC** when taking decisions on nuclear matters. The Commission is best served by clear advice under the umbrella of the Treaty's explicit consultative Committee.

As mentioned, a paramount role of the STC is to provide advice to the Commission on all **nuclear research & training programmes** which, in practical language, encompasses also the development and innovation endeavours, as well as nuclear-related education, skills and competence development, knowledge transfer and management. It is crucial that the EU explores those subjects and routes that are most relevant for the EU as a whole. Granted, and even to be encouraged, that should occur in a spirit of **international scientific collaboration and open exchange** but without being naïve. Indeed, in the last couple of years, the geopolitical context has undergone a drastic change, leading to less international cooperation and intensified strive of regions for more autonomy in the fields of resources, technology development, and knowledge generation and valorisation. Therefore, the EU should **prioritise and concentrate on mastering itself the crucial insights and knowledge** of nuclear scientific principles, concepts and technologies. Furthermore, it must be understood that in a fair, competitive international environment, respect for generated **intellectual property** of all parties (publicly funded labs, private industry within the EU and outside of it) must be guaranteed and monitored. As a result, establishing the right portfolio of 'research and training' projects and commensurate public funding is a major task for the Commission services, thereby relying on the unique expertise gathered in the STC.

The STC members are suitably recognised as **'high-level experts'**, related to their personal expertise in nuclear-related matters but also in the double meaning of 'high level', i.e., both in depth and in breadth: in-depth knowledge of their nuclear-related expertise but also with a sufficiently broad helicopter view to assess the relevance of the nuclear matters for society (in overall energy matters, nuclear medicine, security, safety, radioprotection, etc). The STC considers it as its task to help the Commission promote the most important and relevant nuclear-related research and training projects (as requested by the Treaty), but the STC is not a body promoting nuclear energy as such. The STC **provides unbiased authoritative scientific and technical advice**, taking into account all aspects of the overall energy economy, as well as medical and industrial applications of radioisotopes,[7] so that justified nuclear-related ideas, suggestions and proposals are properly investigated as to their merits and challenges. That way, informed policy and political decisions can be taken based on the outcome of those scientific evaluations so that solutions for

5 The first STC was appointed in March 1958 and held its first meeting on 16 April of that year.

6 The text quoted is that of the consolidated version of the Treaty dd 2016 (doi:10.2860/865952); the original text in the Treaty of 1957 reads: 'The Commission may hold any consultations and set up any study committees necessary to the accomplishment of its task.'

7 See e.g., https://www.iaea.org/topics/industrial-applications: "Nuclear techniques are used to identify and assess the properties of different materials, measure pollution levels, sterilize and disinfect components, monitor and optimize industrial processes and change chemical, physical and biological properties to produce novel materials. Radiation can be used for analysing and processing a range of substances."

resolving the weaknesses and imperfections can be addressed.

In the same spirit, it is important to recall that the STC members are appointed **'in their personal capacity'**. They are formally appointed by the Council (hence by the Member States) after consultation with the Commission for a renewable mandate of five years. However, they do not represent their country or organisation. As the Treaty states: "They shall not be bound by any other instructions."

The STC decides by **consensus**, thereby paying much attention to understand and deliberate on initial minority positions in the final opinions so as to accommodate proper concerns. The STC realises that decision procedures by the Council are even more restrictive as they require unanimity for adoption of research programmes.

The STC takes note of the recent legislative developments regarding the '**EU taxonomy for sustainable activities'**.[8] In the light of establishing such taxonomy, the Commission launched an in-depth evaluation process resulting in a Delegated Act to include nuclear energy, subject to certain criteria, in the group of technologies which 'are in line with the EU climate and environmental objectives and which will help accelerate the shift from solid or liquid fossil fuels, including coal, towards a climate neutral future'. The technical assessment was based on a report drafted by the Joint Research Centre (JRC), considering the **'do no significant harm'** criteria of the Taxonomy Regulation. The report was reviewed by two expert groups, the STC's Article 31 Expert Group on Radiation Protection and the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER). Based on these inputs, the Commission has adopted its Delegated Act, which was published in the Official Journal on 15 July 2022 and applies as of January 2023.[9] Subsequent to adoption of the Delegated Act, there was a consultation with Member States, and following this, no blocking majority prevented the entry into force.

Realising the situation that **Member States are not aligned on their views related to nuclear subjects**, the STC wishes to stress that it is in every **Member State's interest**, also in those Member States not open to fission-generated electric and/or thermal power production, to be able to rely on a competent group of national and EU scientists for advice. Clearly, sufficient (in-depth and broad) nuclear-related research must be performed within the EU to remain on top of 'progressing insight and understanding', new developments and scientific breakthroughs. It will be crucial not only to follow-up current, established practices in existing facilities but it is expected that new initiatives will be launched in a diversity of subjects as there are current and future nuclear (fission and fusion) systems with new/different fuel cycles (upstream and downstream), their design and operation, safety principles, waste transmutation activities, radiological understanding and use of medical radioisotopes. All Member States must realise that nuclear technology deployed in other Member States or outside the EU also may have cross-border impacts (benefits and challenges), related to international transport of nuclear materials, nuclear medical radioisotopes, safety and radiological effects and combined nuclear waste repositories but also the behaviour of the electricity market.

The future STC must continue to understand and acknowledge the **political constraints** influencing decisions on funding for **Euratom research and training**. Due attention is to be paid to the varying – and possibly opposing or conflicting interests – of participating Member States in some areas, whether or not related to the scientific objectives of the projects. The STC is therefore advised to develop its opinions and recommendations in such a way that progress is most likely to be achieved. It is also important that the STC remains **proactive** with regard to giving advice and insists on **interacting** in a timely way with the Commission services to better understand what type of advice is requested and to collect from the Commission the necessary information and input documents to develop substantiated positions. Proactivity is ever more important in these times of shifting energy policy and market landscapes for nuclear

8 https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

9 Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities (OJ L 188, 15.7.2022, p. 1).

and of strong changes in the geopolitical context. That way, the STC can maintain and even increase its responsiveness to the needs of the European institutions.

3. WORKING METHOD AND PRACTICES OF THE STC

As a general rule or custom, the STC meets about twice a year (spring and autumn) in a plenary setting, in principle at the premises of the European Commission in Brussels. Under normal circumstances these plenary meetings are in-person. Because of the Covid pandemic that hit Europe starting in March 2020, only two physical plenary meetings were held in 2019. Since then and over the period 2020-2022, all plenary meetings have taken place online. As of 2023, physical meetings are planned but (for the time being) a hybrid meeting format is foreseen.[10] It will be up to the new STC to decide on its meeting practicalities.

To allow in-depth reflection, analysis and assessment on all subjects to be considered by the STC, (specialised) working groups (WGs) have been set up during the mandate 2018-2023, covering the following topics: **radiological protection** (including radiobiology), **nuclear fission** (including the fuel cycles upstream & downstream and safety), **nuclear fusion** (including technological implementation towards fusion-generated electric power), **nuclear fission research infrastructures**, **non-energy nuclear applications** and **nuclear-related knowledge, skills, competences, education and training**.

The original idea was to allow for a dynamic reorganisation of the WGs, to adapt to changing circumstances, if so desired or deemed necessary. However, due to the Covid- and energy-crisis disruptions, which unquestionably led to new 'situations' but also to quite some confused and uncertain societal context, it was decided not to change the structure of the WGs and to leave it to the new STC mandate to continue or take new initiatives. To be able to obtain the right advice from the right experts, the future STC may propose to organise dedicated **scientific workshops** and **scientific hearings** and **request frequent reporting** on Roadmaps and from Joint Undertakings, Platforms and Partnerships. From an organisational point of view, the STC could hold meetings at other venues such as, for example, JRC sites.

As part of the context for these legacy messages, the reader can consult the **'STC Strategic Work Plan 2019-2023'**.[11] It describes the items of interest for, and ambitions of, the current STC mandate 2018-2023, henceforth sometimes abbreviated as STC(18-23).

10 The STC meetings on 6-7 March and 12 October 2023 were in-person meetings in Brussels.

11 STC-2019-11 REV 1, 2 March 2020; a copy can be requested from the Secretariat at RTD-EURATOM-STC@ec.europa.eu.

4. STC CONSIDERATIONS ON CURRENT AND FUTURE ISSUES FOR THE EURATOM RESEARCH AND TRAINING PROGRAMME

These considerations **express the latest reflections of the current STC** on some particular STC-relevant subjects. Simultaneously, the messages suggest possible subjects for further examination by the 2023-2028 STC and the research and training programme in the nuclear field carried out by the Commission. This document basically establishes the **concluding opinion of the STC(18-23)**.

In order to convey the appropriate context to the next STC mandate, the current STC has summarised its own thoughts and considerations on present-day and future nuclear research and training subjects, f**ormulated as answers to some pertinent questions**. The questions have helped as a 'navigational aid' ('fil rouge') for examining what has been accomplished during the current mandate compared to what was written in the STC Strategic Work Plan 2019-2023. Where appropriate, the assessment made by the STC(18-23) concludes with recommendations for the STC(23-28).

The STC Strategic Workplan 2019-2023 dates from just before the first lockdown for the Covid pandemic. Recent geopolitical tensions, together with the global energy crisis, tendencies to limit international collaboration and protectionist reactions in many domains, including in research, development and innovation (RD&I), require **a different framework for European positions on RD&I**.

However, notwithstanding the recent shocks and disruptions it is still fundamentally imperative that the EU (and, in fact, the whole world) moves towards a prosperous society by 2050 with a balanced energy trilemma: decarbonised, affordable and secure energy provision. It must be clear that these challenges remain, but **the playing field has changed dramatically**.

Because of the Covid disruption, the new geopolitical context and the energy crisis, it is understandable that not all ambitions of the current STC Strategic Work Plan 2019-2023 have been met and that a new emphasis in certain domains is called for. **It is therefore very important to outline those priority subjects that the next STC should preferentially concentrate on.**

In a first subsection 4.1, five fundamental issues are discussed, thereby expressing the thoughts and views of the current STC, with explicit or implicit suggestions and advice towards the STC(23-28). As said above, the issues were triggered via carefully formulated questions. These questions were seemingly formulated in a general way, but great attention was paid to the **wording** to make sure that every word has its importance.

In a second subsection, 4.2, some elements of the Legacy Messages of preceding STC mandates are reiterated because they deserve to be repeated and emphasised again, be it for their de-facto permanent nature or for their increased relevance in the currently changed international circumstances.

4.1 Paramount/predominant topics to be addressed

A. Safety and radiation-protection research

A fundamental question to be addressed is: "How should Euratom-funded **safety** and **radiation-protection** research for existing and future systems and applications evolve in the next five years (i.e. until 2027) taking into account the shifting policy and market landscapes for nuclear?"

General safety and radioprotection considerations

Without any doubt, radiological protection and safety issues should continue to be prioritised. The key aspects to focus include, amongst others, safety of processes and installations, development of more performing materials, emphasis on critical experimental issues to validate computer codes and in-depth understanding of radiobiological phenomena.

To avoid that the increased interest in some EU Member States in including nuclear power in their energy mix be dampened by the slogan of it being 'insufficiently safe', it is important that **safety-related RD&I** receives the **highest priority** to assess **long-term-operation (LTO) refurbishments** and new **advanced concepts.** This goes hand in hand with a 'rational and judicious' appreciation on 'how safe is safe enough'.

Towards that goal, a more result-oriented focus for Euratom projects is needed. Continued attention must be paid to the **avoidance of severe accidents** (and prevention of large releases of radioactivity into the environment), but also to **minimise the occurrence of disturbing/disquieting incidents**. This entails an overall enhanced safety awareness with increased research on ensuring integrity in long-term operation of existing reactors, the development of new materials for **accident-tolerant fuels (ATF)** and further advanced development in **modelling and management of severe accidents** for current and future facilities. But crucially important for all of the above, there is an essential need for **clear project objectives of delivering tools, guidance and a scientific basis for standards for end users** (nuclear reactor vendors, nuclear regulators and their 'technical support organisations—TSOs).

It is important that the next STC, when developing its advice, takes into account the possibility of an increase of the **budget for the Euratom Programme** as a logical consequence of the 'shifting policy and market landscapes'. As a minimum minimorum, it must be expected that corrections for **inflation** will be implemented. In addition, if those 'shifting policy and market landscapes for nuclear' imply a significant increase in the prospects for the development of commercial nuclear power in those Member States agreeing to include nuclear in their energy mix, then it would be logical that the Community RD&I safety budgets be revised upward **in real terms**.

Safety in existing and future nuclear systems

For the safety of existing systems, a broad scope of Euratom-funded safety research is currently implemented. Although LTO investments should be financed by the industry, some reorientation of Euratom RD&I is called for, especially towards more **fundamental issues** such as **ageing processes** and **material integrity.**

As a readily available transitional measure, certainly in the more stringent electricity markets without ample cheap natural gas, it is plausible that some Member States wish to **prolong the typical operational lifetimes of existing nuclear reactors**. Thereby the main focus must remain on the **safety** of the plants, combined with **reliable** operation for the electric grid (i.e., generating electricity when the grid counts on it). Although the major responsibility for LTO lies with the operators of the plants, by timely performing necessary refurbishments and upgrades of e.g., the Instrumentation & Control (I&C), with the right balance between (at least) non-weakened safety requirements and the inevitable investment costs, there is still **need for public funding on fundamental fuel and material issues** (highly maximised/optimised burn up, coatings, structural integrity — embrittlement, thermal fatigue, stress corrosion cracking — and ageing, amongst others). The future STC should help to assure that the RD&I means are available to perform such basic research pursuing better understanding of the phenomena. Preferentially this could be via continued collaborative projects of industry and the regulators with their TSOs. For more fundamental subjects, a joint effort of specialised laboratories, engineering companies and TSOs may be more suitable. As part of that endeavour, appropriate experimental infrastructures should be available to support LTO.

From a broader perspective, it could be interesting to investigate the scientific-technical constraints on *very long-term operation:* are there any fundamental scientific roadblocks that exclude LTO of the order of 60+ years? This is important for all Member States, those possessing nuclear plants but also for the others. The point is not to ask now for **beyond 60-year operation**, but to already now address the **feasibility** through **scientific and technical analysis**. From the outcome of that analysis, governments can then be informed as to **whether such very-long-term LTO is a viable (technical and safe) option or not** to define their long-term vision on energy mix.

Future STC views would be welcomed on whether the Euratom support rate for research on LTO projects for industry should remain at the

standard 100% or whether it should be lowered. A possible rationale could be a distinction between the study of *fundamental issues* versus *more applied and already routine practices.* In a broader sense, the next STC is invited to reflect on all other projects with industrial involvement and to give advice to the Commission. A well-thought through justification for the recommendations made would be necessary, however.

For the safety of future systems, an appropriate balance should be aimed at between **basic** generic research and **applied** research, the latter in this case especially being research applied to specific innovative systems to support the scientific base for safety assessment and their licensing. In this context, the future STC should reflect on the multitude of new designs, varying from evolutionary types to advanced systems, and ranging from large +1GW reactors to small modular reactors (SMRs).[12] Especially on the advanced reactors typically known as Generation IV (Gen IV), some stocktaking may be recommended; the next STC should perhaps reflect on the need for a possible **prioritisation** of the different concepts. Future advanced systems that appeal to and embrace EU manufacturing and nuclear industry should receive most consideration; those designs without much added value to EU industry should not expect much Euratom funding and should perhaps be content with some limited support for watching brief.

An important part of the RD&I focus should be maintained on **crosscutting** technological topics like materials, monitoring tools, digitalisation of systems and processes, modelling and simulation of multi-physical and multi-scale phenomena that are essential for progress in the nuclear field from licensing to decommissioning through lifelong operation. Benefit should be taken of the progress both in basic research and technology development made in various sectors that has not yet been, or just begins to be, transferred to the nuclear field. Examples are many: new materials, new fabrication technologies, artificial intelligence, smart diagnostics and control, digitalisation and the Internet of Things.[13]

A continued but more *result-oriented administrative effort* must be pursued to establish better **aligned, regulatory safety and radiation-protection standards and rules** within the EU (and, preferentially, on a broader worldwide level).[14] The next STC is encouraged to recommend an extra effort, proposing Euratom-funded studies to foster *further convergence on approaches for nuclear safety* to develop such (binding) uniform regulatory construction and operational 'codes and standards' at EU level and/or beyond.[15] The goal is to go beyond the objectives of the Euratom-funded project HARMONISE.[16] The extra effort must include a timely initiative to start **common training and knowledge transfer to nuclear regulator**s on the new advanced system science and technology (thereby addressing both technical and legal experts, and based on shared harmonised learning material at an EU level and beyond).

Strategic nuclear autonomy within Euratom

The new geopolitical and energy reality calls for some degree of 'strategic autonomy' in the nuclear field. However, the meaning of the EU's 'strategic autonomy' in the nuclear field and how Euratom should implement it is a **complex question** the next STC should reflect upon very carefully.

Indeed, the term 'strategic autonomy' in nuclear technology is 'tricky' since, over recent years, **Europe has lost its leading competences in the nuclear fission field**. Strategic autonomy will require, first and foremost, a '**rebuilding**'

12 For an overview on the various SMRs and their status, see e.g., IAEA "Advances in Small Modular Reactor Technology Developments" (2022), https://aris.iaea.org/sites/Publications.html (where 83 different designs are considered) and NEA-OECD, "The NEA Small Modular Reactor Dashboard" (2023), https://www.oecd-nea.org/jcms/pl_78743/the-nea-small-modular-reactor-dashboard?details=true. See also Gen-IV International Forum (GIF), https://www.gen-4.org/gif/jcms/c_203335/gif-2021-ar.

13 Regarding materials, the "vision paper for a Co-funded European Partnership on nuclear materials" published by the ORIENT-NM project funded under Euratom R&T programme 2019-2020 is a welcome initiative.

14 Beyond-EU collaborations may include the OECD and perhaps still wider, orchestrated by the European regulatory groups WENRA, ENSREG and HERCA, in concertation with the NEA and the IAEA.

15 As an example, the efforts regarding the 'grid codes', and the 'balancing zones' in the European electricity market context, including even non-EU countries and the roles of ACER, CEER, and ENTSO-E may serve as commended.

16 https://www.lei.lt/en/projektas/harmonise/

exercise for which international collaboration is essential. Strong cooperation with the best world players, building joint ventures and, alongside, trying to create conditions for EU leadership, mainly in innovative, future systems, may be the way to go. This rebuilding of the expertise will require a considerable investment effort on the side of the EU and sufficient 'openness' as international partners would want to see a two-way collaboration (give and take), at least initially. In these uncertain times, the OECD countries seem to be the first candidates for such close and intense international collaboration for RD&I projects.

The EU's attrition/erosion of its nuclear strategic autonomy and thus its leadership correlates with the substantial reduction, in real terms, of the Euratom budget over the past decades. Since 1998, the nominal budget for fission research[17] was increased by a mere 39% while the budget for the EU Framework Programme was increased by an amount of 490%. The *nominal* increase of the budget for fission research effectively signifies a reduction in *real* terms. Even more worrisome, the budget for fission in the present Programme for 2021-2025 has been reduced by 30%, whilst at the same time the Horizon Europe's budget was increased by 22%. An increase for rebalancing the budget of the Euratom Programme should be on the Member States' budgetary research agenda.

The next STC should be ready to provide advice on those areas that should be prioritised for 'rebuilding' the EU expertise in nuclear matters. In the longer term, 'strategic autonomy' in the nuclear field will have to **assure competence** (in the sense of ability/proficiency) within the EU **in all areas of research**: development, engineering, operation and maintenance of nuclear (fission and fusion) facilities. Having all the expertise would allow for fruitful international collaboration from a point of strength rather than having to 'beg' for expertise or to face foreign monopolies.

For a start, concerning crucial areas for assuring some degree of **'sovereignty' in the nuclear sector** (which also fits in a more broadly re-industrialisation context and policy of the EU), one certainly needs to secure the chain of **computer codes, data** and **basic experiments**. One must also guarantee some **own manufacturing capability or a solid collaboration** with reliable partners for the **upstream fuel cycle**. The serious problem of Europe's dependency on uranium imports and on specific supplier countries has to be addressed. Furthermore, it seems essential to ensure the skills and means needed to process the materials needed for the different **nuclear-quality components and structures** of the nuclear facilities within the EU. For example, there has been loss of knowledge in metallurgy and mechanical forming for forging large components and especially the craftmanship for, amongst others, high-quality welding, and the drive to qualify for nuclear-grade manufacturing and construction.

Not less importantly, there is a chronic need for new state-of-the-art fission **research infrastructures**. Appropriate experimental facilities should be available in all the identified Euratom RD&I priority domains for common research of the Member States (safety, radioprotection, new electricity and/or heat generation systems, etc.). Although the financing of such infrastructures is the *primary responsibility of the Member States (and their industries),* the future STC is invited to reflect on the profoundness of concrete proposals and, if appropriate, advise the Commission on how to allocate or earmark parts of the very limited Euratom budget towards these wishes: give some support for selected preparatory actions for construction of new infrastructure or pay for access to existing ones.

Last but not least, **demonstrators** to be *built and financed by industry* (be it by well-established nuclear companies or by private equity funded start-ups) and the interested Member States are a fundamental necessity for genuine European development of advanced nuclear systems (Gen IV and SMRs). Such infrastructure is needed to validate expectations and to speed up the licensing processes.

Special attention to Small Modular Reactors (SMRs)

More attention is needed on SMRs—both LWR and Generation IV—with a **priority focus on European designs** (and their licensing) aiming

17 Indirect actions (i.e. research grants)

at ensuring that the EU regains leadership and some degree of 'strategic autonomy' on SMRs.[18]

It is said that SMRs are expected to be easier to finance and site, easier and quicker to build and to offer a simpler, more standardised and safer design integrating inherent and passive safety features and enhanced built-in-by-design safeguards. Furthermore, SMRs promise to offer flexible operation so as to 'assist' (in the sense of 'load following' and avoiding hindrance) but also to 'strengthen' the electric power system, while, at the same time, offering options for the broader energy economy through hydrogen production, operation in cogeneration mode, heat production and storage. The future STC is, however, invited to **carefully examine whether these claims are justified**, and if so, to identify for which types of design there are still 'imperfections' or 'weaknesses' that can be addressed through dedicated RD&I.

To begin with, a fair degree of RD&I activity should be devoted to those **designs which could be licensed in the shorter term** with the objective of streamlining their licensing in EU countries based on the best regulatory and institutional standards. The funding for such research should be provided by industry, public funds by the interested Member States and, to some degree, by the regulators and TSOs concerned.[19] Some small financial 'encouraging' support provided by the Euratom budget, primarily destined to convene discussions on standards aiming at common EU regulation, may be a wise investment by the EU community. The next STC is invited to encourage the Commission to include such support in the next Euratom RD&I programme.

Notwithstanding the previous point, a substantial part of Euratom support should be devoted to RD&I efforts on **longer-term aspects** for **safety of advanced SMR systems**, thereby focusing on **essential applied physics and technical performance**, so as to guarantee the safest and most reliable behaviour of the advanced reactor schemes. Examples are the new distinctive 'fuel cycles', modelling and experiments for (transient) reactor physics in fast-neutron reactors, peculiar coolant phenomena, development of new sophisticated material compounds/alloys and coatings, the use of more microsensors and micro-electro-mechanical systems (MEMS) to monitor and respond to relevant signals during operation.

B. Nuclear fusion research

On **nuclear fusion**, it is necessary to reflect on the issues raised in the question: "How should the Euratom fusion programme be adapted in the next five years (until 2027) within the current legal and financial frameworks (i.e. roadmap, EUROfusion consortium, cooperation with F4E/ ITER)?"

The current STC acknowledges the recent landmark achievements in **magnetic** fusion from EUROfusion at the Joint European Torus (JET) facility during 2022 and from **inertial** fusion at the National Ignition Facility (LLNL, USA) in 2022-23. These results are the clearest **demonstration of the scientific fundamentals** and, therefore, **the potential for fusion energy** to become a low-carbon energy source. Although essential differences exist between inertial fusion technology and the magnetic-confinement approach chosen in Europe, both add momentum in the field of fusion. The STC furthermore appreciates recent exciting developments to qualify the **stellarator** as a fusion plant, which removes several of the identified challenges for the **tokamak** concept. Since most plasma science and technology challenges are common to tokamaks and stellarators, pursuing alternatives based on, or similar to, these two magnetic concepts, is a safe way to progress. Training is also easily translated between different magnetic confinement machines.

How to accelerate fusion implementation; ideas for an updated roadmap

The current **European fusion roadmap** does not lead to the goal for commercial electricity

18 It is noted that the Commission and European industrial, research and educational stakeholders (and 'acknowledged' by the Council on behalf of some Member States) have established the so-called 'Declaration EU SMR 2030' in April 2023. See https://op.europa.eu/en/publication-detail/-/publication/e7c3556c-d29d-11ed-a05c-01aa75ed71a1/language-en, pp 38-41.

19 To recall, 'industry' includes well-established nuclear companies up to private equity (and/or venture capital) funded start-ups.

generation in the short term. It is clear that time is of essence, the sooner society can benefit from the fusion programme as a whole, the bigger the impact of fusion will be. The new STC should consider whether the current **European (EUROfusion) plans** and activities for fusion energy development should be **revised to incorporate more ambitious timelines and programmes** that foster innovation, and participation of private companies for an **accelerated development of fusion energy**. As part of the ambition, the EU should strive to acquire its **own *complete* competence** (in the sense of capability) in research and development in the field of fusion.

Indeed, the next STC must not refrain from trying to **find answers to 'difficult' and perhaps somewhat challenging questions**. Given the urgent need to decarbonise the world's energy sources together with guaranteeing *firm/dependable but flexible* electricity generation means, the new STC should investigate on **how to best adapt the European fusion roadmap**, considering various (maybe straightforward but perhaps out-of-the-box) paths for a much **faster development** of practical fusion energy, and advice the Commission accordingly. At the same time, the future STC is recommended to reflect respectfully but genuinely on **the role of fusion energy in a future European energy system** which presumably will have large amounts of highly fluctuating energy sources, as well as fission-based SMR's. Eventually, the future STC must stimulate European actors to lay out an **updated and more accelerated fusion roadmap** with a deliberately increased and sustained effort involving **industrial companies**.[20] Such more aggressive, but credible, roadmap **should then be endorsed by Member States**. That recognition would boost industry's and partners' confidence in their investments and promise of returns in fusion research. The future STC is advised to constructively challenge that updated roadmap while offering valuable and creative ideas, as well.

The **science & technology** strands of the fusion programme need further **convergence and integration** on the path of fusion towards electricity and/or heat production on a commercial scale. The current STC recommends that a global analysis of the T**echnological Readiness Level** (TRL) for critical technologies necessary for future 'demonstrators' or 'first pilot plants' should be further pursued by fusion stakeholders and independent experts urgently. This TRL analysis must **identify key research areas to accelerate the parallel development of critical technologies** towards future pilot plants and to speed up the track between ITER and a next step. This parallel approach would not only help in the acceleration of the fusion roadmap but also in **bridging the industrial gap** through the sequential advancement of fusion. The new STC should follow up on this advice and sharpen it if necessary to obtain timely results.

The next STC should make an extra effort to better grasp **the future 'strategic' plans of the other countries and companies** (including startups) with major fusion-energy expertise and aspirations. These include all ITER partners and private initiatives (especially in the USA, Japan and the UK). This reflection must culminate in clear 'Terms of Reference' for recommending an in-depth *study* to have a clear understanding of the realities of such programmes.[21]

The STC notes that, as we approach the moment when the viability of nuclear fusion energy is determined, it is crucial that **Intellectual Property** (IP) for key technologies is not only developed but also held in Europe, from fuel cycle & tritium breeding to materials development, to name a few. We are at the crossroads in fusion energy where the EU risks having most of the relevant IP developed for ITER 'open' to the whole world, while substantial **Public-Private Partnership** (PPP) investments elsewhere may be generating IP that will belong to private companies and might not be widely available.

20 Recall that 'industrial' allows for a broad spectrum of well-established nuclear companies up to private equity (and/or venture capital) funded start-ups.

21 The recently published study here referenced may be a relevant starting point: European Commission, 2023, "Foresight study on the worldwide developments in advancing fusion energy "https://op.europa.eu/en/publication-detail/-/publication/83bc3ecd-b19c-11ed-8912-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search&WT.URL=https%3A%2F%2Fenergy.ec.europa.eu%2F

The impact of accelerated fusion plans on the future organisation of EU fusion research; Implementation of increased industrial involvement

The STC notes that boosting the commercial development of fusion energy and promoting the creation of PPPs would imply **new challenges in the organisation and governance** of the European fusion programme. The implementation of this transition should begin with the extension of the Euratom Programme (2026-2027).

The current STC encourages the next STC to have **a frank discussion** with the Commission on a possible **restructuring of the fusion programme** to get **European industry more 'comprehensively' involved**, especially the design, safety and licensing activities of future fusion power *pilot plants.*[22] The efforts and accomplishments achieved by European industry, under the auspices of, and managed by, 'Fusion for Energy' (F4E) for the European in-kind component-procurement contribution for the experimental ITER device, are absolutely recognised and commended.[23] [24] Clearly, the lessons learned during ITER construction can inform the relationship with industrial companies and help define their future extended role and the scope of their activity. Nevertheless, a more extensive, all-encompassing approach towards construction of a full-fledged fusion power plant will be most desirable, and actually inevitable.

Towards successful construction of a genuine, convincing fusion pilot power plant, it seems advisable to get ***different*** **industrial sectors** involved to get fresh ideas and guidance on practical and technological limitations of components or subsystems which are precision-sensitive and/or delicate for a reliable and safe fusion-reactor operation. Without being exhaustive and by way of example, the following industrial expertise should be called upon:

- Component-manufacturing and system-integration companies having practice in conceptual and detailed design, component and system specification, procurement, construction, assembly and commissioning of major non-nuclear facilities.[25]
- When coming closer to full-fledged fusion power *plants* and when 'licensability' becomes an issue, one should engage established nuclear *fission* plant construction companies where, besides precision manufacturing, reliability and safety issues are also crucial. Architect Engineering companies should be included in the industry considered.
- Crucially importantly, companies with expertise in *fusion* systems should be confronted with this 'diverse' panoply of industrial companies in order to assess and converge on ideas that can be discussed and tested with and evaluated and assessed by, the fusion physics and technology lab-based EUROfusion community.
- Finally, in parallel, it is important to already involve nuclear **regulators** and their TSOs to get an early feel of the safety- and radiologically-imposed constraints for future fusion concepts.

More concretely, for the **construction** of future major fusion facilities, the new STC is thus respectfully urged to reflect on original/innovative/creative **organisational models**. Specifically, the approach based on an **industrial architect-engineer** (AE) to properly **manage and co-ordinate** the projects, warrants due consideration. As part of the job, such AE is to oversee and follow-up closely well-defined dedicated subcontracting to specialised engineering companies for design and licensing studies, component & system specification, and integration & assembly. As such, *clear and undisputable guidelines, standards & protocols* can be given to manufacturing component workshops & companies, thereby better ensuring nuclear-grade quality assurance. In such construction philosophy, the 'historic' **European** plasma-physics and dedicated fusion-technology oriented **'fusion community'** (mainly through EUROfusion and F4E) will have **the primary**

22 Recall that in a in fusion context, 'industry' also refers to a broad spectrum of well-established nuclear companies to private equity (and/or venture capital) funded start-ups.

23 F4E is fully called the "European Union Joint Undertaking for ITER and the Development of Fusion Energy".

24 European companies across the large spectrum of technologies have contributed to ITER: magnets, vacuum vessel, buildings, in-vessel components, cryogenic plant &fuel cycle, remote handling, antennas & RF equipment, neutral beam heating, diagnostics, etc.

25 Such as e.g., big accelerators, big process industries, big cryogenic facilities, instrumentation and control, aeronautics, space industry, etc.

scientific and technical advisory role, thereby supporting the **decisions on the fundamental design options**, after which the AE organises the integration and construction management.

The STC recommends investigating how **PPPs** should be embedded in the holistic approach of EUROfusion to address the remaining fusion technological challenges as well as exploring other collaborative entrepreneurial schemes. Likewise, the degree of strategic **international collaboration** (and with whom) must be reflected upon to assess optimisation of the returns. From these perspectives, a possible role of fusion **start-ups in technology transfer** should not be dismissed, and certainly encouraged.

The STC recommends monitoring the **impact of the whole fusion programme** on science (excellence) and technology (patents) and its direct impact on industry. As commercial fusion energy moves closer to practical reality, technology- and knowledge transfer from publicly funded fusion research, to new fusion companies and industry in general, needs to be further nurtured.

Private initiatives on fusion research as an example for institutional European research?

The last few years have seen a number of **private fusion companies emerge**. Today, private investments flow into the development of the two main concepts being pursued in the EU Fusion Roadmap, the **tokamak** and the **stellarator**. Non-EU initiatives claim a notable presence. A prominent case is *Commonwealth Fusion Systems* (CFS), which received its first funding in 2018. It is a spinout of MIT in Cambridge, MA, USA and has raised more than two billion dollars in private capital to pursue its **high-field, compact tokamak fusion device on a significantly accelerated time scale**.[26]

The **US government** launched a programme in 2022 called *'Developing a Bold Decadal Vision for Commercial Fusion Energy'* aimed at a deployment of fusion energy much faster than what is currently being envisaged in the EU. This US programme calls for substantial governmental resources allocated to **PPPs** to commercialise fusion. The **UK** has also taken steps to become attractive to fusion companies. In particular, it has established a clear legal framework for fusion reactors distinct from fission reactors.

Since 2022, some private stellarator startups have also emerged with initial funding, including *Type One Energy* (29 M$; USA), *Renaissance Fusion* (15 M€; France) and *Princeton Stellarators* (4 M$; USA). The private fusion companies *Tokamak Energy* and the originally Canada-based *General Fusion* now operate in the UK. Fortunately, some private fusion companies are also increasingly emerging in the **EU**: *Renaissance Fusion* is based in France, and *Proxima Fusion*, *Gauss Fusion* and *Marvel Fusion* are based in Germany.

Critical/crucial RD&I actions to be resolved for ITER to be a success

The main **challenges** facing ITER and future magnetic confinement fusion reactors are related to the **integration and control of various physics and technological processes** required to achieve sustained high-gain (Q) fusion power production. Specifically, ITER is designed to demonstrate fusion power production with $Q \geq 10$. ITER will not generate electricity but will be an important experimental step towards electricity production from a follow-up demonstration fusion power plant.

One of the **key physics challenges** is achieving and **maintaining high energy confinement** in the plasma. This is necessary to achieve the temperatures and pressures required for fusion reactions to occur. **Controlling and avoiding disruptive instabilities** is a particularly **critical challenge** for ITER. In addition, there are **key technological challenges** that must be overcome. **Tritium technologies** are required to produce and handle the tritium fuel used in the reactor. **Plasma facing components** must withstand the extreme heat and particle fluxes present in the plasma. An essential element is the realisation of a **materials test facility**, such as **IFMIF-DONES**, for validating materials to be used in the harsh conditions of a fusion power plant. Therefore, a strong EU programme of accompanying research and innovation is needed alongside ITER and a next step towards a first fusion power plant.

26 MIT = Massachusetts Institute of Technology

The next STC is invited to remain vigilant as to the above-mentioned RD&I challenges, and it should encourage the Commission to assure a strong scientific and technical participation from the EU, as well as coordination among all stakeholders involved in the project. That would ensure that the EU fusion programme can optimally benefit from the experience gained through ITER operation and exploitation.

Radiation protection & safety issues for fusion plants

The STC notes that the guidance prescribed by **regulatory** requirements and made manifest by a **nuclear safety culture** are key elements for the development of commercial fusion. A **'tritium culture'** must also be fostered including:

- development of *key technologies* for efficient breeding, capture, recycling and storage;
- *regulatory requirements* to reduce, as reasonably achievable, the release of tritium in order to maintain the radiation safety reputation of fusion. In particular, sufficient attention must be paid to the radiobiological effects of organically bound tritium;[27]
- tritium, as well as lithium, are *strategic materials* and must be treated as such for securing resources.

Radiological protection issues related to fusion (tritium release, activated materials, maintenance and interventions on equipment, etc.) should continue to be addressed attentively for the long-term success of fusion as this will impact systems design and also **public and the media acceptance**. Although some fusion earmarked budget is currently dedicated to such studies, the next STC should *contemplate* whether *a larger fraction of the fusion research budget should be allocated* to general understanding of the **biological effects of ionising radiation**.

The STC invites its successor to *examine* the importance of establishing a **specific regulatory standard on nuclear fusion safety at the EU level**, and to carefully *scrutinise* how and where that would differ from current nuclear-related regulation (e.g., one may assess whether future fusion power plants could be treated at a regulatory level which corresponds to their hazard potential, related to their maximum possible source term.) *Clarification* on such regulatory and licensing principles should be a milestone on the critical path to launch the planning for a next generation fusion facility (and future fusion power plants).[28]

C. Radioisotopes, radiation protection and the Horizon Europe Health Cluster

An instructive and efficiency-seeking subject that deserves attention is the rightful and benefitting synergy among overall EU's RD&I programmes. In particular, which research questions should be addressed by Euratom-funded actions and which by Horizon Europe when seeking synergies with Horizon Europe's Health Cluster? Which are the common areas where joint action is advisable?

Overall encompassing considerations

Collaborative research between the Euratom Programme and the Health Cluster of Horizon Europe is needed because there are clear synergies to be developed regarding cancer and degenerative diseases, being the two main causes of human morbidity and mortality. Both these diseases are caused by cell aging related to oxidative stress through repeated exposures at low doses to a variety of genotoxic compounds, including ionising radiation and numerous chemicals (exposome). The envisaged collaborations are most relevant for scrutinising the mechanisms of these diseases, for developing specific prevention measures and treatments, and for the treatment of cancer by radiotherapy (external or internal) or in combination with chemotherapy or labelled antibodies. The next STC should stimulate

27 Characterisation of the tritium chemical forms in the release is mandatory. Tritiated water is not really a problem since it does not accumulate in the living organisms. In contrast, tritium bound to organic molecules accumulates in the living organisms and may be responsible for significant exposures and doses.

28 Fusion-specific elements for regulatory considerations have been made in the study: European Commission, 2021, 'Study on the applicability of the regulatory framework for nuclear facilities to fusion facilities'

such collaborations and promote appropriate combined funding.

Issues related to medical-application exposures should be given the highest priority (as these are, by far, the most significant sources of radiation the general population is exposed to) and 'individual response and risks' the second highest. There is a strong link between these two priorities as many people (up to 20% of the population) have an abnormal response to ionising radiation (radio-susceptibility to cancer, radio-degeneration of organs and radiosensitivity to radiotherapy) and are therefore at a higher risk. This considerable fraction of the population could benefit from careful attention to medical exposures.

Therefore, molecular epidemiology with dedicated biomarkers needs to be developed in human cohorts, e.g. women with a family risk of breast cancer, non-smokers having developed lung cancer, children exposed to low doses and repeated low doses, cohorts of patients with repeated exposure as part of screening (e.g. mammography) or treatment. Thus, there is a need for cross-validation research between European laboratories and the development of large cohorts to improve the effectiveness of research and the coherence of the results.

The STC stresses continued importance of research on the biological effects of low-level radiation for medical diagnostics and side effects of radiotherapy. But the research strategy on radiation protection should take a broader view, going beyond the (indispensable) academic research. Indeed, fundamental academic research should be carried out with a view to its impact in practical radiation protection (applied research).

Fundamental radiobiological research on better understanding of the mechanisms

The next STC should recommend more multidisciplinary and integrative research, possibly under the PIANOFORTE Partnership, on the basic mechanisms of the biological effects of radiation to study:

- DNA damage response at the crossroads of the management of all DNA insults (at the origin of cancer and degeneration) whatever the genotoxic compound (combined exposures with ionising radiation);
- outcomes and risk evaluation, in a crosscutting way, applicable to all situations of exposure — medical, natural, environment-exposome, security (including screening operations), space, accident — to all pathologies (cancer and degenerative disease), to education and training and to psychosocial and behavioural consequences in all circumstances.

Research should focus on human beings (rather than animals), meaning that research on human samples and cell lines (coming from various sources, corresponding to the population's diversity and the variety of individual response) and in human cohorts should be prioritised to complete the data from previous research programmes and different sources (e.g. clinical data of treated patients and occupational monitoring data).

It is to be noted that the complexity of exposures — e.g. repetition of dose effects in medicine, differences in response for low energy irradiation (30kV X rays for mammography versus 120 kV for CT scanning) — including combined exposures with other genotoxic compounds, has not been addressed yet.

Production of radioisotopes for medical purposes

So-called 'theranostic' applications, combining diagnosis of disease with functional and metabolic approaches to the treatment of cancers, are essential in modern medicine and have great potential. Consequently, the **research for ensuring availability of corresponding radionuclides and radiopharmaceuticals remains a priority**.

The EU should ensure sufficient **infrastructural capacity for the production of medical isotopes**. In particular, the next STC is invited to keep an eye on the advancement of construction of the material test/research reactors Jules Horowitz (FR) and Pallas (NL) to assure that sufficient timely isotope production capacity exists when the current fleet of materials research reactors in the EU will reach the end of their operational life. Notwithstanding, the question should be raised whether it is necessary to keep using material research reactors for this. The future STC is invited to take a careful look at this question, as dedicated isotope production reactors may be more suited for the job.

Collaboration and synergies with *other* Clusters in Horizon Europe

For the above-mentioned topics of common interest, the next STC is strongly invited to explore and enter into a discussion with the Commission on the possibilities to further explore the synergies between the Euratom Programme and the Health Cluster, the role of PIANOFORTE (being the European Partnership for radiation protection), and the possibility to launch common projects with shared budgets.

The STC welcomes the recent collaboration among different directorates general within the Commission (especially the DGs RTD, SANTE, ENER and the JRC) in preparing the SAMIRA action plan in the context of 'Europe's Beating Cancer Plan'. The current STC encourages its successor to follow these developments closely concerning the actual implementation of the SAMIRA actions in order to help ensure sufficient strategic co-ordination and support for future R&I programmes in the health, digital and nuclear areas.

In an even broader context, the next STC is invited to highlight, examine and promote interesting and important synergies between the Euratom Programme and other Horizon Europe's Clusters like the security area (proliferation, cyber security), accidents and their consequences, space, energy and the climate (role to be played by SMRs in non-electricity producing applications: desalination, cogeneration, high-temperature heat, H2 production, ...back up, ...).

D. Nuclear related education & training and knowledge transfer

The answers to legitimate questions on education and training are far from straightforward. It is both pertinent and urgent to address the issues raised in the question: **"How** can the Euratom Programme stimulate nuclear-related education and training, including the human resource challenges for qualified experts and technicians with adequate background, knowledge and expertise to teach and train the young generation?"

A sustained effort in education and training (E&T) in the nuclear field in the EU is considered essential to maintain the leadership that the Union had/s in certain areas (certainly fusion, but also still fission in some Member States, although waning), to educate the next generation of scientists and engineers needed to continue safely operating fission power plants and other nuclear infrastructures, as well as to perform research and work in non-power nuclear fields (e.g., medical, etc).

Young scientists, engineers and technologists are not eager to come to a field that would be considered as 'has been', without much future. The best way to make everything 'nuclear' again attractive is to correctly communicate on scientific facts to make the nuclear fission, fusion and medical fields appealing and to help politicians with informed decision making, at the same time thwarting opinions from non-specialists which are too often highlighted by the media. The current STC believes that the priority is there, and it invites its successor to monitor the evolution.

Euratom stimulation of nuclear-related education and training is conditioned by stating clear and attractive prospects in the long run for work and career opportunities, facilities, incentives. Many opportunities exist but they should be better promoted in a range of organisations, including international research centres, industrial companies of all sorts and government agencies.

Especially after the recent energy crisis, young people seem to see a future in nuclear and to have a much less politically biased approach to it. The inclusion of nuclear in the green taxonomy of sustainable investments likely helped in that direction.

The challenge of attracting new talents to the nuclear field should be among the most crucial to the EU in the development of its Education & Training strategy, but it has many faces. As an example, the question of how soon fusion electricity will be available should be considered much more deeply by the academic community, as the time scale of these developments may significantly impact on the choice of a field of study for the new generations. In fission education, more focus should perhaps be put on advanced concepts (e.g. Generation IV, SMR, etc), which are more likely to attract new talents. Start-ups, especially in fusion but also in fission, are being very successful in raising money and

promise results in the short term, typically much shorter than public endeavours, which makes the field extremely attractive to young people. However, there should be a high degree of trust/reliability of policies, and efforts should be made to bring together both public and private funding streams, as well as to present a clear and scientifically-based picture to the students, which is rather challenging in view of the many constraints on IP rights.

In particular after meeting with the ENEN and FuseNet management, the current STC recommends that the E&T challenge in the nuclear field should be treated holistically, trying to bring the different threads (fission, fusion and non-energy) together in the development of a true and comprehensive European Nuclear Competence Area.

Of course, in order to do that, there is the need for a strategic plan for education & training, and for a roadmap to implement that plan with clear milestones and outcomes, which seem to be both currently missing at European level. The next STC is invited to reflect on that and to advise the Commission.

The next STC should reflect whether there exists a systematic and sufficient system for education, training and development of nuclear experts and professionals in Europe.

The present STC does not currently have a database of the state of nuclear E&T in the EU. The gathering of such information could be achieved through a collective effort with the support of ENEN and FuseNet, and the STC members, who are in the position to identify the relevant E&T initiatives at both national and collective European level. This exercise could be connected to the related work of the JRC in methodologies for nuclear workforce assessment through EHRO-N. Such connection would give a better view of how far the offer matches the current and mid-term needs and would support informed advice of the future STC on the matter.

In the new geopolitical landscape which has developed recently, there is a clear need for some guidance on international co-operation, in particular in E&T, clarifying which countries can be considered to be reliable partners. There has to be a good understanding of what is meant by the EU's strategic autonomy, which affects for instance the decisions made on the possible needs to develop new computational tools and/or experimental databases versus use of (formerly) available ones, which in turn may require specific focus in the E&T of the developers and users.

The nuclear field, be it fission or fusion, is intrinsically multidisciplinary and requires many different skills and competences, often quite beyond the strictly nuclear engineering ones. An important item to be included in the education and training of nuclear professionals (e.g., via ENEN...) is to convey the important safety culture philosophy. Basically, all educational projects must be immersed in that fundamentally important and essential so-called 'soft skill'. In fact, in the nuclear context, 'safety culture' is actually nothing less than a 'hard skill'. This should be taken into account in the development of any E&T strategy.

Training by research in the field of fission & fusion reactor physics and technology should be stimulated, be it numerically and/or experimentally.

It must be signalled again that there is a lack of available research fission reactors and equipment which can give students hands-on experience to combine with theory. Notably, the existing low-power research fission reactors, which are, due to their operational flexibility and accessibility, highly appropriate for educational and training activities, should be further supported. Access to the JRC's research infrastructures is important in this regard, under different schemes such as its Open Access programme or post-doctoral and (particularly) doctoral programmes, to increase the attractiveness of the field for young talents. These programmes can also play an important role for life-long learning initiatives and should be accordingly funded. The next STC is invited to keep reminding the Commission of these important funding needs.

The STC recognises the value of the existing fusion training programme in EU research infrastructures intertwined with university networks. This programme should be complemented with industry internships (at MSc and PhD levels) to connect a new generation of technicians, scientists and engineers with fusion-related firms. This will furthermore allow combining development of project engineering and management skills with specialised fusion knowledge.

Digital twins, as tools for E&T, Knowledge Management and Communication to the public, integrate a large part of the knowledge accumulated in the nuclear field and are a most promising tool in the education & training of students and young professionals, as well as in the information-communication-participation process of all stakeholders, including the public.

Interested Member States and the nuclear industry (in the broad sense) must realise that budgets and topics in EU projects (e.g., via ENEN) for education and training are not sufficient and attractive to adequately motivate experts and infrastructure operators to be involved in nuclear-related programmes, important to assure future capacities for development of nuclear technologies. Some extra financial support from those Member States and industry should be encouraged.

A stronger effort should be made to develop a level playing field for nuclear compared to other areas. Whereas, e.g., the EUROfusion programme of engineering & researcher grants is certainly helpful to support early careers in the fusion field, nuclear researchers are still generally excluded from ERC grants, which carry a lot of prestige, automatic benefits, etc. Similarly, nuclear proposals can be submitted within MSCA for postdocs, but not for the very important action of doctoral networks. The next STC is invited to examine ways within the Commission how a systematic advocacy effort in both directions could be developed.

Similarly to what had been stated in the fusion context, the STC should encourage and stimulate that there is a timely training and knowledge-transfer collaboration between universities, laboratories, reactor vendors and the technical and legal experts of nuclear regulators (and their TSOs) on the new fission-related design ideas and approaches that need to be licensed. Evidently, it all starts with assuring a good influx of students and educating them in 'advanced' nuclear engineering concepts, but the incumbent regulator experts should not be forgotten. The next STC should pay special attention to fast-neutron reactors, coolants other than water, new types of fuels, materials with non-household characteristics, etc.

4.2 Prioritised follow-up topics signalled by previous legacy messages

The current STC wishes to recall some important legacy messages of the previous STC mandates (2008-2013 and 2013-2018) and reformulate/update their rationale and motives.

A. Socio-economic research

What could be the role of nuclear power generation (both fission and fusion) in the future energy system which must optimise the energy trilemma, with ample variable renewable sources and confronted with a fragmented world and geopolitical tensions? Even though investments will only take place in those Member States choosing nuclear as part of their mix, in integrated markets all Member States will benefit from more firm electricity generation, and all should be interested in safe operation of those plants.

The role of nuclear, new build

The next STC should make an effort and suggest studies to identify the new role of nuclear fission and fusion facilities, being undisputable zero-CO_2 emitting installations, in the future European energy economy. Indeed, in the energy systems of the future with very large amounts of variable renewables, it is important to examine where nuclear reactors fit into such systems. For both nuclear fission and fusion reactors, whereby the cost per unit useful energy 'produced' (be it electricity or heat), is mainly determined by the capital investment cost, the financing method (and thus the cost of capital as expressed by the 'interest rates' and the time of construction) and the capacity or load factor. Nuclear reactors should preferentially continuously operate and produce as much as possible valuable 'output'. However, future electricity systems will most likely require 'flexibility' from dispatchable generation technologies, in turn resulting in reduced load factors for electrical grid infeed for those technologies. To reconcile both conditions, nuclear facilities must value other output routes, and find its place in an integrated overall energy economy, characterised by exchanges of different

energy carriers and in various sectors. In those Member States open to the nuclear option, the 'port of entry' for nuclear reactors (be it fission or fusion) will likely be driven by security of supply concerns, related to long-term energy storage. But to better justify its presence, nuclear will need to boost its value via other desirable output streams.

The next STC should therefore recommend clear-cut studies to explore and appraise the possibility, meaningfulness, and economics of nuclear heat-generating facilities to operate in broadly defined hybrid modes. Besides feeding the generated electric power directly into the electricity grid, the electric energy may be stored in batteries, or in pump-hydro storage facilities, or be used for electrolysis to produce hydrogen. But furthermore, the (high-temperature) heat may be used directly in a co-generation mode, or for sea-water desalination, or higher-temperature assisted electrolysis, or as high temperature heat storage (in firebricks, sand or crushed rocks, or molten salt reservoirs).

The next STC is invited to reflect whether it would be helpful in gaining broader support for advanced nuclear technology to encourage early and unbiases assessments of new technological options under research. Such assessment studies on a European level should include comparison with other energy options.

The next STC should together with the Secretariat examine how other Commission services, e.g., especially those proposing and supervising the Horizon Europe Cluster Climate & Energy, can be persuaded to launch combined studies (to the benefit of both programmes), with shared budgets.

Rational risk versus risk perception

It is a fair question to wonder whether sufficient efforts have been made on the subjects of risk perception, now that permitting/licensing seems to be extremely difficult also for non-nuclear undertakings, such as new pipelines, electric-power grid extension, new power plants (including wind farms), carbon capture and storage and shale gas exploration. The next STC should advise the Commission to check internally how it could be possible to collaborate on this risk perception subject with Horizon Europe projects. In particular, the Commission is invited to reflect on common projects with the Horizon Europe Climate & Energy Cluster, with shared budgets, since acceptability of many planned investments due to the 'perceived' dangers of non-ionising electromagnetic radiation originating from high-voltage electric power lines is not straightforward. Through such collaboration, common guidelines may be established to the benefit of both the Euratom and Horizon Europe programmes. As a start, the confusion regarding the possible/alleged biological effects of non-ionising electromagnetic radiation versus the clear guidance principles regarding protection against ionising radiation may be considered as a first research subject.

The fundamental issue regarding acceptability on nuclear-related subjects finds its origin in the biological effects of ionising radiation. This applies to normal operational practices, ranging from small releases and effluents from industrial & nuclear facilities, over internal and external irradiation for medical purposes, to possible accidental releases. Therefore, two actions remain pertinent. Firstly, since overall health is the main concern of any individual, the right scientific knowledge on radiological effects on humans and environment must be conveyed in understandable but precise language to the population and its elected representatives. In addition, the efforts for radiation protection measures and culture (radiation detection and measurement, source minimisation, shielding, working procedures, Alara) should be clarified. Secondly, the order of magnitude of the effects on individuals and populations must be put into perspective with other common-day risks that are accepted without any reflection or hesitation. In that context, the next STC should stress that more attention is to be paid to the difference between 'rational risk' as properly defined in the safety-engineering field of study, as being the probability of occurrence of a particular type of damage, with the concept of risk perception often distorted via risk-aversion tendencies (being a negative bias commonly observed in human behaviour). The next STC is strongly invited to reflect on the possible way to tackle this dissonance on risk, perhaps via recommending combined social, behavioural/psychological, medical and scientific-technical studies. Subjects of broad interest may be the exposures to natural background radiation and existing naturally occurring radioactive material (NORM) sites, but also other exposure risks

such as traffic accidents, silent pollution killers, dangerous long-lived chemical substances, etc.

The STC understands that a project called ECOSENS was recently launched within the Euratom R&T programme 2021- 2022. The aim is to develop economic and societal considerations for the future of nuclear energy in society, bringing natural, social sciences and engineering into one project and opening up to the social, political, cultural and ethical context. The next STC is invited to assess the ECOSENS results and to define possible further initiatives.

The new STC should reflect upon the value of updating past ExternE studies on the assessment of environmental externalities of energy use based on new factual insights on the impact of energy use on climate change and drawing on the widespread development of life-cycle assessments of energy use (keeping in mind that such an initiative would need to rely on resources and competences beyond the Euratom perimeter).

The next STC is invited to examine the proliferation-related issues possibly expected to arise on the various trajectories to fusion energy and on which strategies to propose or develop for ensuring adequate proliferation resistance.

B. Synergies with the Joint Research Centre (JRC); Enhancing the impact of direct actions and the role of the JRC

The synergies with the Joint Research Centre (JRC) should be explored based on the JRC's approved workplan, delineating and explaining the so-called direct actions. The STC appreciates information provided by the JRC at previous STC meetings. Future STCs should insist on such JRC briefings on a regular basis concerning the Euratom direct actions it implements. However, it would be very helpful for the next STC if more information would be shared on the future planning, the scope and expected impact of direct actions. In that respect, the approved workplan of the JRC for 2023-2024 has been shared with the STC. That work programme should be the starting point for discussions on the impact of JRC nuclear activities and on enhanced synergies among indirect (RD&I) and direct (JRC) actions. A meeting with JRC should be scheduled at the beginning of the mandate of the next STC for this purpose.

Clearly, there is still some potential for further integration and bridging of research from both direct and indirect actions within the Euratom Programme and with wider future research portfolios. Knowledge management and foresight exercises being developed in the JRC could help to achieve maximum impact from the combined results of both programmes. During the past two STC mandates some progress has been made but the future STC will need to be vigilant as to how the synergies between direct and indirect actions and the wider synergies from the non-nuclear parts of the Horizon Europe programme can be further pursued.

C. Transmutation of nuclear waste

On Transmutation of nuclear waste, the following questions still linger. "What is the precise meaning of closed fuel cycles? How much can Partitioning & Transmutation simplify the designs and reduce the costs for geological disposal? How to deal with the current stock of spent fuel in certain countries? To what extent could transmutation reduce the waste burdens?

Given the reconsiderations on including nuclear energy in the energy mix in several Member States of the EU, it is indeed pertinent to obtain clarity about the above-stated questions. The future STC is invited to obtain more transparency on those issues, via hearings or via dedicated studies to clarify the options. As already signalled by a previous STC, it remains appropriate for the STC to undertake further detailed analysis of the challenges and opportunities presented by transmutation in combination with deep geological disposal and to ensure there is an appropriate European focus on the safety and sustainability of this technology. In addition, it would be worthwhile for the STC to get a better understanding on the actual state of play of 'new' ideas such as electrorefining & pyro-preprocessing, different from the current PUREX process.