Brussels, 29 March 2023

European Defence Fund

Indicative multiannual perspective 2021-2027

(Releasable version of Annex 2 of Commission Implementing Decision C(2023)2296 final dated 29 March 2023)

European Defence Fund indicative multiannual perspective

TABLE OF CONTENTS

I. INTRODUCTION

This multiannual perspective presents possible call topics that are considered beyond those of the current work programme. This is intended to facilitate the coordination of the Member States and associated countries[1] long-term planning, in line with the main outcomes expected from the EDF support, especially for large capability projects that need to be supported through several work programmes over the EDF duration.

In addition, in order to allow industry and Member States to focus and invest into cooperation in a more structured and transparent way, the following table provides percentage indications of the EDF budget envisaged to be allocated to some categories of actions throughout the multiannual financial framework (2021-2027).

The multiannual perspective is indicative. It does not constitute or generate any commitment from the Commission. The table below and the content of the multiannual perspective will be revised annually according to the discussions leading to the preparation of the successive annual EDF work programmes and subject to the availability of annual appropriations.

Category of actions	Indicative EDF budget contribution during 21-27
1. Defence medical support, CBRN, biotech and human factors	
2. Information superiority	> 10 %
3. Advanced passive and active sensors	
4. Cyber	
5. Space	> 10%
6. Digital transformation	
7. Energy resilience and environmental transition	> 5%
8. Materials and components	
9. Air combat	> 10%
10. Air and missile defence	> 5%
11. Ground combat	> 10%
12. Force protection and mobility	
13. Naval combat	> 10%
14. Underwater warfare	
15. Simulation and training	
16. Disruptive technologies	4% - 8%
17. Open calls for innovative and future-oriented defence solutions	

1 Member States and associated countries are hereafter referred to as Member States

II. INDICATIVE PLANNING PER CATEGORY OF ACTIONS

For each EDF of the categories of actions addressed in this indicative multiannual perspective, the selection of topics for the EDF work programmes 2024, 2025 and 2026 will be subject to discussion, assessment, consolidation and justification of the proposals from Member States, including new ones, as well as to the availability of the results of EDF precursor programmes awarded projects and the outcome of the EDF calls for proposals.

1. Defence medical response, Chemical Biological Radiological Nuclear (CBRN), biotech and human factors

Medical response and CBRN capability development is characterised by a constant flow of innovation, which is the result of a high level of research and development within the industry and specialised research organisations, and of close co-operation with the users, notably Member States' medical and CBRN commands/centres. The ability to consider and incorporate human factors, evolving defence capabilities and technical systems, are necessary to obtain intended utility. European defence industry generally acts as integrator of civil solutions in offerings to military customers. Considering the high competition particularly with companies from US and Asia, as well as its reflection in Member States' and European defence capability priorities, a sustained level of investment at European level is very relevant in this domain. Special attention is therefore given to the continuous and strategic development of capabilities in the areas of Detection, Identification and Monitoring of CBRN threats as well as development of medical CBRN countermeasures.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the MCBRN category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- CBRN system of systems EU MSs approach (standardisation) and technologies integration
- Set of available defence medical countermeasures jointly procured (EU autonomy)

2. Information superiority

Information superiority is essential for any operation, as it concerns the entire cycle of the military decision-making process, with ever shorter timelines and an ever-increasing amount of data to collect and process. It addresses a broad range of technologies and capabilities allowing command entities at all levels to base their decisions on suitable, timely and accurate information and to transmit information swiftly and securely to the relevant actors. In the context of the EDF, joint R&D actions regarding information superiority will support the enhancement of the Union's freedom of action in the field of command, control, communications and computing (C4), Intelligence, surveillance, target acquisition and reconnaissance (ISTAR), but also joint electronic warfare, hence reinforcing the strategic autonomy of the Union. The EDF Programme Committee has indicated the level of ambition in terms of EDF budget contribution to information superiority to more than 10% of the total EDF budget.

In line with the action plan on synergies between civil, defence and space industries, possible synergies with other initiatives at EU level should be systematically taken into account where relevant. In addition, efforts should be made to ensure synergies and complementarity with other EDF categories of actions, notably with advanced passive and active sensors, cyber, space, digital transformation and materials and components, in order to address, in a timely manner, cross-cutting technologies relevant for information superiority.

- In the field of **Command and Control (C2)**:

In the context of the Common Security and Defence Policy (CSDP), operation headquarters (OHQ) for specific missions and operations (executive or non-executive) are currently chosen from a list of available facilities. While the EU does not have a permanent military command structure, the Military Planning and Conduct Capability (MPCC), established in 2017 as part of the External Action Service (EEAS)/EU military staff (EUMS), represents the first step towards a permanent EU OHQ.

In the context of the Permanent Structured Cooperation (PESCO), 6 Member States are involved in the project 'Strategic C2 System For CSDP Missions And Operations' (EUMILCOM) with the aim to improve the command-and-control systems of EU missions and operations through the provision of an ambitious strategic level suite of capabilities, in a modular and scalable approach. In April 2021, the participating Member States have adopted the high-level requirements for such a project, developed in close cooperation with the MPCC.

In the context of the European Defence Industry Development Programme (EDIDP), the project 'European Strategic Command and Control' (ESC2) has been launched in 2020 with the objective to deliver a design for further development by 2023, in line with the objectives of the EUMILCOM PESCO project.

Against this background, and in line with CDP priorities and CARD findings, the EDF ambition should be to support the development of a reliable prototype of a European C2 software suite able to allow secure and effective planning and conduct of CSDP missions and operations at strategic and operational levels. This European C2 software suite should be interoperable with NATO and Member States' C2 systems to the greatest possible extent, but also with any relevant EU tools contributing to the situational awareness, and is intended to complement and enhance emerging C2 capabilities currently used by the MPCC. In order to meet this objective, a dedicated topic has been introduced in 2022 targeting a software suite model, without excluding further iterations.

In parallel, it appears that symmetric and asymmetric threats inside and outside the EU territory require fast response and the ability to rapidly deploy Special Operations Forces (SOF) to areas of interest, whenever needed. Indeed, in the context of CSDP operations, SOF-led Small Joint Operations (SJO) can provide a wide range of flexible military options for rapid and effective response across the spectrum and at all stages of the rapidly evolving crisis management landscape. In line with the objective of the related PESCO project 'SOCC2 for SJO', the development of dedicated SOF Command Post and C2 systems has been addressed in 2022, which should provide adequate flexibility, interoperability, deployability, scalability, robustness, discretion and redundancy, notably concerning communications systems and networks. Complementary development efforts, notably to further mature required key

[2] One deployable Special Operations Forces (SOF) tactical Command and Control (C2) Command Post (CP) for Small Joint Operations (SJO)

technologies possibly identified during the initial development phase, could follow. EDF supported actions would incentive joint procurement of developed products by interested Member States.

Furthermore, Single European Sky (SES) interoperability is likely to be a significant challenge for the coming years for all Member States. The adaptation of military Air-C2 systems to cross border and Single European Sky (SES) interoperability regulation, especially regarding the civil-military/military-military coordination and the connected secured, reliable, and automated exchanges of data needs to be completed in the near future. Confidentiality, including the operational need to "anonymise" some military flights, is also a critical aspect to be considered. To tackle this challenge in a timely manner, a dedicated research topic has been introduced in 2022. Follow-up topics could be foreseen. In any case, it requires coordination and synergies between various EU funded activities, while avoiding unnecessary duplications.

- In the field of **Communications**:

Advanced, reliable and interoperable concepts and solutions for communication are critical for joint operations. This is particularly the case for radio communications, including waveforms, but also tactical communication and information systems.

In line with CDP priorities and CARD findings, the ambition of the EDF should be to support the development of the development of tactical CIS solutions including European standards, including in the field of ISR network systems, which are compliant with national and NATO standards, hence sustaining a domestic market, reducing the dependencies on third parties and contributing to the EU strategic autonomy.

In the context of EDIDP, a project aiming at the development of an interoperable secure defence communications system compliant with the 'European secure software defined radio' (ESSOR) programme and Software Communication Architecture (SCA) software defined radio platforms, has been launched in 2021. Depending on the results of this project and in order to meet the ambition of European standards, a follow-up topic could be supported in the frame of EDF.

In addition, wideband and reliable communication systems for operational interoperability, mobility and security that are robust against detection, acquisition and jamming are key capabilities for defence operations and electronic warfare, including far from the battlefield. This issue has been addressed through the EDF call for proposals in 2021 related to robust defence multi-dimensional communication standards, with the aim to demonstrate different interoperable tactical bubbles and end-to-end tactical networking, also integrated with military assets. Depending on the results of the project selected for funding, a follow-up topic could be addressed in the future, but also tactical communication systems. Moreover, systems supporting dynamic spectrum management could be valuably addressed in order to manage RF interferences in highly dynamic communication environments, including through AI multifunctional aperture systems.

Moreover, developing a new generation of a scalable and multifunctional cognitive transceiver family with artificial intelligence features for military use in manned and unmanned platforms and for command entities in the context of joint operations in multi-domain environment could be addressed. System design should support secure communication, network data link, positioning, blue force tracking, identification friend or foe, electronic warfare capabilities and AESA control.

- In the field of **Intelligence, surveillance, target acquisition and reconnaissance**:

Complementing space capabilities, unmanned aerial vehicles (UAV) and remotely piloted aircraft systems (RPAS), including high altitude platform systems (HAPS), are essential vectors for intelligence, surveillance, target acquisition and reconnaissance (ISTAR). They are critical to achieving and maintaining battlefield superiority in any operation. It is therefore important for the EDF to support collaborative actions in this area in order to (1) mitigate or reduce the risk of dependencies on third country suppliers for such technologies, (2) help to sustain the European defence technological and industrial base in the field of aeronautics, including the supply chain, and (3) incentivise joint procurement at EU level.

Since its launch in 2016, the medium-altitude long-endurance remotely piloted aircraft system (MALE RPAS) programme conducted in the framework of the organisation for joint armament cooperation (OCCAR) and financially supported by 4 Member States, has successfully passed a number of significant milestones in terms of development. This development programme received financial support from the European Defence Industry Development Programme (EDIDP) in 2021.

In line with CDP priorities and CARD findings, the EDF ambition regarding MALE RPAS should be to further support in due course the development of technologies and systems to be used with the aircraft, thus contributing to EU strategic autonomy while ensuring the openness of the supply chain throughout the Union whenever possible. Complementary topics could also be envisaged regarding various related operational requirements when using such a capability. Airborne *Laser communications* and *Detect and avoid* is addressed in 2023, which would be of critical importance for ISTAR operations, notably in view of the MALE RPAS, notwithstanding other complementary topics to be considered before the end of the current MFF.

In addition, next generation of tactical UAS for use in military operational domains, as well as for dual use. The flexibility that a multi-purpose/multi-role system provides to tactical commanders will therefore contribute to information collection and timely delivery of the information obtained for use in the production of intelligence and situational awareness. In the context of the EDIDP, the project 'Low Observable Tactical Unmanned air System' (LOTUS) has been launched in 2020, with the aim of developing an all-European interoperable tactical RPAS with increased survivability and advanced autonomy. A complementing topic is addressed in the EDF Work programme 2023 in order to address e.g. mission autonomy, environmental resistance and ability to have some specific payloads on board. Moreover, in the framework of the Permanent Structured Cooperation (PESCO), ten Member States are involved in the project 'Next Generation Small RPAS' (NGSR) which aims at developing the next generation of tactical UAS supported by technologies and standards that allow an open architecture, autonomy, modularity, and interoperability to maximise system effectiveness to allow European countries to reach that capability. The EDF ambition should be to support the emergence of a European market offer for tactical RPAS with enhanced capabilities that could be jointly procured by interested Member States and could be used for ground, maritime, air and special force operations, as well as by non-military agencies such as border control, law enforcement or disaster management.

Stratospheric persistent airborne systems are particularly suitable for complementing the set of means for ISR to gather relevant and critical information supporting military operations. They are easily and quickly deployable, characterised by very long-range and long-endurance features, with low operational constraints and able to collaborate and interoperate with multiple

different systems. Against this background, a call for proposals related to high altitude platform systems (HAPS) has been launched in 2021 under the EDF with the aim to demonstrate the relevance of ISR stratospheric systems to support military operations. Depending on the results of the project selected for funding, a follow-up action could be considered, with a view to develop a prototype, thus paving the way for a joint procurement by the interested Member States.

All the ISR vectors mentioned above, like the other manned and unmanned air assets, are to be integrated safely and effectively in non-segregated airspace, notably in the context of the Single European Sky. In that respect, the EDIDP project '*European Detect and Avoid System*' (EUDAAS) has been launched in 2021 with the aim develop and validate a European detect and avoid solution so that RPAS can operate along with other manned and unmanned aircrafts. A follow-up topic is therefore addressed in 2023 in the frame of EDF. The ambition of the EDF support in that field should be to help reaching a level of maturity allowing to integrate the envisioned European detect and avoid capabilities into the maximum possible assets within the various Member States' fleet.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to discussions on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the C4ISR category of actions should be to support the achievement of the following main expected outcomes:

- Prototype of a European C2 software suite (contributing to an EU OHQ)
- Joint procurement of a SOFC2
- EU certified and combat-proven standards for tactical communications and radio interoperability
- MALE RPAS prototype, leading to joint procurement
- HAPS prototype, leading to joint procurement
- Tactical RPAS prototype, leading to joint procurement
- Detect and avoid capabilities for extensive integration in platforms

3. Advanced passive and active sensors

'Advanced passive and active sensors' are enablers for many defence capabilities. The category embraces a large spectrum of technologies with a focus on opto-electronic technologies, sometimes called "optronic" technologies, and radar systems. The considered technologies can be active (including generation of waves to probe the environment) or passive (detecting waves or particles present in the environment) and will include networked sensing systems.

Since sensors are relevant across the defence, space and related civil industries and contribute to Europe's technological sovereignty by reducing risks of overdependency on others for things we need the most, they are categorised as critical technologies in the 2021 Action Plan on Synergies between Civil, Defence and Space Industries. While radio-frequency applications and multi-sensor, multi-domain networking of sensors are quite specific to the defence sector with only few exceptions, advances in the optical sensor field are also supported by a few EU initiatives in the civil sector. However, those initiatives mostly focus on supporting pilot production for advanced solutions and in general overlaps with defence technical requirements remain limited.

European cooperation on sensors is useful to strengthen the supply chains for advanced sensors in order to ensure that armed forces of the Member States can have access to the most performant equipment and are able to fulfil their allocated tasks without relying exclusively on the support of allied forces. Another focus of European cooperation must lie in the field of interconnection and interoperability of sensors. Sensors providing data in standardised formats improve the value of the data by allowing their smooth integration in the Intelligence Surveillance and Reconnaissance cycle but also by facilitating the interconnection of systems. The interconnection of multiple sensor systems can significantly improve the quality of the information provided and enable a higher detection performance and coverage for sensing. It is therefore important that even for specific sensor types such as optronic sensors, the system design and data output already enable further interconnection and data fusion.

As an enabling technology, sensors are rarely mentioned as stand-alone cooperation projects. Technological advances contribute to capacities in the field of information superiority in general and to air and ground combat capabilities in particular. Sensor requirements, which may be very specific to particular applications (such as underwater and CBRN applications), might be considered in the corresponding dedicated category of action.

- In the field of **optronic detectors**:

Research topics included in the EDF work programmes 2021 and 2023 focussed on strengthening the supply chain for various infrared detector technologies. The WP 2021 included the EDF-2021-SENS-R-IRD topic to establish technologies for read-out integrated circuits that could connect to different infrared detectors and thermal modules, therefore supporting several EU products. A development action to push the technology even further could be addressed in the future. A complementary call included in the 2023 work programme focusses on substrate and epitaxy supply chain technologies, cryogenic and ROIC bumping technologies to achieve an overall strengthening of the European supply chain for infrared detection systems. In the following years, the EDF could support efforts to validate various innovative optronic sensor technologies and concepts, possibly through a cross-border defence innovation network.

- In the field of **radio-frequency systems**:

Research topics on advanced radar technologies were included in the EDF work programmes 2021 and 2022. Those topics support a collaborative approach to new concepts of radio-frequency systems that have to become more versatile and more adaptable and need to be able to cope with threats that are more difficult to detect and track.

Follow-on activities in the field of radio-frequency systems to enhance their adaptability and flexibility could be considered in the future, with a focus on multifunctional AESA RF systems, building on technological advances as those achieved through the PADR action PADR-EMS-2019, or a topic following more closely the EDF-2021-R-RADAR topic.

- In the field of **multi-sensor systems**:

In 2022, one research topic targeted covert sensing, i.e. the capability to sense without being detected, which focusses on passive sensors, active sensors with low probability of intercept and the interplay of those sensors.

A research topic on multi-sensor integration for increased resilience of micro-drones or robots in hostile and complex environments could be addressed in the future. Implemented in form of a technological challenge, this topic could target improved navigation in GNSS-denied,

unknown and complex environments, as well as increased resilience against adversarial countering efforts.

In complement to the capabilities for endo-atmospheric interception and space-based early warning supported by other categories of action in the years 2021 and 2022 respectively, the 'Advanced passive and active sensors' category issues a call on sensor grids in 2023. This call has the ambition to support the development of concepts, architectures and a proof-of-concept demonstration for networked sensing capacities based on various European assets in order to detect small, fast or highly manoeuvrable targets. This is in line with the PESCO project TWISTER that aims at improving ability to detect, track and counter missile threats.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the SENS category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Concepts and prototypes of interoperable passive and active, stationary and mobile sensors, as well as multi-sensor systems
- Support of supply chain for optronic detectors and radars
- Technological leap in the field of cognitive (adaptable) systems with a focus on RF

4. Cyber

More investments for cyber-R&D are necessary for increased resilience, improved cybersecurity and cyber defence capabilities. Identified vulnerabilities reveal high EU dependency on third countries on cybersecurity and cyber defence technologies, which has a clear effect on the EU's strategic autonomy. Incentivising cooperation in R&D for cybersecurity and cyber defence leading to the development of cyber defence technologies and systems is in line with EU ambition to strengthen cyber resilience and capability building. This contributes to the objective of ensuring full-spectrum cyber defence capabilities and is coherent with priorities set in the Defence Package of February 2022, Strategic Compass and identified in the joint communication on the Defence Investment Gaps Analysis. The EDF cyber category priorities and topics included in EDF WP21-23 and onwards address identified capability gaps and are coherent with CDP Priorities (*"Enabling Capabilities for Cyber Responsive Operations").* Actions are in line with the action plan on synergies and the EU Policy on Cyber Defence which highlights the need for a full-spectrum cyber defence, including active cyber defence capabilities.

In view of increasing cyber defence capabilities, R&D for improved cyber situational awareness, strengthening cyber operational capabilities, including detection, protection and response, are needed, as well as cyber training and exercises platforms for interoperability. Special attention will be given to research actions and projects addressing new technologies developed against new and evolving cyber threats.

- In the field of **Cyber defence operations**:

In the context of the rapidly evolving landscape of threats and to counter the increased risks and cyber-attacks, one topic is addressed in the EDF WP 23 under the development call, aiming at improving the cyberspace operations capabilities.

Further topics could be considered under this category in the future, depending on progress made in joint projects funded under the EDIDP and the EDF.

In addition, with a view to increasing cyber capabilities, increased research efforts are needed. Therefore, a research topic on automation of security penetration tests is addressed for 2023 and could valuably include a spinning-in approach of results from civil programmes. In addition, a possible but non-exhaustive list of areas of interest related to this field is suggested under the non-thematic calls:

- Cyber security talent screening
- Blockchain for Identification Friend or Foe (IFF)

Disruptive cyber defence technologies, e.g. focusing on quantum, could be considered in the future, possibly within the category of actions dedicated to disruptive technologies.

Research and/or development actions for cybersecurity and defence related to specific capability domains or areas (e.g. cyber solutions embedded in weapon systems or cybersecurity and resilience of autonomous vehicles in military operations) could be considered. This would support cyber defence in line with the emerging technologies and would contribute to the main expected outcomes.

Based on the existing short-term cyber defence capabilities gaps, development actions for cyber training and exercises are needed. Therefore, technologies and applications for cyber defence trainings and exercises could be considered. In addition, development for defensive informational operations, such as a follow-up action on EDF 2022 cyber and information toolbox could be considered. As they are basic building blocks for safe and secure defence systems, verifiable, secure and trusted IT components could be considered, possibly through a spin-in approach. Further topics could be considered in view of enhancing the security and safety of IT components, which could address hardware but mostly software considerations.

Based on the existing short-term cyber defence capabilities gaps, development actions for cyber training and exercises are also needed. Therefore, technologies and applications for cyber defence trainings and exercises could be considered, notably with a view of increasing and strengthening cooperation and capabilities of Cyber ranges.

Cyber operation capabilities lie on a continuous improvement process. To address the concept of operation for cyber defence, the area of adaptive defence networks, as well as defensive informational operations, could be supported, notably in the context a follow-up action on EDF 2022 Cyber and information toolbox.

- In the field of **Cyber defence Situational Awareness**:

Member States have identified the need of facilitation of establishment of proactive detection capabilities and improve cyber situational awareness which contributes to more effective cyber operations capabilities. This could include or be connected to development of a holistic threat hunting model. The EDIDP already addressed cyber situational awareness (e.g. ECYSAP 2019). A follow-up topic addressing cyber defence situational awareness tool is included in the EDF WP23. Developments to information sharing tools could be foreseen based on national

requirements, including incident coordination systems with functionalities for EU-wide opportunities.

Synergies with other research programmes will be taken into account in order to avoid unnecessary duplication of efforts and to allow an efficient uptake of results.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the CYBER category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Creation of two persistent main lines of collaborative actions contributing to the development of European common and/or interoperable tools for:
  - cyber operations and incident management
  - information warfare defensive operations and preventive measures
- Resilience for cyber-physical systems

5. Space

Military operations rely heavily on space-based data or space-enabled capabilities, including dual-use ones. Space capabilities can provide fast, globally available (including in Space itself), continuous and discreet services for situational awareness, in support to decision making and conduct of military operations, as well as for the assessment of their specific results. Military applications and use cases require space capabilities to provide secure, robust, reliable and highly performant services in an evolving threat environment. In the context of the EDF, joint R&D actions in the space domain will target consolidation of the demand of capabilities, access to more performant services (e.g. broader bandwidth, increased area-access, continuity of services, higher reactivity and resilience) and improved interoperability while contributing to the reinforcement of the strategic autonomy of the Union. Identified axes of effort described below are in line or significantly contribute to the Capability Development Priorities identified in 2018. The EDF Programme Committee has currently indicated the level of ambition in terms of EDF contribution to Space to more than 10% of the total EDF budget.

In line with the action plan on synergies between civil, defence and space industries[3] and the upcoming EU Space Strategy for Security and Defence, possible synergies with other initiatives at EU level (Space programme, Horizon Europe…) should be systematically taken into account where relevant.

- In the field of **Earth observation for ISR applications**:

Some Member States are already developing and using, in a national and sometimes multinational framework, their own military-class space capabilities for ISR applications.

[3] COM(2021) 70 Final, dated 22 February 2021
https://ec.europa.eu/info/sites/info/files/action_plan_on_synergies_en.pdf

However, these high-end capabilities suffer some limitations (e.g. revisit, reactivity, spectral diversity). In parallel, the private sector is offering an increasing range of services (very high-resolution low revisit satellites and high revisit constellations of medium- to high-resolution small satellites, not limited to imagery) to an increasing range of customers, including Ministries of Defence. This commercial offer is usually not designed to meet defence needs as a priority and suffers some limitation (e.g. security, non-EU dependences). Finally, the Union's Copernicus programme offers a wide range of Earth Observation services in support to various EU policies, including security (maritime surveillance, border control and support to external actions) which may be further developed within the next decade.

In the framework of the Permanent Structured Cooperation (PESCO), seven Member States are involved in the project 'Common hub for governmental imagery' which aims at facilitating the exchange of classified governmental imagery at European level between Member States as well as with EU entities.

In this context, the EDF ambition should be to support the development by 2030 of the prototype of a European space-based ISR constellation able to provide reactivity (e.g. tactical tasking of satellites and delivery of space ISR, if needed via a secure space-based communication infrastructure[4]) and near real time monitoring (e.g. high revisit on areas of interest) while offering diversity of sources (e.g. night vision/infrared, hyperspectral, radar, signals intelligence). Such capability might take the form of a constellation of small satellites and complement existing high-end national/multinational governmental and commercial capabilities. It will also cover ground segment aspects, including, where possible, those promoted within the PESCO framework. Synergies with the EU Space programme should also be explored (e.g. shared use of the system based on predefined use cases, possible agreed governance and co-financing), in view of a potential future Earth observation governmental service[5].

The EDIDP already addresses the early development stage of technologies and products for small optical satellites for maritime surveillance (OPTISSE 2019 – 12 months; NEMOS 2020 – 24 months). Building on this momentum and in view to meet the abovementioned objective while expanding the scope of ISR beyond sole maritime surveillance, 2022 calls for proposals addressed a topic on Innovative multi-sensor space-based Earth observation capabilities towards persistent and reactive ISR to initiate the development (studies, design) of such constellation of small satellites for ISR applications (not specifically focussed on maritime surveillance). A complement of development (up to full prototyping) could be considered in the future.

- In the field of **space domain awareness (SDA)**:

While Space is widely recognised as a congested, contested and competitive environment, only a limited number of EU Member States are developing and using Space situational awareness (SSA) capabilities so far (which are mainly national demonstrators or secondary missions of assets not designed to perform SSA). From the operational perspective, these Member States are cooperating within various multinational frameworks, including the EU Space Surveillance and Tracking (EU-SST) framework where they provide Space surveillance and tracking services (e.g. collision avoidance, re-entry analysis, fragmentation analysis). In parallel, the

4 That could for example be the Secure connectivity constellation promoted by the Commission

5 For which the Commission engaged with EDA, who shared with DG DEFIS the Common Staff Requirements and Business Cases established within the Project team Space-based Earth observation (PT SBEO)

private sector in Europe is starting to offer SST/SSA services, including to Ministries of Defence. However, the EU and its Member States are still lacking a full spectrum of SSA capabilities to ensure an autonomous, sustainable and secure development of activities in Space while monitoring and protecting their space assets against an increasing range of threats[6]. Such SSA capabilities and EU-SST services will be key for the development of a European approach of Space traffic management (STM).

In the framework of the Permanent Structured Cooperation (PESCO), four Member States are involved in the project 'European military Space surveillance awareness network' which aims at developing an autonomous and sovereign EU military SSA capability that is interoperable, integrated and harmonised with the EU-SST framework initiative.

In order to detect, identify and characterise the threats on space-based infrastructure and services, the EDF should therefore have the ambition, in synergy with the EU Space programme where possible, to support the full development of the prototype of a European SSA capability, able to provide a comprehensive space picture and deliver services to both defence and civil end-users. This could take the form of a network of national and multinational/EU assets[7], allowing sharing and processing of SSA data and delivery of ad-hoc services. Such EDF support should lead by 2030 to the joint procurement of SSA capabilities interfaced with EU-SST.

The EDIDP already addresses the early development stages of enhanced sensors (SAURON 2020 – 30 months) and advanced command and control (INTEGRAL 2020 – 28 months) for SSA. In addition, EDF 2021 selected an SME project aiming at developing microsatellites for GEO orbit surveillance and intelligence (NAUCRATES 2021 - 24 months). Building on this momentum and in view of meeting the abovementioned objective, a follow-up topic addressing the system as a whole (*i.e.* sensors[8] and C2) is addressed in the work programme 2023. Depending on the achievable ambition for this topic, a complement could be foreseen in the coming years in order to reach the expected outcome by the end of this Multiannual Financial Framework (MFF).

- In the field of **space-based missile early warning**:

Whereas the (ballistic) missile threat is growing (e.g. development of missile and/or space programmes, rupture of landmark arms control pacts), the Union and its Member States lack operational early warning capability and fully rely on non-EU partners.

In the framework of the Permanent Structured Cooperation (PESCO), six Member States are involved in the project 'Timely warning and interception of with space-based theatre surveillance' (TWISTER) which aims at strengthening the ability of the Europeans to better detect, track and counter missile threats through a combination of enhanced capabilities for space-based early warning and endo-atmospheric interception.

In this context, the EDF should have the ambition to support the development of a space-based early warning capability to detect the departure of missiles (e.g. ballistic, hypersonic) and to

6 Definitions of SSA in the defence domain and in the civilian domain have a different coverage. SSA for defence includes the need to characterise and anticipate potential unfriendly behaviours in space which is not covered by "civilian" SSA definition

7 Including those that could be hosted by the EU Secure Connectivity infrastructure

8 Including new compact spaceborne hyperspectral cameras and miniaturised FMCW-based space radars or more in general miniaturised compact sensors for nanosatellites for space-to-space SSA

track them before handing over to ground based radars, thus directly contributing to the protection of the EU territory against missile threats. Such a development could also contribute as a major milestone to a more ambitious European anti-missile defence capability (see 'Air defence'), able to accommodate various actors, technologies and products. The prototype of such space-based missile early warning capability should be developed by 2030.

The EDIDP already addresses the early development stage of the space-based early warning capability (ODIN'S EYE 2020 – 24 months). Building on this momentum and in view to meet the abovementioned objective, a topic on space-based early warning against missile threats has been included in the work programme 2022 in order to reach a design phase. A follow-up action could be considered to reach the main expected outcome by the end of this MFF and could take place in the future.

- In the field of **positioning, navigation and timing and navigation warfare (PNT and NAVWAR)**:

The emergence of new threats like advanced electronic warfare (e.g. sophisticated jamming, spoofing, cyber-attacks of different level, hybrid threats) and even possible attacks on space and ground infrastructure, calls for improvements of robustness and resilience to ensure adequate level of PNT performances and dependability for EU forces in any operational situation. Besides, EU defence users and equipment currently rely on non-EU GNSS providers.

To improve the EU strategic autonomy, PNT solutions, in particular Galileo PRS-enabled receivers for various defence equipment and applications in conjunction, where appropriate, with other PNT sources, need to be developed and progressively integrated into military platforms to address such emerging challenges and set up effective capabilities. At the same time, European NAVWAR capabilities against the abovementioned threats need to be developed in order to increase the overall resilience of the PNT solutions.

In the framework of the Permanent Structured Cooperation (PESCO), six Member States are involved in the project 'EU radio navigation solution' (EURAS) which aims at promoting the development of EU military PNT capabilities and future cooperation taking advantage of Galileo and the public regulated service.

In this context, the EDIDP and the EDF are already actively contributing to this objective with advanced development of PRS receivers (GEODE 2019 – 72 months) and with a space and ground-based NAVWAR surveillance capability (NAVGUARD 2021 – 48 months). In the future, follow-on developments around Galileo PRS receivers and/or NAVWAR capabilities should be envisaged (e.g. integration into various equipment and platforms, NAVWAR operational centres in military C2).

- In the field of **secure satellite communications**:

A limited number of Member States are developing and using military-class satellite communications, while other Member States rely on other governmental secured assets or commercial providers, which are offering an increasing range of secure communication services. Being able to exchange (classified) data with a guaranteed availability in any operational scenario is a key element associated to strategic autonomy. The increasing number of SatCom applications (e.g. UAS, broadband), and the multiplication and sophistication of threats (e.g. cyber, hybrid, ground- and space-based) will require increasing SatCom capacity and coverage, as well as robustness and resilience. Interoperable and secured satellite

communications for defence would need to be ensured, for effective and adequate services over time and space for defence users, addressing the proliferation of security risks, allowing new usage, while leading to increased EU interoperability, availability, and reduced dependency on non-EU SatCom service providers.

The EDF is already contributing to this objective with the preliminary development of a European protected waveform (EPW 2021 – 39 months) aiming at creating a European standard for secure satellite communications with adaptable security and resilience layers. In parallel, the Union is paving the way to a future secure connectivity space infrastructure (space connectivity constellation) that could implement this EPW standard to offer governmental satellite communication services benefitting both civilian and military end-users (e.g. additional bandwidth for defence applications that require low latency and/or do not require military SatCom, improved geographical coverage, relay for other space-based or ground-based capabilities). Follow-up actions could be envisaged in the future to further analyse the potential synergies with the space connectivity constellation.

- In the field of **responsive space**:

While ESA is co-financing the development of a light to heavy space launcher family (Vega and Ariane) operated from the European spaceport in French Guiana, the Union and its Member States are currently lacking responsive and mobile launching solutions able to place discreetly into specific orbit, within a 48h notice, microsatellites for specific defence applications.

In the framework of the Permanent Structured Cooperation (PESCO), seven Member States are involved in the project 'Defence of Space assets' (DOSA) which aims at increasing EU's operational efficiency in the space domain by making the best use of current and future space assets through cross-cutting space functions of reactive access to space and in-space manoeuvrability, space resilience and training for space military operations.

In this context, the ambition of the EDF should be to support research and future development of such responsive space systems, starting with a research topic in 2022 in order to set the ground for further developments. This could be completed with a follow-up topic in the future.

This field also includes in 2023 a research topic on the surveillance of threats and the protection of space assets, in order to consolidate the common understanding of potential threats and the concept of operations (CONOPS), to study and select the best promising technologies to counter such threats and to develop a roadmap for technological bricks. One of the SME projects selected after EDF 2021 calls (SPRING – 24 months) may contribute to prepare the ground, not excluding possible follow-up actions in the future.

- In the field of **space data processing**:

In order to catch up with the "data wall", it is of high importance that the Member States and the EU tackle in a concerted and efficient manner the question of space data processing, making best possible use of Artificial Intelligence techniques.

The EDIDP and the EDF already address the development of such data processing for ISR applications (PEONEER 2019 – 36 months; IntSen2 2021 – 24 months). As a horizontal research topic relevant for 'Earth observation/ISR' and/or for 'Space domain awareness', processing of space military and/or dual use data for specific defence applications could be

considered in the future, for example with a focus on combined optical and radar satellite imagery analysis to maximise extraction of the information[9]. Suitability for a "technological challenge" approach to foster emulation and innovation could be looked at.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the Space category of actions should be to support the achievement of the following main expected outcomes:

- Joint procurement for integration of PRS receivers into EU MSs military systems (autonomy/synergy Space/Defence)
- Joint procurement of SSA capabilities interfaced with EU SST
- Space-Based Early warning prototype
- Space-Based ISR constellation prototype
- Potential synergies with the space connectivity constellation, subject to further analysis

6. Digital transformation

Digitalisation and big data have made Artificial intelligence (AI) and autonomous systems a reality, even though we are only at the beginning of technological progress in these domains. These new technologies transform the conduct of defence activities. There is thus a need create and develop core AI technologies for computer-aided decision-making, human-system cooperation, robotics and autonomous systems for defence. This involves the creation of representative data to train and test the systems, and the organisation of objective and comparative evaluation campaigns, or "technological challenges", to drive progress toward defence needs while leveraging civil research and generating spill over effects. There is also a need to develop defence big data and cloud services in order to manage, share, and make efficient use of the ever-increasing amounts of data involved in defence activities. .

This 'Digital transformation' thematic category focuses on core technologies addressing several capabilities in a crosscutting way. Dedicated AI-related technologies for specific capabilities, such as unmanned systems, situational awareness, Intelligence, Surveillance and Reconnaissance (ISR), training & mission planning, medical support, maintenance and logistics, etc., are covered under other thematic categories.

- In the field of **trustworthy artificial intelligence**

Technologies should be further developed to enhance AI system performances on challenging types of data (images, video, audio, speech or text, etc.) encountered in defence applications. Such systems are needed to process large amounts of data and to ensure efficient human-machine interactions. An important cross-cutting need is to create technologies for trustworthy autonomous learning, i.e. the ability of a system to adapt and learn from its environment, including from user supervision, without intervention from expert developers nor regression. Such technologies can be highly disruptive and have high impacts for many capabilities,

9 This could also support the parallel development of the multi-sensor ISR constellation

especially when the information to manage is highly variable or unpredictable and high adaptability is needed. These technologies would also alleviate the current need to provide data to the system developers to get improvements, which is an issue when confidential data is involved. They would more generally enhance technological independence. Related to autonomous learning, there is also a need to ensure that AI systems can explain and justify their results to the users, a feature referred to as explainable AI. Another need is to develop dedicated hardware architectures for energy-efficient AI. This is essential for embedded systems, where energy consumption is a bottleneck. It is also important for other systems, as the energy consumption and environmental cost of computing centres becomes more and more significant. Dedicated hardware, and especially analog hardware, is also more difficult to hack, and therefore contributes to cybersecurity. It also links more tightly the knowledge acquired by to the system to the hardware device embedding it, thus increasing traceability, accountability and trust.

- In the field of **micro and nano drones and robots**

In the field of robotics, a crosscutting and particularly challenging area of R&D is autonomous micro and nano drones and robots, including swarming. This is likely to become be in some operational situations the main if not the only option to protect our forces and conduct operations. It requires multidisciplinary research to get a tight integration of AI, sensors, effectors and energy storage. The challenge is not only to develop high-performing systems, but also safe and trustworthy ones.

A related topic on increased resilience of micro-drones or robots in hostile and complex environments could be addressed in the future in the field of multi-sensor systems under the Advanced passive and active sensors category.

- In the field of **defence big data and cloud**

The amount of data produced by the defence operational and R&D activities is huge and ever increasing. Most of it is unused, even though a significant part would be very useful. This is due to the lack of pooled management of data collection, storage and curation. There is therefore a need to support the development of such pooled services. Two types of facilities should be considered, depending on whether the information to manage is classified or not. Secure data cloud facilities serve smaller communities with lower amounts of very specific data, while data collection and curation centres serve larger communities with larger amounts of more general-purpose data. Access to data sets of verified quality and integrity is in

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the DIGIT category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Energy-efficient, trustworthy and adaptive AI core technologies for integration into defence systems
- Safe and trustworthy micro and nano drones and robots
- Shared databases for training, testing and certification of AI systems, and the associated environment to produce, curate and distribute them
- Military operational cloud systems

particular important to contribute to the trustworthiness of the systems developed using this data.

7. Energy resilience and environmental transition

The aim of this category of action is to create and develop energy efficient solutions and green technologies in the defence sector. In the context of the current planetary crisis (climate change, biodiversity loss and pollution, all driven by natural resources depletion), the overall contribution of this category will support Europe in achieving ambitious environmental objectives. The European Green Deal with its strong focus on climate neutrality has become one of the new EU's priorities that should be reflected in all EU policies and programs. The ecological transition will reshape geopolitics, including global economic, trade and security interests. In addition, it should be recognised that the global climate and environmental challenges are significant threat multipliers and sources of instability. These challenges can become sources of conflict, food insecurity, population displacement and forced migration. State and non-state actors compete for the access to the scarce resources (*e.g.* critical raw materials but also water and arable land), which can lead to crises and conflicts. Some of them will affect the EU and require a common response.

In March 2020, the EU adopted a new Circular Economy Action Plan (CEAP) - one of the main blocks of the European Green Deal, Europe's new agenda for sustainable growth. The CEAP states "*Circularity is an essential part of a wider transformation of industry towards climate-neutrality and long-term competitiveness*. *It can deliver substantial material savings throughout value chains and production processes, generate extra value and unlock economic opportunities. Despite efforts at EU and national level, the amount of waste generated is not going down*". The defence activities need to contribute to the reduction of waste by developing innovative technologies to address *e.g.* waste management, safe use of chemicals, component tracing, environmental protection, water management, and green military components, through design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling.

Water is an increasingly scarce commodity and often imposes a substantial logistic burden on remote operations. Cheaper, high-throughput and ruggedised treatment technologies for water from a variety of sources, but also advanced packaging and preservation technologies are important.

In parallel, energy security is fundamental for any military activity. Movement, endurance and ability to perform any kind of operation depends on the availability of energy supply. Increasing demand of energy for modern capabilities requires an easy access, efficient storage and sustainable usage across all military domains. Climate changes prompts a move towards sustainable power sources beyond fossil fuels, generate challenges and threats alternating the way our forces operate, driving the capability requirement and ultimately influencing defence research and development.

Since military forces consume a lot of energy, security of supply is critical. For forward forces deployed to operations and missions in harsh environmental conditions, technologies reducing the dependency on large supplies and minimise fuel transportation, thus limiting logistic footprint and operational vulnerabilities, will be needed. This translates into higher level of manoeuvrability, independence and therefore of effectiveness of the deployed forces. New developments should focus therefore on high density/high power storage system (e.g. customised batteries, fuel cells, multi-sources energy systems, etc.), as well as modern energy conversion technologies and alternative propulsion (air, ground and sea) on existing and future

platforms will hinge on the ability to downscale its energy sources and render them more efficient.

The EDF Programme Committee has agreed on the level of ambition in terms of EDF budget contribution to energy resilience and environmental transition to more than 5% of the total EDF budget.

- In the field of "**future efficient and multi-sources energy solutions**"

The increase in energy consumption should be achieved by means of new power supply such as renewable energies, high energy sources hybrid powertrains or energy production, batteries, energy storage and fuel cells. However, these new forms of consumption pose a challenge for their integration in weapon systems, for their technological development and for their logistics operational management.

In the context of the Permanent Structured Cooperation (PESCO), six Member states are involved in the project "Energy Operational Function", which has a dual objective of developing new systems of energy supply for camps deployed in the framework of joint operations and for soldier connected devices and equipment and ensuring that the energy issue is taken into account from the design of combat systems to the implementation of the support in operations, and including in the framework of operational planning.

In line with the objectives/priorities set out in the Common Security and Defence Policy (CSDP) and Strategic Compass for innovating, the energy efficiency in the defence sector should be enhanced, including for CSDP missions and operations, and without reducing operational effectiveness. Furthermore, develop common benchmarks and standards for the increased use of renewable energy sources and the resilience of defence-related critical infrastructure are to be addressed.

The EDF ambition should be to support the development of a prototype of a future efficient and multi-sources energy solutions for the defence sector operating under harsh environmental conditions, hence paving the way for a future joint procurement at EU level.

EDF already contributes to this objective through two complementary topics included in the 2021 EDF work programme dedicated to "Energy independent and efficient systems for military camps" and "Next generation electrical energy storage for military forward operation bases". Both call topics aim at developing a sustainable, deployable, safer and cost-efficient energy storage system that operates in a severe military environment subject to different geographical locations, weather and climate conditions (including extreme environments). Depending on the outcome of this call and on the results of the project awarded, a follow-up topic could be considered in the future.

- In the field of "**Efficient engine representative of new architecture and technologies**"

Improved energy generation (propulsive and non-propulsive) technologies are needed to meet increasing electrical demand, including power density considerations. Moreover, these constraints are common for high value military equipment for next generation platforms.

The EDF ambition should be to support the development of a prototype for efficient and engine representatives of new architecture and technologies respectively adapted to these areas (air

combat aircraft, Main Battle Tank (MBT) and naval vessels), thus paving the way for a future joint procurement at EU level.

The EDF already contributes partially (only for air combat aircraft) to this objective with a topic included in the EDF 2021 work programme dedicated to *Alternative propulsion and energy systems for next generation air combat systems.* The envisioned project aims at full European technological sovereignty of military air platforms and will develop new technology building blocks of next generation propulsion and energy integrated systems which will be evaluated on a dedicated European propulsion and energy ground test platform. Depending on the outcome of this call and the results of a project possibly awarded, a follow-up of this topic could be considered in the future.

- In the field of "**environmental transition**"

a) Water reuse

Drinking water is a crucial need for military operations. The experiences in arid regions showed that there is a need for the reuse of water to enable military operations. The new modular military field camp will use technologies for water reuse to reduce the demand for fresh water. Since the application of this technology is quite new for mobile water supply, experiences are very limited. There is a need to assess different concepts and the corresponding technology to ensure a save water reuse throughout the entire water cycle of a camp. Graphene and its oxide form – graphene oxide (GO) – are new materials with potential applications in this area. The research activities should create an innovative concept for water supply in a military field camp for regions with scarce water resources, possibly elaborating on the microbiological properties of graphene materials. Special emphasis will be placed on innovation and standards that can help reduce the environmental footprint of armed forces and create possibilities to re-use valuable components and scarce materials. In order to avoid duplication of efforts and funding, synergies with other research programmes should be considered. In particular, with the graphene flagship, Europe's funded project gathering nearly 170 academic and industrial partners from 22 countries, to explore different aspects of graphene and related materials.

The EDF ambition could be to support the development of a prototype of technological solution to ensure safe reuse of water for military and peace keeping missions.

b) Sustainable components for defence applications

The specific challenge is to advance the state-of-the-art in the research of, and innovation in, new high performance lead-free piezoelectric materials for military underwater sensors applications to replace titano-zirconate Pb_1-xZr_xTiO_3 (PZT), with a view to future phases of development and industrialisation, leading to the prospective establishment of at least one European supply chain in this domain. New materials can also provide the opportunity to generate additional benefits, for example, enlarging the operational frequency bandwidth of sensors or source generators, improving duty cycle limitations or reducing the sensor size. These opportunities can upgrade the performance of the sensors and should hence be considered in the evaluation of materials and processes to be studied.

Compliant with REACH regulations, other relevant regulations, such as the Restriction of Hazardous Substances (RoHS) or Waste Electrical and Electronic Equipment (WEEE), require the elimination of lead and its salts from consumer goods and industrial devices.

c) Recycling in defence

No formal statistics are available on the amount of waste produced by the defence sector. Most of the waste is burned or put into landfills – neither being in line with responsible environmental behaviour nor with the goal of reducing ecological footprint. Therefore, the aim to analyse, test and validate suitable solutions for mechanical and "green" chemical recycling of waste of soldier individual equipment (uniforms, helmets, boots, rucksacks, plastic elements, harness, etc.). Furthermore, there is a need to explore the feasibility of innovative technologies, create adequate processes and validate the technology to pilot (prototype) solution that significantly changes today's (not sustainable) practices in waste management. It is essential to find solutions that are both cost-effective and consider defence requirements and specificities. A special emphasis will be put on innovation and standards that can contribute to the reduction of the environmental footprint of armed forces and create possibilities to re-use valuable components and scarce materials.

The EDF ambition could be to support the development of a prototype of innovative solution for recycling soldier equipment.

The research will provide the basis for further developments of technology that could have major impact for recycling. The outcome of this action could be usable and adjustable across armed forces of EU Member States.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the ENERENV category of actions should be to support the achievement of the following main expected outcomes:

- Prototype of a future green, efficient, resilient, safe and multi-sources, energy solutions for the defence sector operating under harsh environmental conditions
- Demonstrator of efficient and green engine representatives of new architecture and technologies, respectively adapted to each of the following capability:
  - next generation air combat aircraft
  - next generation Main Battle Tank (MBT)
  - next generation naval vessels
- Prototype of technological solution to ensure save reuse of water for military and peace keeping missions
- Prototype of green innovative solution for recycling soldier equipment

8. Materials and components

Materials and components are enablers for a large spectrum of solutions at the core of the development of military capabilities. This category supports technologies for a large spectrum of products and systems strongly linked with other categories of EDF work programme. Particular material research might be included in other categories if the targeted application is specific enough, e.g. in SENS for optoelectronic detector material. Topics to be addressed are also linked to progress made in joint projects funded under the PADR, EDIDP and the EDA Cat B programme.

Most of the activities in this category of action are related to the Capability Development Priorities of cross-domain capabilities contributing to achieve EU's level of ambition. On the intergovernmental side, five EU MS have joined the PESCO project 'Materials and components for technological EU competitiveness' (MAC-EU) that targets in particular materials and components technologies for which the security of supply and the freedom of use may be restricted.

Access to critical materials and components is a challenge common to space, defence and security sectors, as pointed out in the Action Plan on Synergies between civil, defence and space industries. Advanced materials technologies and semiconductors and microelectronics are identified as critical technologies relevant across industries. Strategic dependencies must be better identified and mitigation measures analysed. In this respect, it is important to assess the risk that the operational use of the technology might be compromised or denied. The Observatory on Critical Technologies will provide monitoring and analysis of such technologies, with a first pilot focussing on a selection of semiconductor components.

The sustainability of strategic supply chains in the fields of materials and components has been in the focus of the Commission even before the establishment of the EDF and the risks for defence supply chains has been highlighted by several reports[10]. New materials have also been identified as one of the technologies reshaping defence markets by the Strategic Compass.

Materials used must enable and enhance the performance of defence capabilities while complying at the same time with the Zero Pollution principle of the European Green Deal. Taking into account aspects of sustainability in materials research presents many advantages from an ecological, logistics and security of supply point of view. Therefore, materials developed should comply as much as possible with the Zero Pollution Principle under the European Green Deal (COM/2019/640 final). Even though defence applications can be exempted from regulations such as REACH, efforts to comply with safety and sustainability requirements can lead to better spin-off opportunities, thereby strengthening the EDTIB. With respect to electronic components, the characteristics small, light-weight and of low-power consumption (SWaP) are critical to most defence applications due to the challenging operating conditions in this sector. Defence R&D could both take advantage of the civil efforts to improve energy efficiency and also contribute to new solutions that might be taken up by civil applications. Call topics issued in the category MATCOMP will therefore request to take eco-design, circularity and sustainability into account where possible, while call topics that focus on the replacement of material or production techniques (including recycling) are addressed by the category ENERENV.

The uptake of R&D efforts originating from civil research should be particularly promoted in this category of action. This is realised through the use of EUDIS measures in the form of a spin-in call in 2023 that provides follow-up funding for add-on R&D addressing the specific requirements for defence applications. This cross-fertilisation could also prove particularly effective in the area of materials, which has broadly been addressed by civil R&D programmes in the past. Therefore, the topic addressing joining, repair and maintenance is designed as another EUDIS measure, namely a cross-border defence innovation network.

10 "Materials dependencies for dual-use technologies relevant for Europe's defence sector", Joint Research Centre, 2019. "European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020", Joint Research Centre, 2020

With respect to this category, the two main fields on which future defence systems and technologies rely are the use of advanced materials and critical components and electronics.

- In the field of **advanced materials**:

The performance of defence ballistic systems needs to be improved to address safety and higher survival of military personnel. At the same time, novel threats in different military applications require the use of solutions which could ensure the necessary protection. Furthermore, soldier equipment needs to allow for activities that are often physically demanding, while bringing protection, situational awareness and preserving capacity to act, endurance, and mobility. Research activities on existing materials or new materials or concepts of protection considering the specificities are thus necessary for fulfilling safety criteria but also flexibility of equipment. This was addressed EDF 2021 Work Programme by a research call on materials and structures for protection in hostile environment and in 2022 by a development call for smart and multifunctional textiles for defence applications. A subsequent call for protection in hostile environment could be envisaged in the future. As those calls are linked to soldier equipment, they are also related to the category PROTMOB as well as to PADR efforts supported by the call 2017-FPSS on Force Protection and Soldier Systems.

The EDF 2023 work programme includes a research call on novel high-performance materials that have the potential to fulfil the particular requirements for defence applications, i.e. to withstand high temperatures or yield significant weight reduction. This call is specifically designed to support the spin-in of innovative solution from civil applications.

A topic to support a development action for materials and techniques that need to be adapted and certified for defence applications in the domain of repair, joining and maintenance has also been issued in 2023. Based on previous results obtained for civil or defence applications the goal is to propel such technologies across the valley of death. This call is designed to support a cross-border defence innovation network that will host the test platform and will provide test and other services to innovative players.

Performance of materials can be significantly changed by using innovative assembly techniques. For example, architectured materials that follow a top-down design process could have the potential to outperform materials developed through bottom-up improvements. Such novel design processes for materials could be addressed in the future. This topic could also have a link to metamaterials, where assembly techniques targeting geometrical properties can lead to radically different properties than their bulk counterpart, and which are potentially covered by the category on disruptive technologies for defence in the same year.

New manufacturing techniques such as additive manufacturing could have beneficial impact on the logistics footprint and availability of some technical equipment. This might be most critical in the medical domain and additive manufacturing techniques applied to defence medical equipment and spare parts, as well as bio printing in the defence context, could be considered.

- In the field of **critical components and electronics**:

EU programmes in the civil sector play an important role in the field of critical components and electronics. Advanced materials as well as micro/nano-electronics and photonics are two of the six Key Enabling Technologies (KETs) which receive prioritised support to research and innovation. Semiconductors were also highlighted by the updated industrial strategy. Another initiative currently prepared by the Commission is the European Chips Act that has the aim to

mobilise additional public and private investments into the semiconductor supply chain, in complement to existing Horizon Europe and Digital Europe measures.
Initiatives such as the European Alliance for Industrial Data, Edge and Cloud and the Industrial Alliance on Processors and Semiconductor Technologies have been created to engage a wide range of partners in joint action. Important Projects of Common European Interest are initiated by Member States and bring together private actors and other players to overcome challenges in the area of innovation and infrastructure. Although those initiatives have a focus on civil applications, industries active in the security and defence environment can participate. This initiatives could also benefit the progress in the fields of security and defence, as pointed out by the Roadmap on critical technologies for security and defence issued in the 2022 defence package. Synergies with other research programmes, and in particular the Space Programme and Horizon Europe's funding for electronic components will need to be considered to avoid unnecessary duplication of efforts and the efficient uptake of results. However, requirements on electronics and other components can radically differ for defence applications and industrial production faces economic viability challenges due to small production volumes. Therefore, specific support and strategies for defence applications must be put in place to close technological gaps and strengthen technological autonomy.

An element to create a more robust supply chain is the capacity to integrate electronic components from different providers into one product. One of those enabler capacities are packaging technologies. Packaging technologies need to respond to specific requirements for defence applications. They need to protect the electronic components from tough environmental conditions while being able to manage the frequencies and temperature management needs of high power or high frequency applications. Advances in this field are again enablers for different applications in different domains. A dedicated support is necessary as the volume necessary for defence applications is too limited to attract R&D investments. They are addressed by the 2022 call 'Packaging technologies for critical defence components'. In the same vein, the standardisation of chiplets can allow to interconnect components originating from different manufacturers thereby creating a more robust and dynamic industrial landscape. The support of chiplet standards for defence-specific components could complement efforts from the civil sectors in the next years.

In the future, supply chain for electronic components that are relevant for defence applications, e.g. system-on-a-chip or system-in-package including components such as Analogue-digital converters (ADC/DAC), field programmable gate arrays and RF CMOS components, could be considered. A related effort had been triggered by the PADR call EDT-02-2018 that addressed the design and validation of a European high-performance, trustable (re)configurable System on Chip / System in Package (SoC/SiP) suitable for multiple defence applications.

Research on advanced components for radio-frequency application, focussing on GaN, as supported through the 2021 call, is an important enabler for applications in the higher frequency band and lower microwave bands. Depending on the outcome of this call, a follow-on on advanced components for radio-frequency application could be envisaged in the future.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the MATCOMP category of actions should be to support enabling technologies and capabilities for a variety of defence applications and thereby supporting all other categories of actions, in particular by contributing to:

- Support of supply chains for electronic components
- Support of innovation for high-performance and protective materials
- Certification of technologies for manufacturing and maintenance

9. Air combat

The category 'Air combat' consists in the development and the effective integration of air combat systems and technologies in overarching systems that allow data exchange and sensors networking in order to operate in more and more complex air environments. All these capabilities would operate in the future through a combination of manned and unmanned platforms, possibly integrated in larger joint operational contexts, with a collaborative combat approach. It includes a broad range of high-end capabilities, manned or unmanned, from vectors to effectors, including dedicated weapon systems and payloads. In particular, next generation fighters and helicopters systems and technologies, including cutting-edge self-protection capabilities, are critical to achieve the desired air supremacy and penetration mission requirements. According to the collaborative warfare concept that will drive the near future operations, all these air combat systems should be interoperable and interconnected in a large perimeter with different generations of various aircraft, satellites, naval and ground assets, but also compliant with NATO, EU and national regulations, standards and architectures when appropriate. These capabilities require long development cycle and heavy investments.

The EDF Programme Committee has indicated the level of ambition in terms of EDF budget contribution to air combat to more than 10% of the total EDF budget.

- In the field of **air fighters**:

Current fleet inventories indicate that several air combat systems currently operational (e.g. Rafale, Eurofighter, Tornado) might reach the end-of-lifecycle in the upcoming years. Member States are planning to invest in the development or acquisition of next generation air fighters that should have at least, stealth, survivability, enhanced capabilities and improved connectivity enabling them to operate in networks of assets, including unmanned ones, and be able to use wide options of improved standoff weapon systems.

Supporting the CDP priorities and CARD findings, the EDF ambition in this field should be to support the development of key components, technologies and functions, including through a digital twin approach, which could be eventually integrated in the envisioned next generation air fighter systems. By doing so, the EDF will sustain the European value chains and help maintaining critical skills in design, testing, certification and production chains related to the required cutting-edge aeronautic technologies, while ensuring interoperability of future fighter systems.

To meet this ambition, an EDF call for proposals related to enhanced pilot environment for air combat has been launched in 2021 with a view to address the enhancement of fighter cockpits

through notably adaptive human system collaboration, visualisation, crew monitoring and interaction modalities. Depending on the results of the project selected for funding, a follow-up topic could be considered in the future.

In addition, a topic aiming at exploring the other cutting-edge technologies and components that would be required for next generation of fighter systems, including combat UAV to be possibly used in cooperation with fighters, could be valuably considered.

- In the field of **helicopters**:

With their unique ability to take-off and land from almost anywhere, the importance of rotorcrafts in military operations is widely recognised as they are considered powerful multi-domain operations enablers. Military rotorcrafts are indeed fulfilling various missions like Armed Reconnaissance, Strike, Combat Search-And-Rescue (SAR), MEDical EVACuation (MEDEVAC), Utility, Air Assault and Close Aerial Support, which are critical for the success of military operations. Furthermore, beyond their pure military role, military helicopters are also key assets for a better Civilian Defence (Security & Protection) and EU-internal resilience, with critical contribution to disaster relief, civilian Search-And-Rescue, and sanitary crises.

The EDF ambition could be to support the development of a prototype for a European next generation rotary wings system, possibly with high-speed, long-range and high-altitude features, hence paving the way for a future joint procurement at EU level.

To meet this ambition, an EDF call for proposals related to studies for next generation vertical take-off and landing (VTOL) systems has been published in 2021. Depending on the outcome of this call and on the results of the project selected for funding, a follow-up topic could be considered in the future.

- In the field of **collaborative air combat**:

Jointly building a European perspective enabling the Member States to address at middle and long-term collaborative air combat capabilities combining future air combat systems, manned or unmanned platforms, legacy platforms and their evolution, including sensors and effectors, is a critical challenge. With the plausible introduction of unmanned systems into air combat, future interoperability requires a far deeper interconnection that can be provided through cutting-edge technologies, including new generation of tactical data links.

The EDF ambition in this field could be to support the development of European standards for collaborative air combat, in combination with fully operational standards for the insertion of unmanned platforms into non-segregated airspace, that could be integrated in various development and upgrading programmes related to air combat.

To meet this ambition, an EDF call for proposals related to collaborative air combat has been published in 2021. Depending on the results of the project selected for funding, a follow-up topic could be considered in the future.

- In the field of **endurance and survivability**:

Fixed and rotary wings platforms should be able to operate with long endurance, notably through air-to-air refuelling, and should be equipped with self-protection systems that would allow them to counter attacking threats possibly hampering the air mission in contested environments.

Investigating on enhanced air-to-air refuelling capabilities could be valuably considered in the future in the frame of EDF.

Regarding self-protection capabilities, depending on the outcomes of the EDIDP CARMENTA[11] project launched in 2021, a follow-up topic is included in 2023 with a view to develop and validate a prototype.

In addition, as European forces increasingly face sophisticated long range IADS and A2/AD systems, airborne electronic warfare capabilities become more and more critical. Following the actions conducted under EDIDP REACT project , a follow-up topic is addressed in 2022 through EDF, without excluding further iterations, with the objective to develop a state-of-the-art airborne electronic warfare capability to be jointly procured and possibly usable on manned and unmanned platforms.

Air combat should take advantage of the actions carried out under other categories as, for example, the next generation of propulsion and energy systems for air fighters addressed in the framework of the energy resilience and environmental transition category, and other topics related to advanced passive and active sensors, cyber and space.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the AIR category of actions should be to support the achievement of the following main expected outcomes:

- Critical components and technologies for next generation fighter systems
- EU standards for collaborative air combat
- Prototype of next generation rotorcraft, leading to joint procurement
- Joint procurement of an airborne electronic warfare capability

10. Air and missile defence

The 'Air and missile defence' category embraces a large spectrum of capabilities leading to protect EU forces and populations against aerial threats, from counter-UAS to ballistic missile defence.

The EDF Programme Committee has agreed on the level of ambition in terms of EDF budget contribution to air and missile defence to more than 5% of the total EDF budget.

- In the field of **counter UAS:**

A wide range of unmanned air systems (UAS), including off-the-shelf commercial drones and mini/micro-UAS possibly flying in swarms, are increasingly used for attack or intelligence gathering purposes and these pose ever more threats on forces and populations.

[11] Future European Self Protection System for Fixed Wing (Transport, Mission) and Rotary Wing (Transport, Combat) airborne platforms

In line with CDP priorities and CARD findings, the EDF ambition in this field could be to support the development of active and passive protections against armed and intelligence gathering UAS that will increase force protection, resilience of critical infrastructures, and contribute to information superiority.

An ongoing PESCO project is aiming at the development of a system able to counter the threat posed by mini and micro UAS and able to be employed for homeland defence, security and dual use tasks.

In the context of the EDIDP, the project JEY-CUAS (Joint European sYstem for Countering Unmanned Aerial Systems) launched in 2021 is paving the way for the development of a joint European counter unmanned air systems capability. Depending on the results of this project, a follow-up topics is addressed in 2023 with a view to develop a prototype and leading to possible future joint procurement at EU level. Taking into consideration various solutions for C-UAS already developed throughout the Union, with different applications and outcomes, a technological challenge in this area could be considered in order to trigger a step forward leading to let the Member States identify the best solutions.

- In the field of **ballistic missile defence**:

The emergence of new threats such as manoeuvring ballistic missiles, hypersonic cruise missiles or hypersonic glide vehicles represents an additional challenge for European and NATO ground and naval-based air defence systems.

The EDF ambition in this field could be to support the development of a prototype of a European endo-atmospheric interceptor. To meet this ambition, the initial phase of development has been addressed in 2021 and 2023, not excluding further follow-up actions.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the AIRDEF category of actions should be to support the achievement of the following main expected outcomes:

- Prototype of endo-atmospheric interceptor
- Prototype of counter UAS, leading to joint procurement

11. Ground combat

Land platforms and their weapons systems are crucial capabilities for all land operations. This category focusses on major land combat systems (e.g. MBT[12], ATV[13], APC[14]), Unmanned Ground Systems (UGS) and indirect fire while ensuring collaborative combat for European land forces.

The European capability landscape displays a lack of coherence through the high number of different types of land combat systems, including the diverging logistic systems behind, their status of modernisation and upgrade. This is reinforced by diverging approaches of Member

[12] Main battle tank
[13] All-terrain vehicle
[14] Armoured personnel carrier

States to prepare for the future as regards land platforms: digitalisation and systems-of-systems approach vs increase in numbers of combat systems. Reducing the diversity of types of land platforms and converging the approaches to prepare the future will be the major challenge across all planning horizons. Against this background, Member States should cooperate on developing and refining generic open architectures standards in collaboration with the defence industry, while also developing modular and open platforms that can be easily upgraded and reconfigured in light of technological evolutions.

The EDF Programme Committee has agreed on the level of ambition in terms of EDF budget contribution to ground combat to more than 10% of the total EDF budget.

- In the field of **land platforms**:

Future capability and operational challenges require the development of next generation and the modernisation of current platforms (e.g. ATV, LAV[15], IFV[16], APC) , armoured with enhanced interoperability, agility, survivability, mobility, durability, versatility, security including cyber, as well as the ability to operate in adverse conditions (facing challenging threats in various environments), addressing a large range of missions, in digitised battlefield and network centric environments, and to obtain scalable effects and other ground platforms such as logistic support vehicles, engineering vehicle, while ensuring efficient maintainability and support, high level of operational readiness and optimised life cycle cost.

The MBT capability is an essential backbone for high intensity land-based operations. The combination of mobility, firepower and protection has proven its relevance in conventional warfare. Many MBT assets currently held by Member States are ageing or obsolete. In recent years, Member States have unveiled plans to modernise in-service platforms as well as to replace capabilities close to the end of operational life, presenting an opportunity for potential future collaboration to improve overall EU MBT capability.

- In the field of **collaborative combat**:

A very harsh environment with high intensity activities characterises the future battlefield, including the land domain. Indeed, the land environment is recognised as hostile, very diverse on the planet scale, fast changing (so that existing maps rapidly do not apply anymore) and complex (with terrain compartments which may block vision as well as communication links), presenting various levels of structuration (from open to urban terrain, which represents a real challenge for image processing or for autonomous vehicles and robotics). It fully includes the 3rd dimension and thus the requirement for wide connectivity and interaction (expanded situational awareness and cross-platform collaborative engagement) with different sensors and effectors in the land domain (i.e. manned platforms, UxV and dismounted soldiers) and with sensors and effectors from other domains (air, space and cyber) as well as underground infrastructures in urban areas.

- In the field of **indirect fire**:

Due to the evolution of the defence context in Europe, land forces need the ability to operate in a high intensity threat environment, facing potential technically advanced adversaries. In this

[15] Light armoured vehicle
[16] Infantry fighting vehicle

context, associated firepower to protect forces such as artillery capabilities, including ammunition, need to have their range, precision and efficiency improved.

- In the field of **unmanned ground systems**:

There are significant cooperation opportunities in the Union regarding unmanned systems, which could be based on a shared operational concept and the resulting harmonisation of requirements. Moreover, the CDP analysis identifies the need to deploy unmanned systems to reduce the danger to human personnel and manned platforms, as well as to increase robustness, sustainability and resilience of ground systems. A comprehensive set of unmanned systems should contribute to the capability of land manoeuvre in the joint operational environment to gain positional advantage in respect to the adversary. The strategic relevance of the manned/unmanned teaming and adaptive cooperation between manned & unmanned systems is also linked to the improvement of land systems' capability to conduct complex operations through the increasing use of unmanned assets.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the GROUND category of actions should be to support the achievement of the following main expected outcomes:

- Joint development and procurement of a different set of vehicles and integration of technologies for vehicles upgrades
- Contribution to future MBT and other armoured vehicles development
- BLOS capability jointly procured
- Development of a long-range indirect fire demonstrator
- UGS jointly developed and ready to procure
- Contribution to enhanced connectivity and interaction among land platforms (manned/unmanned, mounted/dismounted) and initial integration of collaborative land combat capabilities into national platforms

12. Force protection and mobility

Force protection and mobility at all levels minimises losses to hostile action while ensuring security of supply for the forces on the battlefield. The availability of capabilities to ensure advanced protection of forces and mobility is an important operational requirement.

Force protection and mobility has a broad range of aspects, which vary from design parameters of major combat platforms to individual soldier systems. The European Capability landscape is characterised by a variety of standards and systems.

Preserving the overview on force protection and mobility needs and activities, including the cutting edge of technologies usable in this context remains a major challenge across all planning horizons.

- In the field of **soldier systems**:

Soldier Systems support force protection, increase operational effectiveness, reliability and endurance of individual soldiers and formations. They comprise the gender-neutral equipment

of individual military personnel to be able to operate with a sufficient level of protection in any operational environment. Soldier Systems are a primary force multiplier. The development and integration of cutting-edge technology in soldier systems is key for forces and should provide soldiers with an improved situational awareness, decision-making aids, effective engagement, operation in GNSS denied environments, and provide simple and effective human-machine interfaces to support soldiers' manned-unmanned teaming. There is an industrial overcapacity in the field of Soldier Systems at EU level, which led to fragmentation in R&D investments, and which also resulted in the development of various not interoperable systems. The development of an EU open architecture in soldier systems is therefore paramount.

- In the field of **future cargo capabilities**:

Tactical transport aircrafts are the workhorses of battlefields, fulfilling missions such as airdrop delivery, parachutist drop, logistics, medical evacuation (MEDEVAC), air to air refuelling, special missions under harsh and adverse conditions, which are critical for the success of military operations. Beyond their pure military role, tactical transport aircrafts are also key assets for a better civil defence/protection and EU-internal needs, with critical contribution to disaster relief, search-and-rescue and sanitary crises response. The Future Mid-size Tactical Cargo aircraft (FMTC) addresses this need within the European transport portfolio.

Strategic air transportation of outsized cargo (SATOC) is a core capability for rapid military projection over long distances and mission support worldwide. All operations carried out so far have always had to fall back on this important capability for deployment and later sustainment. Beyond their military role, SATOC aircraft are also key assets for critical and essential contribution to immediate logistical support over large distances, disaster relief and fast general crises response. Currently, there is no adequate service provider who has the appropriate capability to support the Member States' needs, hence studying the possibility of a future aircraft development or appropriate contractor support is addressed in 2023.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the PROTMOB category of actions should be to support the achievement of the following main expected outcomes:

- Standardisation of European soldier systems and systems jointly procured (e.g. equipment, interconnection)
- Contribution to improvement of soldiers' situational awareness, decision-making, effective engagement, operation in GNSS denied environments, and teaming with UxS through enhanced Soldier Systems.
- Contribution to FMTC development
- Contribution to SATOC development

13. Naval combat

The EU is surrounded by oceans and seas, which are essential for the European economy. The EU Maritime Security Strategy identifies a vast spectrum of challenges, threats and risks that could condition an open, safe and secure global maritime domain. Naval power and supremacy at sea is crucial for the European armed forces to fulfil their missions and to defend European

citizens and territory as well as to enable power projection in more remote geographical areas. It has also a key role in peace and crisis times to support a credible foreign policy.

Evolving operational environment and threats require the development of cutting-edge maritime systems and platforms, which should be able to operate interconnected in a fully integrated way, under challenging multi-domain threat conditions (land, aerial, surface, subsurface and cyber), including, where necessary, in extreme climates and geographical environments (*e.g.* the Arctic), as well as to comply with the requirements of most advanced environmental legislation.

From a technological and industrial perspective, despite the fragmentation of the naval EU internal market, the European naval industry remains competitive at global level and could maintain its technological leadership. However, the capacities of system integrators and equipment suppliers represent a strategic asset of the European naval sector to be preserved and strengthened.

Having the above in mind, the EDF Programme Committee has currently indicated the level of ambition in terms of EDF contribution to naval combat, together with underwater warfare, to more than 10% of the full EDF budget.

Two main lines of work are considered for the EDF 2021-2027:

1) Support to development actions aiming to provide Member States with effective **state-of-the-art capabilities.** Those actions refer to either **new naval vessels and systems or the upgrade or current assets**.

   These actions are fully aligned with the Surface Superiority module of the Capability Development Priority Naval Manoeuvrability, and support capability needs in the fields of Maritime Situational Awareness and Power Projection. They are also in line with opportunities identifies by the CARD when addressing the need for consolidation of the capability landscape in the naval domain. Furthermore, these actions are usually developed in the context of PESCO projects, such as the European Patrol Corvette or the Medium Size Semi-Autonomous Surface Vehicle.

   Considering the EU diversity as regards main naval scenarios, missions and current capabilities of the EU navies, these actions might not interest, jointly, a large number of Member States, nor involve all the EU naval actors. Hence, in these cases, inclusivity should be sought through the widest possible supply chains.

   EDF could strongly support actions in this area with a significant budget and consider subsequent actions to support follow up development phases once the initial action has progressed adequately.

   In this category we can include:

   - modular and multirole patrol corvette addressed by EDF in 2021 and 2023;
   - medium-size semi-autonomous surface vessel addressed by EDF in 2022;
   - naval collaborative surveillance addressed by EDF in 2022, that could be considered for a follow-up in the future and set up the basis for a future topic on naval collaborative engagement.

2) **Support to research and development actions** whose results can benefit most of, if not all, the EU naval actors. Those actions would focus on **technologies, standards, or systems to be integrated**, in one way or another, in **specific naval projects**. They should be considered real enablers for both the naval industry and the EU Navies. By nature, these actions are inclusive.

   Two examples of these naval actions attracting broad interest and involvement, are the research project OCEAN 2020 funded under the PADR, and the development project SEA DEFENCE funded under the EDIDP.

   As regards EDF 2021, it is worth mentioning the topics *Digital ship and ship digital architecture* and *Ship structural health monitoring* as clear examples of actions whose results related to digital transformation in the naval sector, can be easily capitalised in the future by other specific projects.

Some naval projects are currently paving the way for future wider actions under other categories like, for example, the Small optical satellites for maritime surveillance funded under EDIDP (OPTISSE and NEMOS). The Space category can now take advantage of the momentum created and expand the scope of ISR beyond maritime surveillance as it could be considered together with innovative multi-sensor space-based Earth observation capabilities.

In the same way, the naval combat category of actions should benefit from the actions carried out under other categories as, for example, the design of naval green fuel under innovative propulsion systems for defence applications, addressed in 2023 in the framework of the energy resilience and environmental transition category, and other potential topics in the information superiority, advanced passive and active sensors, cyber and disruptive technologies (e.g. laser-based weapon systems) categories.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the NAVAL category of actions should be to support the achievement of the following main expected outcomes:

- Joint procurement of a modular and multirole patrol corvette class
- First ship of a medium-size semi-autonomous surface vessel class, including different mission modules, leading to joint procurement of the class and including the development of standards related to automation
- Joint procurement and integration in different platforms of a Naval Collaborative Surveillance capability
- Development activities leading to a Naval Collaborative Engagement capability
- Development of standards related to Smart Ships and digital transformation

14. Underwater warfare

Underwater warfare remains an essential element of operational plans of European navies and is an integral part of naval capability development. Underwater warfare is also to be seen in the context of EDF to encompass seabed warfare activities including protection of critical infrastructure. The Strategic Compass echoes these requirements, reiterating the need to protect critical maritime infrastructure including the seabed by developing joint operational, capability and technological solutions. The capability to counter underwater threats is a fundamental

enabler of securing freedom of action. The range of capabilities needed span from underwater effectors to mine countermeasures, including their enablers such as situational awareness. The future of underwater warfare is subject to the general megatrends of digitalisation and convergence. The EDTIB has a relatively adequate global position but continuous R&D efforts are required to safeguard technological sovereignty in this highly sensitive and export restricted area.

The dominant lines of technological evolution concern issues such as swarm technologies with autonomous features operating in several environments where the same system can perform multiple tasks. Future systems are foreseen to perform intelligence gathering, communication, analysis, positioning, surveillance, and engagement tasks in a joint and networked fashion. Actions addressing solutions to the general underwater challenge, namely the exchange of broadband information in real time, would address the needs of the broader domain. It is therefore essential to consider the underwater environment together with its interfaces from air to seabed, but also its specific threats and enabling infrastructure. Actions under the EDF target enabling technologies for **future effectors**, their **countermeasures,** and their support functions.

- In the field of **Mine Warfare**:

In this area next-generation modular mine countermeasures (MCM) solutions, detection of underwater threats, and agile multipurpose effectors - with a focus on innovation – are sought. The aim is to develop remotely operated highly scalable networked systems with autonomous features that are ready for market uptake. Modularity and scalability are critical characteristics for integration with and updates of legacy systems. Signature management countering multi-influence underwater sensor threats could be considered in the future. A related strand of interest lies in quantum magnetometers as part of a multi-influence sensing network.

- In the field of **Anti-submarine Warfare**:

Any type of underwater vehicle or moving threat is considered relevant for anti-submarine warfare (ASW). New hard-kill solutions need to be researched and developed, in particular for counter-torpedo subjects without limiting targets to be affected to only torpedoes. Adaptive solutions using networks of manned and unmanned resources for the complete kill-chain are essential. The capability enhancement is preferably striving for platform agnostic approach, thus providing future procurement opportunities for a larger group of capability owners.

- In the field of **Situational Awareness and C2**:

Digital infrastructure, net and data-centricity for integrated above and below surface communications and cyber security-by-design for systems of systems should be considered. This will contribute with enablers to other capabilities (such as MCM and ASW). Advanced cognitive sensor technologies with dual- or multifunction capabilities will enable the future integrated (underwater) operational environment. Modular and non-static sensor and communication node platforms are included in the scope. Development of ultra-sensitive acoustic sensors based on quantum technologies could be considered. This technology is currently being explored by EU competitors. Furthermore, for safe and secure communication systems, Quantum Key Distribution (QKD) can provide information-theoretic security for radio and underwater communications.

For all fields, where relevant, development actions that enhance diver operations in contested environments, can be addressed. Equally, critical marine infrastructure may be addressed under any field of approach. Critical component and material enablers for underwater warfare are addressed under the category of actions of material and components. Certain sensor related technological research may be addressed also in category of actions for sensors. Some of the more disruptive components, in particular quantum technology related, can be addressed in the disruptive technologies category of action.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the UWW category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Prototype of a semi-autonomous modular MCM suite
- Prototype of an unmanned ASW-solution
- Development of an advanced underwater observation and communication system for long ranges
- Development of swarm systems for multiple mission types

15. Simulation and training

The aim of this category is to create and develop simulation solutions. This is in line with the EU Strategic Compass, and more specifically the ACT, under acting together for readiness and interoperability[17], but also in INVEST under coherent and ambitious capabilities for high-end training systems[18]. It is also a MS goal in defence capabilities, expressed in EDA under CapTech Experimentation, System of Systems, Battle Lab and Modelling & Simulation (M&S), in short "CapTech Simulation".

The use of simulations and simulators to provide training procedures improves individual and collective capabilities. Military forces train with a wide range of simulated weapons, ships, aircraft, and other vehicles in conjunction with live training on actual equipment. Within the military, and in other professions, Modelling & Simulation (M&S) helps provide a safer and lower resource-intensive rehearsal capability for a wide variety of training. Military simulations are models in which theories of warfare can be tested and advanced without the need for actual hostilities. It is also known as war games, and supported by AI[19] can speed up the decision-making process during war-games. They exist in different forms with various degree of realism. Despite artificial intelligence being a hot topic among military technologists for years, the training community is only in the beginning stages of exploring how to apply it to their high-tech simulators and modelling software.

[17] We will organise training and exercises within the EU framework to increase readiness and interoperability that improve the preparation of military forces

[18] In the EU framework, notably through Permanent Structured Cooperation and the European Defence Fund, we are already developing command and control systems, armoured vehicles, missile systems and artillery, patrol corvettes, unmanned air and maritime systems, electronic warfare capabilities, space surveillance, cyber rapid response and high-tech training systems

[19] Artificial Intelligence

Training is one of the most employed of the M&S applications, but there are many other ways that M&S enables defence functions. In particular, M&S is used to analyse and inform the MoDs decision-making departments in acquiring new capabilities, adopting new tactics, processing intelligence, and testing systems before they are put into the hands of our fighting forces.

M&S helps to reduce costs, increase the quality of products and systems, and document and archive lessons learned. Because the results of a simulation are only as good as the underlying model(s), engineers, operators, and analysts must pay particular attention to its construction. To ensure that the results of the simulation are applicable to the real world, the user must understand the assumptions, conceptualisations, and constraints of its implementation. For example, during the recent events, the U.K. Ministry of Defence was able to make model of a Russian invasion of an "Eastern European country" to see how heavy armour vehicles get bogged down in mud based on weather and terrain data. It also did something similar with fuel and logistics to see how that would affect Russian trucks. Future expectations include prioritisation of rapid prototyping and development cycles with upgrades through software packages to reduce the overhead costs of upgrading physical training systems. A trend that is expected to continue is the gradual adoption of live, virtual, and constructive blended architectures and strategies, with a strong focus on upgrading and integrating legacy training systems. Additionally, there is a trend for digital twins[20] with the purpose to run cost-effective simulations, together with augmented reality and metaverse[21].

So far, MS are participating in or supporting several projects in this category, under several actions:

- In the context of the Permanent Structured Cooperation (PESCO), six Member states are involved in the project integrated European joint training and simulation centre (EUROSIM), and four Member states are involved in the project main battle tank simulation and testing centre (MBT-SIMTEC).
- In the frame of EDIDP, simulation was included in two ways, as separate project like VireTS project (D) (EDIDP-2020) and FIIST project (D) (EDIDP-2020), or inside other projects as part of a prototype and testing activity as a mean to get initial results.
- In EDF work programme 2022, a call for proposal is in category of Simulation and Training with the topic Modelling, simulation and simulator integration contributing to decision-making and training (D).

There are few fields to exploit, such as:

- In the field of **Modelling and Simulation**:

The EDF WP 22 addressed one topic in this category, that could lead to a joint procurement, namely modelling and simulation contributing to decision making and training, including the integration of various simulating systems already in service, and addressing various levels from strategic / decision making and as low as tactical or in the field of training.

[20] Digital twin is a virtual/ digital replica of physical entities such as devices, people, processes, or systems that help businesses make model-driven decisions

[21] Metaverse is a hypothetical iteration of the Internet as a single, universal and immersive virtual world that is facilitated by the use of virtual reality (VR) and augmented reality (AR) headsets

MS have identified the need to improve the capability to create 3D terrain models that could be considered, notably in specific areas of interest or of conflict, especially where no physical presence / training is possible.

- In the field of **Digital twins**:

Digital Twins are addressed in several projects, as a method to test before the actual prototype for example UxVs. This area could be considered in the future.

- In the field of **Augmented reality**:

Augmented Reality (AR) is a real-time interactive first-person experience that augments the user's real-world environment with computer-generated content using 3D registration (alignment) of the virtual content and the real world through pose tracking. The application of augmented reality technology in military exercise training helps to innovate exercise training methods and increase the degree of actual combat. The application of the military training system based on augmented reality technology can build an extremely realistic combat training environment based on real events or schematics.

- In the field of **Artificial Intelligence (AI)**

Wargames, supported by AI, can speed up the decision-making process and could be considered for EDF support in the future.

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the SIMTRAIN category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Foster innovation and cooperation for stakeholders in the defence M&S domain
- Create an ecosystem in simulation
- Prepare and align the technical solutions to facilitate joint procurements

16. Disruptive technologies

The EDF Regulation states that the Fund should support actions that are conducive to developing "disruptive technologies for defence"[22]. Nevertheless, the EDF regulation also mentions that as disruptive technologies can be based on concepts or ideas originating from "non-traditional" defence actors, the Fund should allow for sufficient flexibility regarding the consultation of stakeholders and the carrying out such actions.

[22] Broadly speaking, "disruptive technology for defence" means an enhanced or completely new technology that brings about a radical change, including a paradigm shift in the concept and conduct of defence affairs such as by replacing existing defence technologies or rendering them obsolete.

On the basis of these assumptions, two main lines of work are considered for the EDF 2021-2027:

1) **disruptive technologies based on concepts or ideas originating from "non-traditional defence's state-of-art[23]",** such as Artificial intelligence (AI), big data, the internet of things (IoT), autonomous systems (AS), biotechnologies and quantum technologies.

   Applied to the defence domains, the impact of these techniques could be very large. Indeed, their applications in a military operational environment could also help to cover the military capabilities gaps in the fields to be covered according to the EDF Regulation.

   The key point is the "orientation" of the research on and/or the application of these "cross-board" technologies towards topics addressing or enabling concrete defence capabilities.

   - In the field of **Artificial Intelligence**:

   Future military capabilities will include a significant share of systems that will make massive use of AI techniques.

   EDF WP 2021 topic (even if under the "Digital transformation" category of actions) has already tackled the problem of robustness and frugality in military AI software components to facilitate the development of new systems that can make use of less training data than current state-of-the-art deep learning algorithms, while maintaining similar performance to provide better control over the output space in order to ensure a more consistent behaviour, and to limit the development efforts when adapting systems to new data.

   Nonetheless, Manned-Unmanned Teaming (MUM-T), coupling human intelligence with artificial intelligence (AI) in planning and decision-making processes, is revolutionising mission autonomy. Indeed, incorporating unmanned autonomous systems into mission planning expands mission parameters and tactical sphere while decreasing the risk to human and technological assets in uncertain or hostile environments.

   Moreover, AI techniques could also be applied in support of the development of capabilities under the conventional operational domains. For example, in the naval domain, the continuous growing in the number of sensors and volume of data related to the detection, classification and identification of surface and underwater contacts makes highly recommendable the implementation of techniques that let us to automate these tasks. On these premises, the incorporation of advancing processing techniques based on AI into the systems of the vessels are recommended to lower the operator workload and increase the accuracy and speed of the processes.

   - In the field of **quantum technologies**:

   The possession and deployment of quantum technologies for sensing is potentially a game changer in many defence applications, which means that maturing and mastering these technologies is necessary for mission superiority, but also competitiveness.

   EDF 2021 WP already addressed, in particular, quantum sensors for positioning, navigation and timing (PNT) and target acquisition (TA), including chip-sized accelerometers and

[23] cf. NATO - Topic: Emerging and disruptive technologies

gyroscopes, quantum vector magnetometers for magnetic navigation/geo-referencing based on magnetic anomaly maps, and electromagnetic and optronics sensing.

This could be considered in the future either as 2021 follow-up topic aiming at elaborating on the results achieved by the project selected for funding following the EDF calls for 2021, or focused on different defence applications, like cyber defence or cryptography/communications.

In view of the definition of the topics to be addressed, with particular regard to the quantum sensors, a realistic assessment of operational benefits for defence applications and potential synergies with civil programmes should be performed in comparison with the outcomes of the EDF-2021-DIS-RDIS-QSENS topic.

In principle, coordination and consistency with other categories of actions, such as "Digital transformation", will be ensured to avoid duplications.

2) **emerging technologies equally disruptive**, **contributing to** (or complementing) **the development of innovative defence systems**, such as laser-based or RF-directed energy weapons, over-the-horizon radars applications, adaptive camouflage, or electromagnetic artillery systems.

- In the field of **directed energy weapons**:

Directed Energy Weapons (DEW) systems have the potential to change the course of future conflicts, particularly when facing evolving conventional and unconventional threats, which are extremely agile and low detectable, where there is an emerging need for highly-precise, targeted and agile weapon systems.

Laser-based DEW (LDEW) systems provide a cost-effective answer to all these capability needs. Nevertheless, in particular conditions (e.g. urban environments, law enforcement, public events), a surgical control of the collateral damages and preservation of human lives is of utmost importance.

In many of these scenarios traditional effectors are no longer employable while it could be more effective exploiting Radio frequency (RF) Directed Energy Weapon (DEW) to bring attacks that are less-than-lethal and cheaper. One of the major advantages offered by such weapons is the reduced requirement for accuracy compared to many conventional weapons, such as artillery. The destructive energy of the weapon is delivered almost instantaneously and many targets can be engaged at the same times.

However, the main limitation of RF DEW is that, unlike LASER, it is not possible to produce a narrow, high-powered, focused RF beam. In principle, any equipment that employs modern electronic components is at risk from RF DEW attack. The impact of such an attack could include armoured vehicles and ships operating erratically or becoming completely inoperative, and aircraft falling out of the sky. Therefore, a deep knowledge on RF DEW lethality could also help to identify the methods available to counter them.

Ongoing EU-funded research (both under PADR and EDF WP 2023) is paving the way to the design and build an EU high-power laser effector to be integrated, once mature, in military systems (air combat, naval, land or C-UAS).

In this perspective, DEW could be envisaged in the future, either focused on Laser based or RF techniques.

With the same approach, aimed, on one side, at ensuring adequate funds to promising techniques enabling the development of innovative defence systems and, on the other side, at providing consistency with the previous EU-funded research, the following aspects could be considered:

- Compact Digital Radio Frequency Memory (DRFM) jammers for Electronic Warfare (EW) with swarms of drones.
- Over-the-horizon radars applications (2021 action's follow up).
- Metamaterials, including tuneable metamaterials, as an additional degree of freedom for the design of future antennas or signature management.

Also for the abovementioned topics/fields, consistency with other categories of actions will be ensured to avoid duplications.

In the light of the above and in accordance with the EDF Regulation provisions stating that between 4-8% of the EDF budget shall be dedicated to disruptive technologies, it is intended to have addressed every year:

- at least one thematic disruptive topic;
- one non-thematic call addressing disruptive technologies in any area of interest for defence (indicative lists of area of interest could be annually provided to orient the proposals towards concrete defence capabilities development).

Main expected outcomes from EDF 2021-2027 support:

Without prejudice to the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF ambition in the DIS category of actions should be to support the achievement of the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Demonstrator of a medium calibre electromagnetic artillery system (contributing to long range indirect fire capability development)
- Prototype of directed energy weapons (contributing to the development of innovative air combat, naval and land systems)
- Other disruptive technologies, including quantum, metamaterials and AI techniques for defence application