ATLA
Acquisition,Technology & Logistics Agency

# R&D Vision

Toward the Realization of a Multi-Domain Defense Force and Beyond

## Explanatory Documentation

# Underwater Warfare Initiatives

March 31, 2020

**Acquisition, Technology & Logistics Agency**

## What is the "R&D Vision?"

The R&D vision is a document which presents the principles on Research & Development (R&D), technological challenges, and roadmaps of the technologies required to realize our future defense capability for the purpose of strategically conducting advanced R&D from the viewpoint of the mid-to-long term.

The Ministry of Defense (MOD) has formulated *R&D vision concerning Future Fighter Aircraft* in 2010, and *R&D vision of Future Unmanned Vehicles* in 2016 based on *Strategy on Defense Production and Technological Bases and Defense Technology Strategy*. According to the direction shown in *National Defense Program Guidelines for FY 2019 and beyond* (approved by the National Security Council and Cabinet on December 18, 2018), the MOD has formulated the new R&D vision. They are leading to encouragement to acquisition and enhancement of the capabilities required for cross-domain operations such as "Electromagnetic spectrum (EMS) technologies", "Technologies for Persistent ISR including Space", and "Cyber defense technologies" as well as leading to that in traditional domains such as "Underwater warfare technologies" and "Stand-off defense technologies" in order to contribute to realization of Multi-domain Defense Force and to realize technological innovation required for further enhancement of future defense capability.

According to the R&D vision, the MOD will hereafter strategically foster technologies that become necessary in the future and conduct R&D effectively and efficiently.

Remarks: A decision-making whether to initialize a development for a deployment or not is comprehensively done by the perspective of defense program on various then-conditions including progresses of researches conducted depicted on the R&D vision, a latest national security environment, an availability of procuring a foreign weapon system, etc.

# Table of Contents


Correspondence with the R&D Vision Document 2

Introduction 3

Underwater Defense System Issues 4

Technologies for the MOD/SDF to acquire 5

Advanced Technologies Required for Underwater Defense Systems 6

Direction of R&D Initiatives 7

Leading Technological Issues Which Should be Addressed 8

Technology Acquisition Process 14

R&D Roadmap 15

Future Concepts 16

Conclusion 18

Reference

Underwater Defense System Components 19

# Correspondence with the R&D Vision Document




**Introduction** (p.3)

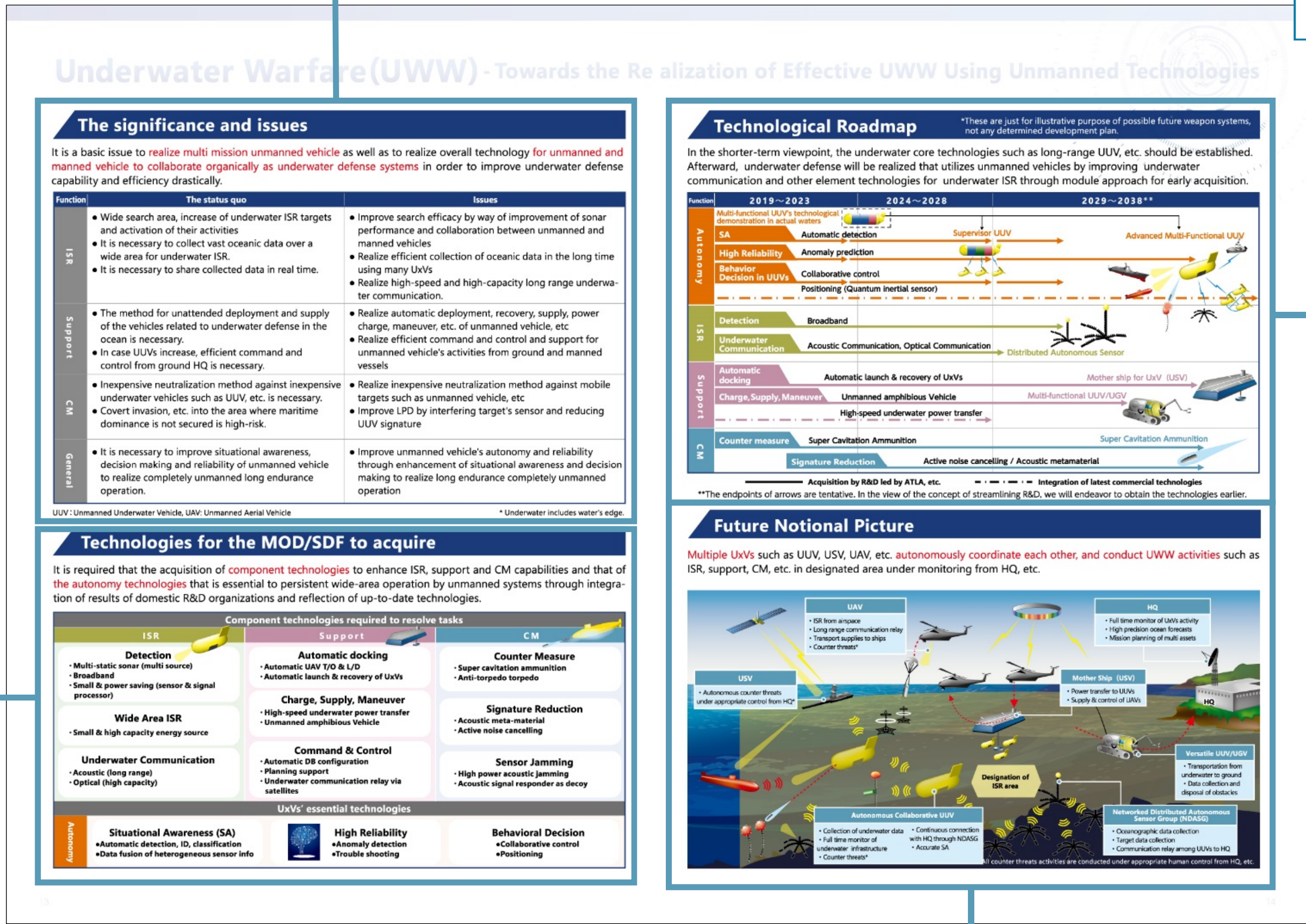
**Underwater Defense System Issues** (p. 4)

**Technologies Which Should be Acquired by the Ministry of Defense and the SDF** (p. 5)

**Advanced Technologies Required for Underwater Defense Systems** (p. 6)

**Direction of R&D Initiatives** (p. 7)

**Leading Technological Issues Which Should be Addressed** (p. 8 -13)

Underwater Warfare(UWW) - Towards the Re alization of Effective UWW Using Unmanned Technologies

## The significance and issues

It is a basic issue to realize multi mission unmanned vehicle as well as to realize overall technology for unmanned and manned vehicle to collaborate organically as underwater defense systems in order to improve underwater defense capability and efficiency drastically.

| Function | The status quo | Issues |
|---|---|---|
| ISR | • Wide search area, increase of underwater ISR targets and activation of their activities<br>• It is necessary to collect vast oceanic data over a wide area for underwater ISR.<br>• It is necessary to share collected data in real time. | • Improve search efficacy by way of improvement of sonar performance and collaboration between unmanned and manned vehicles<br>• Realize efficient collection of oceanic data in the long time using many UxVs<br>• Realize high-speed and high-capacity long range underwater communication. |
| Support | • The method for unattended deployment and supply of the vehicles related to underwater defense in the ocean is necessary.<br>• In case UUVs increase, efficient command and control from ground HQ is necessary. | • Realize automatic deployment, recovery, supply, power charge, maneuver, etc. of unmanned vehicle, etc<br>• Realize efficient command and control and support for unmanned vehicle's activities from ground and manned vessels |
| CM | • Inexpensive neutralization method against inexpensive underwater vehicles such as UUV, etc. is necessary.<br>• Covert invasion, etc. into the area where maritime dominance is not secured is high-risk. | • Realize inexpensive neutralization method against mobile targets such as unmanned vehicle, etc<br>• Improve LPD by interfering target's sensor and reducing UUV signature |
| General | • It is necessary to improve situational awareness, decision making and reliability of unmanned vehicle to realize completely unmanned long endurance operation. | • Improve unmanned vehicle's autonomy and reliability through enhancement of situational awareness and decision making to realize long endurance completely unmanned operation |

UUV : Unmanned Underwater Vehicle, UAV: Unmanned Aerial Vehicle

* Underwater includes water's edge.

## Technologies for the MOD/SDF to acquire

It is required that the acquisition of component technologies to enhance ISR, support and CM capabilities and that of the autonomy technologies that is essential to persistent wide-area operation by unmanned systems through integration of results of domestic R&D organizations and reflection of up-to-date technologies.

Component technologies required to resolve tasks

| ISR | Support | CM |
|---|---|---|
| **Detection**<br>・Multi-static sonar (multi source)<br>・Broadband<br>・Small & power saving (sensor & signal processor) | **Automatic docking**<br>・Automatic UAV T/O & L/D<br>・Automatic launch & recovery of UxVs | **Counter Measure**<br>・Super cavitation ammunition<br>・Anti-torpedo torpedo |
| **Wide Area ISR**<br>・Small & high capacity energy source | **Charge, Supply, Maneuver**<br>・High-speed underwater power transfer<br>・Unmanned amphibious Vehicle | **Signature Reduction**<br>・Acoustic meta-material<br>・Active noise cancelling |
| **Underwater Communication**<br>・Acoustic (long range)<br>・Optical (high capacity) | **Command & Control**<br>・Automatic DB configuration<br>・Planning support<br>・Underwater communication relay via satellites | **Sensor Jamming**<br>・High power acoustic jamming<br>・Acoustic signal responder as decoy |

UxVs' essential technologies

| Autonomy | | | |
|---|---|---|---|
| | **Situational Awareness (SA)**<br>•Automatic detection, ID, classification<br>•Data fusion of heterogeneous sensor info | **High Reliability**<br>•Anomaly detection<br>•Trouble shooting | **Behavioral Decision**<br>•Collaborative control<br>•Positioning |

## Technological Roadmap

*These are just for illustrative purpose of possible future weapon systems, not any determined development plan.

In the shorter-term viewpoint, the underwater core technologies such as long-range UUV, etc. should be established. Afterward, underwater defense will be realized that utilizes unmanned vehicles by improving underwater communication and other element technologies for underwater ISR through module approach for early acquisition.

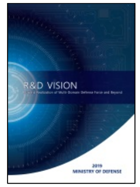


**The endpoints of arrows are tentative. In the view of the concept of streamlining R&D, we will endeavor to obtain the technologies earlier.

## Future Notional Picture

Multiple UxVs such as UUV, USV, UAV, etc. autonomously coordinate each other, and conduct UWW activities such as ISR, support, CM, etc. in designated area under monitoring from HQ, etc.







**R&D Vision**

**P13-14**


**Technology Acquisition Process** (p. 14)

**R&D Roadmap** (p. 15)

**Conclusion** (p. 18)

**Future Concepts** (p. 16 -17)

## National security environment surrounding Japan

While nations are expanding and deepening their relationships of mutual dependence to a greater extent, the changes in the power balance are accelerating and becoming more complex as the countries surrounding Japan extend their national strength even further, and the existing order is becoming increasingly uncertain. Under these conditions, a type of competition which aims to create an international and regional order which is personally advantageous and expand influence is manifesting itself between nations across the political, economic, and military spheres.

In addition, Japan is a maritime nation, and strengthening the order of "Open and Stable Oceans" based on the rule of law, freedom of navigation, and other fundamental rules and ensuring the safety of maritime and air traffic is the basis of peace and prosperity.

## Perception and initiatives regarding underwater activities in foreign countries

In recent years, China has been rapidly expanding the quality and volume of its activities in maritime and air spaces through its naval military power, etc. Submarines are also no exception as activities by Chinese Navy submarines have been continuously verified in the Indian Ocean. Moreover, a Chinese Navy submarine was first spotted within the contiguous zone of Japan around the Senkaku Islands in January 2018. The Chinese Navy is continuing to build up its submarine fleet, and activities by their submarines may expand and become more frequent in the future.

Based on Chinese and Russian efforts to modernize their military forces and the diffusion of military technologies, the U.S. is advancing its "Third Offset Strategy" to maintain U.S. military superiority, which places a particular emphasis on artificial intelligence and autonomy. Regarding underwater activities, due to the challenges presented by transmitting radio waves underwater and engaging in remote operation, it is hoped that autonomous unmanned underwater vehicles which can make their own decisions will become a new type of underwater military power from the perspective of the increasing risk of damage to submarines due to the reduction in the number of U.S. nuclear-powered submarines and improvements in anti-submarine capabilities by nations that constitute potential threats.

## Current state and future direction of research and development regarding underwater activities at the Ministry of Defense and SDF

Because it is extremely important for Japan as a maritime nation to strengthen the order of "Open and Stable Oceans," it has been proactively engaged in the research and development of submarines, sonar, torpedoes, mines and other underwater equipment to ensure the safety of maritime traffic. In addition, regarding unmanned underwater vehicles, Japan has worked on mine hunting vehicles which are directly operated via a cable for a long time. However, from the standpoint of reducing manpower based on the declining birthrate trends, 4D*-mission support, and protecting personnel from danger, in recent years Japan has been researching and developing unmanned underwater vehicles which are untethered, autonomous, and operate automatically based on pre-defined specifications. Artificial intelligence and other technologies will be applied going forward, requiring initiatives for further automation and advanced autonomy in underwater activities.

* 4D: Dirty, Dull Dangerous and Deep.

### Initiatives based on these conditions

① As a maritime nation, it is perpetually important for Japan to ensure the safety and stable use of the underwater domain.

② Activities by Chinese submarines are becoming more frequent, and underwater ISR in the areas around Japan will continue to be a major issue going forward.

③ Due to the difficulty in securing personnel because of the advancing birthrate decline and possible increase in the use of unmanned underwater vehicles by foreign countries, Japan's underwater activities must become more efficient through automation and manpower reduction in the future.

Therefore, from a technological standpoint that the Ministry of Defense and the SDF must take the lead in underwater defense systems and acquiring operational capabilities with a particular focus on unmanned underwater vehicles and other autonomous systems and proactively introduce superior dual-use technologies. The Ministry of Defense and SDF will identify the technological issues, including ensuring the integration with existing equipment, which both organizations should resolve and promote various policies by developing an executable roadmap to steadily ensure Japan's technological dominance.

## Issues in implementing underwater defense systems

| Issues in implementing underwater defense systems | |
|---|---|
| Against a backdrop of large-scale investments in advanced research areas such as artificial intelligence and quantum related technologies, technological innovation to realize rapid improvement in underwater defense capabilities through unmanned systems has been positioned as a fundamental issue of this vision in order to effectively respond to the trend by surrounding countries to engage in the development of unmanned vehicles and the expansion of submarine activities based on the outlook for population decline that Japan is directly facing. | |
| **Issues regarding underwater ISR** | ● Manpower reductions and labor-saving efforts on manned ships to effectively handle underwater targets over a vast sea area with limited assets<br>● ISR efficiency through coordination with manned ships and coordinated searching with multiple UUVs (Unmanned Underwater Vehicle) equipped with sonar and other detection performance improvements and various sensors<br>● Using many UUVs to efficiently collect a massive amount of oceanographic data required to predict the propagation of sound in water including the water temperature, salinity, ocean currents, water depth, bottom sediment, and the presence of precipitate and realizing high-speed, high-capacity, long-distance underwater communications to share the obtained information in real-time with assets on land, on the water, and underwater<br>● Implementing continuous monitoring of assets which are important to Japan such as ports, bases, and other facilities, anchored vessels, underwater infrastructure, and other using unmanned vehicles |
| **Issues regarding underwater support** | ● Implementing efficient command and control/support for unmanned vehicle activities through land-based headquarters/manned ships, etc.<br>● Implementing the automatic launch and recovery, resupply, power feeding, maneuvering of unmanned vehicles, etc.<br>● Replenishment of resources and energy to submarines, UUVs, and other vehicles engaged in covert activities underwater using unmanned vehicles<br>● Use unmanned vehicles to efficiently perform work such as transporting, constructing, inspecting, and repairing underwater infrastructure and equipment which can also be utilized during large-scale natural disasters |
| **Issues regarding underwater countermeasures** | ● Searching and disposing of mines and other underwater obstacles with unmanned vehicles for the purpose of protecting manned assets and unblocking harbors and waterways<br>● Using UUVs with a high degree of autonomy and reliability that can operate for long periods of time for covert penetration into regions where maritime supremacy is not ensured, construction of underwater equipment, launch of torpedoes and missiles under appropriate human intervention, insertion of UAVs (Unmanned Aerial Vehicle) for reconnaissance and electronic warfare, and the removal of underwater infrastructure |

* Underwater includes the shoreline.

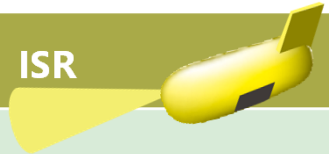
# Technologies for the MOD/SDF to acquire



Regarding the issues with ISR, support, and attack, component technologies for improving capabilities and the autonomous technologies which are the foundation of constant and continuous operation of unmanned systems across a wide area must be acquired. Therefore, continuous technology improvements through the incorporation of the results from Japanese R&D institutions and the application of the latest technologies will be implemented.

## Component technologies required to resolve tasks

### ISR



#### Detection

- Multistatic sonar (multiple sound sources)
- Broadband support
- Miniaturization and power reduction (sensor and signal processing sections)

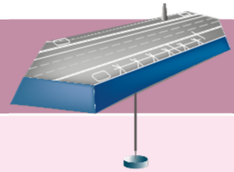
#### Wide area ISR

- Automatic 3D multipoint measurement of the ocean environment
- Miniature, high-capacity energy sources

#### Underwater Communication

- Underwater acoustic communication (long distance)
- Underwater optical communication (high data rate)

### Support



#### Automatic connection

- Unmanned vehicle automatic takeoff and landing
- Automatic launch and recovery of unmanned vehicles
- Automatic replenishment

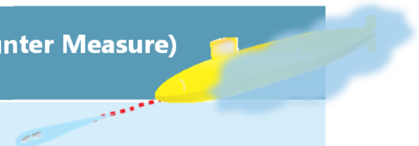
#### Power transfer, replenishment, and maneuvering

- High speed underwater power transfer
- Amphibious unmanned vehicle technologies

#### Command Control

- Monitoring
- Automatic database construction
- Operation plan support
- Underwater communication relays through satellites, etc.

### CM (Counter Measure)



#### Threat Countermeasures

- Super cavitation ammunition
- Anti-torpedo torpedoes

#### Signature Reduction

- Acoustic meta-materials
- Active noise reduction

#### Sensor Jamming

- High-power jamming sounds
- Deceptive acoustic signal responders
- Laser jamming equipment

## UxVs' essential technologies

**Autonomy**

#### Situation awareness

- Automatic target detection and identification
- Integration of heterogeneous sensor information

#### High reliability technologies

- Anomaly prediction and detection, self-diagnosis
- Anomaly response and troubleshooting

#### Behavioral decision

- Avoidance
- Collaborative control
- Positioning

## Technological progress in underwater defense systems

- To realize underwater defense systems which can effectively and efficiently protect Japan's vast territorial waters and Exclusive Economic Zone, in addition to improving the mission capabilities in each of the ISR, support, and attack phases, it is important to utilize highly autonomous unmanned vehicles to constantly and continuously implement such missions across a wide area.
- Regarding ISR, research and development of broadband and multistatic sonar is actively being pursued, and the results have been incorporated into existing equipment. Research into underwater communication technologies using acoustics and lasers is also being conducted in Japan, but there are barriers to practical application which must be overcome. Technologies for miniature and high capacity batteries, which are essential to persistent ISR, are making remarkable progress in the civilian sector.
- Regarding the support phase, the civilian sector is working on underwater power transfer technologies. Foreign countries are proactively developing technologies for launching and recovery of unmanned vehicles from ships, some of which are in the operational stage.
- Regarding the attack phase, continuous research and development is being conducted in the defense field to improve capabilities in terms of attack, detection prevention, and jamming.
- While autonomy is being broadly applied on the ground and in the air in various fields such as self-driving vehicles and artificial satellites, a higher degree of autonomy is required underwater due to limitations on the use of communications and sensors.

## Direction of future development

| | |
|---|---|
| **ISR** | ● while improving the precision of sonar prediction, research into detection methods which do not depend on acoustics is also required. Moreover, regarding various sensors and information processing equipment, performance improvements must be balanced against miniaturization and power saving to equip them in unmanned vehicles. With the expansion of the role fulfilled by unmanned vehicles, it is becoming more important for underwater communications to support longer distances and higher speeds. In order for a large number of unmanned vehicles and sensors to constantly and continuously fulfill their mission across a wide area, technologies for miniature and high-capacity energy sources are essential. |
| **Support** | ● the Ministry of Defense and SDF must advance research into technologies which are specific to defense fields such as mother ships that launch/retrieve, maintain, and control unmanned vehicles, amphibious unmanned vehicles which perform transportation and other tasks between the sea and land, operation plans which deploy many unmanned vehicles across a wide area, as well as analysis of the data collected by unmanned vehicles and forecasts of ocean conditions based on that information. |
| **CM (Counter Measure)** | ● unmanned vehicles are required to carry out missions in coordination with manned ships. Moreover, research into advanced technologies for improving the stealth capability of unmanned vehicles expected to operate under high threat conditions is required from the perspective of zero casualties. These technologies may also be applied to manned ships. |
| **Autonomy** | ● in order to operate underwater where communication is limited or under high threat conditions, highly autonomous systems must be built which do not rely on direct command and control from the outside except when necessary. Moreover, the integrated operation of many different kinds of unmanned vehicles is required to effectively defend a vast sea area. In addition, technologies for increasing system reliability are required for long-term operation without direct human intervention. |

## Building research and development environments

- Regarding the laws which regulate the operation of unmanned marine vehicles (unmanned vessels), while guidelines have been prepared in Japan at the current time, the details need to be separately adjusted. Going forward, the safe operation of many unmanned vehicles will require the development of laws and other environmental improvements in cooperation with related institutions.
- Regarding technology demonstrations for comparatively miniature assets, it would be preferable to incorporate new technologies into the actual equipment or a customized version to verify the performance in an actual environment early on. For large-sized assets, it will be necessary to implement technology demonstrations while reducing risk by (1) setting interim goals in a staged manner, building prototypes, and improving performance and (2) sufficiently verifying in advance whether the asset responds appropriately to failures which may occur on the ocean and situation associated with harsh environments.

## Advanced technology targets required for underwater defense systems

| | |
|---|---|
| **ISR** | ● Sonar performance improvements such as multistatic and broadband support, and miniaturization and power reduction to equip these improvements on unmanned vehicles<br>● Miniature and high-capacity energy sources for the constant and continuous operation of many unmanned vehicles and fixed sensors across a wide area<br>● Measure and estimate the underwater temperature, etc. across a wide area and at deep depths and increase the precision of sonar prediction by also considering the submarine topography and bottom sediment<br>● Establish chemical, magnetic, and other technologies for detecting underwater threats that do not depend on sound<br>● Establish underwater communications designed for long distance, high capacity, anti-interception, and high damage resistance characteristics to enable the collaborative operation of manned ships, unmanned vehicles, fixed sensors, and various other assets |
| **Support** | ● Achieve cooperation between many unmanned vehicle groups without human intervention except when necessary on the sea through automatic takeoff, launch and recovery, and automatic resource replenishment<br>● Extend the activity time of UUVs and other underwater assets through underwater power transfer facilities and transportation from underwater to land through amphibious unmanned vehicles<br>● Build constant underwater surveillance systems using mutually collaborative UUVs and distributed autonomous sensors by means of operation plan support based on monitoring from a land-based headquarters, automatic database construction, and highly precise forecasts of ocean conditions |
| **CM (Counter Measure)** | ● Expect that countries with threat potential will use unmanned vehicles on a large scale, disable manned and unmanned threats through sensor jamming technologies<br>● Improve stealth characteristics through acoustic meta-material technologies which control sound reflections<br>● Active noise reduction which emits sounds and vibrations with the opposite phase from sound sources and actuators equipped on the hull to cancel out the ship's own sound<br>● Respond to mines and other underwater threats with inexpensive methods such as super cavitation ammunition |
| **Autonomy** | ● Autonomous mission execution (situational awareness technologies, behavioral decision technologies) that does not rely on control from a land-based headquarters, etc.<br>● Predict the occurrence of internal ship anomalies, detect them after they occur, and troubleshoot by falling back (high reliability technologies) |

# Leading Technological Issues Which Should be Addressed (1/6)

## Autonomy

**Red**: technologies which must be researched and developed primarily by the Ministry of Defense and SDF
**Blue**: technologies which can utilize the results of other equipment
**Gray**: technologies acquired through joint research with other institutions
**Light blue**: technologies awaiting progress in the civilian sector

| Important component technologies | | Technology overview | Technological issues | Expected results |
|---|---|---|---|---|
| Situation awareness | Integration of heterogeneous sensor information | Integrate information from optical, acoustic, and other heterogeneous sensors to recognize targets and environmental conditions | Merging detected objects, time synchronization | Autonomous mission execution by unmanned vehicles even when direct human control is limited or not present at all |
| | Automatic underwater target detection and identification | Automate the detection and identification of submerged and bottomed targets such as underwater vehicles and mines | Learning the shapes and behaviors of threatening ships, unmanned vehicles, and underwater devices, image analysis algorithms | |
| | Automatic target detection and identification of surface targets | Automatically identify ships, etc. from the obtained visual images, etc. to extract suspicious ships | | |
| High reliability | Anomaly prediction and detection, self-diagnosis technologies | Technologies which monitor the internal condition of the vehicle to predict/detect/identify anomalies and breakdowns and determine the residual function level to troubleshoot | Verification and demonstration through system design and construction, testing | Prevents problems from occurring in unmanned vehicles and autonomously responds when problems do occur to execute missions for long periods of time without direct human intervention |
| | Troubleshooting and functional continuity technologies | Redundancy, degradation functions, and action selection to persist and continue the mission during anomalies | Decision autonomy | |
| | Improved reliability of mounted devices | MTBF* improvements in inertial navigation equipment, power source equipment, and other reliability management items | Redundancy for mounted devices with a comparatively short MTBF | |
| Action decision (navigation) | Self route setting | Sets the route to the specified forward sea area and sets a new route in the event of a mission change | Establishing a rerouting function with limited communication dependence | Autonomous mission execution by unmanned vehicles even when direct human control is limited or not present at all |
| | Avoidance | Avoiding ships, floating objects, and submarine topography on the surface and underwater | Highly precise detection of fishing nets and other small underwater objects, improving detection robustness, and matching the way of ship steering of humans | |
| | Autonomous ship steering under severe weather | Autonomous ship steering which adapts to various weather and sea conditions, etc. | Ship steering algorithms which adapt to the environment | |
| | Self positioning estimation | Estimates the vehicle's own absolute position and the relative position with the target and corrects for the difference between the calculated value and true value | Implementing high-precision self positioning estimation through quantum inertial sensors | |
| | Action assessment (navigation) | Self-assessment of actions taken when advancing, returning to base, or during other non-mission actions to assess whether they were appropriate based on the results | Can be handled during development | |
| Action decision (mission) | Attitude control | Controls the attitude for UUV navigation | Development of the weight balance control algorithm and mechanism (Can be handled during the development stage) | |
| | Action assessment (mission) | Self-assessment of actions taken to assess whether they were appropriate based on the results | Observation of action results | |
| | Decision-making | Comprehensively judges its own state and the surrounding conditions to decide the next action to take | Estimation, learning, and the handling of challenging events with low probabilities | |
| | Collaborative control | Collaborative control of UUVs, USVs*, and manned vehicles | Action algorithms to enable various assets to collaborate and execute a mission, preparation of communication standards | |

*MTBF: Mean Time Between Failure
*USV: Unmanned Future Vehicle

# Leading Technological Issues Which Should be Addressed (2/6)

## ISR (1)

**Red**: technologies which must be researched and developed primarily by the Ministry of Defense and SDF
**Blue**: technologies which can utilize the results of other equipment
**Gray**: technologies acquired through joint research with other institutions
**Light blue**: technologies awaiting progress in the civilian sector

| Important component technologies | | | | Technology overview | Technological issues | Expected results |
|---|---|---|---|---|---|---|
| Detection | Acoustic detection | ISR/ASW* sonar | Multistatic sonar (multiple sound sources) | Sonar which uses multiple transmission and reception signals from multiple unmanned vehicles | Increase data processing volume, automatic detection, reverberation prediction, knowing and synchronizing with the position of accompanying vehicles | Acoustic detection of quiet targets |
| | | | Broadband technologies | Broadband support for sonar using single crystal elements, etc. | Single-crystal element manufacturing, cost reduction | |
| | | | Miniature power-saving sonar | Miniature and power-saving sonar mountable on unmanned vehicles | Resolving the trade-off between wavelength and detection distance | Operation of sonar on UUVs of various sizes |
| | | | Towed/seafloor-mounted array mechanism | Towed/seafloor-mounted array mechanism for extension and winding and its automation | Implementation of the array extension/winding mechanism and control | |
| | | | Hydrophone array laying technologies | Operation/control of vehicles required for array laying | Laying site multibeam surveys, laying planning (approach to the sea floor), array extension/vehicle's attitude control for laying | |
| | | | Sonar automation technologies | Run sonar-based detection, tracking, identification, and other functions without human operation | Embedding sonar personnel operations and target identification into programs | |
| | | | Vehicle operation technologies | Automatic vehicle control for estimation, etc. of the target position, course, and speed | Vehicle motion control for Target Motion Analysis (TMA*) | |
| | | MCM* sonar | Real-time signal processing | Synthetic aperture processing within the unmanned vehicle | Can be handled during the development stage | Operation of synthetic aperture sonar for mine detection by unmanned vehicles |
| | | | Analysis support | Analysis support for synthetic aperture sonar and other detection images | Integrated display methods | Power saving operation of synthetic aperture sonar |
| | Non-acoustic detection | Surface sensors | SIGINT* automatic information gathering capability | Gathers radio waves and other information automatically and remotely | Collaboration with manned ships, aircraft, and ground-based facilities, data analysis within the unmanned vehicle | Execution of electronic warfare by unmanned vehicles |
| | | Other | Target detection technologies based on chemical composition | Detect targets based on chemical substances included in the seawater | Measuring and identifying chemical substances released by targets | Detection of quiet targets |
| | | EM field detection technologies for aircraft | EM field buoy sensor-mounted technologies | Mount EM field sensors on buoys with restrictions on mounting space, power, etc. | Making EM field sensors non-magnetic, miniature, high sensitivity, power-saving and optimization of the placement of EM field sensors on buoys | Detection of underwater targets by EM field buoys |
| | | | EM field noise compensation technologies | Reduces oscillation noise, geomagnetic noise, etc. occurring in EM field buoys | Various types of EM field noise compensation for EM field buoys on the actual sea | |
| | | | Target signal extraction technologies | Detection of EM field signals from underwater targets by EM field buoys | Target signal extraction by EM field buoys on the actual sea | |

*ISR: Intelligence, Surveillance and Reconnaissance   ASW: Anti-Submarine Warfare   MCM: Mine Countermeasures   TMA: Target Motion Analysis   SIGINT: SIGnal INTelligence

# Leading Technological Issues Which Should be Addressed (3/6)



## ISR (2)

**Red**: technologies which must be researched and developed primarily by the Ministry of Defense and SDF
**Blue**: technologies which can utilize the results of other equipment
**Gray**: technologies acquired through joint research with other institutions
**Light blue**: technologies awaiting progress in the civilian sector

| Important component technologies | | | Technology overview | Technological issues | Expected results |
|---|---|---|---|---|---|
| Wide area ISR | Automatic 3D multipoint measurement of the ocean environment | | Seawater temperature and other environmental measurements using UUVs | Measurement systems that can measure to deep depths, cost reduction | Forecasts of ocean conditions, sonar prediction with improved precision |
| | Miniature, high-capacity energy sources | Lithium-ion battery technologies | Lithium-ion batteries which are the energy source for power and sensors | Energy density and safety improvements | Long-term activity of unmanned vehicles and distributed, autonomous sensors through high-capacity energy sources |
| | | Fuel cells | Fuel cells which are the energy source for power and sensors | Storage capability improvements through long-term storage of liquefied gas, hydrogen absorbing alloys | |
| | | Snorkel | Apply internal-combustion engines to UUVs | Automation, unmanned operation | |
| | Energy management | Support for electric power demand Improved fuel consumption | Optimal allocation of power to components | Establishing an energy demand prediction model | Long-term activity of unmanned vehicles and distributed, autonomous sensors through efficient energy consumption |
| | | Standby | Silent standby, anchoring, hibernation | Assessing silent standby positions | |
| Underwater communication | Underwater acoustic communication | Multiplexing | Technologies for communicating simultaneously with multiple nodes | Measuring the communication distance, propagation conditions, etc. and selecting the appropriate parameters | Sharing of underwater target data, etc. by underwater assets, collaboration between underwater and surface assets |
| | | Reduction of doppler effect | Communication by moving nodes | Synchronizing to signals with large Doppler shifts | |
| | | Modulation methods | Selects the modulation method suited to the data volume, signal-to-noise ratio, and other operating conditions | Measuring the communication distance, propagation conditions, etc. and selecting the appropriate modulation method | |
| | | Robustness | Robust underwater acoustic communication through frequency spreading and networking | Underwater application of radio wave communication technologies | |
| | Underwater optical communication | | Short range, high-capacity communication using light waves | Quantum entanglement delivery, decryption, robustness improvements | |

## Support (1)

**Red**: technologies which must be researched and developed primarily by the Ministry of Defense and SDF
**Blue**: technologies which can utilize the results of other equipment
**Gray**: technologies acquired through joint research with other institutions
**Light blue**: technologies awaiting progress in the civilian sector

| Important component technologies | | | Technology overview | Technological issues | Expected results |
|---|---|---|---|---|---|
| Automatic connection | Automatic launch and recovery of unmanned vehicles | | Unmanned launch and recovery, management of UUVs and USVs mounted on mother ships | Launch, recovery, takeoff and landing technologies, control technologies for nearby unmanned vehicles, high-speed deployment technologies | Make the entire underwater defense system including replenishment by mother ships into an unmanned operation, improve continuity and wide range response |
| | Unmanned vehicle automatic takeoff and landing | | Unmanned takeoff and landing, management of UAVs mounted on mother ships | Automatic takeoff and landing technologies, command and control technologies | |
| | Automatic resource replenishment | | Transport supplies from land, manned ships, or unmanned vehicles to manned ships or unmanned vehicles | Ship position control, automation of resupply facilities, automation of resources on ships | |
| Power transfer, resupply, and maneuvering | High speed underwater power transfer | | Underwater energy resupply | High-power support | Long-term activity of unmanned vehicles and distributed, autonomous sensors through energy resupply from mother ships |
| | Amphibious unmanned vehicles | Underwater and shoreline mobility | Attitude and cruise control which accounts for ocean wave and other disturbances based on peripheral environment recognition | Drive control according to the environment, driving characteristics (soft ground, reef lagoon, and reef crest), and drive system complexity | Seamless activity underwater, along the shoreline, and on shore |
| Command and control | Operation plan support | | Draft UMS* action plans on land | Detailed simulations for action plan drafting | Effective ISR using many unmanned vehicles |
| | Monitoring | | Monitoring and control of unmanned vehicles during missions | Communication technologies for monitoring | |
| | Automatic database construction | | Construct databases with oceanic and target information from many unmanned vehicles | Organize diverse data from a variety of sensors in an efficient and usable format (data capacity, processing time, etc.) | Forecasts of ocean conditions, sonar reconnaissance, target identification, and other precision improvements through massive data |
| | High-precision forecasts of ocean conditions, sonar reconnaissance | | Forecasts of ocean conditions (ocean currents, temperature, salinity, etc.) and predictions of sound wave propagation paths based on those forecasts | Using data gathered by unmanned vehicles, improving precision | Drafting of efficient acoustic search plans based on accurate reconnaissance, noise removal |
| | Manned ship collaborative CDS* | | Command and control of unmanned vehicles to implement ASW in collaboration with manned ships | Development of algorithms for the optimal placement of manned ships and unmanned vehicles | Mutual collaboration between multiple unmanned vehicles and manned ships to improve overall defense capability |
| | Underwater communication relays through satellites, etc. | | Underwater communication relays through satellites, UAVs, etc. | Antenna miniaturization, operation automation, connectivity improvements (antenna attitude control), communication cost reduction | Communication between unmanned vehicles deployed on the sea to other unmanned vehicles and land-based headquarters (data sharing, command and control, collaboration) |

*UMS: Unmanned System CDS: Combat Direction System

# Leading Technological Issues Which Should be Addressed (5/6)



## Support (2)

**Red**: technologies which must be researched and developed primarily by the Ministry of Defense and SDF
**Blue**: technologies which can utilize the results of other equipment
**Gray**: technologies acquired through joint research with other institutions
**Light blue**: technologies awaiting progress in the civilian sector

| Important component technologies | | Technology overview | Technological issues | Expected results |
|---|---|---|---|---|
| Total systems | Concept evaluation technologies | UUV concept evaluation through operation simulation | Evaluating the simulation validity | UUV design optimization |
| | OA* support | Standardization | Preparing standards | Low costs, ensure general-purpose use and extendability |
| | Use of COTS* products | Utilization of consumer products | None | |
| | Modularization | Modularization of mounted devices | Size and weight optimization | |
| Information protection | Cyber attack countermeasures | Counter unmanned vehicles, etc. through electronic warfare | While the foundational technologies are common to the civilian sector, responses based on threat analysis according to technological progress and the operation of unmanned vehicles are required as is equipment-specific target setting | Stable operation of underwater defense systems and information maintenance |
| | Information protection during capture | Prevent internal information leaks and modification in the event of capture, etc. | Technologies also common to other equipment | |

*OA: Open Architecture COTS: Commercial Off the Shelf

## Attack

**Red**: technologies which must be researched and developed primarily by the Ministry of Defense and SDF
**Blue**: technologies which can utilize the results of other equipment
**Gray**: technologies acquired through joint research with other institutions
**Light blue**: technologies awaiting progress in the civilian sector

| Important component technologies | | | Technology overview | Technological issues | Expected results |
|---|---|---|---|---|---|
| Threat countermeasures | Super cavitation ammunitions | | Projectiles which use cavitation to significantly reduce water resistance | Occurrence and maintenance of cavitation, targeting and launch by unmanned vehicles | Low cost target countermeasures |
| | Anti-torpedo torpedoes | | Torpedoes which destroy the torpedoes of the target | Detection of the target's torpedoes and guidance | Hard kill of target's torpedoes |
| | Underwater equipment transportation /laying | Mounting capability | Mount and transport a sufficient quantity of underwater equipment within the size and power restrictions of unmanned vehicles | Support for a variety of underwater equipment | Operation of underwater equipment (mines, sensors, etc.) by unmanned vehicles |
| | | Laying capability | Capability to lay underwater equipment in the desired location | Underwater equipment dropping mechanism | |
| Signature reduction | Silence | | Passive acoustic detection prevention | Can be handled during the development stage | Reduce the possibility of detection due to sound |
| | TS* reduction | | Active acoustic detection prevention | Can be handled during the development stage | |
| | Acoustic meta-materials | | Reduce the TS by using acoustic meta-materials to transmit the detector sounds | Broadband support for the target frequencies, increasing the degree of design freedom | |
| | Active noise reduction | | Cancel out a vehicle's own noise by transmitting sound waves with the opposite phase | Equipment miniaturization | |
| | Low UEP* | | UEP detection prevention | Reduction through optimization of heterogeneous metal placement<br>Reduction through counter electric currents | Reduce the possibility of detection due to underwater electrical fields |
| | Low magnetism | | Magnetic detection prevention | Reduction through magnetic substance management<br>Reduction through degaussing coils | Reduce the possibility of detection due to magnetism |
| Sensor jamming | High-power jamming sounds | | Disable target sonar by emitting high-volume sounds | High-power transmitters | Disable the active sonar of threats or reduce the search efficiency through deception |
| | Deceptive acoustic signal responders | | Amplify and transmit the received sound to make an unmanned vehicle appear to be a manned ship | Support for frequency band used by threats | |
| | Coating application | | Apply coatings used underwater which interfere with the blue-green light waves | Environmentally-friendly coatings | Jam the laser communications and laser-based sensing of the target |
| | Deception capabilities | | Generate deceptive radio wave and acoustic signals to make unmanned vehicles look like other manned ships | Mounting deception equipment on unmanned vehicles, threat countermeasure algorithms | Escorting of manned ships by unmanned vehicles |
| | Flywheels | | Convert and store electrical power as kinetic energy | Flywheel manufacturing technologies, inertial control | Transmit active sonar and deceptive signals by generating a lot of power in a short period of time |

*TS: Target Strength

UEP: Underwater Electric Potential

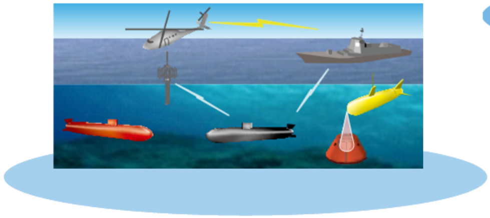
Achieve collaboration between manned ships and unmanned vehicles over the short-term and establish the organic collaboration of unmanned vehicles over the medium to long-term

Technology level

Incorporate civilian technologies and also pursue in parallel the possibilities of joint research and development with foreign and domestic institutions, etc.

**Manned ships**

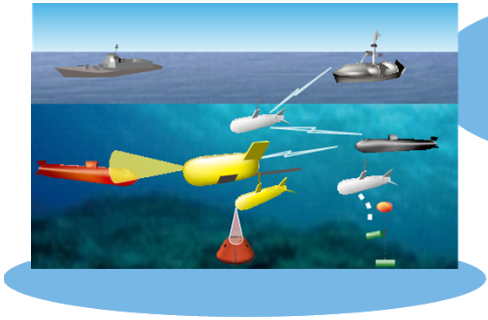
Reduce manpower through automation of manned ships. Substitute unmanned vehicles for specific missions



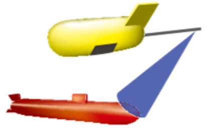
Automatic target detection and identification

**Collaboration between manned ships and unmanned vehicles**

Replace some manned ships with unmanned vehicles. Extend the capabilities of manned ships through collaboration with unmanned vehicles

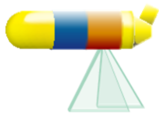


Collaborative behavior control
Long-distance acoustic communication



Antisubmarine search UUV

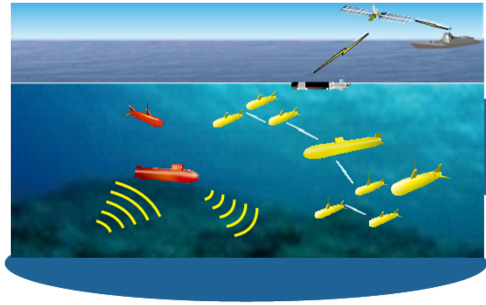
Realize UUVs that can execute various tasks through module replacement



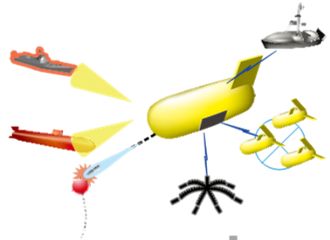
Ocean patrol UUV

**Organic collaboration of unmanned vehicles**

Groups of unmanned vehicles autonomously execute missions and improve the mission achievement level

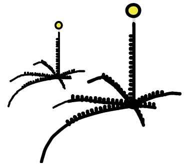


Anomaly prediction and detection
Operation plan support
Automatic resource resupply



Advanced multi-functional UUV

Advanced autonomous system



Distributed, autonomous sensors

**Mission achievement level improvements**
(Improvements in wide area, continuous ISR and countermeasure capabilities)

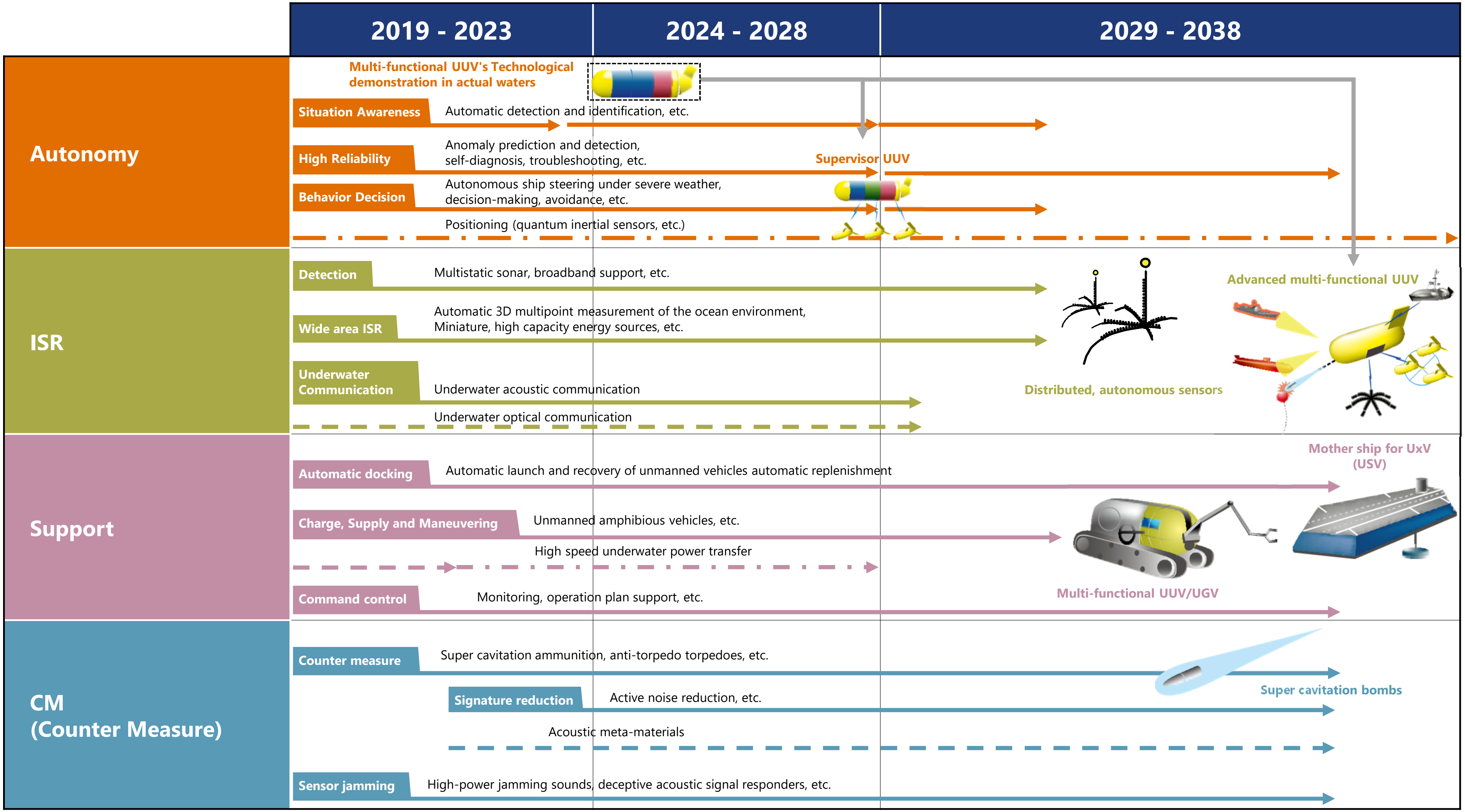
Number of service personnel required for missions

Level of unmanned vehicle autonomy

Current — Approx. 10 years from now* — Approx. 20 years from now*

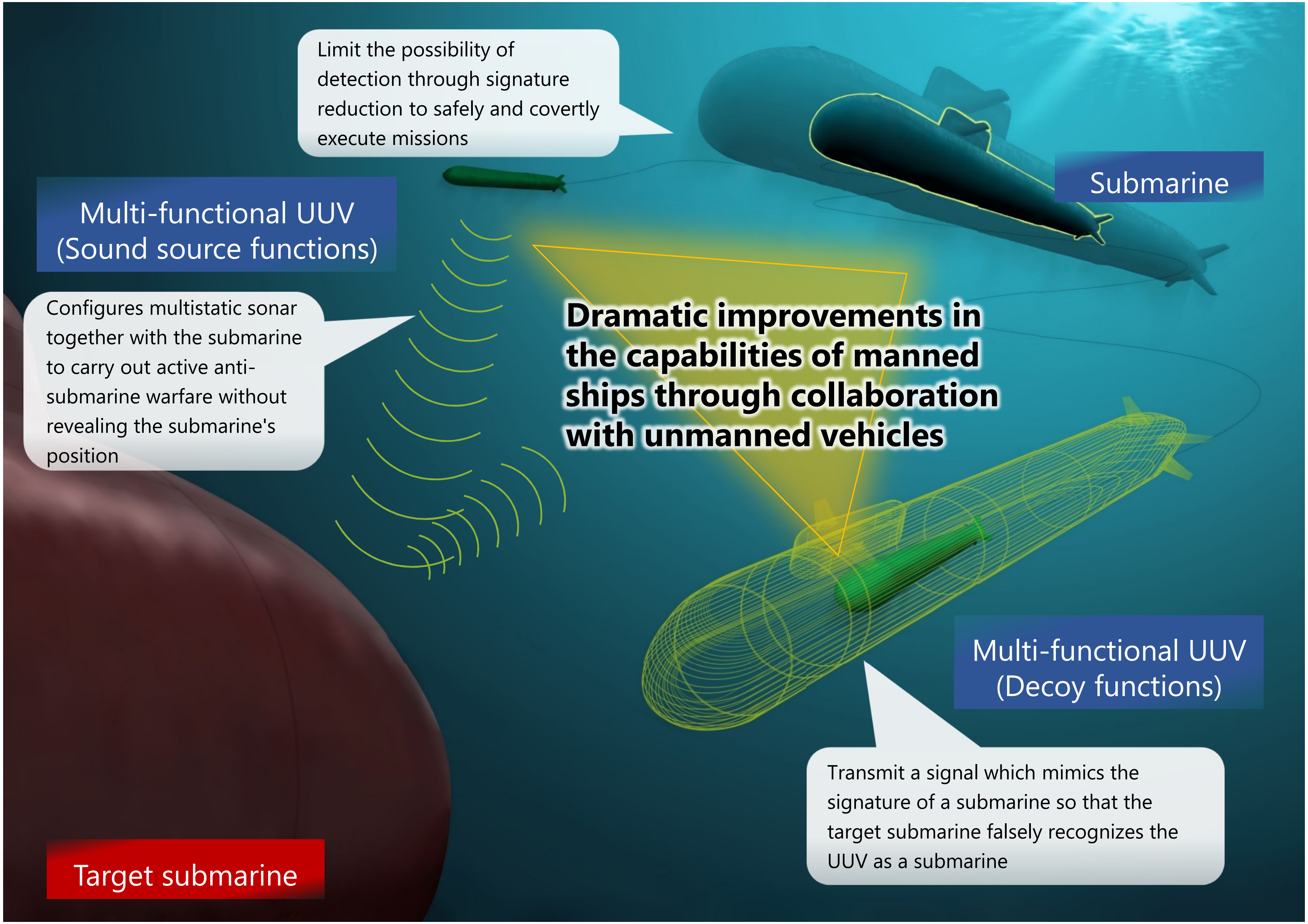
*The years are only tentative. In light of the rapid research and development approach, we will strive for early technology acquisition.

# Research and Development Roadmap

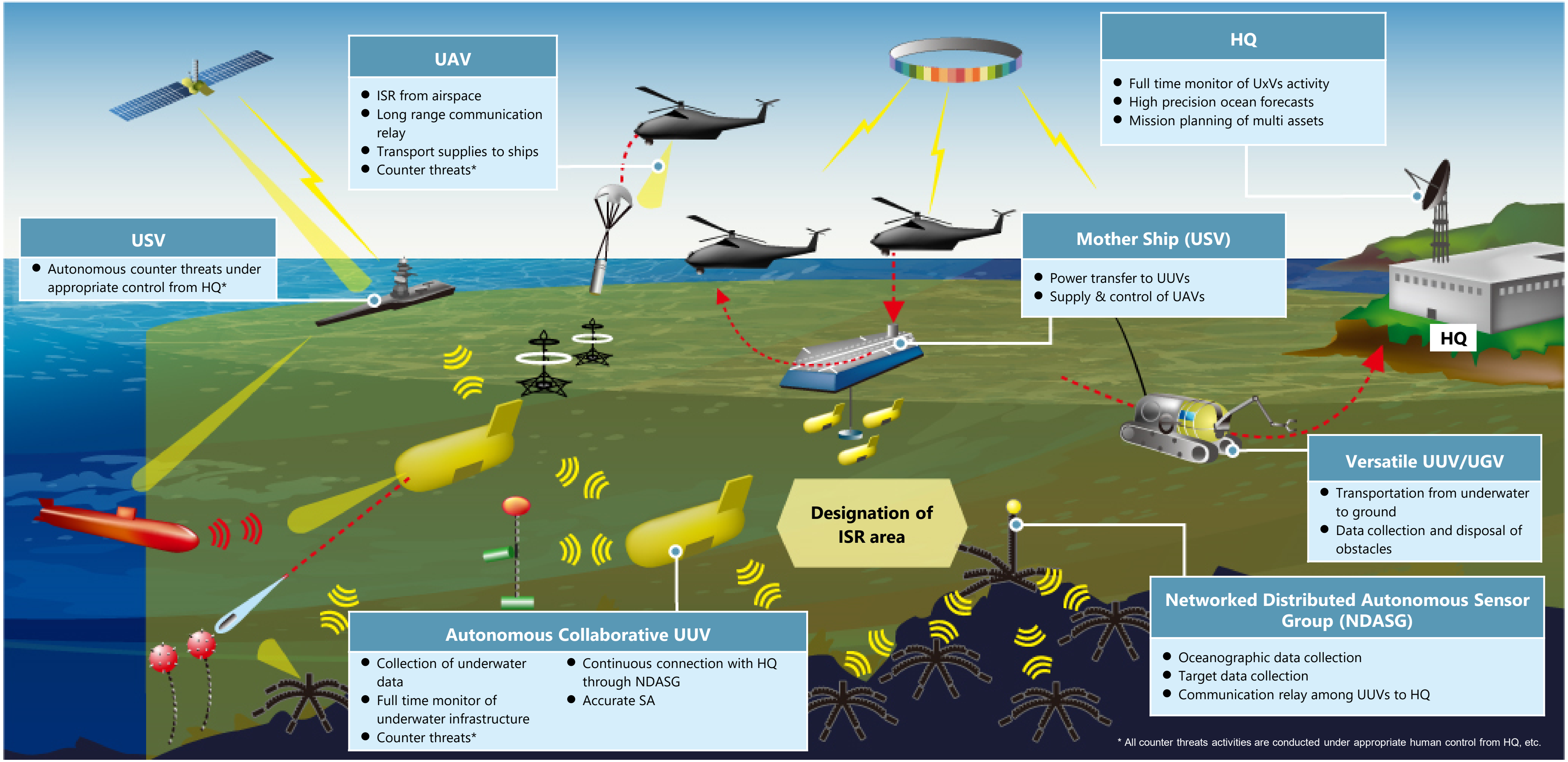



Primarily acquire through research and development
Acquire through joint research
Acquire through new civilian technologies

Note 1 Sufficiently examine the operational, technology, and cost aspects of establishing a specific research and development project.
Note 2 This slide illustrates future equipment which could conceivably be realized and does not indicate a development schedule.
Note 3 The endpoints of the arrows are only tentative. In light of the rapid research and development approach, we will strive for early technology acquisition.


Limit the possibility of detection through signature reduction to safely and covertly execute missions
Multi-functional UUV (Sound source functions)
Submarine
Configures multistatic sonar together with the submarine to carry out active anti-submarine warfare without revealing the submarine's position
Dramatic improvements in the capabilities of manned ships through collaboration with unmanned vehicles
Multi-functional UUV (Decoy functions)
Transmit a signal which mimics the signature of a submarine so that the target submarine falsely recognizes the UUV as a submarine
Target submarine

Multiple UxVs such as UUV, USV, UAV, etc. autonomously coordinate each other, and conduct UWW activities such as ISR, support, CM, etc. in designated area under monitoring from HQ, etc.



# Conclusion

## Primary method of advancing research and development

- Because the technologies pertaining to unmanned vehicles including unmanned underwater vehicles and their operation are rapidly advancing, the concepts and road map indicated in this R&D vision shall be revised as necessary according to technological progress, etc. It is expected that the latest research and development in strategically important technology fields will lead to the cultivation and strengthening of Japan's technology foundation as well as the invention of superior equipment.
- Unmanned underwater vehicles require a massive number of technologies and acquiring them all through Ministry of Defense and SDF initiatives is unrealistic in terms of both cost and the implementation period. Research and development of unmanned underwater vehicles is also advancing in the civilian sector. In particular, MOD shall endeavor to incorporate underwater communication technologies, technologies for collaboration between many different models, and group control results, etc. from the civilian sector to efficiently acquire those technologies.
- Concerning the implementation of the research and development, MOD shall endeavor to utilize ocean environment test evaluation facilities, etc. and appropriately demonstrate prototyped and developed unmanned underwater vehicle technologies to rapidly and efficiently develop superior equipment by accurately and inexpensively assessing the effectiveness of the equipment in a more realistic environment.

## Close observation of foreign and domestic trends concerning the ocean

- Japan follows the Basic Plan on Ocean Policy established under the Basic Act on Ocean Policy and promotes various ocean-related policies. The Ministry of Defense also promotes various policies based on the Basic Plan on Ocean Policy in addition to coordinating and cooperating with the relevant ministries and agencies and government organizations as needed regarding maritime national security including underwater activities.
- Maritime Domain Awareness (MDA) is an initiative being advanced in the U.S. and Europe. In addition, the Headquarters for Ocean Policy indicated in July 2016 that it would strengthen Japan's capabilities in this area and is reinforcing this initiative. Due to the fact that MDA initiatives by foreign countries may have an impact on the underwater and surface activities of unmanned underwater vehicles, such initiatives must be closely observed going forward.

## Response to international initiatives concerning the handling, etc. of unmanned vehicles

- Because it is difficult for radio waves to propagate underwater and continuous communications with a remote, manned headquarters poses a challenge, there is a stronger need for underwater unmanned vehicles to autonomously make decisions and determine actions without receiving direct human control compared to air or ground-based unmanned vehicles. Currently, there is an international debate concerning Lethal Autonomous Weapon System (LAWS*), and weapons with autonomous functions may be examined in terms of the operational and institutional aspects in the future. The Ministry of Defense and SDF are proactively participating in this debate to achieve a common understanding with international society and shall vigorously undertake research and development into the autonomous technologies required to realize effective underwater unmanned vehicles.
- A unified understanding of the handling of unmanned underwater vehicles (vessels and warships, etc.) has not been achieved on an international level. In using unmanned underwater vehicles, close attention must be paid to potential future trends in the development of Japanese and international law concerning the handling of unmanned underwater vehicles.

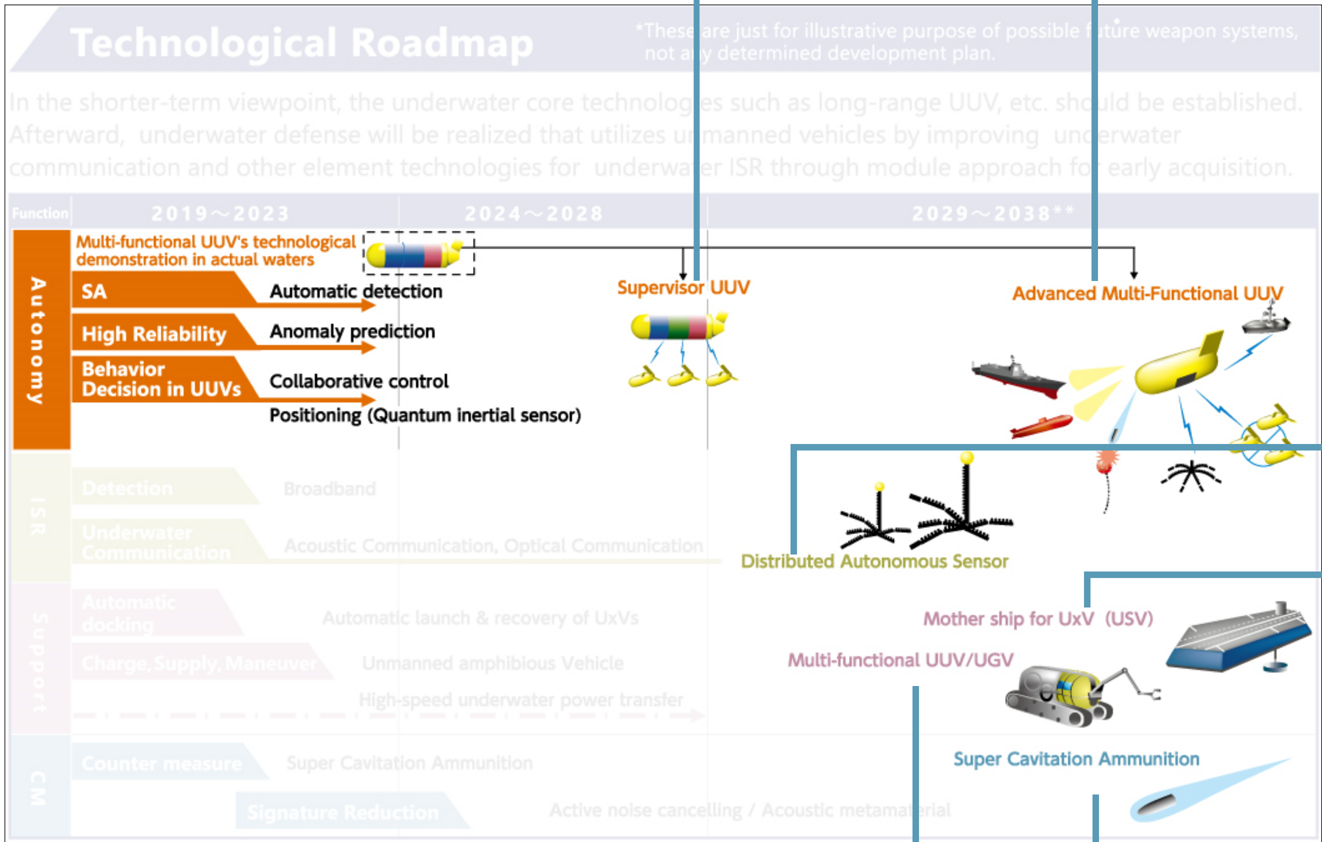
*LAWS: Lethal Autonomous Weapon System

## Reference

# Leading Technological Issues Which Should be Addressed in Underwater Defense Systems

# Correspondence with the R&D Vision Document (Roadmap)

**Underwater Defense System Components**
**- UUVs, Rotary Wing UAVs** (p. 21-23)




**Underwater Defense System Components**
**- Distributed, Autonomous Sensors** (p. 24)

**Underwater Defense System Components**
**- Mother ship for UxVs (USV)** (p.25)

**Underwater Defense System Components**
**- Multi-use UUV/UGV** (p. 26)

# Underwater Defense System Components - UUV (1/2)



## Multi-purpose UUVs

UUVs which are capable of executing various missions including the monitoring of submarines and other ships, laying underwater equipment, and the gathering of oceanic information, etc.
In addition to being able to swap sensors and energy sources according to the mission through a module structure, the applicable missions are increased by a high level of autonomy.

## Primary functions

**Common functions**

- Underwater communication (manned vehicles, unmanned vehicles, sea floor sensors, etc.)
- Surface communication (stable communication methods under severe weather)
- High precision navigation
- Obstacle avoidance (underwater and surface)
- Anomaly prediction and detection/troubleshooting
- Low acoustic signature
- Underwater charge

**Support for a variety of missions**

- Underwater monitoring
- Surface monitoring
- Oceanographic observation
- Acoustic deception, etc.

## Primary abilities

**Autonomy**

Target: autonomous capability which can continue long-term missions without direct human intervention

Technological issues: anomaly prediction and detection technologies, high reliability technologies, action decision technologies

**Endurance**

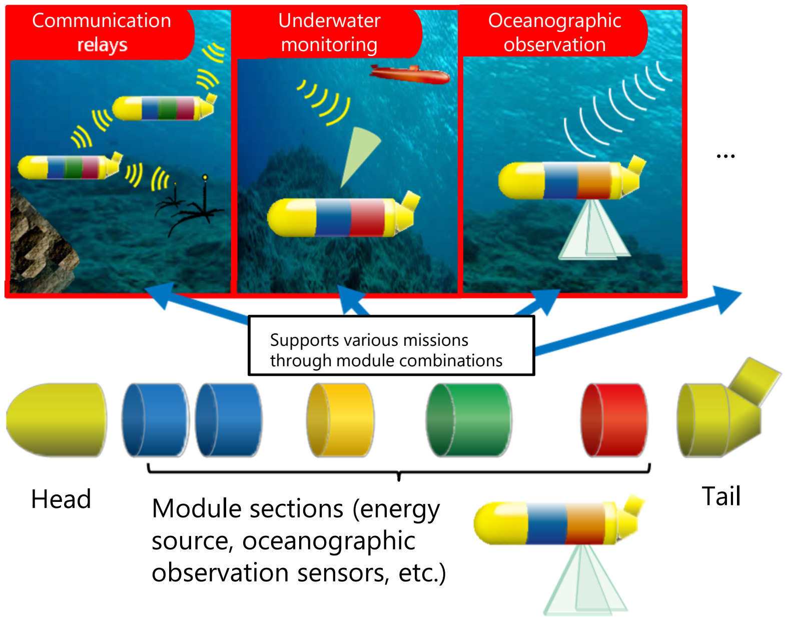
Target: several months

Technological issues: high energy density power sources which consider silence and safety, reduction of power consumed by mounted devices

**Detection performance**

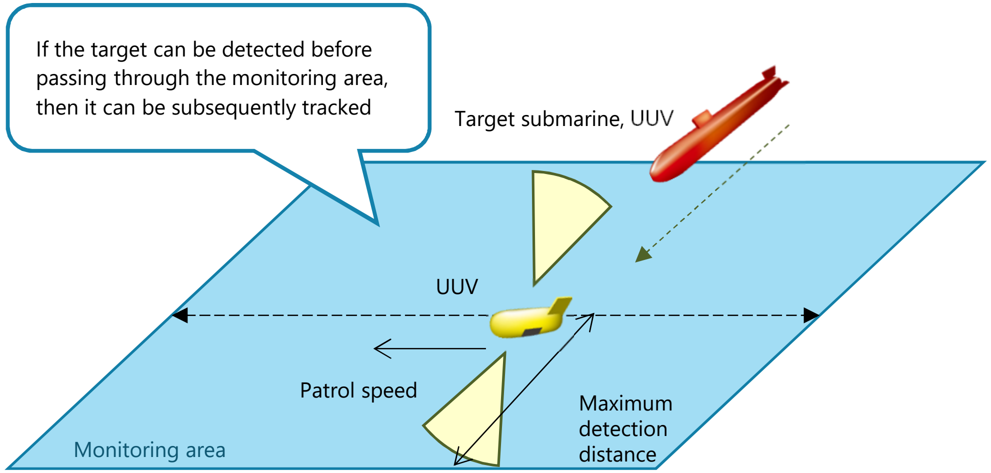
Target: long-distance detection capability between several to ten-odd kilometers

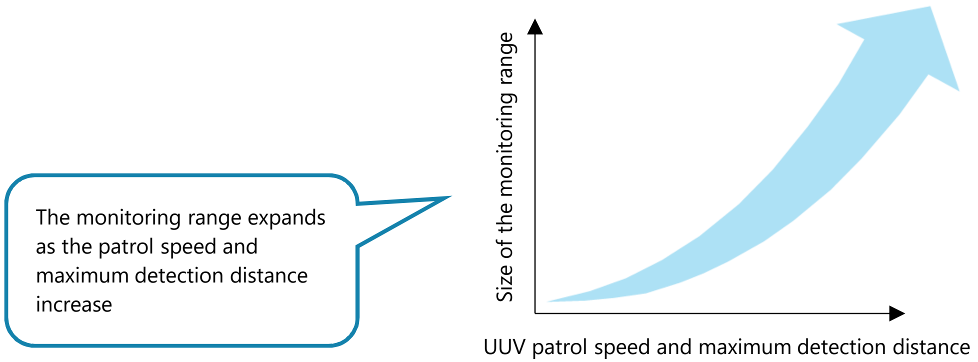
Technological issues: low self-noise, progress of signal processing technologies, improvement of reconnaissance precision, improvement of automatic detection and identification capabilities



## Improvement of UUV underwater ISR capabilities

Expand the monitoring range of each vehicle through improvements in detection performance including improvements in automatic detection and identification capabilities and the realization of power sources which enable the acceleration of the patrol speed and long-term operation. In addition, implement efficient underwater ISR through collaboration between manned ships and unmanned assets.



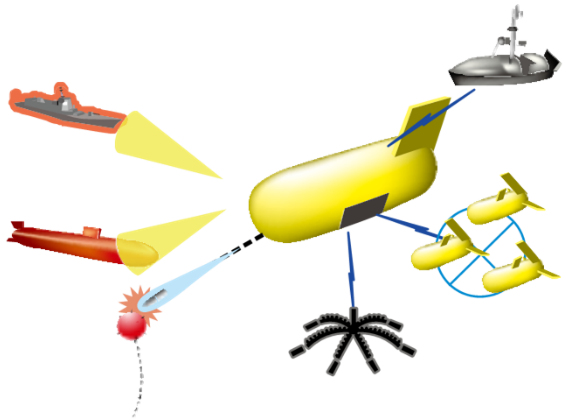




## Advanced multi-functional UUV

Many unmanned vehicles collaborate to execute a mission to remove threatening submarines, UUVs, and underwater equipment, etc. Because inexpensive threats are expected to appear going forward, inexpensive countermeasure methods and detection prevention technologies for engaging in activities under high threat will become important.

Applicable technologies (examples)

- Super cavitation ammunitions: projectiles which use cavitation to reduce water resistance
- Acoustic meta-materials: used on the hull surface to transmit the opponent's detector sounds
- Active noise reduction: generates sounds and oscillations with the opposite phase of the vehicle's own noise to cancel out that noise



## Rotary wing patrol UAV

Detects and responds to submarines, UUVs, and other underwater threats. In addition, it also carries out a support mission in relaying communications, monitoring the ocean surface, and transporting goods. Through resupply from a mother ship, this UAV monitors a vast region of the ocean for a long period of time.

[Comparison with fixed-wing UAVs]
(1) Capable of using suspended sonar
(2) Easy takeoff and landing on a mother ship due to VTOL capability
(3) The poor fuel consumption compared to typical fixed-wing UAVs can be reduced through collaboration with the mother ship

## Primary functions

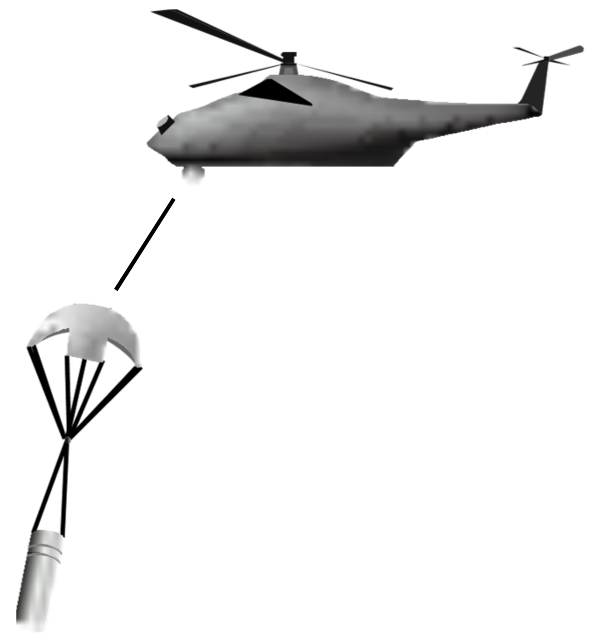
- Take-off and landing on a mother ship-type of USV
- Relaying of over-the-horizon communication from surface assets
- Ocean surface monitoring via radar and optical sensors
- Sonobuoy laying and acoustic analysis
- Detection via suspended sonar and communication with underwater assets
- Transportation of goods between USVs
- Launching of torpedos

## Primary abilities

**Autonomy**

Target: achieve the same level of functionality and performance as the current rotary wing patrol aircraft without a pilot

Technological issues: automatic takeoff and landing technologies, action decision technologies, surface and underwater target automatic identification technologies

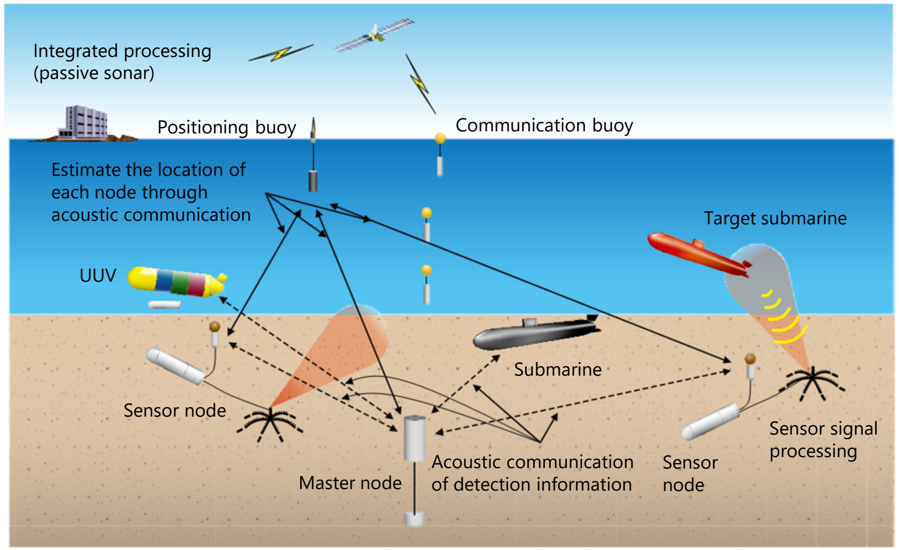


## Distributed, autonomous sensors

Distributed, autonomous sensor network system which is deployed to the sea floor from aircraft, ships, and underwater vehicles, etc. to autonomously perform ISR on submarines for a fixed interval and transmit the detection information via a communication buoy. The establishment of this system will dynamically change the monitoring range with respect to submarines as they become more silent and stealthy and improve continuous ISR functions.

## Primary functions

- Automatic target detection in sensor node
- Self positioning estimation by the sensor nodes and the master node through the positioning buoy
- Acoustic communication relay between nodes
- Communication of detection information by the master node
- Mobile deployment of each node




## Primary abilities

**Size and weight**

| | |
|---|---|
| Target: | size and weight which can be deployed from a UUV |
| Technological issues: | high energy density battery technologies |

**Detection performance**

| | |
|---|---|
| Target: | control the power consumption of the entire system while multiple sensors collaborate to improve detection capabilities<br>Operate for about one week using only the built-in batteries<br>Detection distance of tens of kilometers using multistatic detection (equivalent to or greater than the acoustic communication distance between each node) |
| Technological issues: | autonomous control technologies for a single sensor node or multiple node collaboration (transition between a low power consumption state and an active state), sensor deployment technologies, target signal detection and identification technologies |

**Acoustic communication**

| | |
|---|---|
| Target: | stable, long-distance transmission of large-capacity data (tens of kilometers) |
| Technological issues: | acoustic communication technologies which select the modulation method suited to the data volume to send, signal-to-noise ratio, and other operating conditions |

## Unmanned vehicle mother ship (USV)

Launch and recover small UUVs and USVs as well as take off and land UAVs together with supporting constant and continuous ISR across a wide area by unmanned vehicles through resupplying energy and resources to these unmanned vehicles. In addition, enable the organic collaboration of many assets by relaying communication between underwater assets and satellites.

## Primary functions

- Autonomous cruising (stable operation under severe weather)
- Underwater communication (manned vehicles, unmanned vehicles, sea floor sensors, etc.)
- Satellite communication
- Automatic launch and recovery of small UUVs and USVs, automatic takeoff and landing of UAVs
- Resupply of resources (batteries, underwater equipment, etc.) to unmanned vehicles
- Underwater charge to UUVs

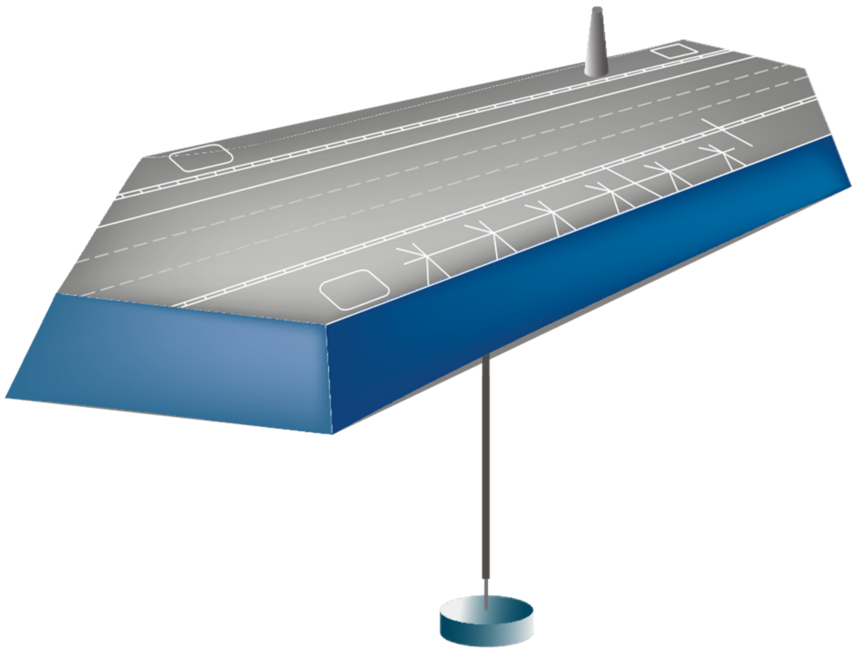
## Primary abilities

**Seaworthiness**

| | |
|---|---|
| Target: | several months of stable operation |
| Technological issues: | Sea-keeping, self-protection (stealth characteristics) |

**Control capability**

| | |
|---|---|
| Target: | control multiple unmanned vehicles (UUVs, USVs, UAVs) in the vicinity of the mother ship to efficiently launch/land, resupply, and charge |
| Technological issues: | control of nearby unmanned vehicles (knowing the positions, establishing communication), underwater communication (high-capacity laser communication, long-distance acoustic communication) |



## Multi-purpose UUV/UGV

Unmanned vehicles which can execute a variety of missions close to the shoreline such as information gathering, failure management, delivering resources to advance units, etc.
Uses sensors to recognize the surrounding environment along with attitude and cruise control which accounts for ocean wave and other disturbances to seamlessly perform information gathering, failure management, delivering resources, and other activities underwater, along the shoreline, and on shore to expand the number of applicable missions.

## Primary functions

- Driving characteristics (soft ground, reef lagoon, and reef crest)
- Compound drive (submerged navigation, shoreline and on-shore travel)
- Autonomous movement
- Attitude and cruise control
- Transportation (small-scale resource delivery)
- Information gathering and environment recognition (underwater, along the shoreline, and on shore)
- Failure management

## Primary abilities

**Mobility**

Target: seamless activity underwater, along the shoreline, and on shore

Technological issues: drive control according to the environment, driving characteristics (soft ground, reef lagoon, and reef crest), and drive system complexity

**Autonomy**

Target: system which uses attitude and cruise control functions, etc. to limit human intervention

Technological issues: attitude and cruise control, self positioning estimation, troubleshooting, autonomous action route creation which utilizes environment recognition information

**Information gathering, failure processing**

Target: operational efficiency equal to or greater than a reconnaissance diver

Technological issues: underwater, shoreline, and on shore environment recognition and failure management, improvement of failure and other automatic detection and identification capabilities