Intermediate Scientific report
“Working with two deep-sea ROVs”
(French Oceanographic Fleet)

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Acronyms:

CNFC: National Committee for coastal fleet

CNFH: National Committee for offshore fleet

CTD: Conductivity, Temperature, Depth

EEZ: Exclusive Economic Zone

FOF: French Oceanographic Fleet

FOF - CS: FOF Scientific Committee

HOV: Human Operated Vehicle

HROV: Hybrid Remotely Operated Vehicle

INEE: National Institute of Ecology and Environment (CNRS)

INSU: National Institute of Universe Sciences (CNRS)

IPEV: Institute Paul Émile Victor

mbsl: meter below sea level

MESRI: Ministry of Superior Education, Research and Innovation

MNHN: National Museum of Natural History

ORP: Oxidation Reduction Potential

ROV: Remotely Operated Vehicle

SWG: Scientific Working Group

UMR: Mixed Research Unit

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1. The scientific working group of "Scenario with 2 deep-sea ROVs"

1.1. Context and objective

As part of the evolution plan of the French Oceanographic Fleet, the Directory Steering Committee and the MESRI have confirmed in March 2018 to withdraw the usage of the submarine *HOV Nautile* in the medium term and to begin investigating of a "scenario with two deep-sea ROVs", including the revamping and modernizing of the *ROV Victor6000*. The outcomes are subject to the positive accreditation by the Direction Steering Committee of the initial (Phase 0) conclusions to be carried out by the Fleet Directorate, so as to assess its technical and budgetary feasibility.

The technical Phase 0 of this project had to take into consideration the current technological advances (marine instrumentation or in other domains) or early-stage developments, as well as the emergence of new needs. The approach should provide a project calendar enabling still the availability of two deep-sea operational vehicles to the scientific community and providing the time necessary to acquire the financial support to build the new vehicle.

The outcomes of the technical Phase 0 have been presented in December 2018 to the FOF – CS, then to the Direction Steering Committee. Following the positive evaluation by the FOF – CS, the Direction Steering Committee decided to launch the Phase 1 aiming at a preliminary definition with the following objectives:

- Definition of the scientific needs and requirements associated with the potential scenario of "working with 2 deep-sea ROVs";
- Definition of the technical functionalities derived from the scientific requirements;
- Writing of a technical report of the system according to the definition of the scientific need;
- This will be done in close link to the revamping and modernizing stages of the *ROV Victor6000*.

The final report will provide the grounds for the technological development of a new deep-sea ROV combined with the modernization of the *ROV Victor6000*, while gathering, scrutinizing and complying with the scientific needs.

1.2. Mandate of the Scientific Working Group

The Directory Steering Committee decided to constitute of a Scientific Working Group composed of representative scientists of the marine scientific community (IFREMER, Marine Universities, MNHN, Universities, IRD and CNRS) who will be using the deep-sea vehicles in the forthcoming years. It is anticipated that the contribution of this SWG is to better define the scientific needs anticipated from the prospectives of different scientific fields and the potential breakthrough required that the new ROV conception should comply to. For this purpose, the SWG will address the following issues:

- Deployment scenario in a context of exploration, medium- to local-scale zone, site survey and fixed site operations, technical and instrumental requirements, and expected operating mode during oceanographic cruises;
- Environmental constraints that the new ROV will have to sustain such as the working immersion, withstanding water currents, geographic working area, seafloor relief (underwater topography), fault scarps…;

- Combined deployment of deep-sea vehicles such as joint operations with AUV and ROV, shuttle between sea surface and bottom seafloor, communication needs between vehicles during deployment…

The scientific requirements that the SWG will highlight, will establish the references to write the functional specifications. The contribution of engineers of the Submarine System Unit will be to evaluate and propose the technical solutions to comply with the scientific needs and to unlock technical keys in order to propose several choices of system architecture.

At the final stage of Phase 1, the SWG will have to evaluate and validate the preliminary functional definition of the new ROV and the modernization of *ROV Victor6000* as a response to the scientific needs. Then, the SWG will follow up on the evolution of the two projects along their different stages of design and development by providing advices or arbitrate between several technological routes according to the scientific objectives that need to be achieved. The SWG stands guarantor for the scientific requirements.

1.3. Members of the Scientific Working group

The Directory Steering Committee elaborated the SWG by consulting the CNFH direction which evaluates oceanographic cruise proposal for which deep-sea vehicles are requested, and the national organisms contributing to the FOF (i.e. IFREMER, CNRS, IRD, Marine University and IPEV). Special attention has been paid to cover a wide range of scientific research disciplines and the gender equity.

The SWG is composed of the FOF deputy director, the director of the Underwater Systems Unit associated with 3 engineers in charge of deep-sea vehicle systems, and 20 scientists from different institutions and professional status coming from various national laboratories. P. Morin, as the representative of the FOF direction, organized on the 17th April 2019 a kick-off plenary meeting for the SWG hosted by the IPGP. At this occasion, a chair and a co-chair were proposed to the SWG in order to organize at best the discussion between each organism as defined by their missions and to ensure the inventory of the national scientific needs as about 3600 scientists/engineers are using the FOF for their research (French Oceanographic Fleet foresight, Jeandel 2017).

The member names, affectation and expertise are compiled in Table 1.

Name	**Affectation**	**Post/Expertise**
Pascal Morin	IFREMER, Brest	**FOF deputy director**
Jan Opderbecke	IFREMER, Toulon	**Director of the Underwater Systems Unit**
Ewen Raugel	IFREMER, Toulon	Engineer, in charge of the new ROV development
Patrick Simeoni	IFREMER, Toulon	Engineer, in charge of the ROV Victor6000
Patrick Jaussaud	IFREMER, Toulon	Engineer, in charge of the AUVs and former ROV pilot
Nadia Ameziane	IRD, MHNUN Paris	Marine biology
Sophie Arnaud-Haond	IFREMER, Sète	Ecology, connectivity
Florian Besson	IFREMER, Brest	Geology, hydrothermalism, deep-sea minerals exploration
Philippe Bouchet	IRD, MHNUN Paris	Marine biology, biodiversity
Mathilde Cannat	CNRS, IPGP Paris	Geology, geophysics, deep-sea observatory
Valérie Chavagnac	CNRS, GET Toulouse	**Chair of the working group** Geology, hydrothermalism, deep-sea observatory
Javier Escartin	CNRS, IPGP Paris	Geology, geophysics, specialist AUV & ROV

Marc-André Gutscher	CNRS, LGO Brest	Geophysics, instrumentation
Pierre Henry	CNRS, CEREGE Marseille	Geophysics, geology, instrumentation
Stéphane Hourdez	CNRS, LOV Banyuls	**Animator of the ROV exploration needs working group** Marine biology
Mohamed Jebbar	UBO, Universités Marines Brest	Microbiology
Nadine Le Bris	CNRS, SU Banyuls	Ecology and marine biogeochemistry
Julien Legrand	IFREMER, Brest	**Animator of the ROV shuttle working group** Engineer, instrumentation, deep sea observatory
Marcia Maia	CNRS, LGO Brest	Geology, geophysics
Karine Olu	IFREMER, Brest	**Animator of the imaging working group** Ecology, deep-sea ecosystems
Sarah Samadi	MNHN, Paris	Marine biology
Pierre-Marie Sarradin	IFREMER, Brest	**Co-chair of the working group** Deep-sea ecosystems; deep-sea observatory
Emmanuel Rinnert	IFREMER, Brest	Instrumentation
Céline Rommevaux	CNRS, MIO Marseille	**Animator of the payload working group** Microbiology, instrumentation, deep-sea observatory
Julie Tourolle	IFREMER, Brest	Deep sea ecology

1.4. Working documents

- Rapport technique Phase 0, E. Raugel and J. Opderbecke, 2018.
- Devenir du Nautile, O. Lefort, 2017.
- Rapport sur le plan d'évolution de la FOF, F. Gaill, 2013.
- French Oceanographic Fleet foresight (2017 – 2030), C. Jeandel, 2017.
- Les ressources minérales marines profondes, IFREMER, 2011.
- ESCO – Les impacts environnementaux de l'exploration et de l'exploitation des ressources minérales profondes, CNRS – IFREMER, 2014.
- ICARPII, Arctic research planning - a Roadmap for the Future, 2015.
- Modernisation Victor6000 – Perspective nouveau ROV, P. Simeoni, 2018.
- Schmidt Ocean Institute, 4500m ROV Science mission requirements, 2015.
- Sub-working group reports: imagery, "need for good exploration", shuttle surface-bottom, payload, 2019.

2. The FOF position within the marine scientific research

The FOF has a dedicated research vessel fleet for the offshore environment research:

- 4 research vessels: le *Pourquoi Pas?, l'Atalante, la Thalassa, le Marion Dufresne,* cruising all over the world ocean, only *le Marion Dufresne* can cruise in the Southern ocean but this is not an icebreaker;
- 1 logistic vessel for the world polar regions: *l'Astrolabe*;
- *HOV Nautile6000* for deep-sea exploration and sampling, fully autonomous;
- *ROV Victor6000* for deep-sea exploration and sampling, tethered by an umbilical cable to research vessel;

- *HROV Ariane 2500* for sampling, screening and optical/acoustic mapping, tethered by umbilical cable to research vessel;
- *AUVs AsterX - IdefX 2850* for near-seafloor surveys, acoustic mapping and monitoring, fully autonomous;
- *AUV Coral 6000* for deep-sea surveying, acoustic mapping, monitoring and sampling, fully autonomous, to integrate the Fleet by 2021.

These research vessels can provide sea current (ADCP) gravimetric, magnetic and bathymetric maps along their cruising pathway, deploy scientific instruments from ship deck (CTD/Niskin bottles, rock dredges, ocean bottom seismometers, sediment corers of various type and size and geotechnical probes (Penfeld, Calypso…)) and launch deep-sea vehicles (*AUVs*, *ROV Victor6000*, *HOV Nautile6000*, and *HROV Ariane*) capable of exploring, investigating and sampling the deep-sea environments (fluids, rocks and mineralisations, sediments, in-situ physico-chemical parameters...). This infrastructure is essentially dedicated to scientific research and observations covering domains of Earth and Environmental Sciences as investigated from marine geosciences, biogeochemistry, ocean chemistry, paleoclimatology, paleoenvironment, biodiversity, volcanology...

Notwithstanding the FOF fleet has to respond to monitoring, evaluation and public services instructed by the French Government in link to EEZ geographic boundaries (extension of the continental shelf program) and geohazards (seismic, volcanic and gravitational landslide) as well as industrial and socio-economic affreightment regarding deep-sea mineral and energy resources. The French offshore region outside the metropolitan region has a surface area of about 11 million square kilometers of EEZ, positioning France as the second actor of world maritime space. These EEZs are located in all oceans of the planet (Atlantic, Pacific, Indian and Antarctic), where living, mineral and energetic resources are particularly rich. With the intent to consolidate the French leadership in breakthrough knowledge and development and sustainable management of the maritime environment at EEZs, maintaining the presence of French research vessel with state-of-the-art deep-sea vehicles is at the forefront requirements (Table 2).

	2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Atlantic Ocean	0	37	113	41	10	102	71	n.a.	n.a.
Indian Ocean	110	84	29	116	34	142	95	38	26
Pacific Ocean	99	77	30	43	194	23	29	77	15

French Overseas departments:
Atlantic Ocean: Guyana, Martinique, Guadeloupe, Saint Pierre et Miquelon
Indian Ocean: La Réunion, Mayotte, Iles éparses
Pacific Ocean: New Caledonia, French Polynesia, Clipperton

Table 2: Number of cruise days of the offshore oceanographic fleet to French overseas departments. n.a.: not available. Data source from CNFH.

Since 2009, the FOF provided the infrastructure needs for 80 oceanographic cruises dedicated to the deep-sea environment operating on the 4 high-sea research vessels, deploying all the different deep-sea vehicles and working in all oceans. During these cruises, the scientific objectives covered a wide range of expertise, i.e. geology, geophysics, geochemistry, biology, ecology, …, for which the deployment of one deep-sea vehicle or a combination of two of them (AUVs and ROV/HOV; AUVs and HROV taken as example) was mandatory. This testifies for the dynamism of the French research activities in marine environment, any discipline combined, to explore, investigate and scrutinize this environment so difficult to access.

At present, there is strong demand from the national scientific community for use of the TGIR - FOF as demonstrated by a time lag of at least two years (even longer when considering scientific activities in the Pacific Ocean) between obtaining a “highly favorable” evaluation (P1 – 1st priority ranking) of a cruise proposal by the CNFH, and the operation of a scheduled cruise. This is without doubt a strong and clear message from the scientists to the FOF which needs to maintain, in optimum operating conditions, both the 4 high-sea research vessels that may deploy submarine systems and all the different deep-sea vehicles. For the latter, the recommendation highlighted by the FOF foresight in 2017 is to maintain two deep-sea vehicles of working depth abilities down to 6000 mbsl. Additionally, *L'Atalante* research vessel has almost reach its 30 years of services for the community, indicating a replacement by a new generation of research vessel on a short term. Finally, the investment of the French community in the implementation of deep-sea observatories is on a rising trend, as shown by the EMSO-France program (http://www.emso-fr.org/EMSO-France; through nodes: EMSO - Azores, EMSO - Nice, EMSO - Nice, EMSO - Molène) within the international European program EMSO - ERIC.

3. The scientific community and its research objectives

3.1. The human power

Most scientists (researcher and engineers) working in the ocean science realm are based in about 60 laboratories located across the whole national territory (metropole and French overseas departments). 75% of these laboratories are joint research-units (UMRs) connected to from CNRS (INSU and INEE), IRD, IFREMER, MNHN and universities. The remaining 25% represents sensu-stricto IFREMER units.

The large research programs to which the French scientific community contributes, are international and collaborative in scope with one major objective being to ensure access of acquired data at any location and at any time period to the world-wide scientific community to better understand an oceanic domain so difficult to access. In marine geosciences, the community actively contributes to ECORD (European Consortium for Ocean Research Drilling; http://www.ecord.org), JERICO-NEXT (European Infrastructures for Marine Coastal observatories; http://www.jerico-ri.eu), and EMODNet (European Marine Observation and Data Network; http://www.emodnet.eu). We also participate in international research infrastructures such as EMSO-ERIC (European Multidisciplinary Seafloor and water-column Observatory; http://www.emso-eu) and IODP and national ones such as I-LICO (coastal environment). In marine biology, ecology and biodiversity, the community is structured since the international program the “Census of Marine Life” (CoML, 2000-2010) which focuses on all living organisms from microbial organisms to large predators living from submarine canyons on the shelf to the abyssal environment distributed all over the world ocean. For the latter, biodiversity research programs are coordinated to international programs such as Future Earth, Diversitas - bioDiscovery, bioGenesis, ecoServices, GEOBON). At the European level, the former UE EurOceans, MarBEF and Marine Genomics Network of Excellence are now gathered under a unique networking initiative called EuroMarine (https://www.euromarinenetwork.eu/).

The French marine scientific community, regardless of its area of expertise (geology, micro- to macro-biology, ecology, geophysics, geochemistry, paleo-environment, sedimentology, volcanology...), is initiating and stimulating the national research open-call of CNRS-INSU, CNRS-INEE, IFREMER and IRD coordinated under the Ocean ALLEnvi working group. Their research activities are based upon offshore cruises with the deployment of submarine vehicles and will be described in the forthcoming section.

3.2. The research themes and forthcoming issues

The research activities dedicated to the ocean and which need to be investigated, are both related to fundamental research and to understand services provided by the marine environment. The scientific community is highly active in a wide range of thematic and working areas such as the evolution of the coastline, the dynamic of oceanic mid-ocean ridges and the formation of the oceanic lithosphere, the subduction zones, the volcanic arcs and back-arc systems, the interface of the shelf and slope including submarine canyons and methane/hydrocarbon seeps, the seismic and gravitational geohazards, the interface between the ocean and the oceanic lithosphere, the biodiversity of the deep-sea, the marine minerals and energetic resources, the study of sedimentary archives to understand transfer processes, particles distributions and paleoclimate and paleoenvironmental reconstructions. The society concerns regarding the ocean and it resources, the coastline and the associated geohazards (tsunami, landslide, volcanic eruption), and the different threats on the ocean (climate change, anthropogenic impacts, and resource overexploitation) have increased in recent years renewing the scientific and economic questioning. They can be organized around 3 axes:

- <u>The Ocean System:</u> its geological substratum, its hydrological, biotic and abiotic components, its emerging, preserving and functioning of marine ecosystems, its processes of matter, energy and biomass transfer
  - Structure of the oceanic seafloor such as ridges, subduction zones, volcanoes, back-arc basins and deep-sea plateau, detachment and transform fault;
  - Links between tectonic and geodynamic changes and oceanic dynamic, climate, erosion and sedimentary record;
  - “Source to Sink” mass balance based on sedimentary archives, what are forcing and parameters controlling its dynamic;
  - Paleogeographic and paleoclimatic reconstruction based on sedimentary and biogenic archives (i.e. corals, foraminifera, bivalves);
  - Tectonic formation of passive (Atlantic, Indian and Mediterranean) and active (Japan, Mediterranean, North Andes, South-west Pacific, Indian Ocean) margins, and fluid migration from mantle to seafloor within sedimentary basin;
  - Processes of matter, energy and biomass transfer acting at the interface between the oceanic lithosphere and the ocean, hydrothermal fluxes impacting the ocean composition and deep-sea ecosystems;
  - Exploration, preservation and inventory of marine biodiversity from sea-surface down to the seafloor;

- <u>Marine resources</u>:
  - Evaluation of the mineral, biological and energy resources and of their access in a sustainable

and environmentally friendly way;
  - Understanding the environmental impacts of potential deep-sea mining exploitation on the ocean health and its associated deep-sea ecosystem;
  - Methane cycle in the oceanic domain from its genesis to its storage within the sedimentary archive and its potential impact on the water column and as a greenhouse gas to the atmosphere;
  - Sedimentary and biological archives to better constrain climatic change studies;
  - New resources of polar regions provided by climate change: potential, benefit and drawdown, risk assessments;
  - Evaluating the services provided by the deep-sea ecosystems and the risk of their exploitation;

- Climate change and natural - anthropogenic risks: the prevention of natural risks, in particular for populations living on islands and coastlines, resilience of deep-sea ecosystem to environmental changes, the impact on the societal environment
  - Spatial structure of marine biodiversity and biotic interaction in the context of global change;
  - Physico-chemical stresses induced by human activities on ocean health and ecosystem functioning (exposome evaluation and impacts);
  - Seismic and gravitational geohazards in link to tsunami genesis;
  - Coastal geohazards induced by either human activities or climate change;
  - Shrinking sea-ice cover: the origin of this change and its impact (interplay between the physical and ecological spheres in a changing environment);
  - Anthropogenic induced environmental disaster (chemical waste to coastal domain, oil leaks, nuclear reactor dysfunction...);
  - Impact of “natural hot moments” on the island populations: volcanic eruption such as the “Mayotte “ volcanic-seismic crisis with strong impact for the population in this area (tsunami, …), or the underwater volcanic eruption in the Tonga-Kermadec volcanic arc which has led to a drifting sheet of volcanic scories (twice the size of Manhattan), these two examples occurred during 2019, what’s next? These hot moments may disrupt the environmental conditions of human societies;
  - Micro-plastic vortex in the Pacific leading to death threat on the ecosystem trophic chain thus on mankind;
  - Investigation of Arctic and Antarctic domains a seen for a multidisciplinary approach (ice, water column, ecology, seafloor geophysics and geology…);

Increasingly, oceanographic cruises are following a multi-disciplinary approach to better understand the natural environment by coupling geophysical, geological, biological, geochemical and sedimentary investigations. This is due to the crucial role played by the Ocean system in the Earth system with which it exchanges matter, energy and biomass through several interfaces: via the external envelopes (atmosphere and cryosphere), via the surface continental - ocean continuum (estuaries, lagoons, fjords, canyons...) and via the oceanic seafloor (passive and active margins, subduction zones, abyssal plains, mid-ocean ridges...). Geological, geophysical, biological and geochemical processes taking place at these interfaces have all specific thermodynamic properties acting both at temporal and spatial dynamics that differ from those observed in other sectors of the Ocean (Figure 1).

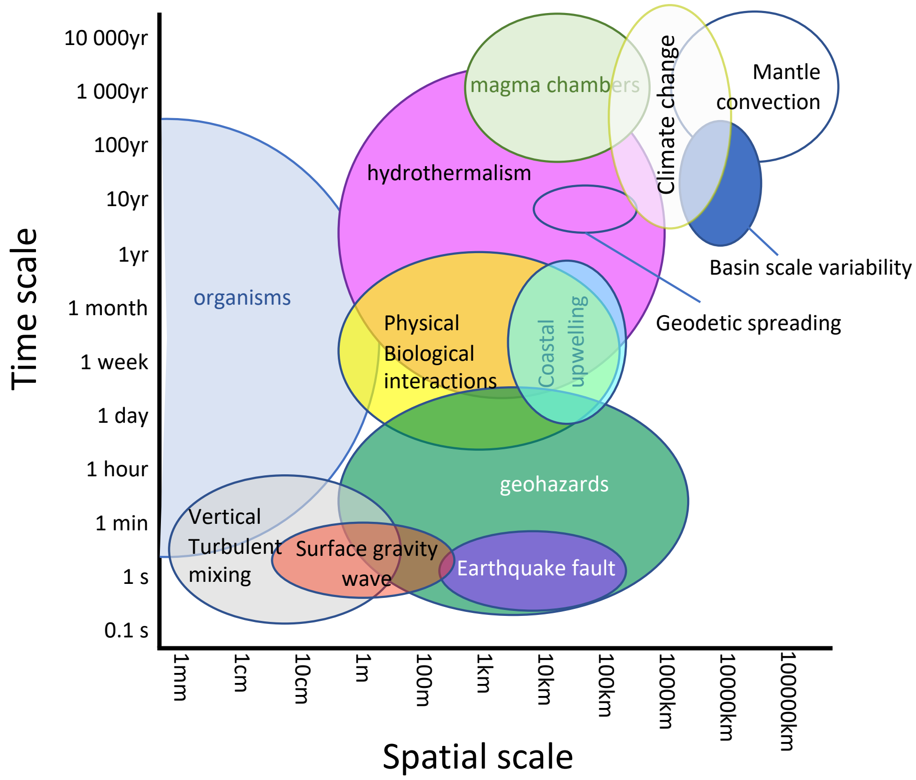

Figure 1: Modified illustration of the overlapping temporal and spatial scales of major ocean and earth processes to which deep-sea submersibles are necessary to deploy for investigation. Adapted from Ruhl et al. (2011).

Thanks to the development of scientific submersibles in the seventies (*HOV Alvin* in 1964, *HOV Nautile* in 1984), the deep-sea is no more an inaccessible environment. Since then, and following the technological developments, the study of the deep-sea evolved from a descriptive approach, to a more systematic one trying to understand its functioning and evolution considering all its different environments. Therefore, the scientific community developed over the year's different complementary approaches from, for example, the exploration at regional scales to the in-situ experimentation (e.g. the growth of a microbial assemblage in a single hydrothermal vent chimney taken as an example), by using and/or combining different deep-sea submersibles with their own specificities and by implementing deep-sea observatories to acquire long term time series.

Finally, in the recent prospective for the Ocean proposed by the Scientific Directions of IFREMER – CNRS, three ecosystems have been identified as specific challenging zones:

1. The French Overseas Departments as vulnerable witnesses of a changing environmental world,
2. The deep ocean as the last frontier to explore, and
3. The arctic ocean as a changing ecosystem with coveted resources.

3.3. The means to achieve the scientific objectives

Over the past 10 years (Table 3), the scientific community used the deep-sea submersibles according to the scientific objectives both in time and space to be achieved; this requires both complementary operations of various vehicles (AUV, ROV, HROV, HOV) for exploration versus fixed site investigation in close link to fundamental research activities, deep-sea observatories (EMSO-France), and survey sites for IODP proposal (IODP-France). Moreover, for the next 2 years, 5 to 6 annual cruise proposals either evaluated positively or in review by the CNFH, request the deployment of deep-sea submersibles as either individual vehicle (AUV, HOV, ROV) or a combination of two of them (AUV/HOV, AUV/ROV). The HROV has been essentially requested by the scientific community working in coastal environments as it has been specified for that purpose and can be deployed on coastal vessels. The scientific community used the specific functionalities of each deep-sea submersible as well as their operating flexibilities to manage at best the allocated time at sea for research (Table 4). The spectrum of deep-sea submersible operation will expand on a short term as the *AUV Coral 6000* will be sea trialed in 2020, and available to the scientific community by 2021. We anticipate for the forthcoming years an increasing number of cruise proposal requesting the combination of AUV/ROV and AUV/HOV for exploration in deep-sea environment between 2500 and 6000 mbsl.

year	Cruises	Research Vessel	Working area	Deep-sea observatory	AUVs	HROV	HOV	ROV
2009	3	Pourquoi Pas?; le Suroit	Marmara Sea, Atlantic Ocean		1		1	1
2010	6	Pourquoi Pas?; l'Atalante	Atlantic and Pacific Oceans, Mediterranean Sea	ESONET - MoMAR-DEMO	1		4	2
2011	10	Pourquoi Pas?, le Suroit, l'Atalante	Atlantic Ocean, Mediterranean sea	ESONET - MoMAR-DEMO	1		3	6
2012	6	L'Atalante, Pourquoi Pas?, la Thalassa	Atlantic and Pacific Oceans, Mediterranean sea	EMSO, ANTARES	1		2	3
2013	8	Pourquoi Pas?, le Suroit, l'Atalante	Atlantic Ocean, Mediterranean Sea	EMSO	2		1	6
2014	7	Pourquoi Pas?; le Suroit	Atlantic Ocean, Mediterranean and Marmara seas	EMSO	1	1	1	5
2015	2	Pourquoi Pas?	Atlantic Ocean	EMSO				2
2016	6	L'Atalante, la Thalassa, Pourquoi Pas?	Atlantic and Indian Oceans, Mediterranean sea	EMSO	1		1	4
2017	6	l'Atalante, Pourquoi Pas?	Atlantic Ocean, Mediterranean sea	EMSO	2		2	4
2018	7	l'Atalante, Pourquoi Pas?	Atlantic Ocean, Mediterranean sea	EMSO			2	5
2019	7	l'Atalante, Pourquoi Pas?, Marion Dufresne	Atlantic and Pacific Oceans, Mediterranean Sea	EMSO	2	2	2	2
2020	6	l'Atalante, Pourquoi Pas?, Marion Dufresne	Atlantic and Pacific Oceans	EMSO	2		2	4
2021	5	l'Atalante, Pourquoi Pas?, Marion Dufresne	Atlantic and Indian Oceans	EMSO	3			3

Cruise proposal in review by the CNFH

Table 3: Cruise inventory enabling deployment of deep-sea submersibles over the last 10 years and the next 2 years using the TGIR FOF. At deep-sea observatory, deep-sea vehicles are mandatory to deploy on the seafloor monitoring stations of communication, power supply and instruments AUVs AsterX & IdefX. HROV ARIANE, HOV Nautile, ROV Victor. Data source from the CNFH.

One of the main issues is to manage a cruise operating in an exploration mode over multiple spatial scales from regional scale (α100 km^2) for geology, tectonic, mid-ocean ridges and basin exploration, medium scale (α10 km^2) for fault or volcano exploration down to local scale (α100 m^2) for in-situ experiments at hydrothermal vent, cold seeps, or mud volcano, finally down to site scale (α10m^2) for long-term monitoring at deep-sea observatory (Table 4). In this context, the use of deep-sea submersibles such as ROV, HOV and AUV, or a combination of those, are mandatory. Meanwhile, the shuttle from sea surface to sea bottom is not considered as a deep-sea vehicle but is extensively used by chief scientists during ROV/HOV dives for swapping scientific tools, rapid recovery of freshly collected biological samples and sending to the seafloor new instruments.

	CORAL	ASTER X / IdefX	NAUTILE	VICTOR	ARIANE
	AUV	**AUV**	**HOV**	**ROV**	**HROV**
Technological specificities					
First scientific use	2021	2004	1986	1998	2016
Max operating depth (mbsl)	6000	2850	6000	6000	2500
Length*wide* height (m)	4.5*0.8*1.2	4.5*0.71	8.0*3.8*2.7	3.07*2.14*2.77	
Weight (t)	3	0.8	18.5	4.6	1.8
Operating team	3 to 4	3	8	8	3
Deployment	dedicated mechanized LARS (Launch and Recovery System)	Dedicated deployment and recovery frame "caliste"	Specific dynema lift line and winch. Dedicated divers and speedboat for launch and recovery	8000m electro mechanical cable, depressor weight and and 200 m leash	Fiber optic cable, depressor weight, tether management system
Environmental constraints for deployment		Sea state 3	Sea state 4 Wind speed 25 Kn Underwater current speed 1Kn	Sea State 4 Wind speed 25 kn 3 m swell	*Sea state 4* *Underwater current speed 0.5Kn* Temperature -2, +40°C
Speed (Max)	Up to 4 knots	2 (5) knots	1 (2) knots	0.8 (1.5) knots	Max 2 knots
Dive duration (h)	24 to 48	16 (100 km sections)	8	Up to 72	4 to 8
Support vessel	Pourquoi pas?, Atalante, Thalassa, Marion Dufresne, Anthéa	Coastal vessels, Pourquoi pas?, Atalante, Marion Dufresne	Pourquoi pas ?, Atalante	Pourquoi pas ?, Atalante, Thalassa, Marion Dufresne	Coastal vessels
Telemanipulation	N/A	N/A	2 arms (7 & 5 fcts)	2 arms (7 & 5 fcts)	2 arms (7 & 5 fcts)
Scientific Payload in water			200 daN	114 daN	
Weight adjustment			200daN Jettison ballast	65daN@2Lmin	
Transportability	2 containers		exceptional convoy	2 containers + 1 plateau	2 containers
Shuttle	N/A	N/A	Up to 2 per dive	Up to 3 per 24h	
Scientific performances					
	CORAL	**ASTER X / IdefX**	**NAUTILE**	**VICTOR**	**ARIANE**
	AUV	**AUV**	**HOV**	**ROV**	**HROV**
Video imagery	X	-	HD and 4K video	HD and 4K video	HD video
Sampling	Water	-	Water, rocks, organisms	Water, rocks, organisms	Water, rocks, organisms
Sampling capacity (weight)	X		+++	++	X
Optical mapping	X		X	X	X
Acoustic mapping	X	X		X	X
Chemical mapping	X	(X)	X	X	
Magnetism, gravimetry,	X		X	X	

electromagnetism					
Large scale exploration / survey α100km^2	++ (survey task: 30m to 100m altitude, speed up to 2.5 m/s)	++	-	-	-
Medium scale exploration / survey 20-100 km^2	++ (Local inspection: 2m to 10m altitude, speed hover to 1m/s)	++	++ Autonomy (free to move) Payload	+	-
Small scale exploration 2500 – 20 000m^2			+++ Autonomy (free to move) Payload	++ Dive duration	++ Cliffs and canyons
Site study			++	+++ Dive duration	++
Deep sea observatory			++	+++ Dive duration	++
Advantage for *in-situ* experimentation			Direct vision Maneuverability (no umbilical cable)	Dive duration (umbilical cable) Team work	Cliff and canyon

Table 4: Specific uses of deep-sea submersibles according to research activities and scientific objectives.

4. Definition of scientific/technological requirements for a new ROV

The FOF prospective (2017 – 2030) which was organized in 2016-2017 and involved the national scientific community (all organisms) recommended to keep both deep-sea submersibles (*HOV Nautile* and *ROV Victor*) in operation for scientific studies, to support public policy, and to ensure their sustainability and evolution for 20 years. **As the MESRI decided on the decommission of the *HOV Nautile* on a short term, we recommend as a top priority to maintain in optimal operational conditions two deep-sea vehicles** (*HOV Nautile* and *ROV Victor*) **for deep-sea investigations (down 6000 mbsl) at least until the new ROV is fully operational and available to the scientific community**. This implies that both *HOV Nautile* and *ROV Victor* vehicles have to be maintained in operating conditions down to 6000 mbsl. In this context of the evolution of deep-sea vehicles system, the SWG identified, in the first place, the different and various limitations of the current deep-sea vehicles system based on functionalities and specificities of each deep-sea vehicle (Table 4). In a second section, the SWG compiled the scientific requirements for which the design of the new ROV is expected to overcome.

4.1. What are the challenges for scientific research?

The functionalities and/or scientific objectives described below have not been prioritized yet.

- Working without the *HOV Nautile*: A significant number of scientists are requesting the *HOV Nautile* to explore and investigate the deep-sea environment. The new ROV design has to provide the means to preserve the specificities of this submersible, i.e. to get a 3D vision and the possibility to observe the deep-sea environments equivalent or superior to the human perception inside the *HOV Nautile*, to navigate freely in the deep-sea without Important constraints from the research vessel positioning and its moving speed, to possess higher payload capacity and higher power potential. In addition, exploration dive is not as straightforward as it seems, even with a working dive plan in hand by the observer. Impromptu and astonishing geological/biological scenes can force the observer to change exploration strategy during a dive. Thus, the new ROV design has to be very maneuverable.

- **Recommendation: The new ROV has to be maneuverable, to provide the potential for the acquisition of 3D data regardless of the dataset, the integration of several types of data (acoustics, optics, etc.), optimized lighting, a 360° data acquisition, the possible orientation of certain sensors (e.g. MBES), adding other types of sensor such as LIDAR, real-time 3D reconstruction of the deep-sea environment. The table below presents how technological advantages may respond to human perception based on our 5 senses.**

	Objectives	**Technological possibilities**
view	3D micro-bathymetry in real-time to improve working condition in the deep-sea; georeferencing of any sample collection; better navigation and positioning;	3D Reconstruction of the deep-sea environment by video – stereo in real time
smell	Detection fluid/gas occurrences and compositions at the deep-sea	Modifying acoustic frequencies
touch	Manipulation and sampling of delicate material Higher carrying charge in link to stations deployed at deep-sea observatory	Force feedback on both arm manipulators Higher power potential
hear	Perceiving the environment and spatialization	Changing acoustic frequency; sonar
taste	In-situ identification of minerals Improving and preserving in a better way, deep-sea organisms, fluids while limiting potential contamination	Changing hyper-spectral imagery Combined micro-biological and fluid sampling with in-situ filtration and fixation for DNA/RNA, gas-tight sampler, in-situ chemical sensor

- Working area: Working down to 6000 mbsl provides access to 98% of the deep-sea environment, such as subduction trench, transform faults and plate junction, mid-ocean ridges, abyssal plains as well as environment of high hydrostatic pressure environment, where any ecosystem uses specific metabolic functionalities and adaptation strategies to thrive. Furthermore, climate change induces shrinking sea ice cover providing potential access to unexplored areas, for which deep-sea exploration vehicles will be necessary. High angle and very deep transform fault in the abyss and fault scarp close to coastal domains are far from being understood and remains difficult to access for the time being. For scientific research in hadal depths (deeper than 6000 mbsl), international and collaborative programs will be foreseen in order to use the Chinese HOV and ROV and the American ROV, all of them dedicated to exploration as deep as 11 000 mbsl.
    - **Recommendation**: **The new ROV has to work down to 6000 mbsl, at least, in harsh environment such as those explored at mid-ocean ridges while providing access to polar region, deep-ocean subduction trench and high angle fault scarp both at mid-ocean ridges and in coastal domains not accessible by the HROV (e.g. Papua New Guinea).**
- Payload capacity in water: The payload capacity is a major hindrance to working in the deep-sea environment as it is limited on ROV, more than on HOV (Table 4). As an oceanographic cruise is multi-disciplinary by essence, a wide range of scientific tools, either autonomous or connected to the power HOV/ROV supply, are set-up on deep-sea submersible. As a result, the chief scientist has to

implement a sampling strategy that sustains the connection between disciplines and overlaps at best the spatial and temporal variabilities of different processes (e.g. geology, ecology, geochemistry…). For example, a ROV/HOV dive should be able to measure in-situ seawater/fluid physico-chemical parameters, to collect rock/micro- to macro-fauna, to collect fluids, to perform sediment coring, to deploy autonomous temperature sensor and to recover small scientific instrument (e.g. in-situ microbial colonizer, autonomous temperature sensor, turbidimeter, current meter…). Part of this limitation has been solved through the use of an elevator shuttle from sea surface down to seafloor (for instruments that are not connected to the vehicle), but this aspect will be further developed in the following section.

- **Recommendation: The new ROV has to provide an increased payload weight in water, at least corresponding to the *HOV Nautile*'s one. The range of scientific tools being extremely wide, the instrument can be set-up either autonomously in the ROV basket or being powered by the new ROV.**

➢ Shuttle from sea surface to seafloor: It is widely used during ROV/HOV dives for exploration and fixed-site investigation as it enables the swap of instruments, the recovery of freshly collected biological samples (only a couple of hours after collection) and the transport of bulky instruments (too large and heavy for set-up in the HOV/ROV basket). Currently, the shuttle uses jettison ballast left at the seafloor (i.e. environmental pollution), is deployed in a free-falling way (i.e. precision uncertainty on the landing position according to deep currents), and is recovered only during day time. This restricts its functionality but it is an essential tool to work with the deep-sea vehicles. However, adding different/alternative functionalities would be worth the effort, such as peripheric drone for optical imaging, communication through wireless (optical) data transfer between either the different submersible (HOV/ROV/AUV), or with the surface, or instruments and ROV basket swap at the seafloor. These functionalities are not an exhaustive list of possibilities but represent potential routes to be further investigated.

- **Recommendation: The new ROV design has to include the development of a new design of a shuttle from sea-surface to seafloor so as to facilitate and optimize the working rhythm onboard the research vessel for sample processing and instrument maintenance (e.g. biological and fluid or sediment samples, autonomous sensor…). This new shuttle has to avoid dive-related environmental pollution (no jettison ballast or other type of weights). Thus, its landing position at the seafloor should be better controlled. The new design should provide easier swap of instrument/samples. Notwithstanding as an interfacing instrument, the conception of this new shuttle has to ensure its inter-operability with all deep-sea submersibles.**

➢ Working in the deep-sea:

- Working with a ROV at sea is based on a strong interaction between the ROV operational team and the research vessel bridge to manage, as it is the case for *ROV Victor*, 3 mobiles which are the submersible, the depressor weight and the ship. The optimization of this dialogue can significantly improve the operations especially during transit time.
- Due to restriction of payload capacity, chief scientists had to make the decision to no longer carry the routine sensors (CTD) during HOV/ROV dives. The CTD sensor provides in-situ measurements of essential oceanographic variables. These variables are extremely valuable

for the physical and chemical oceanographic community to assess biogeochemical cycle, seawater mass circulation and build upon numerical model.

- Two types of modules are actually available for the *ROV Victor* either "route" for micro-bathymetry, photo-mosaic or "sampling" for in-situ physico-chemical measurement and sampling. The swap from one module to the other is a long, delicate and technical operation taking about 12h at sea. This is not an ideal situation where the chief scientist has to choose which module to implement on the ROV while the ROV dive schedule anticipates the use of both of them for research objectives.
- The working speed of the new ROV should be better than the current possibility of *ROV Victor* (0.8 to 1.5 Knots) and should be at the minimum the equivalent of *HOV Nautile* (2 knots). This cruising speed should allow to work in potential deep-sea currents.
- To optimize the research time during oceanographic cruise, the chief scientist wants to deploy at the same time the AUV for micro-bathymetric map and the ROV for local to site scale investigation. At present, it is not possible to do so but would be a valuable asset to maximize operating time. A wireless communication link between two deep-sea submersibles can provide the means for data transfer during diving time.
- While both *HOV Nautile* and *ROV Victor* have good functionalities with both working arms, it would be best to increase their potential with 2 arms of 7 degrees of freedom, 360° rotation for each grab, force feedback on each arm, geo-referencing of the grab position, triggering for gas-tight fluid sampler, fluid temperature sensor and better load carrying capability (heavy weight instrument such as station deployed at deep-sea observatory). An additional arm for maintaining the position of the new ROV in front of the new shuttle would be valuable.
  - **Recommendation: The new ROV conception has to i) be equipped with a routine package of sensors and samplers (CTD, ADCP, dO_2, turbidity …) and plug-and-play slots for specific instruments, ii) provide high working speed (at least 2 knots) and withstand harsh current at the deep-sea, iii) work with 2 georeferenced arms with 7 degrees of freedom, 360° rotation, force feedback, higher carrying load in one grab, *in-situ* temperature measurement (from low to high temperature >400ºC) and triggering fluid sampler. A third arm for connection between the new ROV and shuttle should be evaluated. The fusion of module "route" and "sampling" in a single or modulate/flexible one is highly beneficial for dive working plan.**

➢ <u>Processing of acquired data after dive:</u> Each ROV dive generates a large volume of both data, and samples, especially in a context of long dive (up to 72 hours) and more and more technical ones. This impacts the working load on board the research vessel. An update on the overall system ergonomics may allow us to improve its efficiency.
  - **Recommendation: We propose to improve the processing software for dive preparation, dive logging and post-dive processing of data both during cruises and later on (follow up of samples such as an IGSN code for rocks samples) and the modularity of data acquisition. The software products have to be readily implemented by the full range of users involved in the cruises (including students) without dedicated engineer support. They should provide access to the dive data within a short delay on-board to prepare the next dive.**

- <u>New working tool development</u>: Working in the deep-sea environment requires the development of new tools that need to take into consideration the specification (size, weight, grab handle, hazard …). But the scientific community will appreciate further development for coring different lithologies (rock and sediment), sediment penetrometer (e.g. miniaturized Penfeld), deployment of heavy weight instrument (e.g. station, a cable payout system…), transfer of data and energy without contact between submersible, instrument, observatory station, and semi-autonomous instrument, alternative route for in-situ energy provider, filtration of very large volume of waters, porewater extracting, in-situ fixation of DNA/RNA for micro-organism, versatile fluid multi-sampler (with and without on-line filtration) with flowmeter control for quantitative fluid sampling….
    - **Recommendation: The new ROV has to provide the means to deploy the present time scientific tools/instrument of the community while providing an open platform for future instruments which will be real breakthrough for scientific purposes (e.g. rock corer/driller, possibility of obtaining oriented rock samples, sediment corer, in-situ DNA/RNA fixation, pore water sampling…).**

4.2. The essentials

The objectives are clearly to design a new deep-sea vehicle system at the least with the same working performances as both *HOV Nautile* and *ROV Victor* but with additional breakthrough functionalities that provide the mean to achieve science at the cutting edge for the scientific community, and prepare for the foreseeable needs. The new vehicle will integrate the fleet dedicated for high-sea waters (*Le Pourquoi Pas?, l'Atalante, Le Marion Dufresne, La Thalassa*), and the new generation of research vessel of the FOF in the forthcoming years. Moreover, the new ROV can be deployed from other European research vessel which implies its inter-operability with OFEG ocean fleet. All the different requirements listed below, have to be considered as top priority.

- Working area: **all oceans including the polar regions**, down to 6000 mbsl from exploration to site-survey and deep-sea observatory;

- **How to best match the qualities of *HOV Nautile* by a new ROV design** (medium scale exploration to site scale). The needs are to navigate freely in the deep-sea without constraints from the research vessel positioning and its moving speed, to be maneuverable, to possess higher payload capacity (at least equivalent to *HOV Nautile*'s one), to maintain excellent vehicle stability for precise sampling at the deep-sea and to supply higher power potential (e.g. to withstand harsh currents) but still to maintain its inter-operability with any deep-sea vehicle.

- A submarine vehicles system that is **complementary in its functional and operational specificities**: considering AUVs, ROVs, HOV, HROV and shuttle as a fleet whereby each of them has a specific role for research activities in high-seas from regional to site-scale studies; keeping in mind that the 2 ROVs have to share some essential specificities to allow a permanent complementary but versatile functionality.

- **High payload capacity for both sampling and scientific tools** (including new breakthrough tools) **implemented on the new ROV**, is mandatory for multi-disciplinary high-sea cruise.

- **The Shuttle**: this is a crucial component for exchange of instruments and samples between the surface and the sea-floor and has be **considered as important as any deep-sea vehicle**. Therefore,

the shuttle is an essential part of this new ROV design project. This shuttle has to be compatible for *ROV Victor*, *HOROV Ariane* and other submersible.

- **The routine measurements**: the routine sensing package should provide the mean to cross disciplinary research, i.e. a way to integrate the data acquisition of the deep-sea scientific community with that of the water column research (e.g. Essential Oceanic Variables).
- **Carrying heavy loads**: Deep-sea observatories are based on the deployment of instrumented stations positioned on the seafloor whereby the use of deep-sea vehicles or compatible shuttle will greatly help the operating maneuver.
- **Scientific tools** need to be operated by the two deep-sea ROVs, modularity, **inter-operability is a definite essential**;
- Operations and environmental impact: this is a crucial point and specific attention will be paid to **protect the environment while working in the deep-sea**. This requires avoiding any human-derived products (plastic, jettison steel ballast…) while respecting the deep-sea environment (ecosystem, comprehensive sample collection, minimum impact on local ecosystem…)

5. Summary of preliminary scientific needs

The design of a new ROV requires the expertise of everyone from the FOF management team, the scientists for the research expectation, the engineers in charge of submersible development and the operational team in charge of the deployment of deep-sea submersibles and interfacing scientific instruments on the vehicle.

It is necessary to take into consideration regardless of the technological choices the consequences of the new ROV design in terms of complementarity within the fleet, required weather conditions for its deployment, logistics necessary for its transportation, technical features (dynamic positioning…) and vessel deck equipment (winch, cable…) for its launch.

The objectives of the fleet are to i) maintain 4 research vessels dedicated to high-sea cruises with the ability of deploying the deep-sea vehicles, allowing the presence of French research vessels in the French overseas department and all world oceans, and ii) ensure the operation of two submarine vehicles for deep-sea studies down to 6000 mbsl.

The research themes can be summarized in : i) <u>The Ocean System:</u> its geological substratum, its hydrological, biotic and abiotic components, its emerging, preserving and functioning of marine ecosystems, its processes of matter, energy and biomass transfer; ii) the study of <u>Marine resources (biological, energetic and mineral)</u>; iii) <u>Climate change and natural - anthropogenic risks</u>: the prevention of natural risks, in particular for populations living on islands and coastlines, resilience of deep-sea ecosystem to environmental changes, the impact on the societal environment.
The new ROV has to gather the following specificities:

- all oceans including the polar regions, down to 6000 mbsl from exploration to site-survey and deep-sea observatory;
- exploration skills : The needs are to navigate freely in the deep-sea without constraints from the research vessel positioning and its moving speed, to possess higher payload capacity, to

maintain excellent vehicle stability for precise sampling at the deep-sea and to supply higher power potential
- complementary and specificity in its functional and operational specificities with the other deep-sea vehicles of the French Fleet
- high payload capacity for both sampling and scientific tools implemented on the new ROV Scientific tools, inter-operability with the *ROV Victor*
- associated with a new shuttle to optimize its working potential
- routine sensing package (EOV) should provide the mean to cross disciplinary research
- developed and used in an environment friendly way.

6. The agenda

The scientific needs will be further scrutinized over the forth coming months through the discussions organized by the 4 animators (exploration needs, shuttle, imagery and payload capacity). The outcomes of these brainstorming will be discussed in plenary session in January 2020 in order to prioritize the essentials, and to provide the specificities of the new ROV design.