EXECUTIVE SUMMARY

A Concept of Operations

for a New Deep-Diving Submarine

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Prepared for the United States Navy

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PREFACE

The NR-1 is the Navy's only nuclear deep-diving research submarine capable of scientific and military missions. Its nuclear reactor will be exhausted in 2012; therefore, the NR-1 must be refueled or retired before then. As part of its considerations in this regard, the Navy is developing a concept of operations (CONOP) for a possible replacement platform, initially designated the NR-2.

The study summarized here was designed to provide insight into the capabilities that an NR-2 platform or system might incorporate and help define operational capability requirements based on a prioritization of those capabilities and the missions they would support. We neither discuss potential alternatives to an NR-2 nor analyze the costs associated with the platform. The results of this study will inform a future Navy analysis of alternatives, including a cost-benefit assessment.

The research summarized here is fully reported in *A Concept of Operations for a New Deep-Diving Submarine,* MR-1395-NAVY, RAND, Santa Monica, Calif., 2001. This research was conducted for the Naval Sea Systems Command (NAVSEA) and was carried out within the Acquisition and Technology Policy Center of RAND's National Defense Research Institute (NDRI), a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the unified commands, and the defense agencies.

CONTENTS

FIGURES

TABLES

A CONCEPT OF OPERATIONS FOR A NEW DEEP-DIVING SUBMARINE: EXECUTIVE SUMMARY

MOTIVATION AND OBJECTIVES

The United States has one deep-diving nuclear-powered research submarine—the NR-1. The NR-1 was built in 1969 with state-of-the-art technology as an ocean engineering and research support submarine. It was designed for prolonged operation (30 days) on or near the sea bottom at a speed of up to 4 knots. These characteristics distinguish the NR-1 from the majority of deep submersibles, which are essentially adjuvant vehicles operated from surface vessels. Such vehicles are typically subject to conditions in the water column or on the surface and have limited mobility. Unlike most nuclear submarines, the NR-1 has viewports, along with manipulators that allow the crew to handle small objects.

The NR-1 is an important national asset for a variety of reasons. It has been instrumental in the search for and recovery of underwater wreckage from military aircraft accidents. It was used to map the debris field from the explosion of the space shuttle *Challenger* (when other vessels were hampered by inclement weather) and to obtain forensic information in the crash of EgyptAir Flight 990. The NR-1 has also been used in support of maritime archaeology, oceanographic research, and military operations.

The NR-1 has been refueled and modernized twice. The Navy anticipates that it will require another refueling or replacement by 2012 and has begun to consider what capabilities a replacement, which we here call the NR-2, should have. In this connection, we at RAND were asked by the Navy to assist in two respects:

- Identifying and prioritizing the range of missions the NR-2 would likely be required to execute.
- Establishing the range of capabilities that would have to be incorporated to accomplish those missions.

Taken together, these missions and capabilities form a concept of operations (CONOP) for the NR-2. Other issues relevant to the Navy's considerations presented themselves in the course of the study and were addressed. These included whether a follow-on to the NR-1 was really needed, whether construction of the NR-2 might be funded and the vessel operated by the private sector, and whether the NR-2 needed to be manned. We also propose two initial design concepts. These and the CONOP underlying them can serve as inputs to elaboration by the Navy in an analysis of alternatives that would compare costs and benefits.

Our work on NR-2 missions, capabilities, and design concepts has been informed by the perspective that the NR-2, if built, is likely to be a platform of greater national importance than the NR-1. National undersea security priorities are expanding. The importance of the ocean sciences and related environmental and global issues are drawing increased recognition. Undersea fiber-optic cables are an increasingly important element of the national information infrastructure—an infrastructure that might be viewed by future adversaries as a tempting target.

Without the capabilities that could be provided by the NR-2, we would forfeit, as far as the oceans are concerned, the Joint Chiefs of Staff's Joint Vision 2020's goal of dominance across the full spectrum of conflict arenas—physical and electronic.

APPROACH

To accomplish the tasks assigned, we convened three conferences, where experts in science, national security, and submarine operations contributed to defining likely mission profiles required between 2015 and 2050. These profiles provided the basis for prioritizing design-driving capabilities—i.e., those having a large impact on platform cost—for the NR-2.

For each of the three conferences, we used a "group systems" decisionmaking support approach in which participants used networked laptop computers to identify and prioritize potential mission tasks and capabilities for a new deep-diving submersible. Participants were encouraged to discuss these options openly but also to submit comments and prioritize items anonymously via the computer network. The latter permitted contribution and exchange of viewpoints freed of the reserve that might accompany the expression of opinions in the presence of persons of higher rank or seniority.

Limitations to this approach include those inherent in a group discussion, as opposed to a labor-intensive analysis by a team of experts. The time and analytic tools available could not allow a completely thorough discussion of alternatives and the trade-offs and other analytical considerations they entailed—although such depth of analysis is not essential at this stage. The disciplines represented might not have been sufficient, or the nomination and winnowing process flexible enough, to incorporate the full range of future science missions. Further, the approach could not eliminate biases, but it did allow us to recognize and isolate them.

This summary is organized as follows. After providing some background, we summarize the results of the conferences on scientific and military missions and the capabilities required to perform those missions. We then present two possible design concepts for the NR-2 before offering some concluding observations.

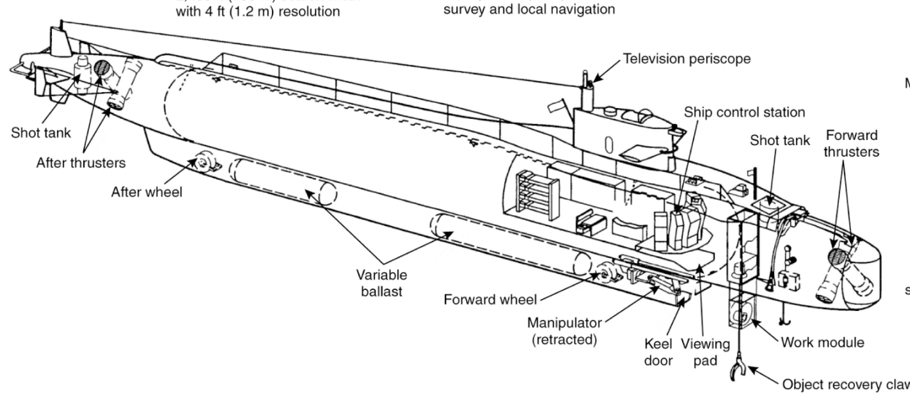
BACKGROUND ON THE NR-1

To gain some perspective on the capabilities proposed below for the NR-2, it will be useful to more fully describe NR-1 capabilities than we did on pp. 1–2. For a view of the NR-1's physical layout, see Figure S.1.

While the NR-1 has a forward-propulsion system and two pairs of thrusters to help it rotate, move laterally, or maintain position in a current, it was not designed to operate autonomously. Because it

Search capabilities

- Side-looking sonar
  - 600 ft (180 m) search width 1 ft (30 cm) resolution or
  - 2,400 ft (730 m) search width with 4 ft (1.2 m) resolution
- Deep Submergence/Obstacle Avoidance Sonar (DS/OAS)
  - Compatible with Deep Ocean Transponder (DOT) for both bottom survey and local navigation
- Sub-bottom profiler
  - Variable power
  - Selectable frequency



Principal characteristics

Length overall	145 ft 9-$\frac{7}{16}$ in. (44.4 m)
Pressure hull length	96 ft 1 in. (29.3 m)
Diameter	12 ft 6 in. (3.8 m)
Maximum beam (at stern stabilizers)	15 ft 10 in. (4.8 m)
Maximum navigational draft	15 ft 1 in. (4.6 m)
Box keel depth (below baseline)	4 ft 0 in. (1.2 m)
Design operating depth	2,375 ft (724 m)
Displacement submerged	366 long tons, 409.92 short tons
Speed, surface/submerged	4.5/3.5 knots
Mean draft	15 ft $\frac{3}{4}$ in. (4.6 m)
Endurance	210 man-days (nominal) 330 man-days (maximum)

Figure S.1—Summary of NR-1 Features

can manage no more than 4 knots (about 4 miles per hour), it is normally towed to and from operating areas by a dedicated support ship. The NR-1 also relies on its support ship for storing retrieved objects, retrieving large objects, rotating science teams or crew members, and replenishing its compressed air system. (Compressed air is needed to surface, by blowing seawater out of ballast tanks; to recharge scuba equipment; and for emergency breathing.)

The NR-1 is equipped with sensors for basic environmental data and with the means to record scientific data. The NR-1's three viewports provide a view forward and down, complemented by 25 external lights, low-light-level 35-mm still cameras, a digital still camera, a color video camera, and other vision aids. The three-dimensional perspective furnished by viewports has been important for ship safety when the NR-1 has been operating near the bottom, and the viewports have been used extensively by scientists. They are of limited use, however, in turbid water, and their locations on the hull have at times limited their utility. The digital camera has permitted real-time images without worries about film exhaustion or flash synchronization.

Complementing its viewing systems, the NR-1 is equipped with a variety of sonars. The most commonly used is an obstacle avoidance sonar, which can help not only in locating obstructions but also in searching and mapping the bottom. While state-of-the-art for its time, this sonar looks forward only; and even in that direction, it has not always detected obstacles as rapidly as desired. Side-looking sonar can also be used to map the seabed, and bottom mapping at high precision is enabled by a laser line scanner. A Doppler sonar provides precise position (accurate to about a foot) relative to the bottom and can also aid in seabed mapping. These bottom-mapping instruments detect not only variations in the ocean bottom itself but also the presence of objects, such as debris, resting on it.

On the surface, the NR-1 uses the Global Positioning System (GPS) and other navigation systems. When submerged but not near the bottom, the NR-1 has used dead reckoning[1] to estimate its position. This practice is not precise, so it has been supplemented by com-

[1] "Dead reckoning" is the process of estimating position by advancing a known position, using course, speed, and time.

munication with the support ship, whose position is known with GPS accuracy, which can track the NR-1 acoustically and communicate the NR-1's position to the NR-1. On the bottom, the Doppler sonar can be used for precise navigation.

The NR-1 has two retractable rubber-tired wheels that support it on the ocean bottom, where ballast and thrusters help it maintain a position. The ability to operate on the bottom at depths to 3,000 feet has allowed the recovery of aircraft debris, permitted such scientific studies as the observation and collection of manganese nodules on the ocean floor, and provided a "safe harbor" during sonar repairs. Wheels provided an ability to fine-tune NR-1's position on the bottom in missions that require fine position manipulation. A hovering submarine cannot be maneuvered as precisely as a bottomed submarine using wheels. Also, currents tend to affect hovering submarines. Precise position adjustments could sometimes be accomplished reliably only by bottoming and using the wheel system.

The NR-1's manipulator can handle small objects (no more than eight inches in diameter) and place them in sample baskets for storage. It also has a recovery claw for somewhat larger objects. The manipulator lacks operator feedback and can inadvertently crush fragile objects. The NR-1 also has a "jetter"—a water jet system for uncovering or burying objects on the bottom.

By the standards of modern submarines, the NR-1 is small. It is about 145 feet long, and 96 feet long inside the pressure hull. Its beam (maximum diameter) is 12.5 feet. The nuclear propulsion plant provides endurance limited only by the vessel's food and air supply, which is sufficient to sustain its two-person crew plus two scientists for up to 30 days. In contrast to modern U.S. nuclear submarines, the NR-1 uses a chlorate "candle" system to generate oxygen. Carbon monoxide and hydrogen produced by the system are removed from the atmosphere by a catalytic converter. Replaceable lithium-hydroxide canisters remove carbon dioxide.

In case of an emergency, the NR-1 can communicate by high-frequency radio over long distances when on the surface. The ability to sit on the bottom can provide a refuge. In the event of an underwater emergency, the NR-1 can release lead shot to increase buoyancy for return to the surface.

SCIENCE MISSIONS AND CAPABILITIES

Missions. Conference participants identified, characterized, and prioritized nine types of NR-2 science mission that might be carried out between 2015 and 2050. Table S.1 lists the nine missions in rank order.

Rankings are displayed quantitatively in Figure S.2. These rankings reflect a variety of perspectives. They are the composite of four separate ranking exercises (displayed in Figure S.3), each with a different criterion and different participants. Missions were ranked according to

- scientific value, by scientists only,
- scientific value, by all conference participants,
- likelihood of federal agency funding, by agency representatives only, and
- projected importance to the nation between 2015 and 2020, by all conference participants.

Within each mission, objectives or subareas were ranked by specialists in that discipline. To give a sense of mission character, we listed in Table S.1 two or three illustrative objectives for each.

Capabilities. Working from information provided by scientists, ship designers, experienced submarine operators, and the Naval Sea Systems Command, RAND identified a set of potentially desirable NR-2 capabilities. These were ranked in importance by scientists participating in the conference as follows:

- Under-ice capability. Scientists agreed that the ability to operate under ice was desirable.
- Remotely operated vehicle (ROV) capability. Ability to employ ROVs or autonomous undersea vehicles. For every mission except ice science and atmospheric science, scientists judged such vehicles desirable.

Table S.1

Science Missions and Illustrative Objectives, by Priority

Mission (Priority)	Illustrative Objectives
Physical Oceanography (1)	Map upper ocean structure and turbulence in normal times and during severe weather events. Measure density flows, convective cells, fronts, eddies, etc.
Ice Science (2)	Map the thickness, extent, structure, and roughness of Arctic sea ice to assess any changes. Conduct sampling of near under-ice water properties to assess the impact on the body of water beneath the sea ice from the gain or loss of ice mass.
Geology and Geophysics (3)	Map and survey specific areas (e.g., hydrate fields, midocean ridges of the lower southern oceans, sites of recent volcanic eruptions, hydrothermal vents). Profile sub-bottom sediments.
Marine Biology (4)	Conduct close, stationary, and prolonged observations of benthic habitats over large areas to map and characterize them. Investigate the effects of artificial structures and material deposition on benthic communities at 1,000 to 2,500 meters water depth.
Ocean Engineering (5)	Search for and recover small objects from deep waters or larger objects from shallow waters. Install, service, and maintain underwater structures and systems—those suspended in the water column and those on the bottom.
Environmental Science (6)	Survey and monitor the results of past waste-dumping sites and characterize future hazardous-waste disposal sites. Perform multidisciplinary studies in marine sanctuaries and other protected areas.
Chemical Oceanography (7)	Determine water mass age and trajectories, ocean ventilation, and source and evolution of Arctic waters and assess pollution, using trace sampling. Measure organic compounds in situ from the bottom to the surface to determine the distribution of biological activity and the biogeochemical processes.
Atmospheric Science (8)	Deploy buoys, ice-penetrating sensors, and other sensors to monitor interactions at the sea-air or ice-air interface. Within the constraints of ship safety, collect data on in-situ environmental conditions under sea ice or heavy weather.
Maritime Archeology (9)	Search for archeological sites and map them in situ. Recover objects (excavating them if necessary).

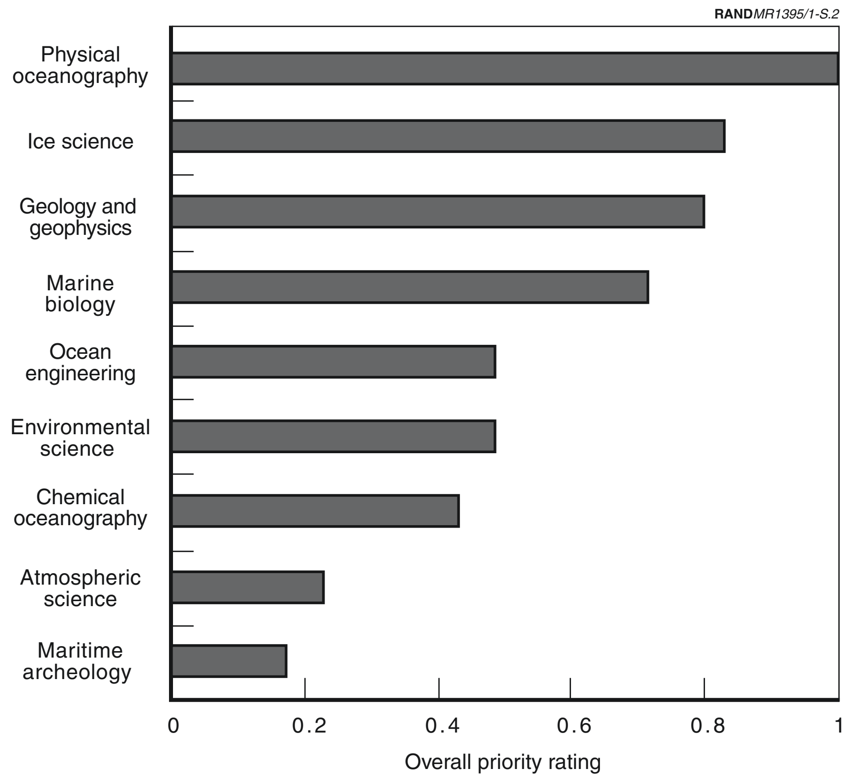


Figure S.2—NR-2 Science Mission Priorities

- Endurance. The consensus was that a minimum of 30 days time on station was needed for all missions except maritime archeology and that 45 days would be desirable for most missions.
- Submerged speed. Scientists thought greater speed necessary to obtain longer survey tracks in a given time available. Speeds of 8 to 10 knots were judged adequate for all missions, and 15 knots desirable.
- Maximum operating depth. Scientists agreed no mission would require an operating depth greater than 1,000 meters (3,300 feet).

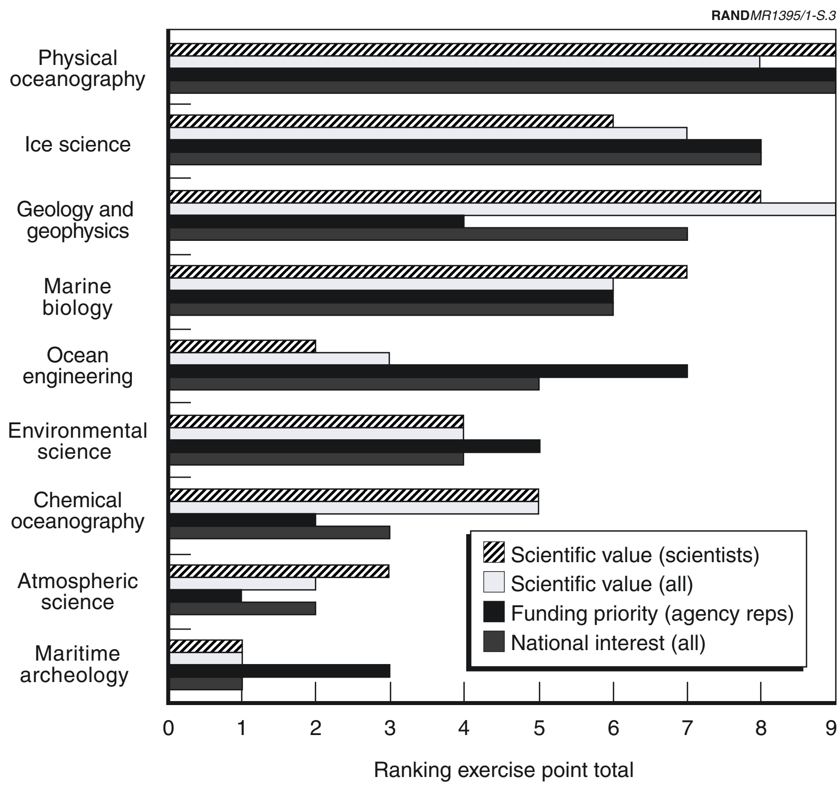


Figure S.3—Prioritizing NR-2 Science Missions: Results of Four Ranking Exercises

- Crew size/augmentation. Scientists found it difficult to meaningfully project needed science team size, which would likely be driven—as in the past—by the details of the mission and space available, as well as other ship capabilities. Some scientists suggested that—in the future—depending on mission areas, science teams might be unnecessary. This was the characteristic they were most willing to trade away.

Mission record reviews and discussions with ship operators and scientists revealed a broader range of capabilities required for each mission area. The following mission capabilities were identified as the most broadly applicable for science missions:

- multipurpose acoustic suite,
- precise navigation system,
- operation on or near the bottom,
- ability to launch, operate, and recover adjuvant vehicles or towed sensor arrays,
- in-situ water sampling,
- ability to undertake coordinated measurements[2] of scientific data, and
- 3-D vision and external, segregated stowage.

MILITARY MISSIONS AND CAPABILITIES

Missions. Potential military missions for the NR-2 were developed and prioritized through two conferences involving civilian and military defense experts, including submarine design experts. They are listed, in composite rank order, in Table S.2. Possible objectives are also given, although here they are simply representative. No priority within mission is implied.

Quantitative priority ratings are shown graphically in Figure S.6. These ratings are the product (normalized to 1.0 for the highest-priority mission) of two other rankings: mission criticality, defined as the relative impact of mission failure on national security (should it be conducted) (shown in Figure S.4) and the expected future frequency of occurrence of the mission (shown in Figure S.5).

The priority scores in Figure S.6 strongly favor the mission to protect national seabed assets, which was ranked first in frequency of occurrence and second in criticality. The frequency ranking derives from two factors. The first is the growing importance of seabed fiber-optic

[2]"Coordinated measurements" refers to data that are geographically or spatially referenced or time-annotated.

Table S.2

Military Missions and Illustrative Objectives, by Priority

Mission (Priority)	Illustrative Objectives
Protection of National Assets on the Seabed (1)	Monitor integrity and security of U.S. and allied undersea information infrastructure. Responsively (all-condition) survey national (East and West Coasts) and military seabed infrastructure for any evidence of potential tampering or intent to tamper.
Offensive Information Operations (2)	Covertly interfere with an adversary's commercial or military communication or information assets; covert destruction/interference with dedicated military communications assets. Implant devices able to sever commercial communication cables on command. Ability to induce uncertainty in adversary through overt operations (by NR-2 or a known NR-2 support ship) in the vicinity of an adversary's communication cables.
Intelligence Preparation of the Battlefield (3)	Covertly map the sea bottom in support of potential future battlespace operations. Support other intelligence missions by ensuring battlespace is free of adversary tripwires.
Forensics Investigation (4)	Gather evidence from bottom sites or regions for in-situ or postmission analysis. Monitor activities and sample materials.
Expanded Intelligence, Surveillance, and Reconnaissance (5)	Sample effluents for evidence of the production of weapons of mass destruction. Obtain images of adversary undersea systems for analysis.
Defensive Information Operations (6)	Examine commercial or military information communication systems for signs of tampering. Recover computer and communications equipment from crash or wreck sites.
Other Covert Operations (7)	Impede adversary vessels' propulsion. Tag adversary assets to enable tracking at suitable ranges. Support of above tasks in shallow water. Support covert missions into highly defended waters to degrade or disable enemy forces.

cables to the U.S. information infrastructure, and the attendant vulnerability they represent. The second factor is that, if built, the NR-2 would be the only dedicated national asset capable of protecting the seabed infrastructure and deterring efforts to damage it. In other words, any time the need for protection or deterrence should arise, the mission could fall to the NR-2.

Covert operations are scored last because of the expectation that the need to conduct them would be rare. The low score of this mission, combined with its distinctively offensive profile, indicates that the consensus of conference participants was that the NR-2's value would be in gathering information and intelligence from sea bottom operations, not from employment as a combatant. This is also consistent with three broader views of the participants:

- The NR-2's leverage would be in completing the national "full spectrum" capability for intelligence preparation of the battlespace.
- The NR-2's value would increase as the transition continues to a cyberwar environment.
- The President and Secretary of Defense have at their disposal many other special operations assets to accomplish "direct action" combat missions.

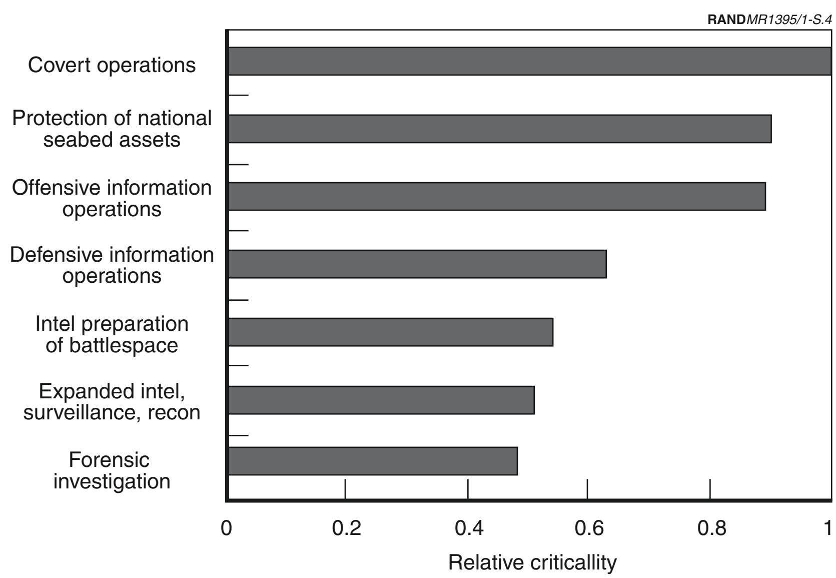


Figure S.4—Priority Ratings of Military Missions by Criticality

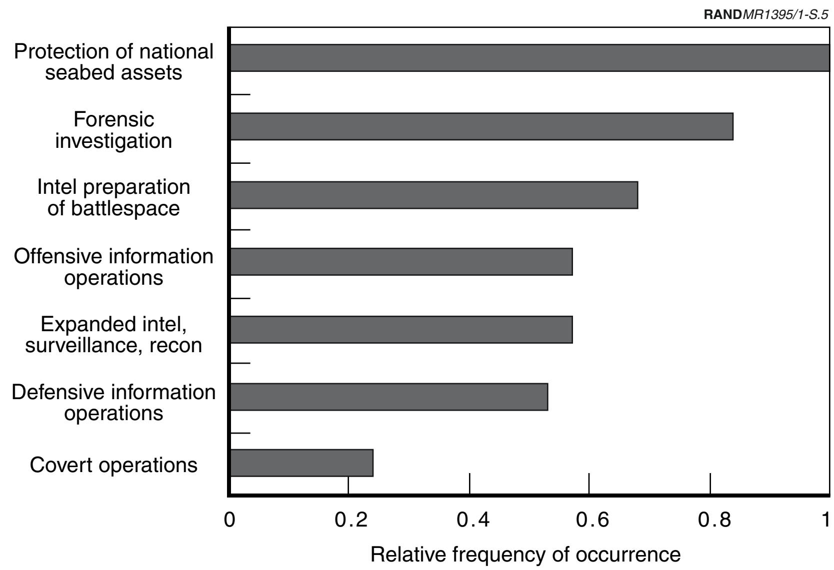


Figure S.5—Priority Ratings of Military Missions by Frequency

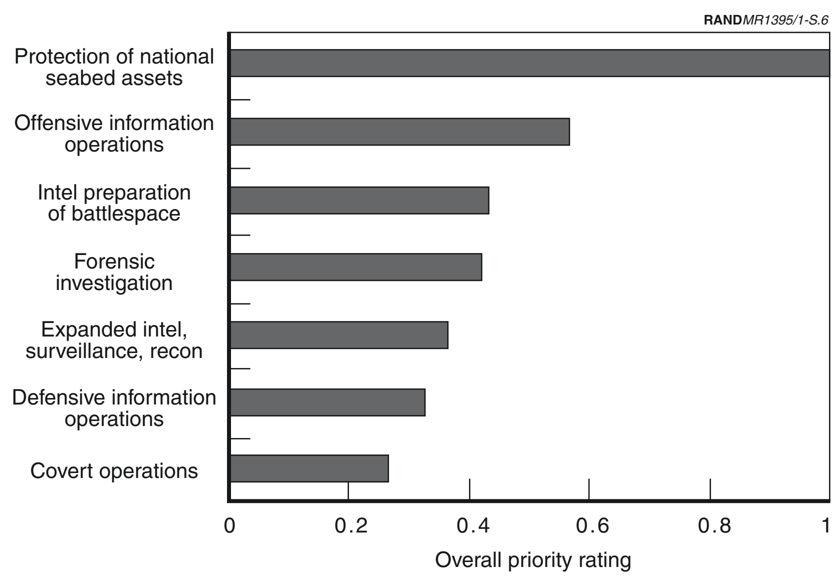


Figure S.6—NR-2 Military Mission Priorities

Capabilities. Conference participants established requirements regarding 10 design-driving[3] capabilities, as follows:

- Autonomy. Three support concepts were considered: that used for the NR-1 (operation in consort with a surface vessel), operation in consort with an attack submarine (SSN), and fully autonomous operation. Participants preferred autonomous operation.
- Quieting. For autonomous operation, most participants favored acoustic and magnetic quieting equivalent to that used on the most advanced U.S. submarines. The other option was for the 1970s–1980s' technology used on *Los Angeles*–class SSNs.
- Endurance. Requirements ranged from 30–60 days on station.
- Speed. Three speed regimes were evaluated. The most important of these was judged to be speed of transit from base to area of interest. A range of 14 to 18 knots was preferred to allow prompt response to tasking and maximize time on station. Eight to 10 knots was judged to be adequate for conducting searches within the area of interest. Burst speed, to allow flight from an area, was given the lowest priority; it was set at 15 to 20 knots.
- Depth. Participants favored a 1,000-meter (3,300-foot) maximum operating depth, whether or not an adjutant vehicle was included. That such a vehicle does not matter in this regard reflects the technological limitations of such vehicles and a preference that the NR-2 be able to bottom for its own protection wherever it is operating.
- Operation on or near the bottom. This and the remaining four capabilities were subjected to a priority analysis similar to those shown previously (see Figure S.7). The need to operate on or near the bottom was unquestioned.
- Ocean interface. Conference participants saw a clear need for ocean interface.[4]

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[3]"Design-driving" characteristics are those that will have a large impact on the cost of a platform.

[4]Any large area exposed to the ocean either across the pressure hull boundary or accessible/manipulatable outside the pressure hull—generally used in reference to the ability to retrieve objects (e.g., ROVs) from outside to inside the pressure hull.

- Shock-hardening. No requirement for shock-hardening was seen.
- Offensive weapons. No need was seen for such a capability.
- Under-ice capability. No need was seen for such a capability.

Though not design drivers, two other capabilities were accorded a high priority by participants in the first military conference. These were payload and sufficient flexibility (or adaptability) of design to accommodate additional missions without redesign or modification to the basic platform.

DESIGN CONCEPTS

Two alternative submarine design concepts for the NR-2 emerged from this study. Both concepts would share design flexibility, ample

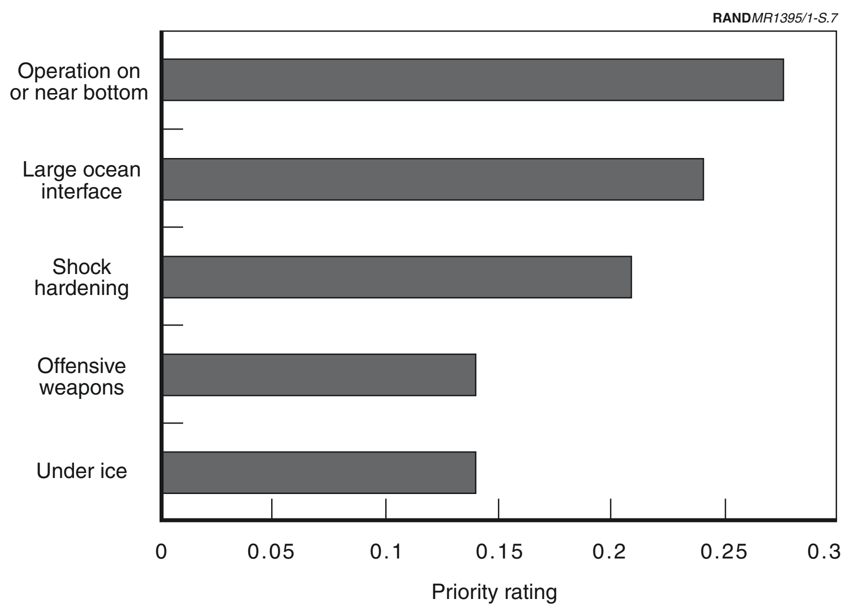

Figure S.7—Prioritization of Selected Capabilities with Respect to Conducting Military Missions

payload capacity, and the ability to operate at depths to 3,000 feet and to operate on the bottom. Both would be able to operate an adjuvant vehicle with a manipulator and would themselves have fine manipulators. Both would have a burst speed capability of 15 to 20 knots. Neither would carry weapons or be shock-hardened. Neither design includes under-ice capability.

Both concepts call for a manned submarine. Manning NR-2 is essential because many NR-2 missions have implicit in them the requirement for responsive evaluation of potentially unprecedented information and extemporaneous mission events.

Both concepts differ from the NR-1 design in important ways because of the potential increase in the likely demand for an ocean-bottom submarine to contribute to national security requirements during its lifetime. This difference is reflected in two capabilities: speed and autonomy.

In terms of speed, if the NR-2 is to be responsive to theater and national taskings, it must have a higher transit speed than the NR-1 does. In addition, if it is to be used increasingly as a military asset and on occasion employed in covert operations, a capability for speed bursts is required.

Regarding autonomy, surface ship support clearly has proven of great merit in NR-1 science support missions. However, greater consideration must be given to designing the NR-2 for capability to conduct missions autonomously if more emphasis is to be placed on missions supporting national security needs. The implications and limitations of surface ship consort on covert missions in particular are clear.

One design concept, then, and the one clearly preferred in the military conferences, is for a submarine capable of autonomous operations under all conditions. This submarine would have enough transit speed (15 to 20 knots) to enable timely response to national security tasking; endurance (about 60 days) to give it useful time on station; and, for missions in hostile waters, enough stealth (state-of-the-art acoustic and magnetic quieting) to avoid encounters during its mission.

An alternative design concept is for a submarine capable of autonomous operations under all but the most stressing conditions. It would have a transit speed of 10 to 15 knots, about 45 days of endurance, and acoustic and magnetic quieting comparable to the *Los Angeles*–class nuclear attack submarine. It would be acoustically quiet at low speeds (6 to 10 knots) but might be relatively noisy at higher speeds. It would be designed for SSN towing or "piggyback." The SSN would compensate for the greater detectability of NR-2 in two ways. First, the NR-2 would spend much of the mission inoperative, passively mated to the SSN, making the NR-2's higher-speed signature moot. Second, when the NR-2 operates, the presence of the SSN would protect the NR-2 and deter potential attackers.

This alternative-concept submarine could perform most military missions autonomously. It could, for example, autonomously inspect bottom objects on the U.S. continental shelves. It could be towed into an area of interest, and the SSN escort could remain in the region until the NR-2 had completed its mission and then recover it.

Although the second design concept is clearly less capable than the first, it would probably be more affordable. Cost savings would come from reductions in quieting requirements, especially at speeds above 10 knots; in propulsion plant size, reflecting the reduced transit speed; in autonomy of operation, meaning less redundancy would be needed; and in the endurance requirement.

Both design concepts robustly support the majority of ocean science mission needs. We acknowledge the support for under-ice capability that was expressed by civilian experts. Absence of under-ice capability is based on the following key points:

- The inclusion of under-ice capability requires compromise; other capabilities would be displaced in this small submarine to accommodate the additional ship control and safety features required for under-ice operations (as a result of the CONOP, the redundancy needed for under-ice operations is necessarily incorporated in the two design concepts).[5]

- Arctic capability is not a high priority for all relevant branches of science. Also, other methods for obtaining needed information in the Arctic (e.g., ice thickness) are available and will likely improve.
- While many important science missions for the NR-2 could be under ice, there remains ample science to be supported in the open ocean.
- Experts see no current need for under-ice capability for military missions.

Table S.3 summarizes two design concept alternatives' support for science mission and military mission objectives for the 16 missions noted.

CONCLUDING OBSERVATIONS

After examining a full range of likely future military and science missions, we conclude that, if built, the NR-2 would be of national importance. It would be the only naval asset with a dedicated capability of operating on or near the ocean bottom. It would thus provide a unique means of

- supporting national oceanographic research on the ocean bottom,
- enabling understanding of U.S. adversaries' exploitation of the ocean bottom, and
- enabling the protection of U.S. national assets on the ocean bottom.

[5]Full assessment of relative impacts of specific capabilities on design was outside the scope of this study. We recommend that the Navy explore the trade-offs associated with under-ice capability for the NR-2.

Table S.3

Design-Driving Values

	Capability												
Mission	Burst Speed (kt)	Transit Speed (kt)	AOI Speed (kt)	Test Depth[a] (m)	Acoustic Quieting	Mag Quieting	Operate on or Near Bottom	Reposition on or Near Bottom	Under-Ice	Offensive Weapons	Ocean Interface	Shock Hardening	Endurance (days)[b]
Science													
Physical oceanography	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Ice science	N/A	10	N/A	250	N/A	N/A	No	N/A	Yes	N/A	Yes	N/A	30
Geological and geophysical	N/A	8	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Marine biology	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Ocean engineering	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Environ science	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Chemical oceanography	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	30
Atmospheric science	N/A	10	N/A	300	N/A	N/A	No	N/A	Yes	N/A	Yes	N/A	30
Maritime archeology	N/A	10	N/A	1,000	N/A	N/A	Yes	N/A	Yes	N/A	Yes	N/A	20

Table S.3—continued

Mission	Capability												
	Burst Speed (kt)	Transit Speed (kt)	AOI Speed (kt)	Test Depth[a] (m)	Acoustic Quieting	Mag Quieting	Operate on or Near Bottom	Reposition on or Near Bottom	Under-Ice	Offensive Weapons	Ocean Interface	Shock Hardening	Endurance (days)[b]
Military													
Protect assets	15–20	14–18	8–10	1,000	SOTA[c]	SOTA	Yes	Yes	No	No	Yes	No	60
IPB[d]	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Forensics/invest	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Expanded ISR[e]	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Offensive IO[f]	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Defensive IO[f]	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Covert ops	15–20	14–18	8–10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
NR-2 design concept													
Preferred	15–20	15–20	10	1,000	SOTA	SOTA	Yes	Yes	No	No	Yes	No	60
Alternative	15–20	10–15[g]	10	1,000	688–SOTA[g]	688–SOTA[h]	Yes	Yes	No	No	Yes	No	45[i]

[a]Given ROV/AUV capability.
[b]On-station days for science, total days for military.
[c]State of the art.
[d]IPB = Intelligence Preparation of the Battlespace.
[e]ISR = Intelligence, Surveillance, and Reconnaissance.
[f]IO = Intelligence Operations.
[g]Possibly greater with support ship tow.
[h]State of the art up to AOI speed.
[i]Military endurance requirement can be met with support ship.

Lack of the NR-2's capabilities would forfeit these benefits. We conclude that such capabilities should be developed because

- the missions requiring undersea capabilities in national security and homeland defense will grow in scope and importance and will exceed the capabilities of the NR-1,
- national oceanographic research support will remain important, and
- the range of capabilities proposed here for the NR-2 will not be available from any other single source.

The private sector was considered as a possible source of support for acquiring the NR-2's capabilities. It is RAND's preliminary judgment[6] that

- the private sector will not be able to provide the expertise and information that will be required of the NR-2 because it will be unprofitable, and
- information that the NR-2 will provide will not or could not be reliably collected by the private sector because it would be too risky or demanding—operationally or technologically.

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[6] We recommend that the issue of obtaining the NR-2's capabilities commercially be further examined in the course of the Navy's analysis of alternatives.