Chapter Two

NR-1

NR-1 DESCRIPTION AND CAPABILITIES

Because the primary focus of this effort is to determine the range of capabilities that a replacement platform for the NR-1 would require, this chapter discusses the capability set that will be lost if the NR-1 is retired in 2012. As capability requirements in Chapters Three and Four are generated and prioritized for the replacement system, this chapter is intended to show the baseline or "state of the art" of the current system at sea. To discuss the potential capabilities of an NR-2, it is important to examine the previous missions by the NR-1. This chapter briefly describes the NR-1 deep-submergence submarine and overviews its capabilities.

NR-1 was designed with an emphasis on prolonged operation on or near seabeds at depths to 3,000 feet. Whereas other nuclear submarines are not designed for prolonged operation on or near the sea bottom, NR-1 has two retractable rubber-tired wheels that support it on the bottom (Figure 2.1). NR-1 is also equipped with two pairs of thrusters, which enable it to maintain its depth without forward movement, to move laterally, and to rotate in its own length.

NR-1 was not designed to operate autonomously. It has a top speed of 4 knots (about 4 miles per hour), so is normally towed to and from operating areas by a dedicated support ship. Also, it cannot replenish its own compressed air system (needed to blow seawater out of ballast tanks to surface, to recharge scuba equipment, and for emergency breathing). Its surface support ship can replenish the compressed air system.

NR-1 has three viewports providing a view forward and down, complemented by 25 external lights, low light level (LLL) cameras, LLL zoom cameras, a color video camera, an electronic still camera (ESC), and other vision aids. It is equipped with sensors for basic environmental data and the means to record scientific data. Seawater can be sampled through the ship's depth-gauge system.

Complementing its viewing systems, NR-1 is equipped with a variety of sonars. It has Obstacle Avoidance Sonar that, along with its safety purpose, can be used to search and map the bottom. Side-Looking Sonar (SLS) can be used to map the seabed to both sides, and a Laser Line Scanner enables high-precision bottom mapping.

NR-1 uses the Global Positioning System (GPS) and other navigation systems on the surface. When near the bottom its Doppler sonar provides precise position (accurate to about a foot) relative to the bottom. Together with its SLS or Laser Line Scan system, the Doppler sonar makes it possible to accurately map such regions as aircraft debris fields.

When submerged but not near the bottom it uses dead reckoning[1] to estimate its position. Also, the NR-1 support ship can track it acoustically and communicate NR-1's position to it.

NR-1 can manipulate objects with manipulator operators stationed inside the viewing ports. Its 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. A special NR-1 tool is its "jetter"—a water jet system for uncovering or burying objects on the bottom.

Physically, NR-1 is a small nuclear submarine. It is about 145 feet long; it is 96 feet long inside the pressure hull. Its beam (maximum diameter) is 12.5 feet. The nuclear propulsion plant provides endurance limited only by its food and air supply. NR-1 can sustain

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

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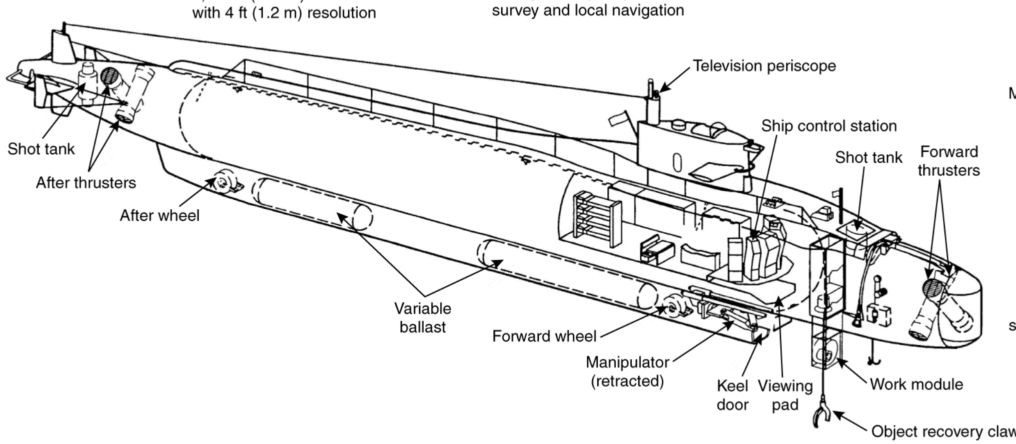
Search capabilities

- 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 2.1—Summary of NR-1 Features

its regular crew plus two scientists for up to 30 days. Unlike modern U.S. nuclear submarines, NR-1 uses a chlorate "candle" system to generate oxygen. A catalytic converter removes carbon monoxide and hydrogen from the atmosphere. Replaceable lithium-hydroxide canisters remove carbon dioxide.

In case of an emergency, NR-1 carries 11 tons of expendable lead shot to increase buoyancy and return to the surface in conjunction with an emergency blow. It can communicate by radio when on the surface. Its high-frequency (HF) radio permits long-range communications. The ability to sit on the bottom also provides a refuge for NR-1 in an emergency.

NR-1 CAPABILITIES REVIEW

This chapter briefly describes the NR-1 deep-submergence submarine and overviews its capabilities.

The following capability insights are based on reviews of 34 of the NR-1 scientific and military operations and missions conducted from 1972 to 1995.

Bottoming

The ability to bottom the ship was used often in scientific and military missions and, based on this study, reasons for a bottoming capability are expected to apply in the future, including the following:

- Bottoming facilitates manipulation tasks, especially where the submarine must hold a position against a cross current or water column motion. For example, critical components of an F-15E fighter aircraft were recovered in water 120–150 feet deep. With five- to seven-foot waves, there was vertical movement throughout the water column. There was no way to compensate for this movement with thrusters or ballast control. Only by bottoming, with thrusters holding the ship down and an additional 1,000 pounds of ballast, was reasonable stability achieved.
- Bottoming facilitates "look but don't touch" operations from close aboard. In a military mission, NR-1 visually examined

exercise mines as though they were actual mines. This was accomplished by bottoming at a safe distance from the exercise mines once they were located. In a science mission to examine manganese nodules, it was possible to examine the nodules in situ under different lighting conditions but from the same angle by bottoming. It also gave scientists time to carefully select nodules for sampling.

- Bottoming provides an alternative to anchoring, especially above rock/coral bottoms. These conditions prevailed during the previously mentioned F-15E component recovery effort.
- Bottoming provides a "safe mode" to be used during engineering casualties to minimize operational impact of those failures. For example, the NR-1 Obstacle Avoidance Sonar (OAS) failed during one mission and the NR-1 could not proceed safely without it. Instead of surfacing, it bottomed briefly to conduct repairs and continued its mission when the repair was completed. Lines streaming from NR-1 were easier to cut loose using the manipulator after bottoming.
- Brief bottoming periods provide the ability to "pause" missions. For example, when a science survey was completed earlier than scheduled, NR-1 was bottomed, a new plan was developed, and the science mission resumed in area.

Ability to bottom adds to NR-1 versatility. Ability to bottom more securely on rock/coral bottoms may be desirable.

Anchoring

NR-1 rarely used its anchor. The original anchoring system, with a single forward anchor, did not provide adequate stability. The present anchoring system, with a single aft anchor, provides no more stability and is problematic when there is a current.

Wheels

NR-1 rolled across the bottom for a few low-priority tasks. Rolling was not used for cable, gas pipe, or oil pipeline inspections.

- Rolling is a way to remove entanglements such as lobster pots or loose lines.
- Rolling can be used to disturb the bottom deliberately. In conducting searches for methane gas seepage sites, NR-1 was bottomed to see if a plume of methane would be released.
- Wheels provided an ability to fine-tune NR-1's position on the bottom, which was used in missions requiring fine manipulation. A hovering submarine cannot be maneuvered as precisely as a bottomed submarine using wheels. Also, currents tend to swing hovering submarines. Precise position adjustments could be accomplished reliably only by bottoming and using the wheel system.

NR-1 tasks accomplished by rolling might have been performed by other means. The manipulator arm or divers can remove entanglements, and a relatively recently installed line-cutting system has reduced the entanglement problem. In searching for methane seep sites, for example, NR-1 might have dragged a weighted line over the bottom to disturb it instead of rolling across it.

The "bicycle" wheel system provided limited stability when NR-1 was bottomed. Also, the OIC during the F-15E component recovery mission was concerned for the wheel suspension system as NR-1 bounced on the bottom with movement in the water column.

Reliable fine-position adjustment on the bottom regardless of currents is a valuable NR-1 capability. While the stability provided by wheels should be improved, the "fine positioning" ability is satisfactory and should be retained.

Viewports

Viewports were used heavily in NR-1 operations. In some instances they might have been replaced by video cameras. In operations close to the bottom they were invaluable for own ship safety.

- Scientists frequently used viewports heavily; no training or adaptation is required to use a viewport.

- High-resolution real-time imagery was required at various times (e.g., to read serial numbers off mine release mechanism components, to identify pieces of wreckage, or to identify shipwrecks).
- Viewports remain the only means of accurately determining NR-1 altitude in operations close to the bottom. Video images are two-dimensional, making it difficult to estimate distances accurately. Sonars do not work at the ranges in question. Only viewports provided the three-dimensional view of the bottom that enables safe operations near the bottom.

Viewport problems and limitations were apparent. In unusually turbid water, with visual ranges down to five or ten feet, viewports had little value. Viewport geometry also was a sometime problem. For example, it is difficult to use a viewport to see under a piece of wreckage (such as an F-15E fuselage). Similarly, it is difficult to see up a vertical object from a viewport located under the bow. On one mission, NR-1 encountered a steep rise without warning (see subsection on "Sensors" below for a discussion of OAS performance). It could not determine the height of the rise with its sonars and the top of the rise could not be seen through viewports. The location of the viewports 30 feet from the bow and under it reduced their effectiveness.

The capability to view the bottom in three dimensions is crucial to ship safety in operations near the bottom. Thought should be given to better visibility from any NR-2 viewport.

Object Manipulation

NR-1 can manipulate both small and large objects. Small-object manipulation was used, for example, in selecting nodules of interest to scientists and in placing, using, and recovering science equipment. Large-object manipulation was used primarily in recovery operations. Ejection seats, canopies, and other large objects were manipulated in the recovery process.

Limitations in NR-1's ability to manipulate objects have been noted. NR-1's manipulator lacks fine control. Its "grip" was occasionally inadequate—the F-15E canopies posed a great challenge. Also, it lacks feedback. In the *Challenger* recovery operation some debris recovery was prevented by the risk that the manipulator would have crushed fragile debris. This is one of the few instances that NR-1 was on site but could not perform a desired task.

The ability to manipulate large and small objects is expected to be key to NR-2 success and should be retained. Finer manipulation control and operator feedback would increase its utility.

Thrusters

Thrusters were essential to success in several missions. They were essential in the following cases:

- NR-1 had to be held against a cross current and bottoming was not an option (because of bottom conditions).
- Thrusters were needed to maneuver NR-1 safely out of tight spaces, such as sinkholes.
- Thrusters were used to help keep NR-1 bottomed against wave action in shallow water.

While operating near F-14 wreckage on the bottom, the OIC log tersely noted that NR-1 had “experienced sudden, dramatic increase in current (up to 1.5 knots). Sort of lost control of ship.” In another mission, NR-1 encountered a bottom suction problem and had difficulty freeing herself from the bottom. Thrust for pulling NR-1 off the bottom was adequate under normal operating conditions. NR-1 occasionally encountered situations in which more powerful thrusters would have been desirable.

Divers

Divers demonstrated their utility in several NR-1 missions.

- NR-1’s manipulator was disabled during the F-15E recovery mission. The problem could not be fixed from within NR-1 but was easily fixed by divers.
- Divers were needed to attach lift bags to heavy objects to be recovered; single manipulators are unsuited to this task.

- In the F-15E component recovery mission, NR-1 was able to lift ejection seats and canopies only with its grapnel. These were then raised to beneath the NR-1 bow, but NR-1 could not deal with these objects beyond that. Divers attaching lines to the objects were required to complete recovery.

The ability to work with divers is satisfactory and should be retained.

Sensors

- The most commonly used sensor on NR-1 is its OAS. It was used for ship safety, to search debris fields, to locate hardware equipped with pingers, and to assist in tow hookup. An OAS better than that installed in 1993 is recommended. There have been reports that "the bottom came up rapidly" as the OAS did not recognize steep rises. Also, OAS is a forward-looking sonar. Sometimes, such as when NR-1 had to back up, a 360-degree field of view would have been helpful.

- SLS is also a valuable sensor. It has been used for geologic surveys in science. It is also well suited for imaging shipwrecks and for surveying debris fields.
- Laser Line Scanner (LLS) systems have also been useful. Parallel gas pipe/oil pipeline systems have been scanned simultaneously by examining one with SLS and the other with LLS. Existing LLS systems can also "see" beyond visual ranges. Thought should be given to extending LLS ranges, perhaps using blue-green laser technology.
- Sub-Bottom Scanner (SBS) systems have the unique ability to help the submarine locate geologic fault lines. This system operates like sonogram technology—a noise source is pressed against the region to be scanned, resulting in images of internal structure. SBS is important when there is risk to bottom systems from fault line slippage.
- ESC images had good quality, their images were available in real time, and they never ran out of film or experienced the flash synchronization problems seen with 35-mm still cameras.

Navigational Accuracy

Navigation accuracy is important in scientific and military missions. For example, NR-1 has been directed to examine specific exercise mines or to map mine-like objects and debris fields. While NR-1 knew the exact location of the mines of interest, it did not know its own position with sufficient accuracy to go directly to them. Instead, it had to search the bottom for objects with known locations. This mission succeeded in part because the crew gathered serial numbers in advance of the mission. When an exercise mine was located, the serial number from the mine-release mechanism told them the NR-1 position in the field. In the recovery of F-15E components, USS *Grasp* identified the location of the debris field prior to NR-1's arrival. However, NR-1 still had to search for the debris field because it did not know its own position with sufficient accuracy to go directly there. In the water column it depends solely on inertial navigation, and that system drifted during the descent.

Early on, the problem of limited navigation accuracy was solved most frequently using a Mark on Top (MOT) from an escort ship. The NR-1 bottoms or hovers for the MOT and ship position is read at MOT. The need for MOT has since been eliminated. Instead, escort ships use a track-point sonar that provides NR-1 position relative to the escort ship, which knows its position with GPS accuracy. The most accurate NR-1 navigation tool is a Doppler sonar that can establish relative position with accuracy on the order of one foot. This allows NR-1 to return to an object on the bottom or a location with great accuracy so long as it operates near the bottom—Doppler navigation does not work for a submarine operating in the water column. The Deep-Ocean Transponder System (DOTS) has a similar problem.

Improved navigation accuracy is recommended if autonomous operation is planned for NR-2. Requirements for precise navigation are defined by the tasks of locating an object with a known position or recording the position of an object so it can be subsequently relocated ("precise navigation" also includes the ability to *place* an object on the seabed and subsequently replace it). The ability to navigate accurately in the water column will also be required for such science missions as physical or chemical oceanography.

Communication

NR-1 can communicate via radio and underwater telephone (UWT). Its radio suite includes an HF set for long-range communications, primarily intended for emergency use. Its long wire would probably not survive long in under-ice operations.

The UWT was not designed to operate in some of the conditions in which NR-1 operated, and communications were sometimes poor in undersea canyons. A more sophisticated communications suite may be needed for under-ice operations.

Autonomy

NR-1 was not designed for autonomous operation and so rarely operated autonomously. Consort ships provided a variety of services. These include the following:

- Providing tow services to and from mission areas. Towing reduced the time to reach operating areas and reduced operational run time.
- Logistic support. Consorts provided a range of logistics support, including high-pressure air.
- Crew exchanges. The ability to exchange science teams enabled NR-1 to conduct a string of science missions without returning to port. This increased NR-1 efficiency when brief science missions in the same area could be strung together sequentially. Consort ships also provided diver services. The consort ship conducted at least one HUMEVAC.[2] Crewmembers were also rotated using the consort ship.
- Storing retrieved objects. Retrieved objects, such as ejection seats, canopies, and missiles, could not be stored on NR-1 and could not be returned safely in the grasp of NR-1's manipulator. Additional storage was required for successful mission completion. NR-1 lacks the ability to segregate retrieved objects. Consort ships provide separate storage.

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[2]A HUMEVAC is an unscheduled/emergency transfer of a crewmember from the ship for humanitarian reasons.

- Supporting large object retrieval. NR-1 was able, for example, to lift F-15E components off the bottom but could not bring them to the surface. A consort ship working with NR-1 accomplished final retrieval.
- Aiding navigation. Consorts provided accurate navigation services during many missions. They were most valuable in such operations as search and recovery or bottom mapping.
- Contributing to bottom surveys. Consorts used their sonar systems to outline debris fields and locate key objects. In the case of the F-15E recovery mission, USS *Grasp* arrived on scene before NR-1 and conducted a preliminary survey for NR-1 to use.
- Providing a surface picture supporting NR-1 ship safety. Surface pictures included area traffic prior to NR-1 surfacing, sea conditions, and forecasts.

Consort ships benefited NR-1. Consort vessels can be expected to be of benefit to NR-2, and NR-2 should be able to work with consort ships.

NR-1 OPERATIONS AND MISSIONS

The following is a list of all known unclassified NR-1 operations and missions, including their dates, objectives, and locations. For operations and missions marked with an asterisk, records have been retained and made available to the National Defense Research Institute (NDRI) for review for this report.

1972	Geological/oceanographic investigation of eastern continental slope of Grand Banks*
1972	Hydrographic/oceanographic operations, undetermined location*
1972	Hudson Canyon oceanographic operations*
1973	Blake Plateau oceanographic operations*
1973	Puerto Rico oceanographic operations*
1974	Lydonia/Gilbert Canyons oceanographic operations*
1975	Transatlantic Telephone VI operations*
1975	Jetter operations*

1976	Jetter trials*
1976	Hudson Canyon bottom exploration operations*
1976	Operation Spacious Sky*
1976	Phoenix air-to-air missile recovery*
1977	Rekyjanes Ridge bottom survey operations*
1979	Trident missile component recovery
1980	Blake Plateau Oceanographic Operations—geological survey for mineral nodules*
1981	Lamont-Doherty Geological Observatory (LDGO) survey operations*
1981	Locate/inspect transponder and locate/input coaxial cable tasked by Naval Undersea Systems Command (NUSC) Detachment Bermuda*
1984	Rekyjanes Ridge survey—marine biology*
1984	Locate fleet ballistic missile submarine (SSBN) propeller
1985	Continental shelf survey—shelf silt drift*
1985	Search for Trident/Pershing missile components
1986	Gulf of Mexico hydrocarbon seeps survey
1986	Space Shuttle *Challenger* debris recovery*
1987	Virginia Capes Naval Oceanographic Office (NAVOCEANO) geodetic survey
1989	Gulf of Mexico various science operations (Texas A&M)*
1989	Dump site survey (National Oceanographic and Atmospheric Agency [NOAA]/National Undersea Research Program [NURP]—examine effect of dumping on sea life*)
1989	Virginia Capes Survey—Recovery of NAVOCEANO Tow Fish*
1989	Blake Plateau survey (U.S. Geological Survey)—sinkhole survey*
1989	Naval Space and Warfare Systems Command (SPAWAR) cable burial—use of jetter*

1990	Charleston Operating Areas Hull Integrity Test Sites (HITS) surveys—detail bathymetric and shipwreck locations for SSN/SSBN sea trials*
1990	Gulf of Maine operations (University of Maine)—marine life and marine biology surveys*
1990	Narragansett Bay bottom survey operations*
1990	Charleston Bump bottom survey operations*
1992–1993	Narragansett Bay operating areas training minefield survey—search for nonresponding acoustic training mines*
1993	Blake Plateau scientific operations—mineral nodules and coral reef surveys
1993	NAVOCEANO surveys Cherry Point operating areas*
1993	Proposed minefield survey*
1993	OAS testing*
1993	Bush Hill, Brine Pool, and Green Canyon*
1993	Viosca Knoll survey*
1993	Oil pipeline survey—search for failure-prone pipeline segments*
1993	Narragansett Bay operating areas survey #2*
1993	Ex-USS *Salmon* operations*
1994	HITS survey(s)
1994	NAVOCEANO surveys Virginia Capes operating areas
1994	Eastern Atlantic SURTASS array recovery
1994	NOAA/NURP science support—various surveys; mid-Atlantic Ridge*
1994	Support to Commander Submarine Development Squadron TWELVE Tactical Development Exercise 13-94
1995	F-15 recovery operations*
1995	Exploration of HMHS *Britannic*, sister ship to *Titanic*, sunk during World War I in the Greek archipelago
1995	Woods Hole Oceanographic Institute (Dr. Ballard) archeological studies in the Mediterranean Sea
1995	NURP geomorphology*

1995	Lightweight torpedo search*
1995–1996	Jason Project—high school students/live TV broadcasts/ship rides—Florida Keys
1996	AOS and acoustic communications research and development
1996	Various scientific surveys (Texas A&M) Florida Keys
1996	NATO support for Norwegian coastline mapping—highlighted by documenting 26 shipwrecks in 24 hours within Bergen Harbor
1997	Archeological and ocean engineering studies in the Mediterranean Sea—Dr. Ballard
1997	Search for Israel Navy submarine INS *Dakar* (lost at sea in 1968)
1998	Low-Frequency Broadband Variable Sonar R&D testing with Naval Undersea Warfare Center
1998	Gulf of Mexico—Texas A&M seabed surveys for geothermal/hydro vents and deep-sea hydrobiology
1998	Bottom survey support for Coast Guard and FBI in investigation of maritime claims against the U.S.
1998	Shallow water initial operations testing of high-resolution side-scan sonar
1999	Bottom search and survey subsequent to the crash of Egypt Air Flight 990