Marine Nuclear Power: 1939 - 2018

Part 5: China, India, Japan & other nations

Peter Lobner

July 2018

Foreword

In 2015, I compiled the first edition of this resource document to support a presentation I made in August 2015 to The Lyncean Group of San Diego (www.lynceans.org) commemorating the 60th anniversary of the world's first "underway on nuclear power" by *USS Nautilus* on 17 January 1955. That presentation to the Lyncean Group, *"60 years of Marine Nuclear Power: 1955 – 2015,"* was my attempt to tell a complex story, starting from the early origins of the US Navy's interest in marine nuclear propulsion in 1939, resetting the clock on 17 January 1955 with *USS Nautilus*' historic first voyage, and then tracing the development and exploitation of marine nuclear power over the next 60 years in a remarkable variety of military and civilian vessels created by eight nations.

In July 2018, I finished a complete update of the resource document and changed the title to, *"Marine Nuclear Power: 1939 – 2018."* What you have here is *Part 5: China, India, Japan and Other Nations*. The other parts are:

- *Part 1: Introduction*
- *Part 2A: United States - Submarines*
- *Part 2B: United States - Surface Ships*
- *Part 3A: Russia - Submarines*
- *Part 3B: Russia - Surface Ships & Non-propulsion Marine Nuclear Applications*
- *Part 4: Europe & Canada*
- *Part 6: Arctic Operations*

Foreword

This resource document was compiled from unclassified, open sources in the public domain. I acknowledge the great amount of work done by others who have published material in print or posted information on the internet pertaining to international marine nuclear propulsion programs, naval and civilian nuclear powered vessels, naval weapons systems, and other marine nuclear applications. My resource document contains a great deal of graphics from many sources. Throughout the document, I have identified all of the sources for these graphics.

If you have any comments or wish to identify errors in this document, please send me an e-mail to: PL31416@cox.net.

I hope you find this informative, useful, and different from any other single document on this subject.

Best regards,

Peter Lobner
July 2018

Marine Nuclear Power: 1939 – 2018
Part 4: China, India, Japan & other nations

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China

Naval nuclear submarines (SSN & SSBN),
floating nuclear power stations and icebreaker

Source: https://en.wikipedia.org/

China

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The beginning of China’s marine nuclear power program

China's marine nuclear timeline

21 Sep 49
People's Republic of China (PRC) formed

1967
Land-based prototype reactor design complete
March 68
Land-based prototype reactor construction started

1981
1st Chinese Type 92 (Xia-class) SSBN Construction Complete
1987
1st Chinese Type 92 (Xia-class) SSBN operational with JL-1 SLBM
1988
China National Nuclear Corporation (CNNC) formed

2002
1st Type 93 (Shang-class) SSN launched
2006
1st observation of a Chinese Type 94 (Jin-class) 2nd generation SSBN
2009
1st successful test launch of a JL-2 SLBM from a Type 094 SSBN

1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s

1950
China Institute of Atomic Energy (CIAE) formed
May 58
Start of the naval nuclear power program with approval of the "09 submarine" program
Later in 1958
Reactor Engineering Research Section (RESS) formed, responsible for the "09 submarine" program

April 70
Land-based prototype reactor construction complete
July 70
Land-based prototype reactor operated at full power
23 Aug 71
1st Chinese sub, Type 91 (Han-class) SSN, underway on nuclear power
1974
1st Chinese sub, Type 91 (Han-class) SSN, operational

1994
Construction started on 1st Type 093 (Shang-class) SSN

2015
1st Chinese 2nd-generation Type 94 (Jin-class) SSBN operational
2018
China announces plans to build a nuclear-powered icebreaker

The beginning of China’s marine nuclear power program

- China’s nuclear industry traces its roots back to 1950 when the China Institute of Atomic Energy (CIAE) was formed.
- On January 15, 1955, Chairman Mao Tse-Tung and the Central Secretariat decided China would develop atomic weapons.
- China’s naval nuclear power program started in July 1958 when Mao Tse-Tung and the Central Military Commission gave approval to start the “09 submarine project”.
- CIAE formed the Reactor Engineering Research Section (RESS) in 1958 and assigned it responsibility for the 09 submarine project.
    - Available information convinced REES that a loop-type pressurized water reactor (PWR) based on the Russian icebreaker *Lenin*’s Afrikantov-designed OK-150 propulsion plant would be the best choice.
    - It was decided early on that a land-based prototype would be built first for testing and training.
    - The reactor design was completed and approved by mid-1960.
    - In 1964, RESS became Reactor Engineering Institute (Code 194).

Source: http://www.navy.mil/navydata/cno/n87/usw/issue_32/china.html

The beginning of China's marine nuclear power program

- The Second Ministry of Machine Building was formed in 1958. It was tasked with the development of all industries associated with production of nuclear weapons and a nuclear submarine propulsion plant.
- The 09 submarine project was severely affected by government-run economic and social transformation programs: Great Leap Forward (1958-1961), Cultural Revolution (1965-1975), and Third Line movement.
  - These three movements resulted in major program delays, funding cuts, and the loss of talented engineers due to political issues.
- The land-based prototype reactor design was completed by 1967, construction started in March 1968, the plant was completed in April 1970, and the plant operated at full power in July 1970.
  - The prototype demonstrated that the reactor design was adequate

Source: http://www.navy.mil/navydata/cno/n87/usw/issue_32/china.html

The beginning of China's marine nuclear power program

- Submarine design progressed in parallel with development of the reactor plant. The layout of the submarine and its subsystems was determined by the use of a full-size wood and steel model used to test fit all the components. This slowed construction but avoided costly rework.
  - Reactor was installed by early 1971.
  - The 1st Chinese Type 091 Han-class sub got underway on nuclear power for the first time on 23 August 1971.
  - Due to developmental issues, the submarine did not join the fleet until 1974.
- The industrial infrastructure that built up around Jiajiang, named the Southwest Reactor Engineering Research and Design Academy, or, First Academy, became China's largest nuclear power industrial complex.

Source: http://www.navy.mil/navydata/cno/n87/usw/issue_32/china.html

The beginning of China's marine nuclear power program

- In 1982 the Second Ministry of Machine Building was renamed the Ministry of Nuclear Industry (MNI) and in 1988 it was reorganized into the China National Nuclear Corporation (CNNC).
  - CNNC consists of over 100 subsidiary companies and institutions and controls the vast majority of civilian and military nuclear programs.
  - Today, the China Institute of Atomic Energy (CIAE) is the main research and development organization of CNNC.
  - CIAE's Reactor Engineering Institute is still the primary design institute for submarine propulsion plants.

Source: http://www.navy.mil/navydata/cno/n87/usw/issue_32/china.html

China’s current nuclear vessel fleet

As of mid-2018

Nuclear submarines are a growing element in China's maritime strategy

Source: Reuters

China’s current nuclear vessel fleet

As of mid-2018

- The People’s Liberation Army Navy (PLAN) operates a large, mixed fleet of conventional and nuclear submarines. The conventional fleet is comprised of 57 attack submarines in several classes and one Type 032 multi-purpose weapons system test platform submarine.
- China’s nuclear submarine fleet currently is comprised of 20 boats in the following classes:
  - SSNs: 14
    - 3 x Type 091 “long-hull” Han-class 1st-generation SSNs
    - 2 x Type-093 Shang I-class 2nd-generation SSNs
    - 2 x Type 093A Shang II-class SSNs
    - Up to 7 x Type 093B Shang III VLS-equipped multi-mission SSN/SSGNs (one or more actually may be a newer Type 095 3rd-generation SSN)
  - SSBNs: 6
    - 1 x Type 092 Xia-class 1st-generation SSBN, which no longer is operational, but has not been decommissioned
    - 5 x Type 094 / 094A Jin-class 2nd-generation SSBNs
- China does not operate any naval or commercial nuclear-powered surface ships. However, a floating nuclear power station is reported to be under construction and a nuclear-powered icebreaker is planned.

Source: http://www.navalanalyses.com/2018/04/infographics-31-peoples-liberation-army.html

China’s marine nuclear infrastructure

China’s marine nuclear infrastructure

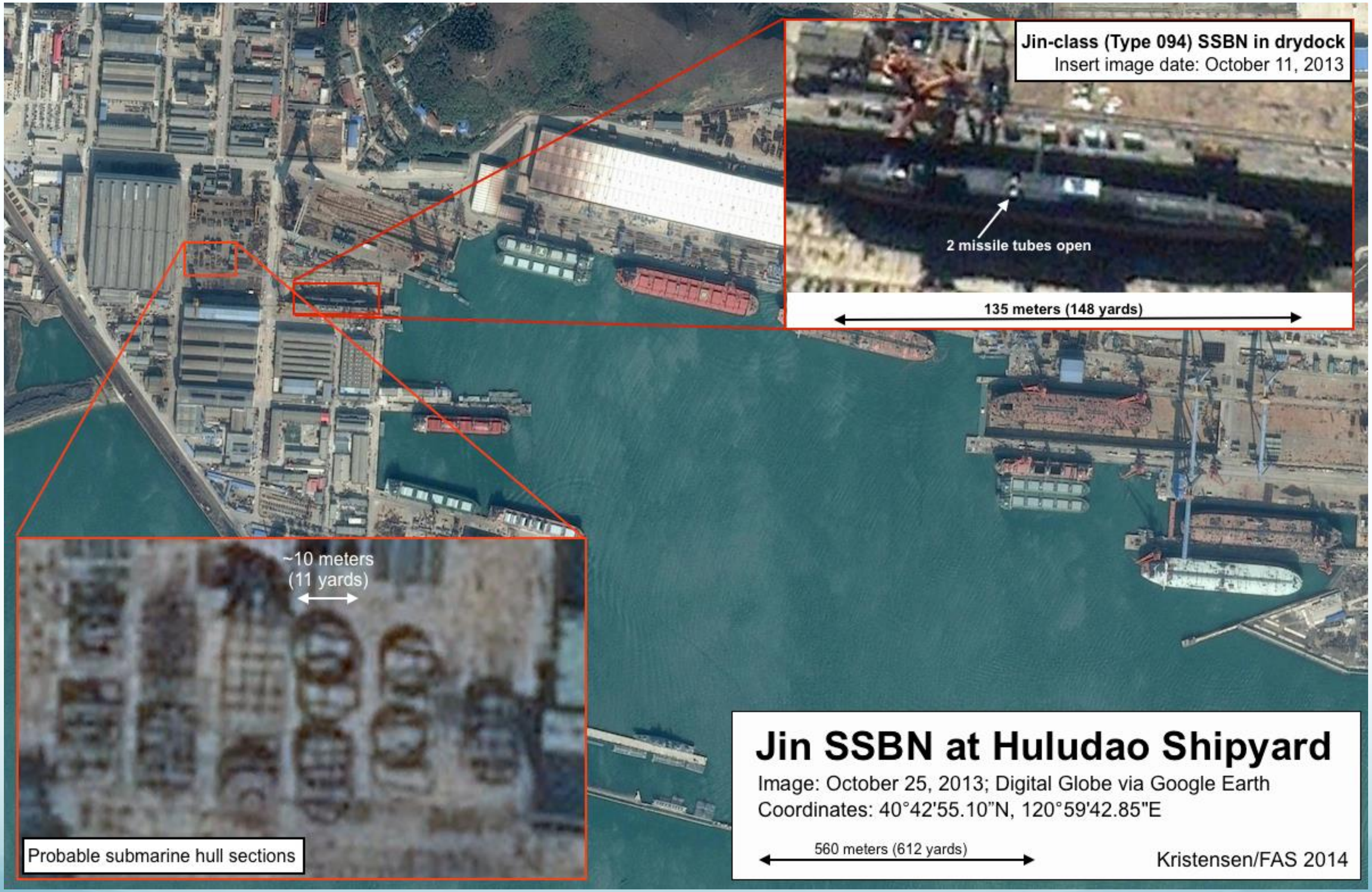
- Uranium enrichment:
  - China produced enriched uranium for weapons, research, and naval reactors at two gaseous diffusion complexes:
    - Lanzhou (Plant 504), which operated from 1964 to 1979
    - Heping (Plant 814), which operated from 1975 to 1987
  - China operates two centrifuge enrichment plants at Hanzhong and Lanzhou to produce LEU for civilian purposes.
  - NTI reported * that, “The government has not declared an official national policy regarding HEU, nor does China declare its HEU stockpiles in its annual plutonium declarations to the International Atomic Energy Agency (IAEA) (INFCIRC/549). China has not declared any HEU as excess to its military needs.”
- Marine reactor design bureaus:
  - China Institute of Atomic Energy (CIAE) Reactor Engineering Institute is responsible for naval reactor design.
  - China is believed to have designed their naval reactors to use low-enriched uranium (LEU) fuel.
  - Two marine pressurized water reactors (PWRs) are being developed for floating nuclear power plants and other marine applications: China National Nuclear Corporation’s (CNNC) ACP100, and China General Nuclear Power Group’s (CGN) ACPR50S.

* Source: Nuclear Threat Initiative (NTI), 21 December 2017, http://www.nti.org/analysis/articles/civilian-heu-china/

China's marine nuclear infrastructure

- China Shipbuilding Industry Corporation (CSIC), Bohai Shipyard (aka Huludo Shipyard), located near Huludo, on the Bohai Sea
  - All of China's nuclear-powered submarines are built here.
  - The submarine hulls are assembled in a large 40,000-square meter construction hall at the western end of the shipyard, rolled across a storage area into a dry dock for completion, and then launched into the harbor. Final outfitting may occur alongside a pier at the Bohai shipyard or at the Xiaopingdao Submarine Refit Base.
  - Nuclear submarine construction occurs along with construction of commercial tankers and cargo ships in half a dozen dry docks.
- Jiangnan Shipyard Group, located in Shanghai
  - This shipyard is building China's conventionally-powered large aircraft carriers (Type 001, 001A and 002).
  - The shipyard has the capability to build large aircraft carriers comparable to the US conventionally-powered Kitty Hawk-class carriers.
  - No nuclear-powered ship has yet been constructed at this shipyard. However, this is the likely future site for building China's first nuclear-powered carrier.

Bohai (Huludao) Shipyard



Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

Bohai (Huludao) Shipyard

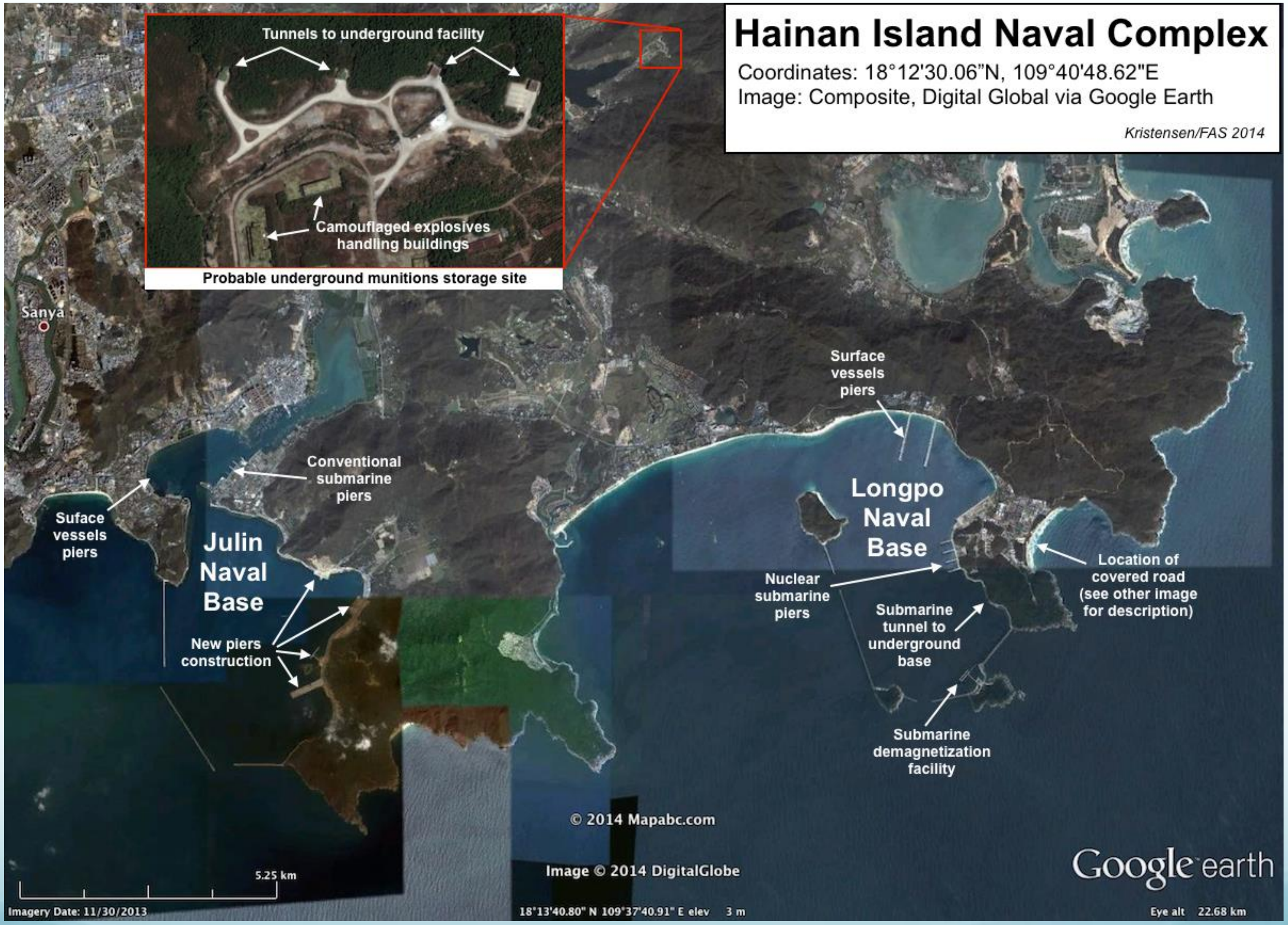
Source: Google Panoramio via https://fas.org/blogs/security/2014/04/chinassbnfleet/

China’s naval bases for nuclear vessels

- The Hainan Naval Complex
  - This naval complex includes the Longpo and Julin Naval Bases, on the southern coast of Hainan Island
  - South Sea Fleet naval facilities are on Hainan Island. These are the closest Chinese naval bases to the contested Spratley Islands.
    - The bases include conventional piers for submarines and surface ships.
    - Nuclear submarines are based at Longpo Naval Base
    - Conventional submarines are based at Julin Naval Base
  - At Longpo Naval Base, the harbor houses SSNs and SSBNs and is large enough to accommodate aircraft carriers.
    - Longpo also has underground submarine pens capable of housing many nuclear submarines.

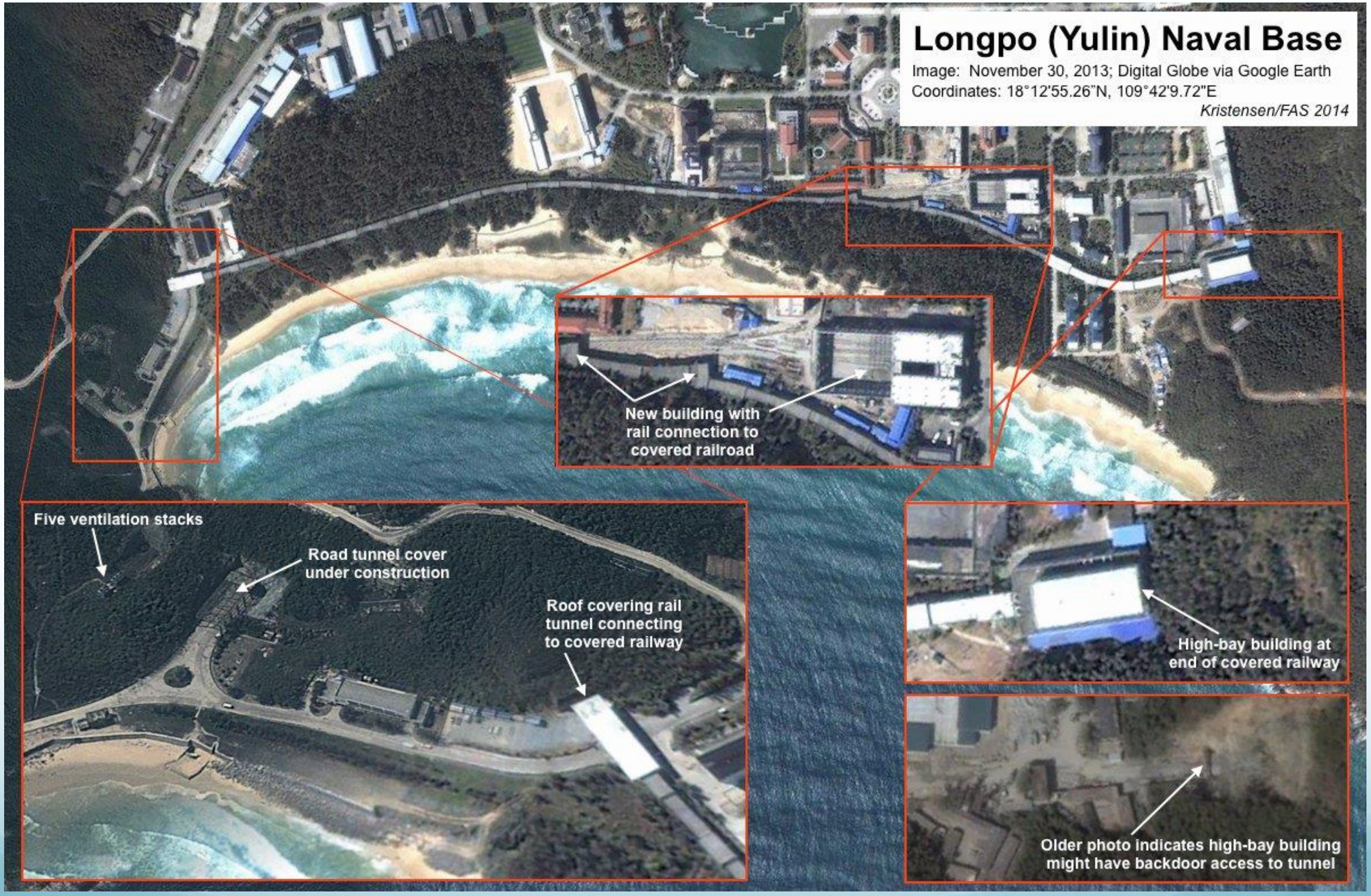
Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

Hainan Island Naval Complex



Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

Longpo (Yulin) Naval Base



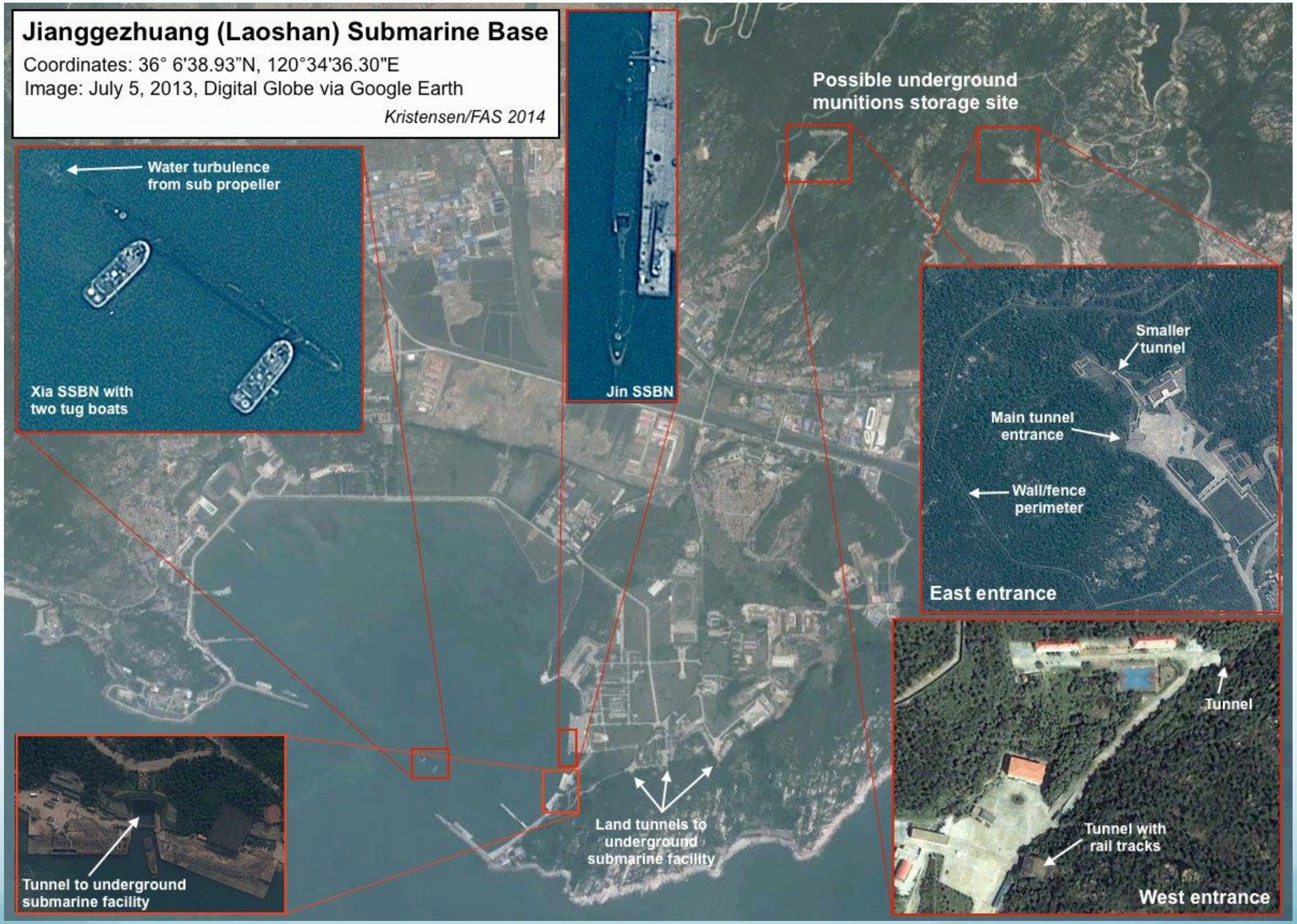
Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

China's naval bases for nuclear vessels

- Jianggezhuang (Laoshan) Submarine Base
  - This base is on the Yellow Sea approximately 18 kilometers (11 miles) east of Qingdao in Shandong Province,
  - This is the North Sea Fleet base and China's oldest nuclear sub base.
  - The 2nd-generation Type 094 Jin-class SSBN was first seen here in 2010. This base also is the home to the 1st-gen Type 092 Xia-class SSBN and several SSNs.
  - The base has a dry dock; the only one at a naval base that has been seen servicing nuclear subs.
  - This base also has a "submarine cave", which is a large water tunnel with access from the harbor and three land-tunnels providing access from various base facilities.
  - Only a few miles north of the base is an underground facility that may be storing munitions for the submarine fleet. As such, it could potentially also serve as a regional storage facility for nuclear warheads for the SLBMs once released to the navy in a crisis by the Central Military Committee.

Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

Jianggezhuang (Laoshan) Submarine Base



Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

China's naval bases for nuclear vessels

- Xiaopingdao Submarine Refit Base
  - This base is on the Bohai Sea near Dalian
  - After completing construction at the Bohai shipyard, the submarine sails to the Xiaopingdao refit base to complete outfitting.
  - This base is used to prepare nuclear and conventional submarines for operational service.
    - Test missiles are loaded into SSBN launch tubes for test launches from the Bohai Sea across China into the Qinghai desert.
  - This base also was used by China's single, conventionally-powered Type 031 Golf-class SSB, which was a submarine test platform used to conduct test launches during development of the JL-1 and JL-2 SLBMs.
  - The newer Type 032 Qing-class test sub likely is based here to support JL-3 SLBM tests.

Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

Xiaopingdao Submarine Base

Source: https://fas.org/blogs/security/2014/04/chinassbnfleet/

China’s nuclear vessels

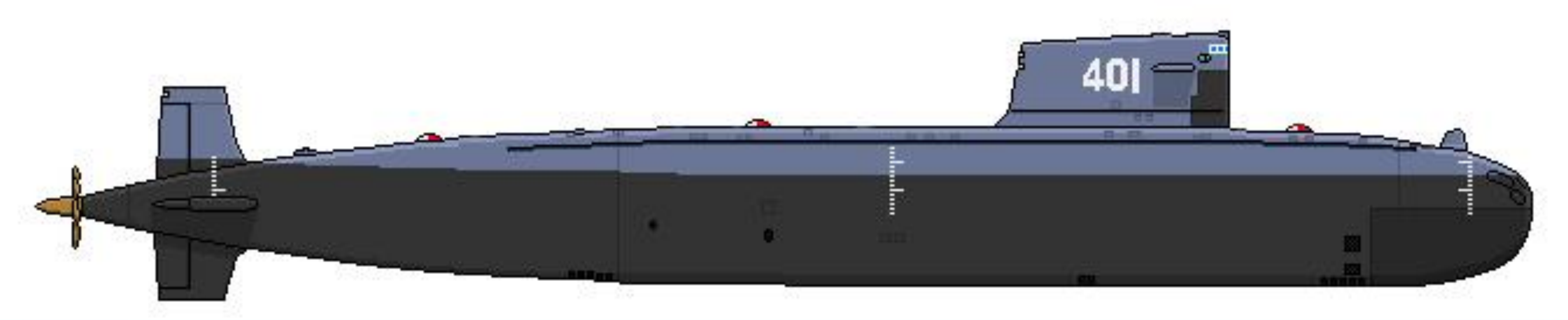
Fast attack submarines,
Strategic ballistic missile submarines,
Future floating nuclear power station,
Future surface ships

Nuclear-powered fast attack submarines (SSN)

China’s fast attack submarines (SSN)

Class	# in Class	Length	Beam	Displacement (tons)	Reactor	Shaft hp	Max speed (kts)	Years delivered	Years in service
Type 091 Han-class	5 (3 active, 2 retired)	Boats 1-2: 98 m (321.5 ft) Boats 3-5: 106 m (347.8 ft)	10 m (32.8 ft)	4,500 (surf), 5,500 (sub)	1 x PWR 58 MWt	11,000 (est)	25 kts	1974 - 1991	1974 - present
Type 093 Shang I-class	2	110 m (360.9 ft)	11 m (36.1 ft)	xxxx (surf), 7,000 (sub)	2 x PWR 150 MWt (est.)	30,000 (est)	30 kts	2006 - 2007	2006 - present
Type 093A Shang II-class	2	110 m (360.9 ft)	11 m (36.1 ft)	xxxx (surf), 7,000 (sub)	2 x PWR 150 MWt (est.)	30,000 (est)	30 kts (est)	After 2007	After 2007 - present
Type 093B Shang III-class (aka Type 093G)	Up to 7 as of mid-2018	110 m (360.9 ft) + VLS hull extension	11 m (36.1 ft)	xxxx (surf), > 7,000 (sub)	2 x PWR 150 MWt (est.)	30,000 (est)	>25 kts (est)	2015 – ongoing	2015 - present
Type 095	Not known	Not known	Not known	Not known	Not Known	Not known	Not known	Not known	

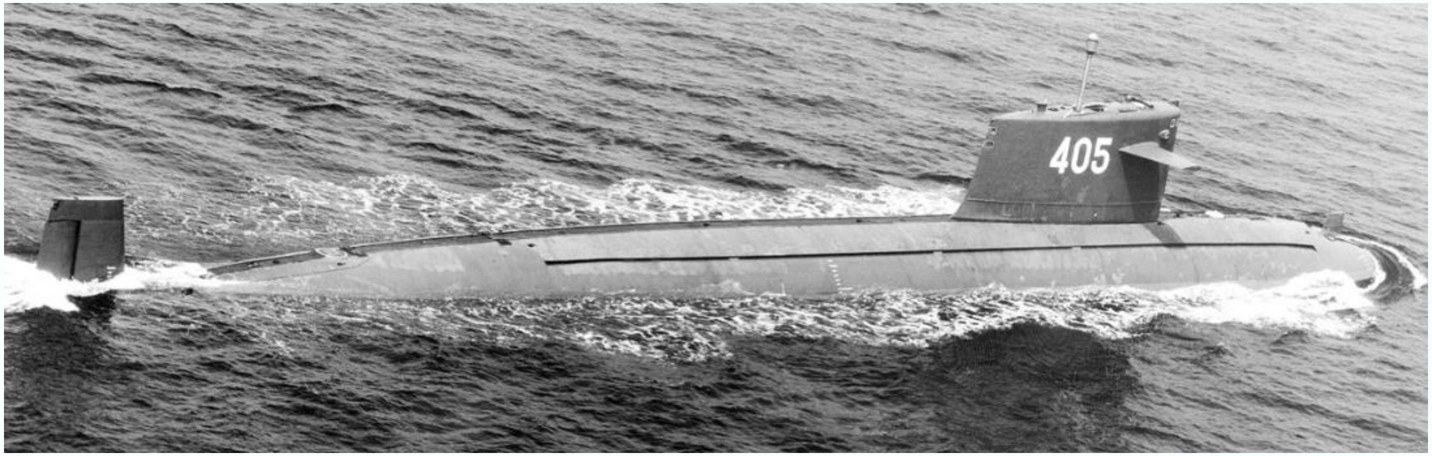
Type 091 Han-class SSN



Source: adapted from www.shipbucket.com

- China's 1st-generation SSN; this class consisted of five boats, hull # 401 to 405.
  - 1st Type 091 got underway on nuclear power for the first time on 23 August 1971
  - The last three Type 091 boats (hull 403 to 405) have longer hulls, with an 8 m (26.2 ft) hull extension added aft of the sail.
- Propulsion: 1 PWR rated @ about 58 MWt; 2 x steam turbines delivering about 11,000 shp (8.2 MW) to a single propeller
  - Reactor design is believed to be based on the Afrikantov OK-150 two-loop PWR used in the Russian icebreaker *Lenin.*
  - Believed to be the same powerplant as on the Type 092 Xia-class SSBN.
- Armament: 6 x 533 mm (21 in) bow torpedo tubes; storage for 20 full-size weapons or 36 mines:
  - Torpedoes; initially Yu-1 and Yu-3; upgraded later to handle Yu-5.
  - YJ-82 short-range anti-ship missile (capability added during mid-life refit)
  - Mines, including full-size torpedoes configured as mobile mines

Type 091 Han-class SSN



Source: https://en.m.wikipedia.org/wiki/Type_091_submarine#/media/File%3AHan_class.jpg

- Operational matters:
  - 1st boat was commissioned in 1974; the 5th and last boat was commissioned in 1990.
  - The noise level of the Han-class is quite high and these boats are easily detected.
  - An early-in-life refit included modifying the nuclear reactor to reduce noise and increase reliability, adding a new French-designed intercept sonar set, and replacing the obsolete Soviet-designed Electronic Support Measures (ESM) suite with a new French system.
  - In the 1990s, the Type 091 SSNs received a modernization refit that expanded their weapons capabilities to include the Yu-5 wire-guided torpedo and the YJ-82 short-range anti-ship missile. Anechoic tiles may have been applied to the hull during this refit.
  - On 25 April 2017, the first Type 091 Han-class SSN, *Changzheng-1*, was opened to the general public as a museum ship at the Qingdao Naval Museum in Shandong Province.
  - As of mid-2018, the last 3 "long hull" boats remain in service.

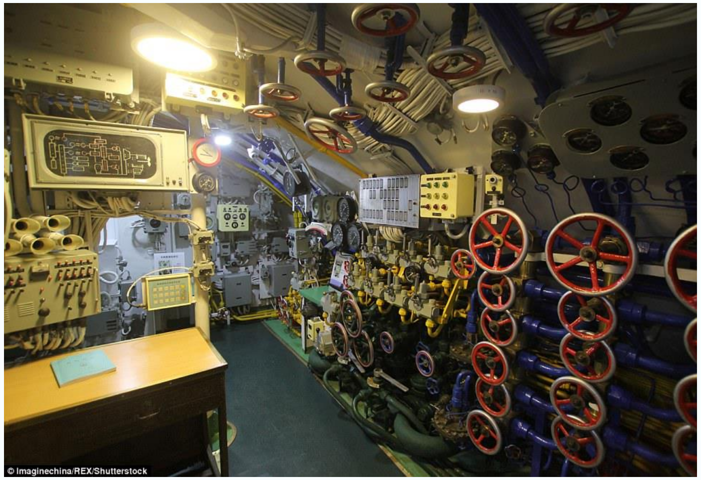
Type 091 SSN museum ship

Changzheng-1 at the Qingdao Naval Museum

Source: Imaginechina/REX/Shutterstock via http://www.dailymail.co.uk/news/article-4452198/China-turns-nuclear-submarine-museum.html

Type 091 SSN museum ship

Changzheng-1 at the Qingdao Naval Museum

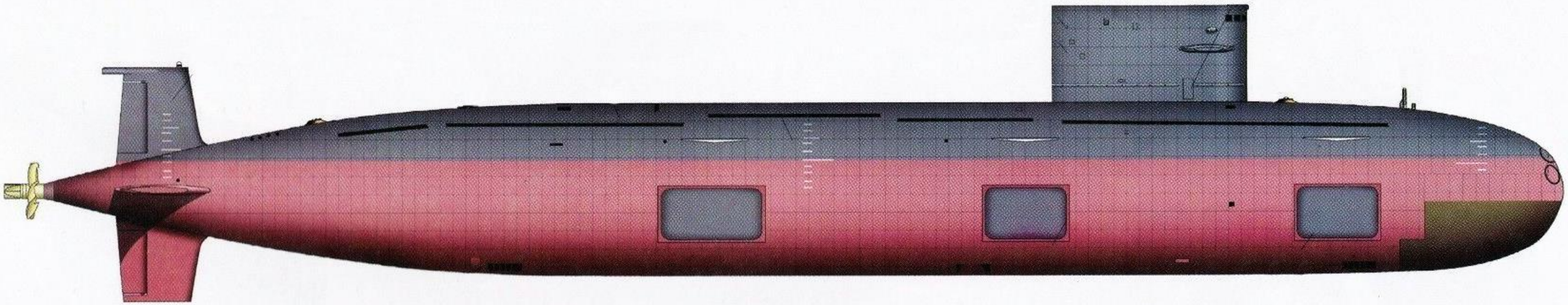


Above: The command center
Below: Torpedo tubes

Above: Throttle control panel (ahead & astern throttle wheels)
Below: Passageway beside the reactor compartment

Source: Imaginechina/REX/Shutterstock via http://www.dailymail.co.uk/news/article-4452198/China-turns-nuclear-submarine-museum.html

Type 093 Shang I-class SSN



Source: adapted from www.club.china.com

- This is China's 2nd-generation SSN. This class is built at the Bohai Shipyard (aka Huludo Shipyard). The lead ship was launched sometime in 2001 – 2002, and commissioned in 2006.
- Propulsion: Several sources suggest 2 x PWRs, like the Russian Project 671 RTM (Victor III) SSN. The secondary steam plant would have to deliver horsepower comparable to a Victor III or Los Angeles Flight I-class sub (about 30,000 shaft horsepower, 22.3 MW) to achieve the attributed maximum submerged speed of about 30 kts. This implies a total reactor power output of about 150 MWt from one or two reactors.

	Shang I	Victor III	Los Angeles Flt 1
Length	110 m (361 ft)	102 – 109 m (334 – 351 ft)	110 m (361 ft)
Beam	11 m (36 ft)	10 m (33 ft)	10 m (33 ft)
Submerged displacement	7,000 tons	6,300 – 7,250 tons	6,927 tons

Type 093 Shang I-class SSN

- The basic Type 093 SSN (the Shang I) represents a significant improvement over the Type 091-class SSN in terms of operational performance and quietness.
- Armament: 6 x 533 mm (21 in) torpedo tubes capable of launching various anti-submarine and anti-surface ship weapons.
  - Yu-5 & Yu-6 torpedoes
  - YJ-82 short-range anti-ship missile
  - Mines, including full-size torpedoes configured as mobile mines.
- In 2009, the US Office of Naval Intelligence (ONI) described the Type 093 as being noisier than a Russian Project 671 RTM (Victor III), which entered service in 1979.
- Two basic Type 093 Shang I SSNs were built and commissioned between 2006 – 2007. Type 093 construction then transitioned to more advanced models.
  - Type 093A Shang II
  - Type 093B Shang III (aka Type 093G)
  - And possibly a special operations force (SOF) model unofficially dubbed Type 093T

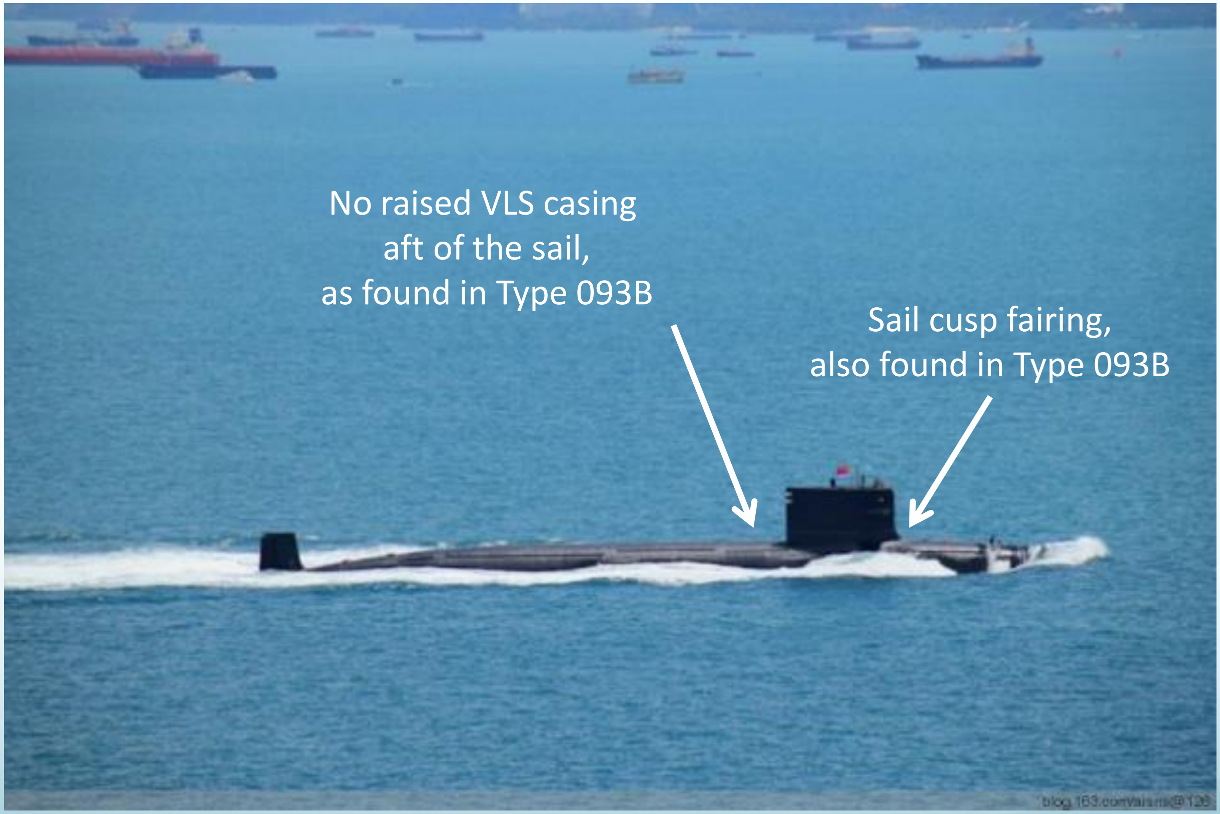
Type 093 Shang I-class SSN

Source, above: http://gentleseas.blogspot.com/2015/

Source, left and bottom right: https://defence.pk/pdf/threads/type-093-ssn.333944/

Type 093A Shang II-class SSN

- The Type 093A is expected to be quieter than the basic Type 093 Shang I-class SSNs.
- Same armament as the Shang I-class SSN.



Type 093A transiting the Straits of Malacca in 2016.
Source: http://china-defense.blogspot.com

Type 093B Shang III-class

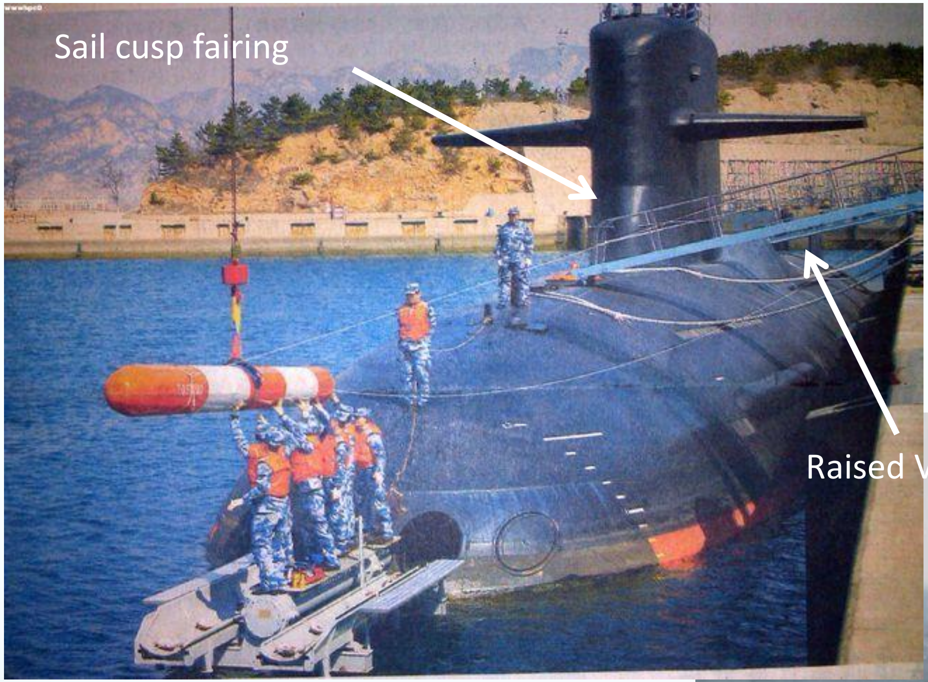
Multi-mission SSN / SSGN (aka Type 093G)

- This is the first Chinese SSN equipped with a vertical launch system (VLS) in a hull extension immediately behind the sail.
  - This Type 093 variant has the revised sail of the Type 093A and additionally has a small raised casing (a small hump) above the VLS launchers.
  - There appear to be 12 VLS launchers in four rows of three launchers.
- With the VLS, the sub's armament suite has been expanded to include:
  - The YJ-18 long-range, anti-ship missile (comparable to the Russian 3M54 Kalibr / Club)
  - The Yu-8 long-range, anti-submarine missile (comparable to the Russian 91RE1 Kalibr / Club-S)
  - A submarine-launched version of the CJ-10 land-attack cruise missile (comparable to the Russian Kh-55 and the US Tomahawk).
- These VLS missiles allow the Type 093B to project power over long distances, including to targets on shore; capabilities not previously possessed by Chinese SSNs.
- In April 2015, *China Daily* reported that three Type 093B SSNs were being readied for commissioning in that year. As of mid-2018, four Type 093B boats are believed to be in service.

Type-093B Shang III-class

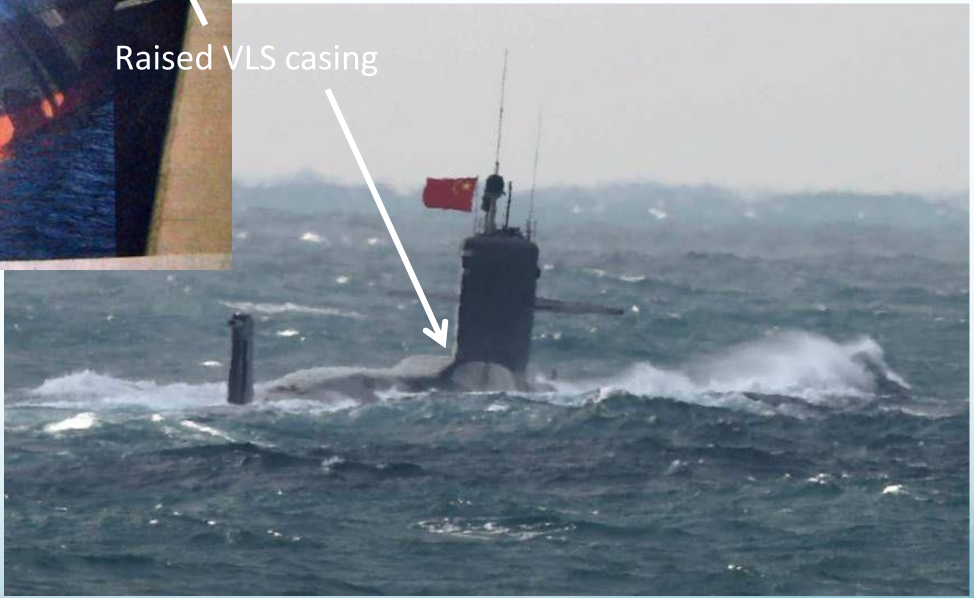
Multi-mission SSN / SSGN (aka Type 093G)

- On 12 January 2018, the Type 093B submarine in the photo below surfaced within the Exclusive Economic Zone (EEZ) around Japan's Senkaku Islands and then moved out to international waters.



Type 093B torpedo handling.
Source: People's Navy Online

- Torpedo loading is accomplished through the torpedo tubes instead of through a separate weapons shipping hatch as as in the US practice.



Type 093B underway on the surface.
Source: Japan Ministry of Defense

Type 093B Shang III-class

Multi-mission SSN / SSGN (aka Type 093G)

图3 仿真模型
Fig. 3 Simulation model

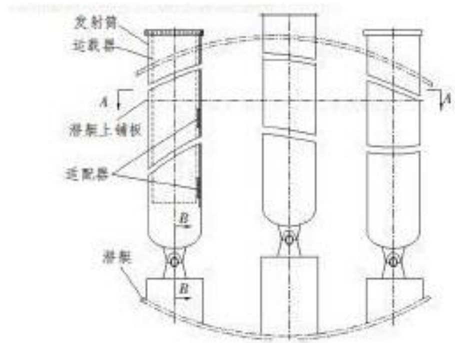


图1 连接结构
Fig. 1 Connection structure

These two models purport to show the physical arrangement of a row of three VLS tubes in a Type 093B hull segment. Hull outside diameter is 11 m (36.1 ft).

Satellite image of a Type 093B dockside. The raised VLS casing is visible in this image.
Source, both images: http://china-defense.blogspot.com/2017/11/satellite-photo-of-day-type-093-shang.html

Type 093B Shang III-class

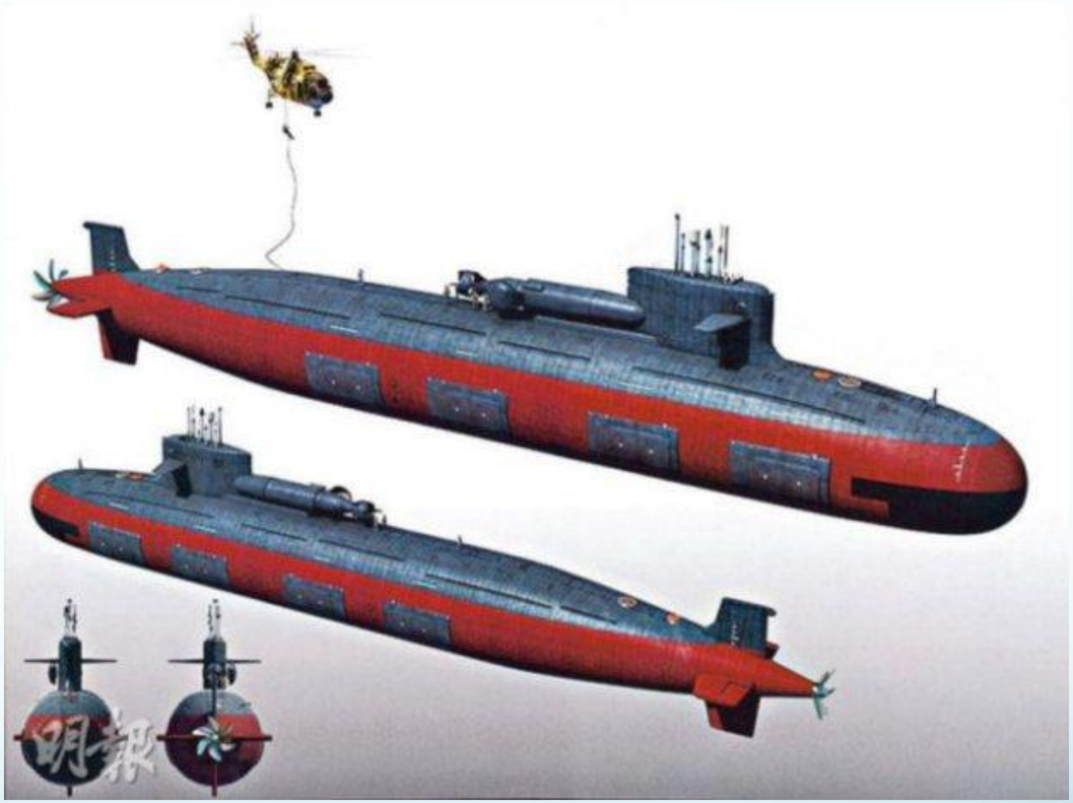
April 2015 speculative general arrangement

Source: http://gentleseas.blogspot.com

Type 093T

March 2015 speculative special operations force (SOF) version

- Another Type 093 variant, referred to as Type 093T, was described on 17 Mar 2015 in an article in the Chinese State-run *Reference News.*
- The accompanying diagram of the sub shows a deck-mounted “wet” hanger capable of housing a mini- sub for special operations forces (SOF).
- The hangar, it was claimed, is intended to accommodate only the first two-thirds of the mini-sub, which “… enters [the] dock space as simple as an ink pen cap.”
- Perhaps this SOF capability can be added to any Type 093 / 093A.



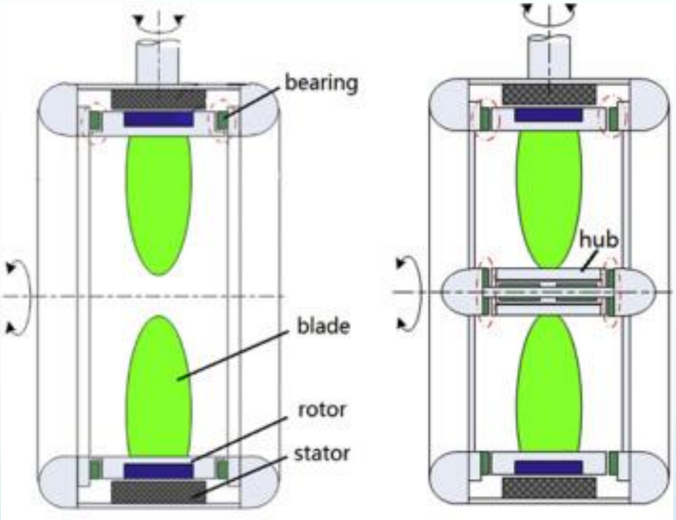
Source: *Reference News*, 17 Mar 2017

Submarine shaftless drive (SSD)

- In July 2017, the Chinese People's Liberation Army Navy (PLAN) claimed to have developed a new electrically-powered pump jet propulsor that would theoretically be much quieter than any current-generation Western submarine propulsion system. Unlike a conventional submarine propulsor design, which is turned by a mechanical drive shaft, the new Chinese propulsor is claimed to be a rim-driven system powered by an electrical motor embedded in the propulsor's shroud, which turns the vane rotor inside the pump jet cavity to create thrust.
- PLAN announced that the new rim-driven pump jet will be fitted onto its next-generation nuclear submarines. However, PLAN did not confirm which of its new submarines might receive the new propulsor technology. Two models known to be under development are the Type 095 attack submarine and the Type 096 ballistic missile submarine.

Submarine shaftless drive (SSD)

- Two basic configurations of rim-driven propulsors are shown in the following diagrams. Motor (stator) windings are in the pump jet shroud, which is directly fixed to the ship's structure and transmits the propulsion force to the submarine.
- The permanent magnets are in the rotor and are driven by the rotating magnetic field created by the stator. The blades of the pump jet are attached to the inner surface of the rotor and may be hub-less (i.e., the tips of the blades don't touch) or it may have a hub connecting all blades into a integrated structure.
- The motor is powered by a stepless, variable frequency converter that determines rotor speed and direction.



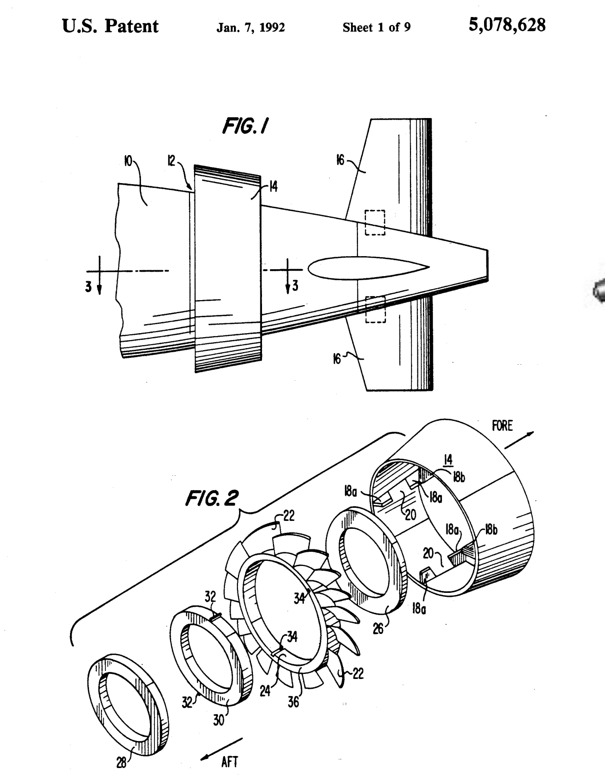
(a) Hub-less RDT and (b) hub type RDT

- Key challenge in implementing SSDs have been in developing the power electronics and the motors capable of reliably generating the propulsion power needed by modern submarines: about 30,000 shp, 22.3 MW for a Type 093 SSN.
- SSD weight is greater than a comparable mechanically- driven propeller or pump jet, making it more difficult to achieve fore-aft balance in a submarine with an SSD.

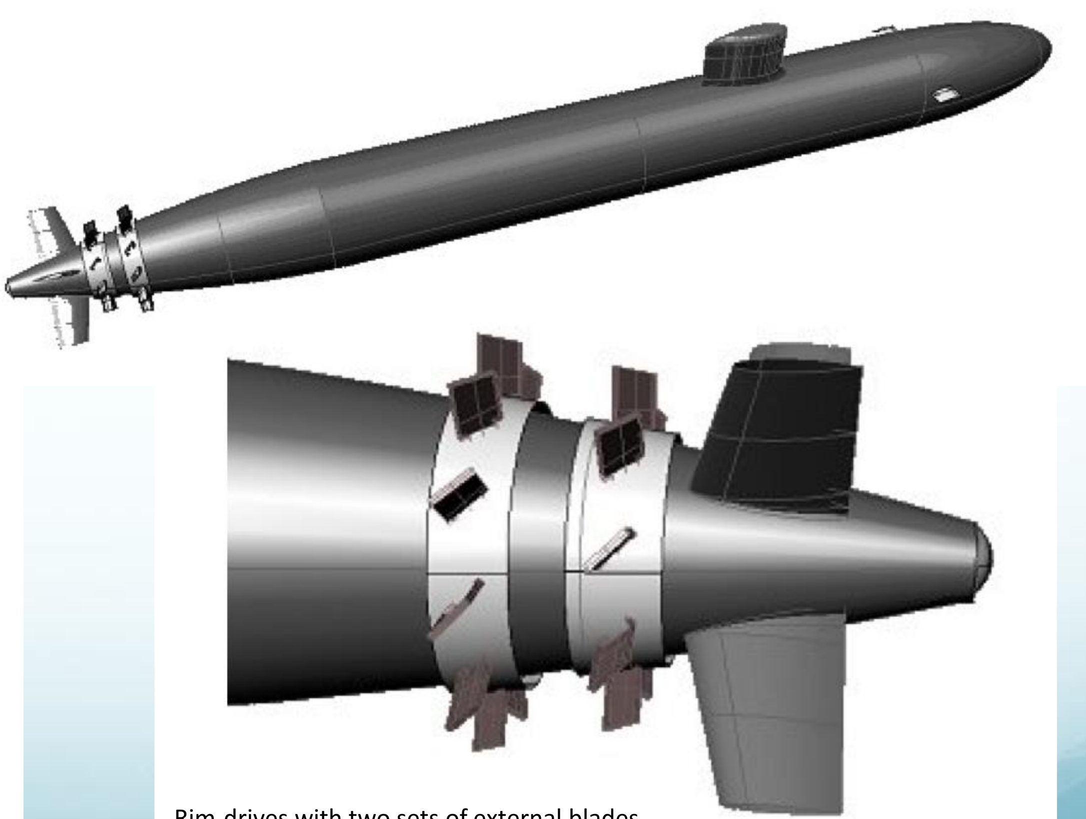
Source: Xinping Yan, et el., "A review of progress and applications of ship shaft-less rim-driven thrusters," Ocean Engineering, Vol 144, November 2017

Submarine shaftless drive (SSD)

- Another SSD concept places the electric motor inside the hull, instead of inside the pump jet shroud.
- In this case, the rotor is external to the hull and may be shrouded or not, as shown in the following two concept diagrams.



Rim drive with shrouded external blades.
Source: Newport News Shipbuilding & Drydock

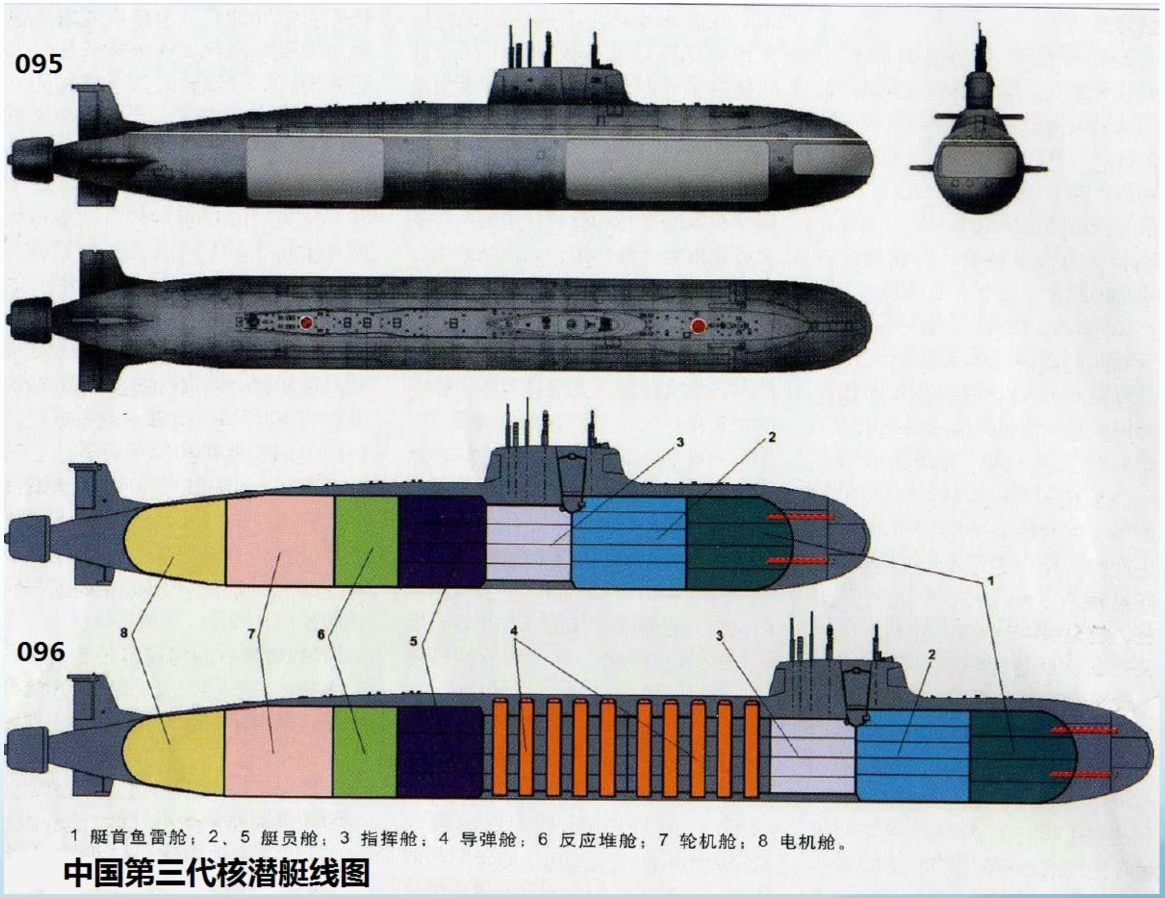


Rim-drives with two sets of external blades.
Source: MIT

Type 095 multi-mission SSN

- China's 3rd-generation SSN currently being developed is expected to feature:
  - Multi-mission capabilities, including removable deck-mounted shelters for special operations forces & equipment
  - A version with a large number of VLS tubes for cruise missiles
  - Advanced nuclear reactor, longer-life reactor core
  - Advanced sonar suite, including flank sonar panels and towed-array sonar
  - Lower acoustic signature
  - Pump-jet or shaftless propulsor
  - Crew escape pod in the sail

Speculative Type 095 SSN highlighting its potential commonality with the Type 096 SSBN



Source: sinodefenceforum.com

Submarine-launched tactical weapons

Torpedoes,
ASW missile / torpedoes,
Anti-ship missiles

Chinese submarine-launched torpedoes

Weapon	Years in service	Weight	Length	Diam	Speed / Propulsion	Range / guidance	Warhead
Yu-1 ASuW torpedo Yu-1A ASW torpedo	1971 - present	2,000 kg (4,409 lb)	7.8 m (25.6 ft)	533 mm (21 in)	39 or 50 kts / Steam powered	3.5 km @ 50 kts, 9 km @ 39 kts / initially straight running gyroscopic; later upgraded for passive acoustic homing ASW	Conventional, 400 kg (882 lb) HE
Yu-3 ASW torpedo	IOC 1984	1,340 kg (2,954 lb)	7.8 m (25.6 ft)	533 mm (21 in)	35 kts / Silver-zinc battery	13 km (8 mi) /Initial bearing, then terminal active / passive homing and re-attack	Conventional, 205 kg (452 lb) HE
Yu-4 ASuW torpedo	IOC 1982 (Yu-4A) 1987 (Yu-4B)	1,775 kg (3,913 lb)	7.75 m (25.4 ft)	533 mm (21 in)	40 kts / / Silver-zinc battery	Upgraded to 15 km (9.3 mi) / Initial bearing, then terminal active / passive homing and re-attack	Conventional, 309 kg (681 lb) HE
Yu-5 ASW torpedo	IOC 1989	1,820 kg (4,012 lb)	7.8 m (25.6 ft)	533 mm (21 in)	50 kts / Otto fuel II engine	30 km (18.6 mi) /Wire guided with terminal active / passive homing and re-attack	Conventional, 205 kg (452 lb) HE

Chinese submarine-launched torpedoes

Weapon	Years in service	Weight	Length	Diam	Speed / Propulsion	Range / guidance	Warhead
Yu-6 ASW & ASuW torpedo	IOC 2005	2,700 kg (5,952 lb)	7.8 m (25.6 ft)	533 mm (21 in)	45 kts / Otto fuel II engine	45 km (28 mi) / Wire guided with terminal active / passive homing, wake homing, and re-attack	Conventional, 210 kg (462 lb) HE
Yu-9 ASW & ASuW torpedo	Not known	Not known	Not known	533 mm (21 in)	Speed not known / Electric	Range not known, guidance similar to Yu-6	Sodium hydride chemical reaction warhead

Yu-1 ASuW torpedo

- The Yu-1 was the first domestically-produced, submarine-launched torpedo deployed by the PLAN.
- Design began in 1958 as a development of the Soviet Type 53 ASuW torpedo. The subsequent Sino-Soviet political split ended the collaborative development relationship, and, by September 1960, the Soviet Union withdrew its advisers.
- By July 1962 Chinese researchers recommended a steam-powered torpedo, and in 1963 PLAN issued an order for its development. This resulted in the Yu-1 torpedo.
- Initial Operating Capability (IOC) was in 1971.
  - Guidance was by bearing-only at launch, then straight running to the target.
  - Modernized later in life with passive acoustic guidance to perform the ASW mission.
  - Some Yu-1 torpedoes have been modified for use as bottom-moored torpedo/mines, similar to the US Mark 60 CAPTOR mine.
- Basic design parameters:
  - Weight: 2,000 kg (4,409 lb)
  - Diameter: 533 mm (21 in)
  - Length: 7.8 m (25.6 ft)
  - Propulsion: Steam-powered
  - Speed: 39 or 50 knots
  - Maximum range: 3.5 km @ 50 kts, 9 km @ 39 kts
  - Warhead: 400 kg (882 lb) high-explosive
- The importance of the Yu-1 torpedo is that through its development program, China established an indigenous torpedo industry.

Yu-1 ASuW torpedo

Source: Max Smith - Self-photographed at the Beijing Military Museum

Yu-1 Torpedoes contra-rotating propeller sectionSource:
Max Smith - Self-photographed at the Beijing Military Museum

Yu-3 ASW torpedo

- The Yu-3 was the first submarine-launched ASW torpedo deployed by the PLAN, intended for use on Chinese nuclear-powered submarines.
- Almost all technology and design was indigenous. Design began in 1964; sea trials started in 1972.
- Initial Operating Capability (IOC) was in 1984.
  - Bearing-only at launch, then passive guidance with a range of about 0.9 km (0.5 naut. mile) and the ability to circle back and reacquire the target if it missed on the first pass.
  - Modernized in 1991 with active/passive guidance. Also modernized to give it an anti-surface (ASuW) capability.
  - Some Yu-3 torpedoes have been modified for use as bottom-moored torpedo/mines, similar to the US Mark 60 CAPTOR mine.
- Basic design parameters:
  - Weight: 1,340 kg (2,954 lb)
  - Diameter: 533 mm (21 in)
  - Length: 7.8 m (25.6 ft)
  - Propulsion: electrical, silver-zinc battery
  - Speed: 35 knots (65 kph, 40 mph)
  - Maximum range: 13 km (8.0 miles, 7.0 naut. miles)
  - Maximum operating depth: up to 400 m (1,312 ft)
  - Warhead: 205 kg (452 lb) high-explosive

Yu-4 ASuW torpedo

- The Yu-4 was China's first modern anti-ship (ASuW) submarine-launched torpedo.
- In 1958, the Soviet Union agreed to transfer technology to the PRC for the then-current Soviet SAET-50 passive-homing, electric-powered torpedo. Technology transfer was incomplete before a political split between China and Russia. Development stalled and then was not restarted until 1966. Five prototypes of the original Yu-4 were presented to the PLAN in 1971, but were not accepted. Development continued.
- Initial Operating Capability (IOC) for Yu-4A was in 1982 and for Yu-4B in 1987.
  - Yu-4A has simple passive homing; Yu-4B has active/passive homing.
  - Seeker range is about 1.4 km (0.76 naut. mi.) and the torpedo has the ability to circle back and reacquire the target if it missed on the first pass.
  - Yu-4 upgrades during its operating life resulted in longer range and higher speed.
- Basic design parameters:
  - Weight: 1,775 kg (3,913 lb)
  - Diameter: 533 mm (21 in)
  - Length: 7.75 m (25.4 ft)
  - Propulsion: Electric, silver-zinc battery; based on Russian SAET-50 torpedo.
  - Speed: 40 knots (74 kph, 46 mph) (upgraded version)
  - Maximum range: Originally 6 km (3.2 naut. mile); upgraded to 15 km (8.1 naut. miles)
  - Warhead: 309 kg (681 lb) high-explosive
- Due to its relative obsolescence, the Yu-4 is largely relegated to reserve roles in the PLAN. Some Yu-4 torpedoes have been modified for use as bottom-moored torpedo/mines, similar to the US Mark 60 CAPTOR mine.

Yu-3 and Yu-4 torpedoes

Yu-3. ASW torpedo Source: http://cmano-db.com/weapon/531/

Yu-4A ASuW torpedo. Source: http://cmano-db.com/weapon/532/

Yu-5 ASW torpedo

- The Yu-5 originally was developed as an ASW weapon for the PLAN's diesel-electric submarines.
- Initial Operating Capability (IOC) was in 1989.
  - First Chinese torpedo to incorporate Otto Fuel II technology, believed to be based on technology in the US Mark 46 Mod I light-weight torpedo, which was recovered in the South China Sea in 1978.
  - First Chinese torpedo to use wire-guidance technology, allowing the operator to steer the torpedo more precisely to a point near the target.
  - The torpedo also has active / passive sonar sensor with a maximum range of 2.8 km (1.5 naut. miles) and the torpedo has the ability to circle back and reacquire the target if it missed on the first pass.
- Basic design parameters:
  - Weight: 1,820 kg (4,012 lb) (est.)
  - Diameter: 533 mm (21 in)
  - Length: 7.8 m (25.6 ft)
  - Propulsion: Otto Fuel II engine
  - Speed: 50 knots (92.6 kph, 57.5 mph)
  - Maximum range: 30 km (18.6 miles, 16.2 naut. miles)
  - Maximum operating depth: > 400 m (1,312 ft)
  - Warhead: 205 kg (452 lb) (est.) high-explosive
- Modifications made in the period from 1995 – 1998 modernized electronics, added an ASuW capability. These torpedoes can modified for use as bottom-moored torpedo/mines, similar to the US Mark 60 CAPTOR mine.

Yu-6 ASW and ASuW torpedo

- The Yu-6 is the first Chinese submarine-launched torpedo originally designed to counter both surface ships and submarines.
- Guidance can be by wire, active and passive homing, or wake homing. If the wire is severed, the targeting information stored in the memory enables the computer on board to calculate the approximate new location of the target, augmenting the acoustic homing to achieve a higher kill probability.
- China is rumored to have recovered at least one US Mark 48 heavyweight, submarine-launched torpedo. If so, then the PLAN may have reverse engineered some design features incorporated in the Yu-6.
  - The Yu-6 is the first Chinese torpedo incorporating modular design and open architecture software programming. When new technologies and programs become available, they can be more easily incorporated.
- Initial Operating Capability (IOC) was in 2005, following about 10 years of development.
- Basic design parameters:
  - Weight: 2,700 kg (5,952 lb)
  - Diameter: 533 mm (21 in)
  - Length: 7.8 m (25.6 ft)
  - Propulsion: Otto Fuel II engine.
  - Speed: 65 knots (120 kph, 75 mph) attack speed
  - Maximum range: 45 km (28 miles, 24.3 naut. miles) at cruise speed
  - Warhead: 210 kg (462 lb) high-explosive
- Yu-6 torpedoes can modified for use as bottom-moored torpedo/mines, similar to the US Mark 60 CAPTOR mine.

Yu-5 and Yu-6 torpedoes

Yu-5 ASW torpedo. Source: http://cmano-db.com/weapon/533/

Yu-6 ASW / ASuW torpedo. Source: adapted from http://cmano-db.com/weapon/2872/

Yu-9 ASW and ASuW torpedo

- The Yu-9 is an electrically-driven counterpart to the Yu-6. Both are designed to counter surface ships and submarines. Guidance can be by wire, active and passive homing, or wake homing. The Yu-9 torpedo is reportedly the first Chinese torpedo to incorporate wire guidance with optical fiber.
- Otto fuel II powered torpedoes can cost up to three times more than an electrically driven counterpart; the Yu-9 was developed as a cheaper alternative to the Yu-6.
- Initial Operating Capability (IOC) was in 2012.
- Basic design parameters:
  - Weight: Similar to Yu-6
  - Diameter: 533 mm (21 in)
  - Length: Similar to Yu-6
  - Propulsion: electric motor
  - Speed: Likely less than Yu-6
  - Maximum range: Likely less than Yu-6
  - Warhead: The Yu-9 is armed with a new warhead not found on other Chinese torpedoes. The new warhead utilizes sodium hydride compounds to create a violent chemical reaction with seawater. On detonation, a large amount of sodium powder is released, which reacts with seawater to produce large amounts of very-high-temperature hydrogen within a very short period of time; the temperature instantly increases to over 2,000 °C within a radius of a few dozen meters as the hydrogen reacts with oxygen, destroying the target even if not hit directly. Development of the warhead was completed by 2006.

Source: https://en.wikipedia.org/wiki/Yu-6_torpedo

Chinese submarine-launched anti-submarine missiles

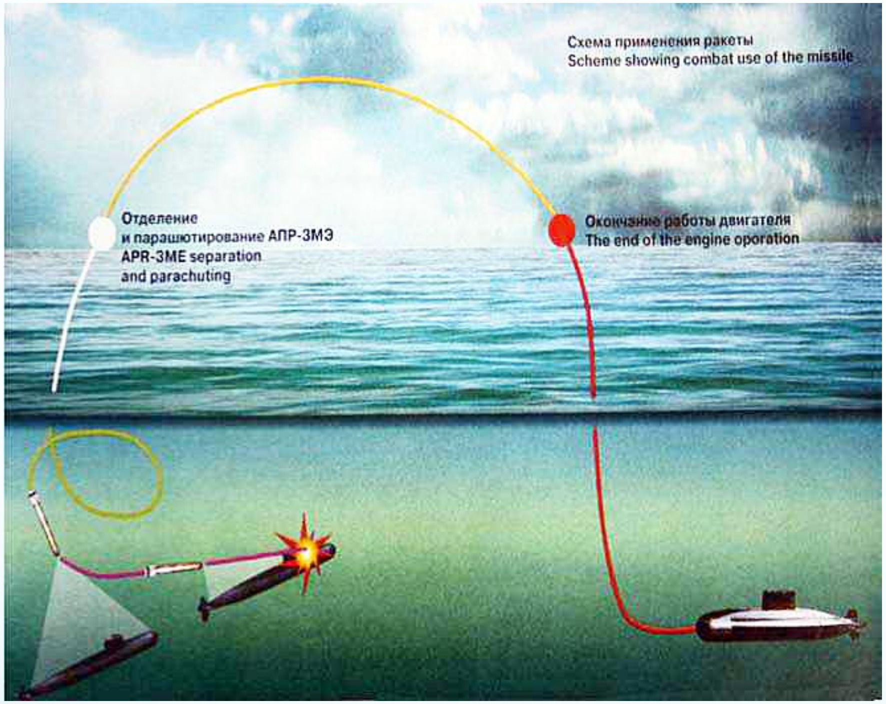
Anti-sub missile	Years in service	Weight	Length	Diam (D) /Span (S)	Speed	Range	Guidance	Warhead
Yu-8	2014 - present	700 kg (1,543 lb)	5 m (16.4 ft)	D = 533 mm (21 in)	Subsonic	30 - 50 km (18.6 - 31 miles)	Missile: Inertial + mid-flight target updates from external sources Torpedo: active / passive homing	400 mm (15.75 in) APR-3ME lightweight ASW torpedo with a 76 kg (168 lb) HE warhead or comparable Chinese torpedo
Long-range ASW missile / torpedo	Under development in 2018. Uncertain if there will be a submarine-launched version	Not known	Not known	Not known	Subsonic	> Yu-8	Not known	Lightweight ASW torpedo, similar to Yu-8

Yu-8 ASW missile / torpedo

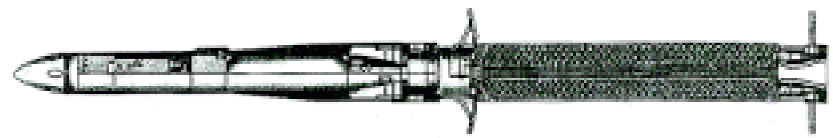
- Original development of Chinese rocket-assisted ASW torpedo weapons began in about 1998 with the CY-1 (Yu-7) and continued through with the CY-2 to CY-5. The Yu-8 ASW missile / torpedo appears to have been developed from these predecessors by the 705th Research Institute in Kunming, under a program begun in 2002 and completed in 2006. The existence of the Yu-8 designation was first revealed in March 2014.
- The Yu-8 appears to be similar to the Russian 91RE1 Kalibr / Club-S (submarine-launched version) and 91RE2 Club-N (surface ship-launched version). The Yu-8 is comprised of a solid rocket booster section and a lightweight ASW homing torpedo
  - After launch from a submarine or surface ship, the Yu-8 missile flies a semi-ballistic guided trajectory to the target area. The missile is able to receive post-launch targeting updates from various sources, such as ASW helicopters.
  - The torpedo is thought to be a Russian APR-3E or a longer-range Chinese version.
  - The active / passive sensors on the homing torpedo are expected to have a detection of 1.1 to 2.5 km (0.6 to 1.3 naut. miles).

Source: Lyle J. Goldstein, “China's New Missile-Torpedo May Curb US Submarine Power,” The National Interest, 16 Aug 2016, and other sources.

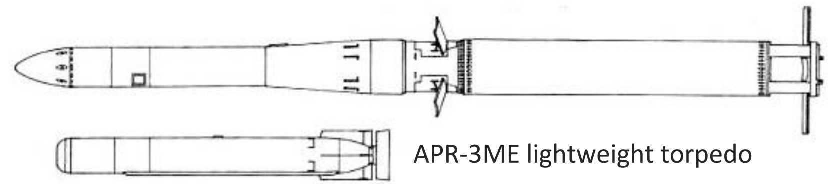
China’s Yu-8 appears similar to Russia’s 91RE1 Kalibr / Club-S



The 91RE1 (Club-S) ASW mission profile is shown above.
The Yu-8 can accept in-flight targeting updates.



91RE1 (Club-S) general arrangement



APR-3ME lightweight torpedo

91RE1 (Club-S) control fins

Source, all graphics this page:
http://armasrusasb.blogspot.com/2017/02/misiles-antisubmarinos-delanzamiento.html

Yu-8 ASW missile / torpedo

- Basic design parameters:
  - Weight: 700 kg (1,543 lb) (est.)
  - Length: 5 m (16.4 ft) (est.)
  - Diameter: Missile section - 533 mm (21 in); torpedo section - 350 mm (13.8 in) (est.)
  - Propulsion: Solid fuel rocket booster
  - Speed (airborne): Mach 0.9 – 0.95
  - Maximum range: 30 - 50 km (18.6 – 31 miles) (est.)
  - Warhead: High-explosive

- Operational matters:
  - PLAN is reported to have successfully tested the submarine-launched version of the Yu-8 anti-missile during a major fleet exercise in July, 2015

Yu-8 launch from a surface ship VLS launcher in 2015.
Source: http://errymath.blogspot.com/2016/05/yu-8-anti-submarine-missile-has.html#.W0p98y2ZOek

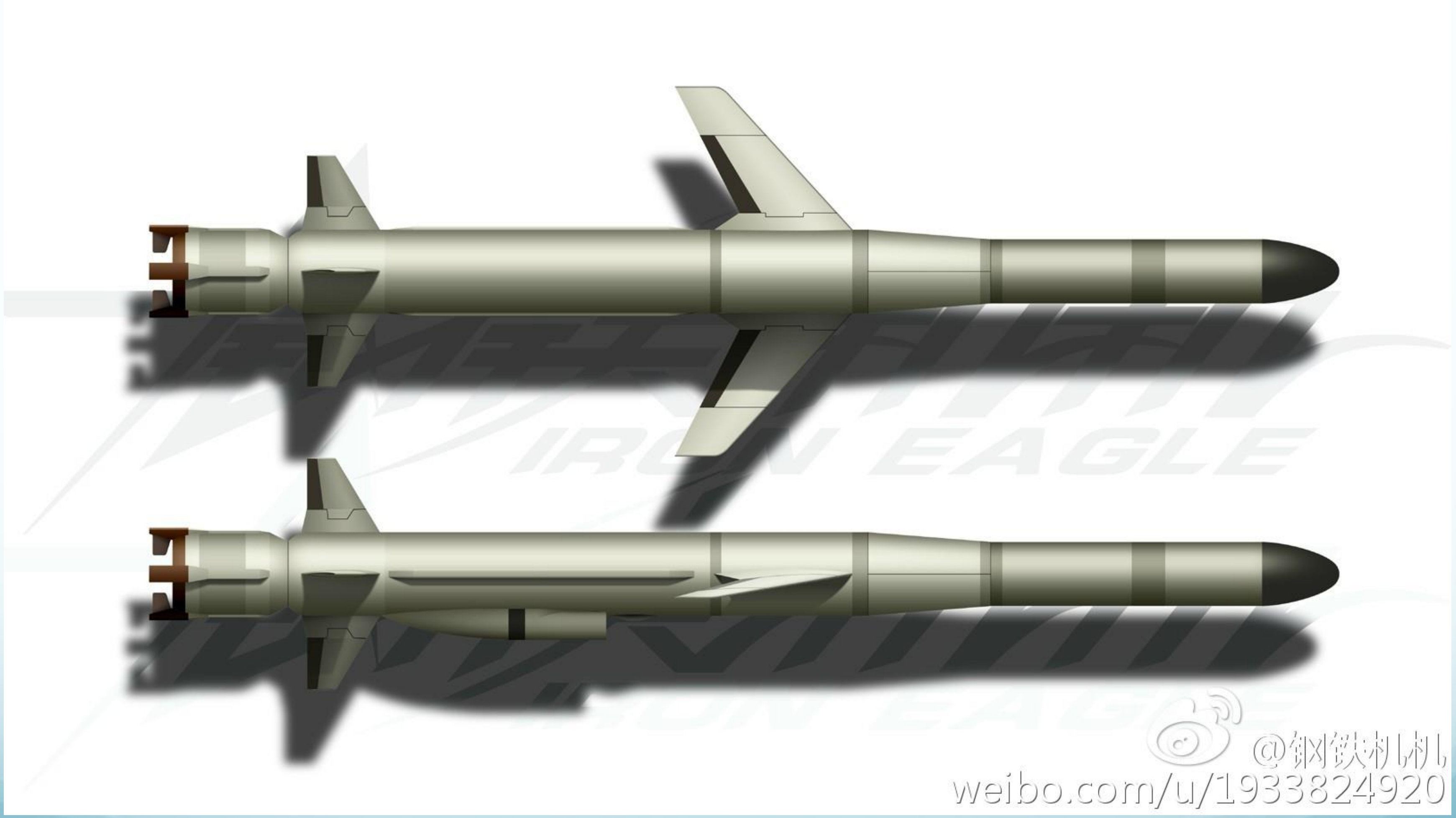
Long-range ASW missile / torpedo

- In November 2016, China unveiled on TV a new, long-range ASW missile / torpedo composed of three main parts: a small solid-fuel booster rocket, a winged section with foldable wings and control fins and an air intake suggesting the presence of a jet engine, and finally, a smaller-diameter nose section that likely houses a lightweight ASW torpedo.

Source: http://www.navyrecognition.com/index.php/news/defence-news/2016/

- This appears to be an ASW cruise missile that likely has a much longer range than the maximum 50 km (31 mile) range of the Yu-8.
- The intended launch platforms are not known. An encapsulated version would be required for submarine launch.

Long-range ASW missile / torpedo



Source: webio.com/u/1933824920 via https://www.sinodefenceforum.com/

Chinese submarine-launched anti-ship missiles

Missile	Years in service / Platform	Weight	Length	Diam (D) /Span (S)	Speed	Range	Guidance	Warhead
YJ-8 (fixed wing) (CSS-N-4 Sardine)	1985 – 1990 / Type 033G Romeo-class SSG (Wuhan A)	615 kg (1,356 lb) excluding booster	5.81 m (19.1 ft)	D = 360 mm (14.2 in) / S = 1.8 m (5.9 ft)	Mach 0.8	≈ 42 km (26 miles)	Inertial + terminal homing	Conventional HE, 165 kg (364 lb)
YJ-82 (CSS-N-8 Saccade)	1990 – present / Han- and Shang I & II-class SSNs, Yuan-class AIP, Song-class diesel-electric	715 kg (1,576 lb)	Missile only: 4.6 m (15.1 ft) Encapsulated missile: 6.1 m (20.0 ft)	D = 533 mm (21 in) encapsulated / S = 1.8 m	Mach 0.8	30 – 34 km (18.6–21.1 miles)	Inertial + terminal homing	Conventional HE, 165 kg (364 lb)
YJ-83	A submarine-launched version may not have been developed	Not known	Missile only: about 5.1 m (16.7 ft) + booster stage	Not known	Mach 0.8 - 0.9	180 km (112 miles)	Inertial + terminal homing	Conventional HE
Kalibr/Klub/Club (3M54E) (SS-N-27 Sizzler)	Purchased from Russia, IOC in 2004 - 2006 / Kilo-class SS	1,780 kg (3,924 lb)	Club S: 6.2 m (20 ft)	D = 530 mm (21 in) encapsulated	Subsonic cruise + Mach 2.5 - 2.9 terminal “sprint”	220 km (137 mi)	Inertial + terminal homing	Conventional HE, 200 kg (440 lb)

Chinese submarine-launched anti-ship missiles

Missile	Years in service / Platform	Weight	Length	Diam (D) /Span (S)	Speed	Range	Guidance	Warhead
YJ-18	Shang III-class SSNs in VLS launchers, possible retrofit to other sub classes	Not known	No known	Not known	Subsonic cruise + Mach 2.5 - 3.0 terminal “sprint”	Comparable to 3M54E	Inertial + terminal homing	Conventional HE, Warhead size likely 180 – 300 kg (397 – 661 lb)

YJ-8 (YingJi-8)

Anti-ship missile (CSS-N-8 Saccade)

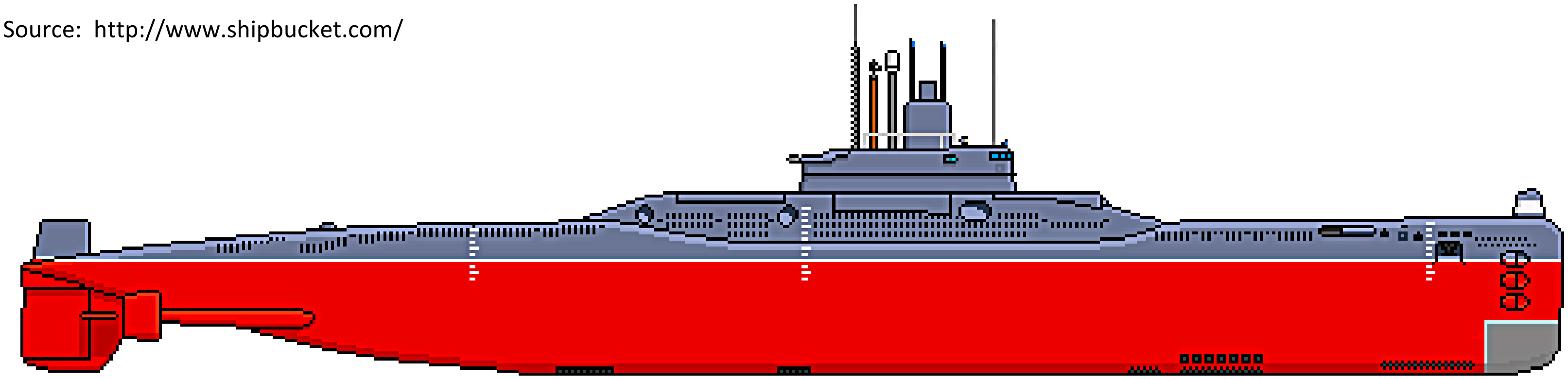
- The YJ-8 (C-801) is a family of anti-ship cruise missiles that was developed in the 1970s for use against medium-to-large surface vessels and could pose a danger to US carrier strike groups.
  - The YJ-8 is roughly comparable to the French MM38 Exocet anti-ship cruise missile.
  - The initial fixed-wing models reached an initial operating capability (IOC) in the PLAN in 1987 on frigates and on one modified Type 033G Romeo-class diesel-electric submarine that could only fire the YJ-8 when surfaced.
  - The YJ-8 uses a mixture of analog & digital electronics; digital altimeter
- Several other more compact versions with folding aerodynamic surfaces (YJ-8A) have been developed for launch from aircraft, surface ships, submarines and land-based vehicles.
- Range is about 42 km (22.7 nautical miles).

Source: Christopher Carlson, “China’s Eagle Strike-8 Anti-Ship Cruise Missiles,” Cold Wars 2013

Type 033G SSG

Romeo SSG (Wuhan A) with YJ-8 fixed-wing anti-ship missile

Source: http://www.shipbucket.com/



- In 1976, No.701 Institute (now Wuhan Ship Development and Design Institute) added the YJ-8 (C-801) anti-ship missile system and its associated Type 358G fire-control radar to one Type 033 Russian-built Romeo-class diesel-electric submarine. Three YJ-8 missile launcher containers were installed on each side of the sail, with the fire-control radar located behind the sail.
  - Design of the modified submarine, designated Type 033G, was completed in 1978, and the construction of the first boat (pennant number 351) began in 1980 at Wuchang Shipyard in Wuhan.
  - The submarine was delivered to the PLAN in October 1983. It was code named Wuhan-A by Western intelligence.
  - In early 1985, Boat 351 carried out three rounds of live fire test of the YJ-8 missile, with all tests being successful.

Source: http://submarinersworld.blogspot.com/2012/04/china-romeo-class-diesel-electric.html

Type 033G SSG

Romeo-class SSG (Wuhan A) with Yu-8 fixed-wing anti-ship missile

- Type 033G design parameters
  - Length: 76.6 m
  - Beam: 6.7 m
  - Displacement: 1,650 tons surfaced; 2,100 tons submerged
  - Speed surfaced: 15 knots; submerged: 12.5 knots
  - Operational depth: 200 m
  - Armament:
    - 6 x YJ-8 anti-ship missiles
    - YU-1 / -1A and YU-4 torpedoes
- Type 033G operational characteristics:
  - A major weakness with the Type 033G is the fact that the submarine could not launch its missiles from underwater. To launch its six YJ-8 missiles, the submarine must fully surface, with its speed less than 8 knots. The six missiles could be launched within 6 to 7 minutes. This seriously limited the submarine’s effectiveness and survivability in real combat.
  - As a result, the submarine served only as an experimental platform, with no subsequent operational units being built. Boat 351 may have been out of service in the late 1990s.

Source: http://submarinersworld.blogspot.com/2012/04/china-romeo-class-diesel-electric.html

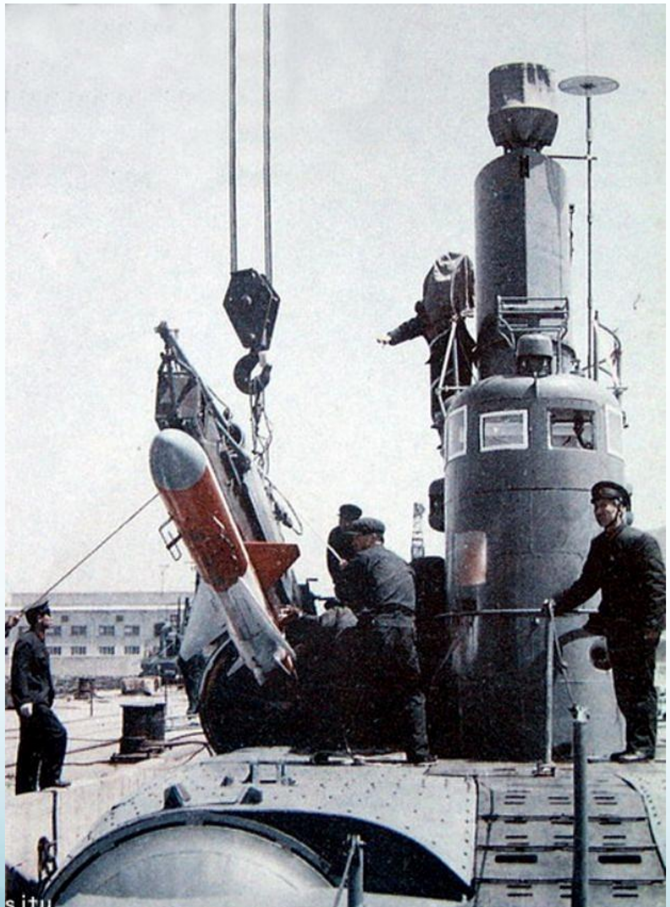
Type 033G SSG

Romeo SSG (Wuhan A) with Yu-8 fixed-wing anti-ship missile

Source,, three photos: http://seesaawiki.jp/w/namacha2/

Type 033G SSG

Romeo SSG (Wuhan A) with Yu-8 fixed-wing anti-ship missile



Source, two photos: http://seesaawiki.jp/w/namacha2/

YJ-82 (YingJi-82), Eagle Strike-8

Submarine-launched anti-ship missile (CSS-N-8 Saccade)

- The submerged-launched version of the YJ-8 is known as the YJ-82. Unlike surface-launched YJ-8 versions, the YJ-82 does not have a booster stage.
  - IOC was in the early 1990s.
  - Range of the YJ-82 is less than the 42 km (22.7 nautical miles) range of the missile versions with a booster stage. The YJ-82 likely has a range of 30 - 34 km (16 - 18 nautical miles). This short range means that the launch will almost certainly be seen by its target, as the missile will be within the radar horizon of most warships by the time it reaches ten meters in altitude after launch.
  - The CJ-801Q is an export version of the YJ-82.
- YJ-82 mission profile: The missile is launched from a 533 mm (21 in) torpedo tube in a buoyant capsule similar to that used by the US UGM-84 Harpoon anti-ship missile. At the surface, a solid rocket motor fires and propels the missile to the target at subsonic speed (about Mach 0.8) and very low altitude; 5 to 7 meters (16.4 to 23 feet) above sea level.

Source: Christopher Carlson, “China’s Eagle Strike-8 Anti-Ship Cruise Missiles,” Cold Wars 2013

YJ-82 (YingJi-82), Eagle Strike-8

Submarine-launched anti-ship missile (CSS-N-8 Saccade)

- The YJ-82 is widely deployed on China's submarines:
  - Type 091 Han-class SSNs
  - Type 093 & 093A Shang I & II-class SSNs
  - Yuan-class air-independent diesel-electric attack submarines
  - Song-class diesel-electric attack submarines
- The newest Type 093B Shang III class SSN/SSGNs may not have been armed with the YJ-82, instead being armed with the more capable YJ-18. *
- The Shang I & II, Yuan and Song-class submarines are expected to be upgraded to use the YJ-18. The Han-class SSNs are not. *

* Source: M. Pilger, et al., "China's New YJ-18 Antiship Cruise Missile: Capabilities and Implications for US Forces in the Western Pacific," United-States – China Economic and Security Review Commission, October 2015

YJ-82 (YingJi-82), Eagle Strike-8

Submarine-launched anti-ship missile (CSS-N-8 Saccade)

Source: Christopher Carlson, “China’s Eagle Strike-8 Anti-Ship Cruise Missiles,” Cold Wars 2013

YJ-83 (YingJi-83)

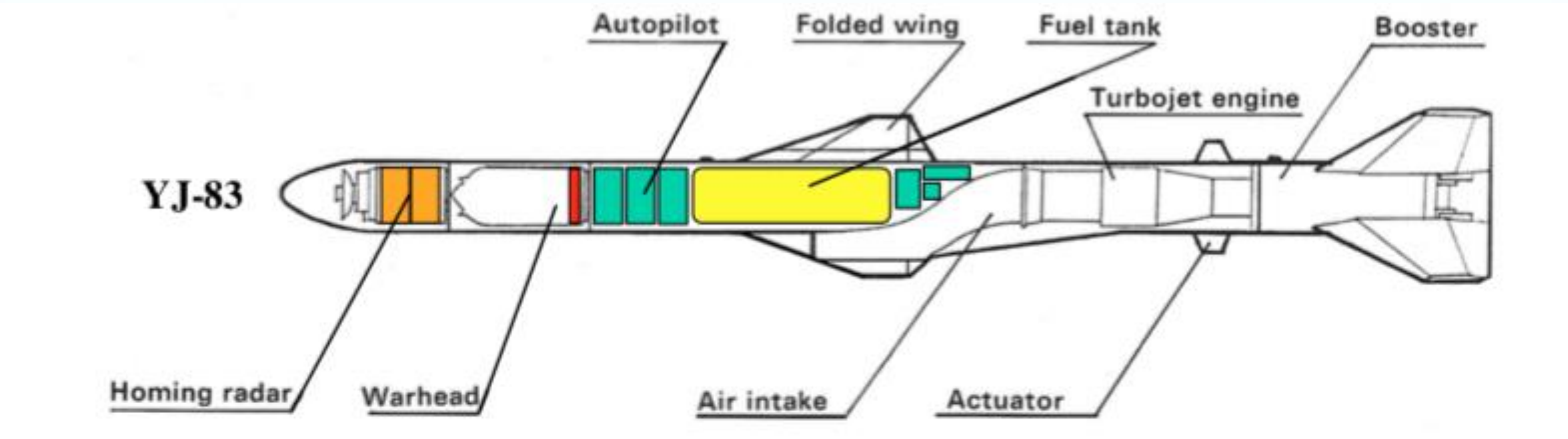
Long-range anti-ship cruise missile

- The YJ-83 is based on the C-802, which was developed by China as an export-only, long-range, anti-ship cruise missile powered by a small turbojet engine.
  - The YJ-83's small turbojet engine appears to be derived from the French TRI 60-2 turbojet, which were first delivered to China in 1987 by the firm Microturbo SA.
  - It appears that China did not adopt the C-802 for its own military.
  - C-802 IOC with Iran was in about 1995.
- The YJ-83 was developed in the early 1990s, with an IOC in the PLAN in about 1998.
  - Uses modern digital microprocessors and a compact strap down inertial reference unit (IRU); also terminal homing.
  - Maximum range is about 180 km (112 miles) with a 190 kg (419 lb) warhead.
- A submarine-launched version, thought to be designated YJ-83Q, has not been observed and may not have been developed.
  - The YJ-83 missile is about 0.5 m (19 inches) longer than YJ-8, and also requires a separate solid rocket booster to get airborne. An encapsulated YJ-83 may have been too long for launching via submarine torpedo tubes.

Source: Christopher Carlson, "China's Eagle Strike-8 Anti-Ship Cruise Missiles," Cold Wars 2013

YJ-83 (YingJi-83)

Long-range anti-ship cruise missile



Source: Christopher Carlson, "China's Eagle Strike-8 Anti-Ship Cruise Missiles," Cold Wars 2013

Kalibr / Club / SS-N-24 Sizzler

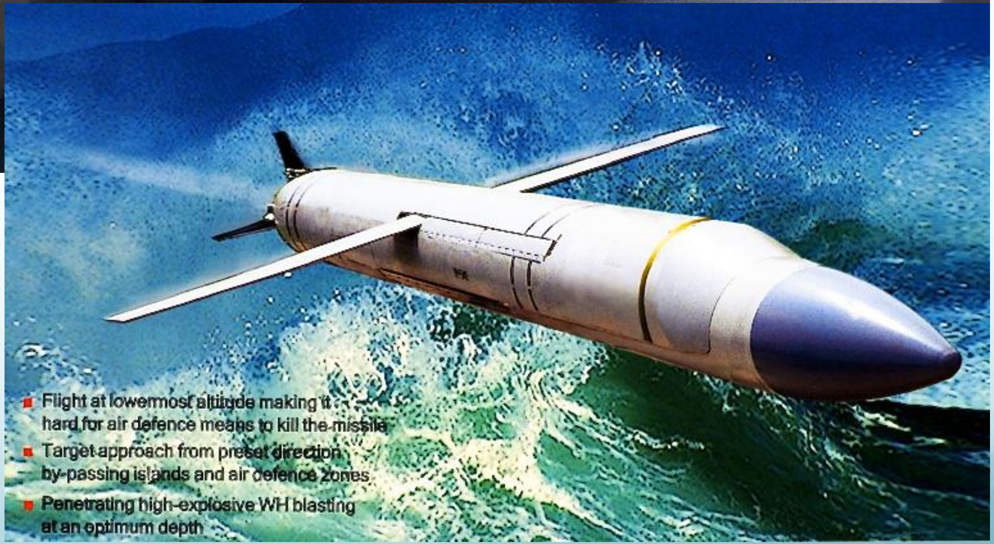
Subsonic + terminal supersonic anti-ship cruise missile (aka 3M54E)

- The Kalibr 3M54E (aka Club, Klub) is a Russian-developed anti-ship cruise missile that is available in submarine-, surface ship-, and air-launched versions. The missile is used by Russian naval forces and and is available in export versions.
  - China is an export customer. China acquired this missile between 2004 - 2006 to arm its Russian-built Kilo-class diesel-electric subs.
- Except in the air-launched version, a small rocket booster launches the weapon, then a turbojet engine powers the missile at subsonic speed until in the vicinity of the target. Then, a small, rocket-propelled “second stage” warhead separates from the subsonic airframe, accelerates to about Mach 2.5 - 2.9, and uses active radar to home in on the designated target.
- The 3M54E can be launched from a submarine via a standard 533 mm (21 in) torpedo tube or from VLS launcher at a launch depth of 30 - 40 m (98 – 131 ft).
- Penetrating high-explosive warhead.
- Range is about 220 km (137 mi).

Kalibr / Club / SS-N-24 Sizzler

Subsonic + terminal supersonic anti-ship cruise missile (aka 3M54E)

Source, above: Allocer via https://commons.wikimedia.org/wiki/File:3M-54E_missile_MAKS2009.jpg



Source: http://www.ausairpower.net/APA-Rus-Cruise-Missile

YJ-18 (YingJi-18)

Subsonic + terminal supersonic anti-ship cruise missile

- The YJ-18 is an indigenous anti-ship cruise missile with operational parameters that are very similar to the Russian 3M54E Kalibr/Club submarine-launched anti-ship missile used by China on its Russian-built Kilo-class diesel-electric submarines.
- Basic operational parameters reported * for the YJ-18 are:
  - Mission profile: Subsonic cruise on a sea-skimming flight path until about 20 naut. miles (23 miles, 37 km) from the target, while still beyond the radar detection horizon for surface ships. Then the warhead section separates from the missile and accelerates to supersonic speed for the terminal homing phase. At maximum range, the cruise phase lasts about 30 minutes. The terminal homing phase lasts about 40 seconds.
  - Propulsion: Turbojet/turbofan for cruise phase; solid rocket for terminal homing phase.
  - Speed: subsonic cruise at about Mach 0.8 (600 mph, 966 kph); terminal homing at about Mach 3.0 (2,283 mph, 3,675 kph) at sea level.
  - Range: Probably comparable to the Russian 3M54: 118 naut. miles (220 km). It is unlikely that the 290 naut. miles (537 km) range cited by Pilger, et al., is correct.
  - Warhead: Conventional high explosive warhead reported variously between 180 – 300 kg (397 – 661 lb). There may be a version with an electromagnetic pulse (EMP) warhead.

* Source: M. Pilger, et al., "China's New YJ-18 Antiship Cruise Missile: Capabilities and Implications for US Forces in the Western Pacific," United-States – China Economic and Security Review Commission, October 2015

YJ-18 (YingJi-18)

Subsonic + terminal supersonic anti-ship cruise missile

- Targeting: China is building a robust C4ISR system for detecting ships and aircraft over the horizon, which would provide targeting data to launch platforms and to in-flight long-range missiles such as the YJ-18.
- In April 2015, the US Office of Naval Intelligence (ONI) confirmed that China has deployed the YJ-18 anti-ship cruise missile (ASCM) on some PLAN submarines and surface ships. China is expected to upgrade most of the submarine using the short-range YJ-82 missile, giving them the capability to launch the YJ-18 (i.e., Type 093 & 093A Shang-class SSNs, Yuan- and Song-class SS). The Type 091 Han-class SSNs are not expected to receive this upgrade. *
  - The Type 093B (aka Type 093G) Shang III-class SSNs have been outfitted with vertical launch system (VLS) missile tubes, and likely already carry the YJ-18.
  - China is expected to deploy the YJ-18 on the Type 095 SSN, which is still under development.
- The YJ-18's greater range and speed than previous Chinese ASCMs, along with its wide deployment across platforms, significantly increases China's anti-access/area denial (A2/AD) capabilities against US Navy surface ships operating in the Western Pacific during a potential conflict. *

* Source: M. Pilger, et al., "China's New YJ-18 Antiship Cruise Missile: Capabilities and Implications for US Forces in the Western Pacific," United-States – China Economic and Security Review Commission, October 2015

YJ-18 (YingJi 18)

Subsonic + terminal supersonic anti-ship cruise missile

YJ-18 missile in flight. Source: https://thaimilitaryandasianregion.wordpress.com/2017/01/page/8/

- The submarine-launched variant of the YJ-18 appears to have been revealed in September 2017 during a university lecture by former Rear Admiral Zhao Dengping, who is a deputy minister with the People's Liberation Army's General Armaments Department. Slides reproduced here are purported to show an YJ-18 underwater launch capsule and a submerged launch. *

* Source: "Submarine-Launched Variant of China's YJ-18 Supersonic Anti-Ship Missile Emerges," http://www.navyrecognition.com/index.php/news/defence-news/2017/

Cháng Jiàn CJ-10 Long Sword

Long-range, land-attack cruise missile (aka DH-10, DF-10A)

- The CJ-10 is a 2nd-generation land-attack cruise missile designed to carry a warhead of up to 500 kg (1,102 lb) and strike targets at distances of up to 1,500 km (932 miles).
  - Externally, the CJ-10 resembles the Russian Kh-55 and the US Tomahawk cruise missiles.
  - The CJ-10 may be a dual-capable (conventional or nuclear warhead) intermediate range missile.
- The CJ-10 is manufactured by the China Aerospace Science and Industry Corporation (CASIC) Third Academy; the China Haiying Electro-Mechanical Technology Academy.
- Numerous variants of the CJ-10 have been developed; land-, aircraft- and surface ship- launched versions have been observed. A submarine-launched version is expected, but, as of mid-2018 has not yet been observed.
- Historically, land-attack cruise missiles have not been carried on Chinese submarines. However, China has developed and deployed several Type 093B (aka Type 093G) Shang III-class multi-mission SSN / SSGN with a vertical launch system (VLS) that is capable of launching larger missiles than can be launched from a 533 mm (21 in) submarine torpedo tube.
  - The conventionally-powered Type 032 submarine appears to be a testbed for VLS-launched missiles, as well as for the JL-3 SLBM and torpedo tube-launched weapons.
  - Type 093B Shang III SSNs have become the first operational Chinese SSNs capable of being armed with a version of the CJ-10 land-attack cruise missiles.

Cháng Jiàn CJ-10 Long Sword

Long-range, land-attack cruise missile (aka DH-10, DF-10A)

CJ-10 mobile launcher.
Source: http://china-defense.blogspot.com/2017/

CJ-10 in-flight configuration. Source:
http://www.ausairpower.net/APA-PLA-Cruise-Missiles.html

- Guidance likely is a combination of inertial + satellite systems + terminal guidance. Available satellite navigation systems include:
  - Russia's GLONASS and the US GPS
  - China's indigenous BeiDou Navigation Satellite System (BDS), which is expected to be operational by about 2020.
- Trials of the land-based version started in about 2004 and missiles were operationally deployed by 2009. The surface-ship-launched version appears to have become operational in 2017.
- Deployment of the CJ-10 on the Type 093B SSN/SSGN and the Type 095 should be expected.

Nuclear-powered strategic ballistic missile submarines (SSBN)

Chinese diesel-electric SSBs are included in this section
in order to provide a more complete story about the submarines
involved in the development, testing and operational deployment
of submarine-launched ballistic missiles (SLBMs).

Chinese strategic missile submarines (SSBN)

Class	# in Class	SLBM	Length	Beam	Displacement (tons)	Reactor	Shaft hp	Max speed (kts)	Years delivered	Years in service
Type 031 Golf-class missile testbed	1	JL-1, JL-2	99 m (324.8 ft)	8.5 m (27.8 ft)	2,350 (surf), 2,900 (sub)	Diesel-electric	6,000	13 – 14	1964	1964 - present
Type 092 Xia-class	1	JL-1	120 m (393.7 ft)	10.0 m (32.8 ft)	xxxx (surf), 8,000 (sub)	1 x PWR 58 MWt	11,000 (est)	22	1981	1987 - present
Type 094 Jin-class	5 delivered Total of 8 planned	JL-2	135 m (442.9 ft)	12.5 m (41.0 ft)	xxxxx (surf), 11,500 (sub)	1 x PWR 150 MWt (est)	30,000 (est)	26	2007 - present	2010 - present
Type 032 Qing-class missile testbed	1	JL-3	92.6 m (303.8 ft)	10.0 m (32.8 ft)	xxxx (surf), 7,306 (sub)	Diesel electric	Not known	14 (est)	2012	2012 - present
Type 096 Tang-class	Not known	JL-3	Not known	Not known	Not known	Not Known	Not known	Not known	Not known	

Type 031 Golf I-class SSB

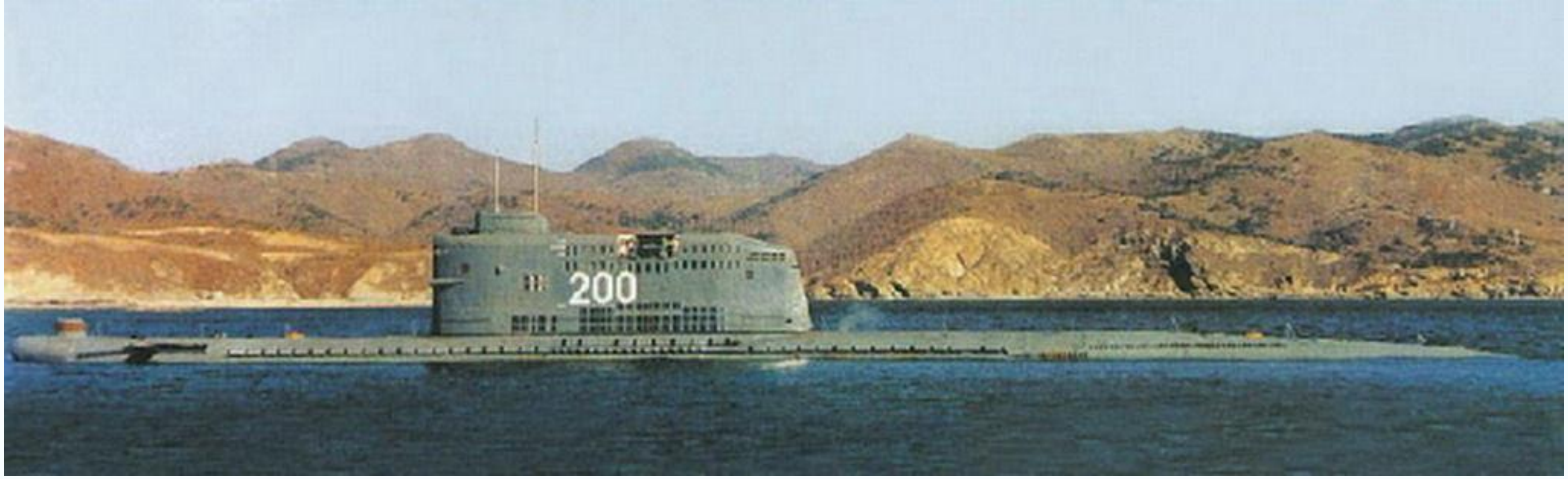
JL-1 & JL-2 SLBM testbed

- Initial Chinese efforts to create a sea-launched nuclear-missile system were based on using two Russian-designed Project 629 Golf -class diesel-electric submarines missile submarines each armed with three Russian-designed R-11F liquid-propellant SLBMs to be transferred from the USSR in the early 1960s. The plans to use the RF-11F were abandoned, but China proceeded to build their version of the Golf-I SSN under license to Russia.
- The Type 031 lead ship was built at Dalian shipyard, it is the only ballistic missile submarine to have license-built outside it's home country.
  - The boat was launched in September 1964.
  - The boat could accommodate only two launch tubes for the larger-diameter Chinese JL-1 solid fuel SLBMs in the sail.
  - Construction of additional Type 031 boats was abandoned by the early 1970s in favor the much more capable Type 092 SSBN. The one completed Type 031 boat (hull # 200) was assigned as an SLBM testbed.

Source: https://www.globalsecurity.org/wmd/world/china/golf.htm

Type 031 Golf I-class SSB

JL-1 & JL-2 SLBM testbed



Source, two photos: https://www.globalsecurity.org/wmd/world/china/golf.htm

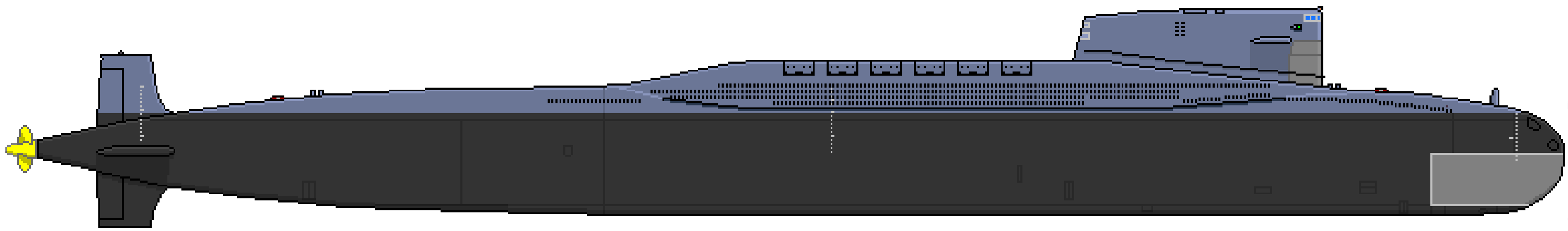
Type 031 Golf I-class SSB

JL-1 & JL-2 SLBM testbed

- Operational matters:
  - From the early 1980s to 1988, Type 031 hull # 200 successfully completed dozens of surface and underwater JL-1 launch test tasks.
    - Oct 1982 surface JL-1 launch; Mar – Apr 1984 underwater JL-1 test shape (mockup) launches; Sep 1985 initial underwater JL-1 launches
    - In September 1988, JL-1 testing transitioned to the Type 092 SSBN.
  - After the JL-1 trials were complete, hull # 200 was placed in reserve.
  - In the 1990s the Type 031 was reactivated for the JL-2 SLBM test program.
    - Only a single launch tube was configured for the JL-2 tests.
    - The JL-2 was test-fired three times from the Type 031: in 2005 (surfaced), 2006 (test failed) and 2008 (successful test).
    - In early 2009, JL-2 continued with a successful launch for the first time from a Type 094 SSBN.
  - With the conclusion of the Type 031's involvement in the JL-2 test program, hull # 200 was again placed in reserve.
  - Type 031 underwent a year-long maintenance refit between 2009 and 2010.
  - Its current operational status is not known.

Source: https://www.globalsecurity.org/wmd/world/china/golf.htm

Type 092 Xia-class SSBN



Source: adapted from shipbucket.com

- This is China's 1st-generation SSBN; derived from Type 091 SSN with an extended hull for the new missile section. The hull was laid down in 1978 at the Bohai Shipyard (aka Huludo Shipyard) and was launched in 1981.
- There appears to be only one SSBN in this class, hull number 406. However, it is believed that a second hull was launched in 1982. There have been unsubstantiated rumors that the second boat was lost in a 1985 accident.
- Propulsion: 1 loop-type PWR rated @ about 58 MWt; 2 x steam turbines delivering about 11,000 hp (8.2 MW) to a single propeller.
  - Believed to be same nuclear propulsion plant as on the Type 091 SSN
- Armament:
  - Initially 12 x JL-1 SLBMs; upgraded to JL-1A SLBMs after a 1995 – 2000 refit.
  - 6 x 533 mm (21 in) bow torpedo tubes with storage for 12 torpedoes (initially Yu-3 ASW torpedoes, likely upgraded to Yu-5 ASW torpedoes later in life).

Type 092 Xia-class SSBN

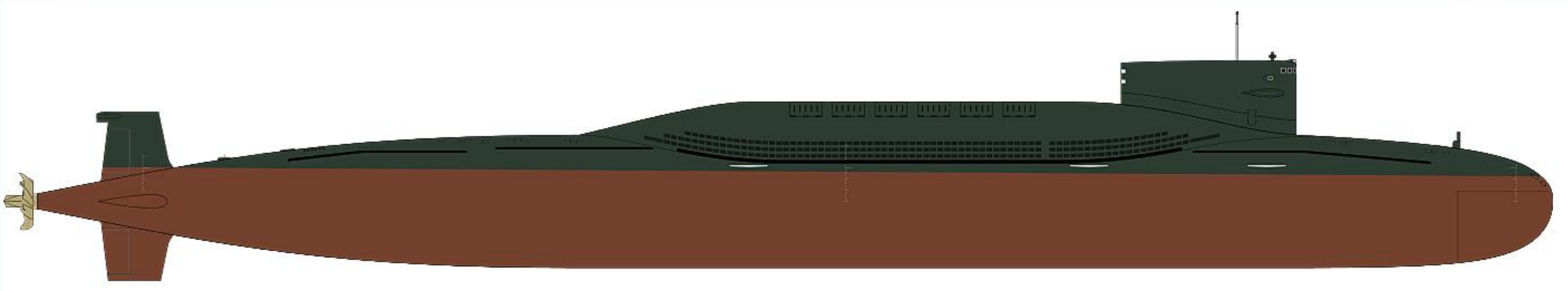
- Operational matters:
  - After launching, the boat spent 6 years fitting out and testing the JL-1 SLBM. Resolution of issues with the missile and/or fire control delayed service entry until 1987 when it was commissioned and named *Changzheng 6*.
    - The Type 092 SSBN’s home port is the Jianggezhuang (Laoshan) Submarine Base, which is part of the Hainan naval complex on the Yellow Sea.
  - Test depth is about 300 m (984 ft).
  - From 1995 to 2000 the boat underwent a refit that included:
    - Modifications to handle the JL-1A SLBM, including a updated fire control system and redesigned missile tubes and casing to accommodate the longer SLBMs.
    - New bow mounted sonar.
    - Implementation of some measures to reduce the submarine’s noise signature.
  - From 2005 and 2007, the Type 092 was undergoing refit or repair at the Jianggezhuang Submarine Base drydock near Qingdao.
  - On 23 Apr 2009, the Type 092 made its “world-wide debut” as part of the 60th anniversary celebration of PLA Navy's founding.
  - The Type 092 reportedly never completed a single deterrent patrol, remaining in Chinese coastal waters due to vulnerabilities related to slow speed, a noisy propulsion plant, and an unreliable reactor. * In recent years, it may have been functioning as a testbed for SSBN systems.
  - US Defense Intelligence Agency (DIA) lists the Type 092 as “not operational.”

* Source: http://www.military-today.com/navy/xia_class.htm

Type 092 Xia-class SSBN

Source (above): tommytoy.typepad.com

Type 094 Jin-class SSBN



Source: en.wikipedia.org

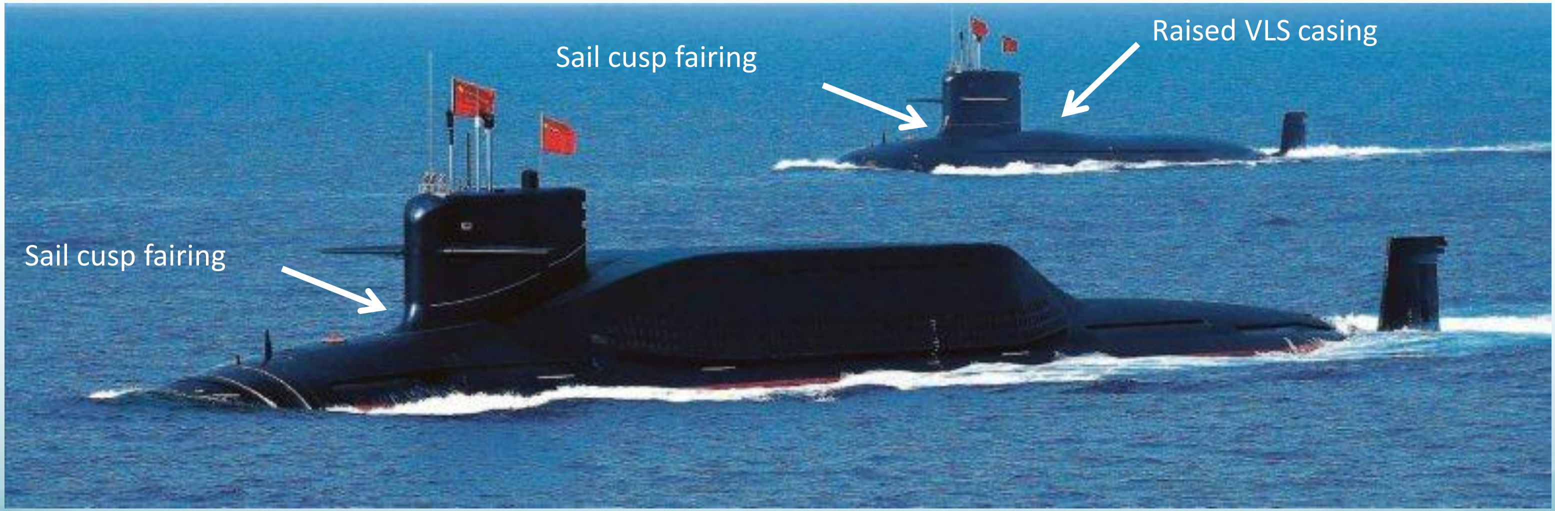
- This is China's 2nd-generation SSBN. 1st unit construction started in 1999 at the at the Bohai Shipyard (aka Huludo Shipyard) and the boat was launched in 2004. 2nd unit construction started started in 2007.
- As of mid-2018, there were four Type 094 SSBNs in China's fleet. All are homeported at the Jianggezhuang (Laoshan) Submarine Base.
  - The Type 094A is a variant with a modified sail resembling a Type 093A/B SSN sail.
  - As many as eight Type 094 / 94A SSBNs may be built, with the last entering service by the early 2020s.
- Propulsion: The nuclear propulsion plant configuration is not known. It likely is similar to the Type 093 Shang-class SSN propulsion plant, which delivers about 30,000 shaft horsepower (22.3 MW) to a single propeller. This implies a total reactor power output of about 150 MWt from one or two reactors. This is consistent with the propulsion power on comparable size SSBNs: the Russian Delta I-class and the French Le Triomphant-class.

Type 094 Jin-class SSBN

- Armament:
  - 12 x JL-2 (CSS-N-14) SLBMs
  - 6 x 533 mm (21 in) bow torpedo tubes with storage for 20 torpedoes or 36 mines.
- Operational matters:
  - Key dates:
    - 2006: 1st Type 094 spotted on commercial satellite imagery of the Xiaopingdao Submarine Refit Base, on the Bohai Sea near Dalian.
    - 2009: 1st successful test launch of a JL-2 SLBM
    - 2010: 1st unit commissioned
  - Type 094 reportedly is noisier than a Russian Delta III SSBN developed in the 1970s.
  - On 9 February 2016, the US Defense Intelligence Agency (DIA) reported in their Worldwide Threat Assessment that the Chinese navy “deployed the Jin-class nuclear-powered ballistic missile submarine in 2015, which, when armed with the JL-2 SLBM, provides Beijing its first sea-based nuclear deterrent.”
  - February 2015: Vice Adm. Joseph Mulloy, deputy Chief of Naval Operations reported that a Type 094 SSBN had conducted a 95 day patrol.
  - It is not known if the Type 094 SSBNs are conducting regular deterrent patrols.

Type 094 Jin-class SSBN

Type 094 SSBN. Source: en.wikipedia.org



Type 094A SSBN and Type 093B SSN. Source: https://sinodefence.com/type-094_jin-class/

Type 094 Jin-class SSBN

Type 094. Source: https://sinodefence.com/type-094_jin-class/#jp-carousel-1555

Type 094 Jin-class SSBN

Source, right: http://www.military-today.com/navy/xia_class_images.htm

Source, left: http://globalmilitaryreview.blogspot.com/2013/07/

Example operating areas for Type 094 SSBN deterrent patrols

Source: Hans M. Kristensen & Robert S. Norris (2018) “Chinese nuclear forces, 2018”, Bulletin of the Atomic Scientists, 74:4, 289-295, DOI: 10.1080/00963402.2018.1486620

Type 032 Qing-class

Weapons testbed submarine

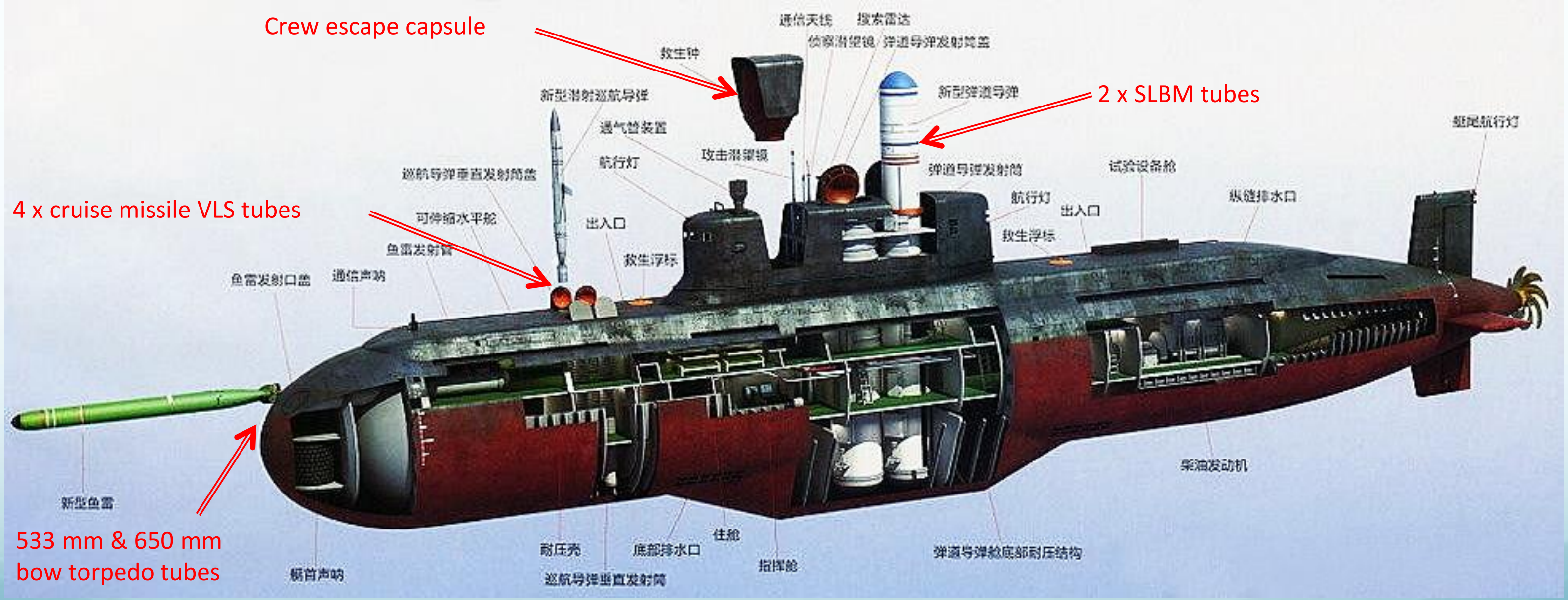
Source: www.shipbucket.com

- Only a single Type 032 submarine has been built. It is a conventionally-powered, double-hull submarine designed for use as a test platform for submarine missile and torpedo weapons systems and a crew escape capsule.
- It is the largest conventionally-powered submarine ever built, displacing 6,628 tonnes (7,306 tons) submerged. The Type 032 has a diesel-electric air independent propulsion (AIP) system and is capable of remaining submerged for about 30 days with a crew of 88, or shorter with a larger complement.
- The Type 032 project submarine begun in January 2005, and construction begun at Wuhan Shipyard in 2008. The submarine was launched on 10 September 2010, and sea trials were completed in September 2012. The submarine entered service on 12 October 2012 with hull number 201.

Type 032 Qing-class

Weapons testbed submarine

- There are two vertical SLBM launch tubes housed in the large sail. The Type 032 is used to test the JL-3 SLBMs. In this capacity, it replaced the Type 031 Golf-class sub that was used to test the JL-1 and JL-2 SLBMs.
- There are four vertical launch system (VLS) cells on foredeck that can launch cruise missiles and similar size devices (i.e., the YJ-18 long-range anti-ship cruise missile and a derivative of the CJ-10 land-attack cruise missile).
- There is a single standard 533 mm (21 in) torpedo tube (port side) and a larger 650 mm (24.8 in) torpedo tube (starboard side) in the bow.



Speculative cut-away view of the Type 032 submarine.
Source: adapted from http://errymath.blogspot.com/2014/10/type-032-world-largest-conventional.html#.W0cGyS2ZNBw

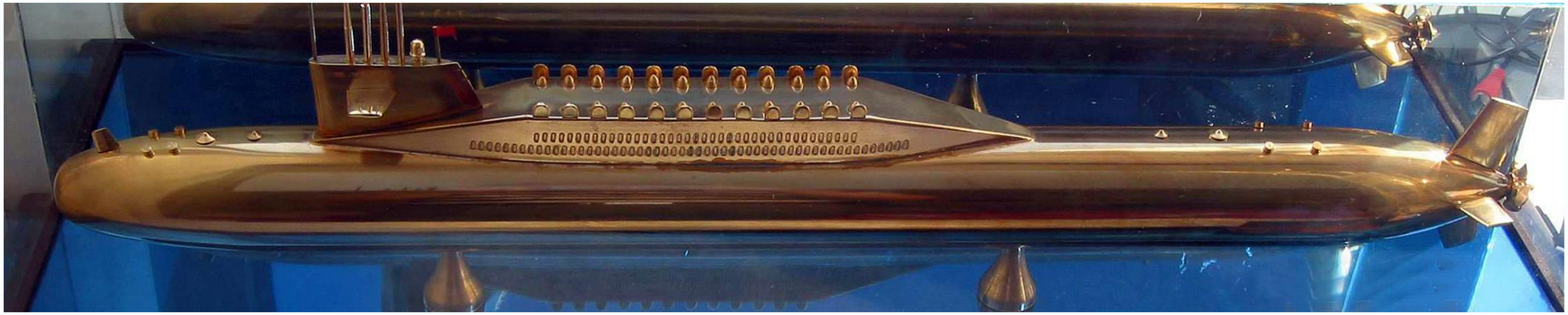
Type 032 Qing-class

Weapons testbed submarine

Source, above: https://thediplomat.com/2014/06/
Source, right: http://chinesemilitaryreview.blogspot.com/2013/11/chinese-type-032-diesel-electric.html

Source, above: http://chinesemilitaryreview.blogspot.com/2013/07/chinese-type-032-qing-class-diesel.html

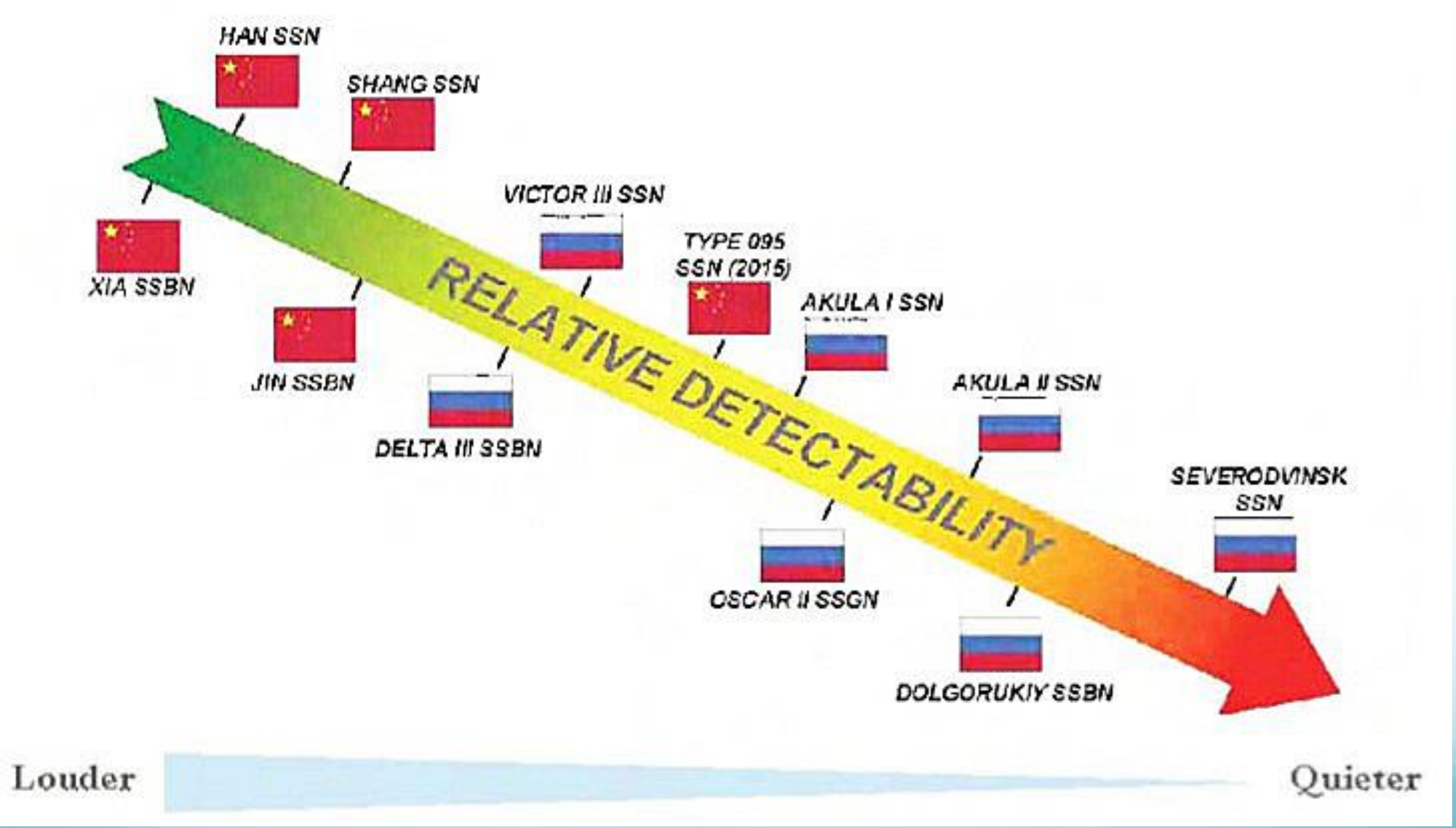
Type-096 Tang-class SSBN



Notional model of Type 096

- This will be China’s 3rd-generation SSBN.
- Propulsion: 1 x PWR and secondary steam plant driving a single shaft and propeller or pump-jet
- Armament:
  - Up to 24 x JL-3 SLBMs
  - 533 mm (21 in) bow torpedo tubes
- Construction status is uncertain:
  - Construction of this class was reported in the Western press as early as mid-2013.
  - The US Defense Department’s 2017 Annual Report to Congress on China's military power claims that construction of China's Type 096 SSBN will likely begin in the early 2020s.
  - The Type 096 may be a candidate for the submarine shaftless drive (SSD) propulsion system announced by the PLAN in 2017.

Relative comparison of Chinese & Russian submarine radiated noise



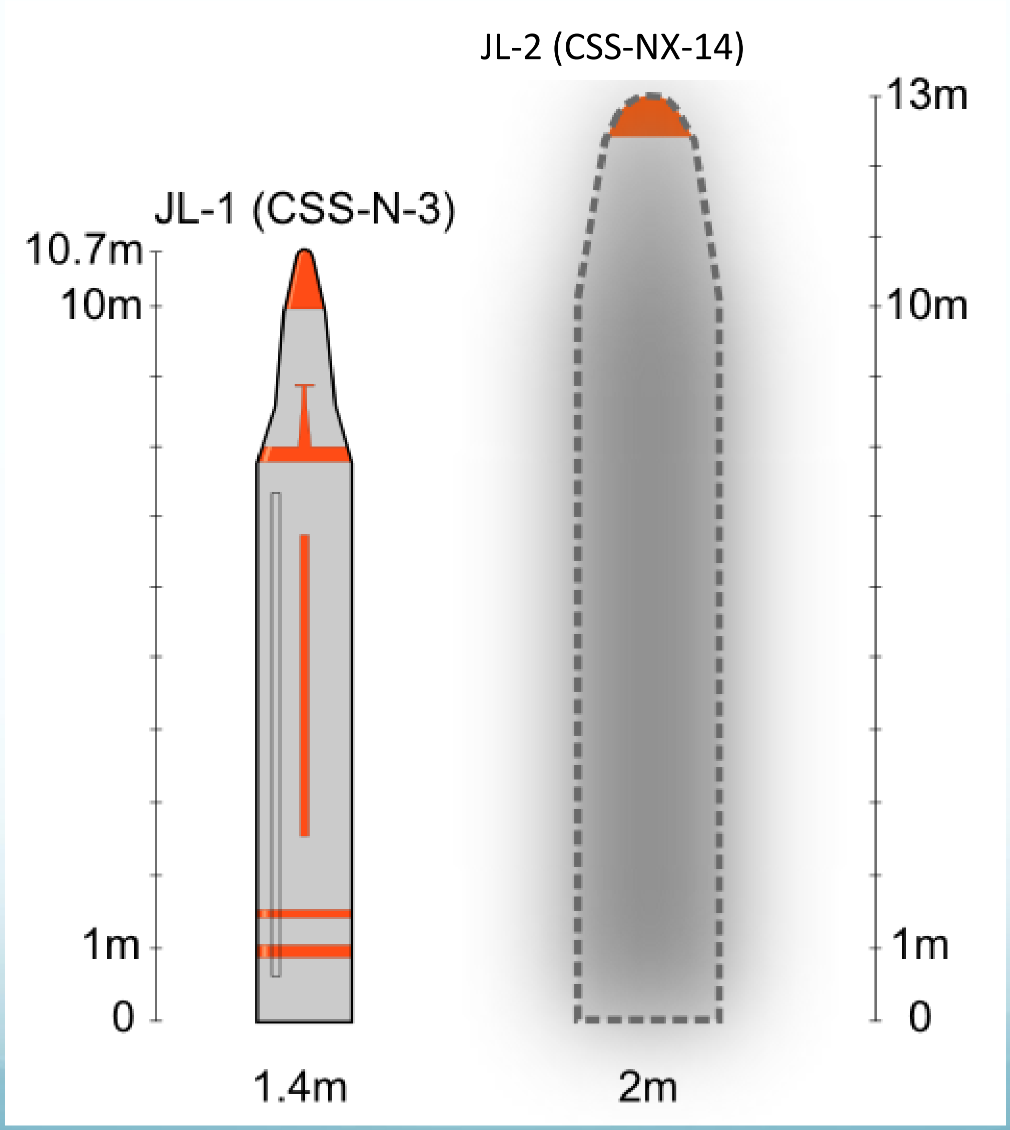
Source: https://fas.org/blogs/security/2009/11/subnoise/

Submarine-launched ballistic missiles (SLBM)

Chinese submarine-launched ballistic missiles

SLBM	Years in service / Platform	Weight	Length	Diameter	# of stages	Range /Guidance	Warhead
JL-1 / -1A (CSS-N-3)	1988 JL-1 Initial Operational Capability (IOC) on Type 092 2000 JL-1A IOC on Type 092 after refit	14,664 kg (32,328 lb)	10.7 m (35.1 ft)	1.4 m (4.6 ft)	2	JL-1 - 1,700 km (1,056 mi); JL-1A – 2,500 km (1,553 mi) / Inertial	Nuclear, 1 @ 250 kT; 700 m CEP
JL-2 (CSS-NX-14)	2015 IOC on Type 094	44,000 kg (93,000 lb)	13.0 m (42.7 ft)	2.0 m (6.6 ft)	3	7,000 - 8,000 km (4,350 - 4,971 mi) (est) / stellar inertial + satellite navigation update	Nuclear, 1 @ 1 - 3 MT, or 3 - 4 MIRV warheads with yield selectable between 20 - 150 kT, 150 - 300 m CEP ----- Possible conventional anti-satellite warhead
JL-3 (JL-2C)	Under development	Not known	Not known	Not known	3	10,000+ km (6,213+ mi)	Nuclear

Comparison of Chinese submarine-launched ballistic missiles



Source
en.wikipedia.org

Ju Lang (*Giant Wave*) JL-1/-1A

1st generation SLBM (CSS-N-3)

- Chinese SLBM development began in 1965, with initial plans for a single-stage missile. In 1967, those plans were were revised and development was refocused on a more capable two-stage SLBM. The design proposal produced by the 4th Academy was approved in November 1967.
- The SLBM development team was transferred from the 4th Academy to the 1st Academy in Beijing in 1970. Five years later, in 1975, SLBM development was again transferred, this time to a new R&D facility (307 Factory) in Nanjing, Jiangsu Province.
- Key dates:
  - 17 June 1981: First land-based pad launch
  - 7 January and 22 April 1982: Two successful land-based tube launches
  - 7 and 12 October 1982: First (surface) launches from China's single Type 031 (Golf-class) SSB (hull number 200)
  - March - April 1984: The Type 031 SSB conducted successful underwater launch tests of four mockup JL-1 missiles to validate the underwater launch system.
  - 1October 1984: JL-1 displayed during the military parade in Beijing marking the 35th anniversary of the founding of the PRC
  - 28 September 1985: The JL-1 missiles failed during the initial set of submerged test launches from the Type 092 SSBN failed, although correct operation of submarine launch systems was demonstrated.
  - 15 & 27 September 1988: Two successful submerged test launches from the Type 092 SSBN
  - 1988: JL-1 IOC
  - 2000: JL-1A IOC on Type 092 SSBN after refit.

Source: http://sinodefence.com/jl-1/

Ju Lang (*Giant Wave*) JL-1/-1A

1st generation SLBM (CSS-N-3)

- Basic missile parameters:
  - Range: JL-1 - 1,700 km (1,056 mi); JL-1A – 2,500 km (1,553 mi)
  - Warhead: 600 kg (1,323 miles), single nuclear weapon @ 200 kT – 1 MT
  - Guidance: Inertial
  - CEP: 700 m (0.43 miles)
- The JL-1 is used on China's single Type 092 Xia-class SSBN, which is equipped with 12 launch tubes. The Type-031 (Golf) JL-1 testbed submarine had two launch tubes.
- The former JL-1 SLBM and its warheads are thought to have been retired and dismantled
- The DF-21 missile appears to be a land-based version of the JL-1 equipped to function as an anti-ship ballistic missile.

Source: http://sinodefence.com/jl-1/

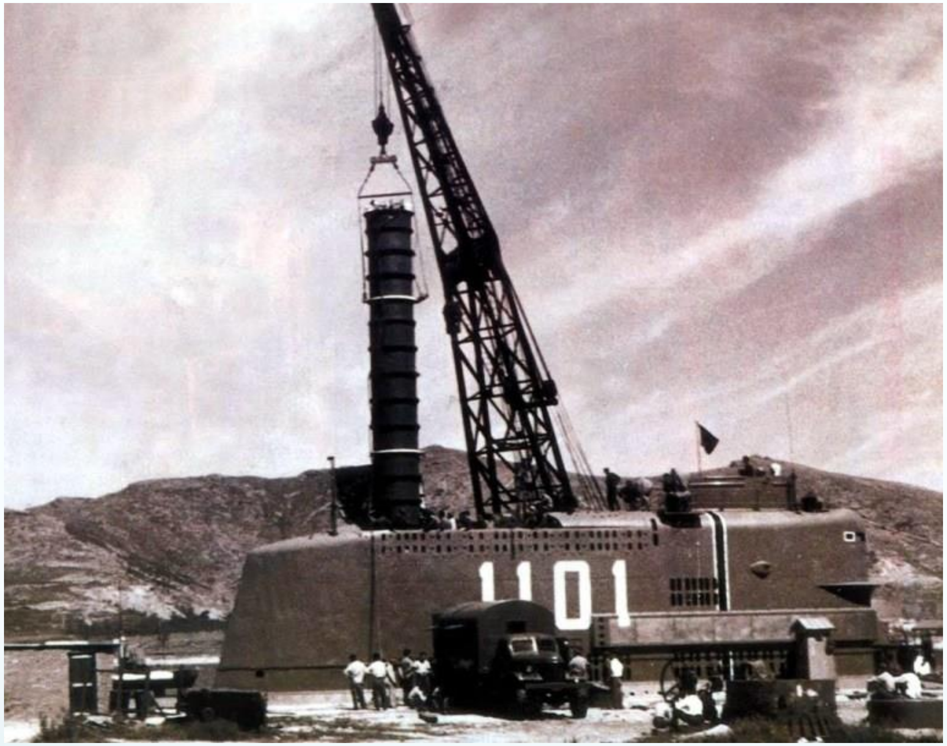
Ju Lang (*Giant Wave*) JL-1/-1A

1st generation SLBM (CSS-N-3)

JL-1. Source: http://sinodefence.com/jl-1/

Ju Lang (*Giant Wave*) JL-1/-1A

1st generation SLBM (CSS-N-3)



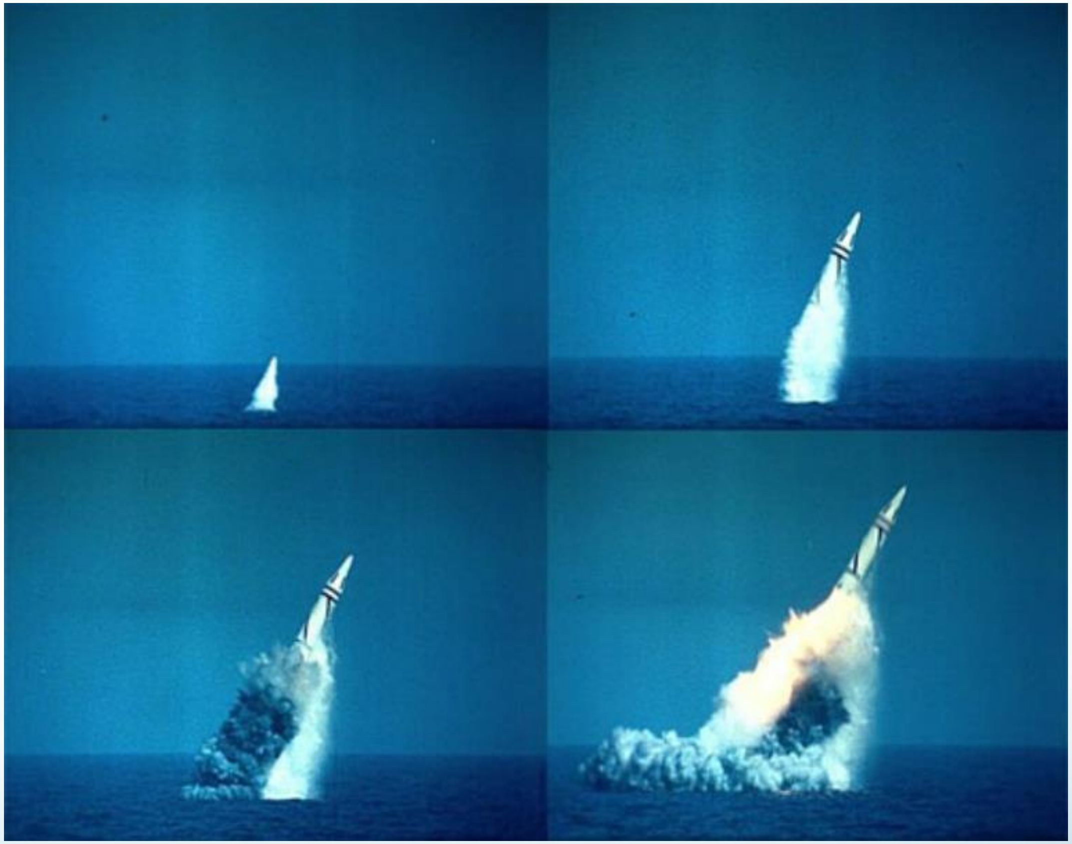
The JL-1/-1A is stored and transported inside a cylindrical missile tube, which is loaded onto the submarine. The photo above shows a JL-1 being loading onto China's only Type 031 conventional SSB, which served as a test platform for the JL-1. The photo to the right shows a JL-1 being loaded on China's only Type 092 SSBN.

Source, both photos: http://sinodefence.com/jl-1/

Ju Lang (*Giant Wave*) JL-1/-1A

1st generation SLBM (CSS-N-3)

- The missile is launched using a 'cold' launch technique, with the missile being ejected from the submarine missile tube by pressurized gas generated by a shipboard system.
- The missile's first-stage engine ignites after the missile has emerged from the water. Flight control is maintained by the gimballing first-stage engine nozzles.



JL-1 submerged launch.
Source: http://chinadefense.blogspot.com/2012/08/china-tests-submarine-launched.html

Ju Lang (*Giant Wave*) JL-2

2nd-generation SLBM (CSS-NX-14)

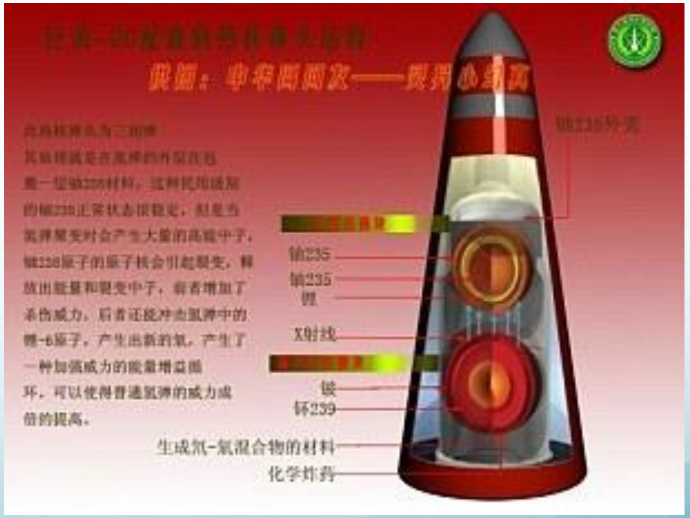
- The JL-2 SLBM is a three-stage, solid-propellant SLBM, designed and developed by the CASIC 2nd Academy. It was developed jointly with the DF-31 land-based ICBM beginning in 1970.
- The JL-2 SLBM has a range of 7,000 - 8,000 km (4,350 – 4,971 miles), with a CEP of 150 – 300 m.
- Nuclear Threat Initiative (NTI) reported that the JL-2 is armed with either a single 1-3 MT warhead or 3-4 MIRV warheads with yield selectable between 20-150 kT.
- The blunt nose configuration in the accompanying photo of a JL-2 launch is consistent with a MIRV warhead.
- A version of the JL-2 may have been configured as an anti-satellite weapon.

JL-2 submerged launch.
Source: http://indiandefence.com/threads/best-photographs-of-chinas-jl-2-slbm-and-df-41-icbm.42914/

Ju Lang (*Giant Wave*) JL-3

3rd-generation SLBM

- The JL-3 (also referred to as the JL-2C) is intended for the 3rd-generation Type 096 SSBN, which is under development and is expected to become operational be the 2020s.
- Actual JL-3 SLBM specifications are unknown. However, likely features could include:
  - Improved volumetric efficiency over the JL-2, delivering longer range and/or greater payload
  - More accurate, smaller CEP
  - MIRV warheads
  - Re-entry vehicles capable of various trajectories, including flat, maneuvering trajectories as employed on several models of the Russian R-29 SLBMs
  - Advanced penetration aids
  - Modern electronic systems
  - Simpler maintenance, reduced life-cycle cost
- The JL-3 is expected to be an approximate counterpart to the US Trident D-5 SLBM.



Above graphic: SLBM and MIRV warhead general arrangement. Below graphic: General configuration of a single reentry vehicle with a thermonuclear warhead. Source: http://www.dailymail.co.uk/sciencetech/article-4110448/

Floating nuclear power stations

CNNC floating nuclear power station concept

- China National Nuclear Corporation (CNNC) signed a 2015 agreement with Lloyd's Register for regulatory support in developing a sea-based, 100-megawatt version of its ACP100 / ACP100+ integral PWR reactor.

CNNC floating nuclear power plant concept.
Source: China National Nuclear Corporation

CNNC ACP100+ integral PWR reactor.
Source: China National Nuclear Corporation

CNNC ACP100

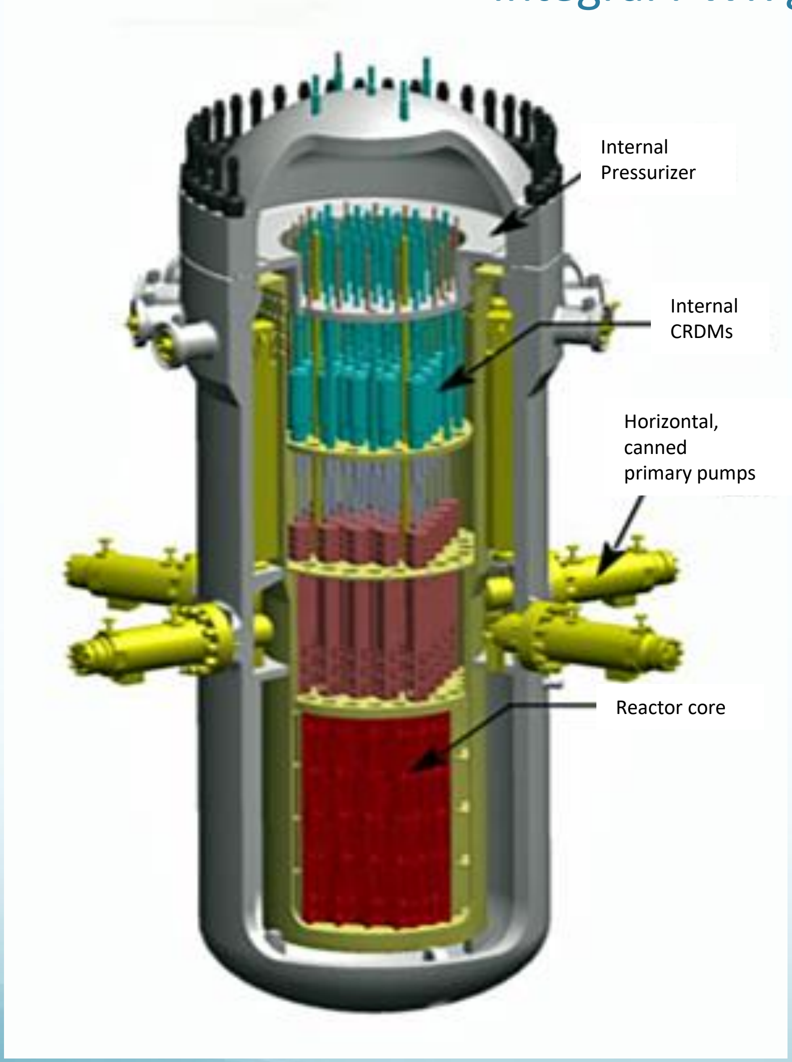
Integral PWR general characteristics

- Reactor power: 385 MWt
- 57 fuel elements (17 x 17 arrangement); average enrichment < 5%
- Refueling period: 2 years
- Integral primary system vessel
  - 16 x once-through steam generator modules located above the core.
  - 4 x vertical canned primary pumps connect by L-shaped co-axial piping to the integral vessel.
- 1 x external pressurizer
- Key primary parameters:
  - Core coolant outlet temp: 323 °C (613 °F)
  - Core coolant average temp: 303 °C (577 °F)
  - Primary pressure: 15.0 MPa (2,176 psig)
- Rated electric power output: 125 MWe maximum; also capable of delivering process heat and distilled water.
- Design life: 60 years
- Similar configuration to Russian RITM-100 & French K-15.

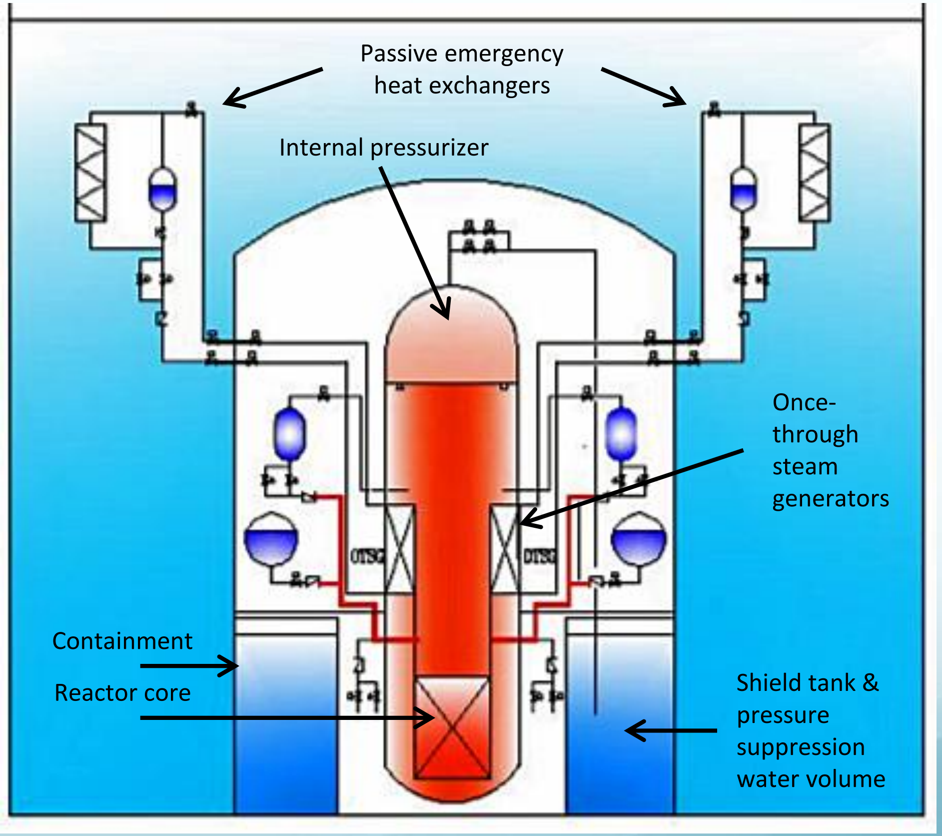
Source: https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-12-11-12-15-NPTDS50984/12_ACP100_DSong_TM_SMR-Tunis_2-5Oct17.pdf

CNNC ACP100+

Integral PWR general arrangement



The ACP100+ incorporates several design simplifications not found in the basic ACP100:
internal pressurizer, internal control rod drive mechanisms (CRDM) and horizontal primary pumps.



Source: adapted from https://www.iaea.org/INPRO/13th_Dialogue_Forum/011_CNNC_s_ACP100_SMR-Technique_Features_and_Progress_in_China.pdf

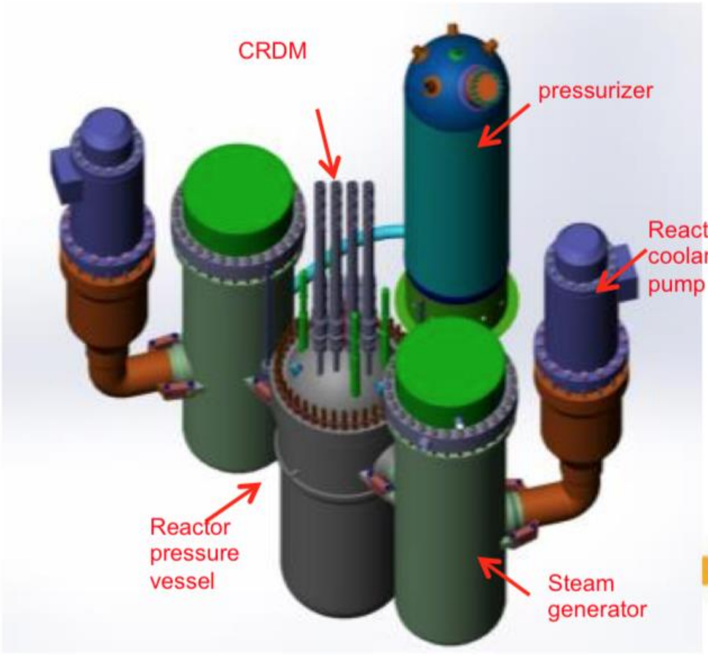
CGN floating nuclear power station concept

- China General Nuclear Power Corporation (CGN), CNNC's main domestic competitor, announced in January 2016 that it would build a floating nuclear plant with a compact ACPR50S PWR to enter service in the 2020s, with a thermal power output of 200 MWt and an electrical output of 50 MWe.
- CGN is a state-owned corporation, established in 2013 from the former China Guangdong Nuclear Power Group.

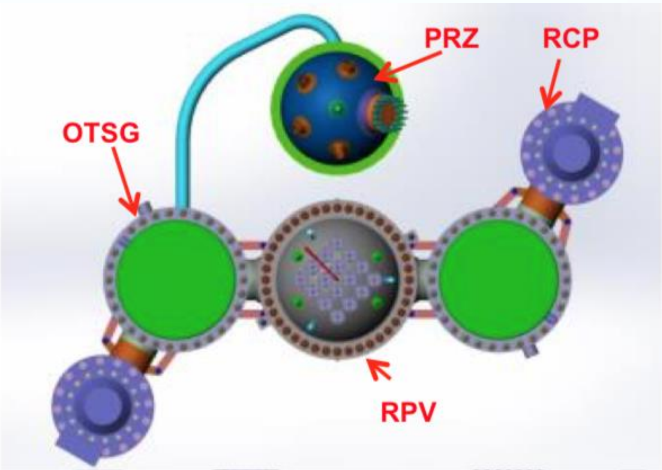
Source, two graphics: China General Nuclear Power Group

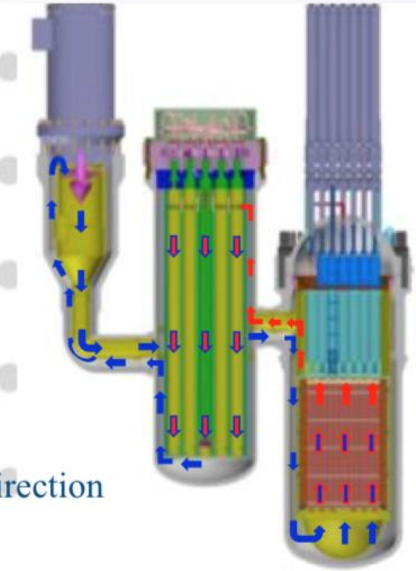
CGN ACPR50S

Compact PWR general arrangement



Compact layout of shorter pipes to reduce the LOCA probability



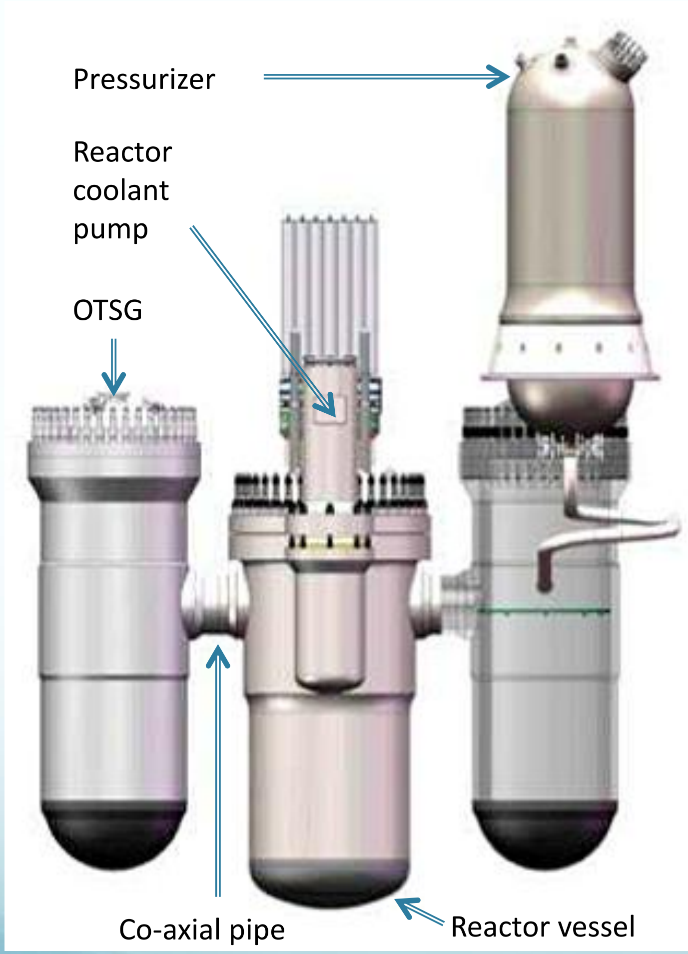


Coolant flow direction

Source: https://www.iaea.org/INPRO/13th_Dialogue_Forum/026_ACPR_SMR_of_CGNPC.pdf

CGN ACPR50S

Modular PWR general characteristics

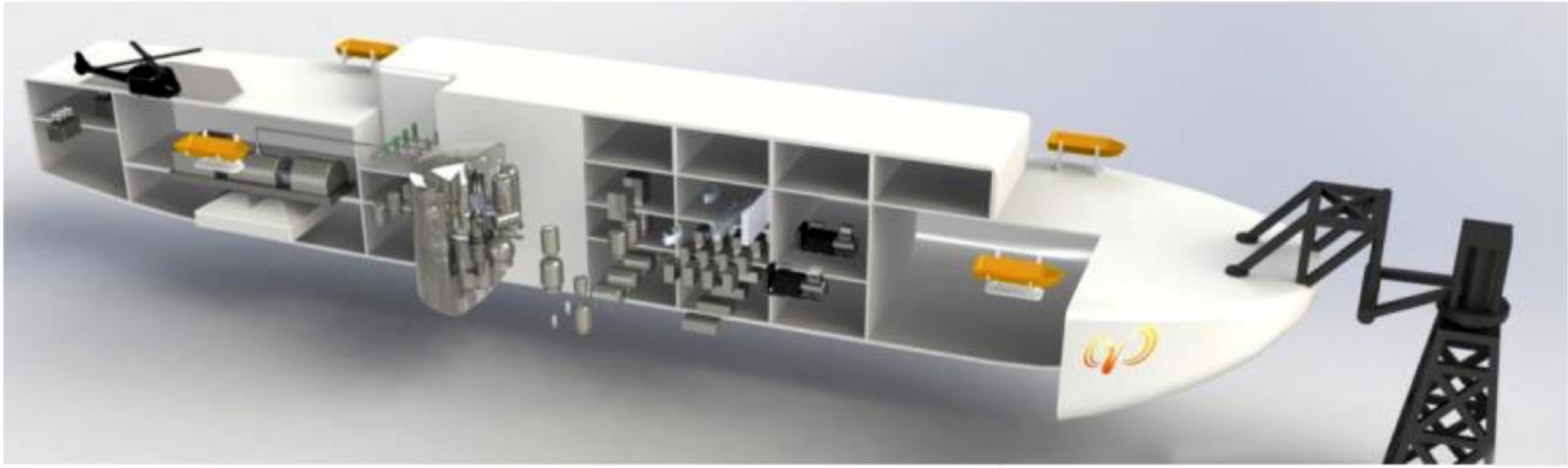


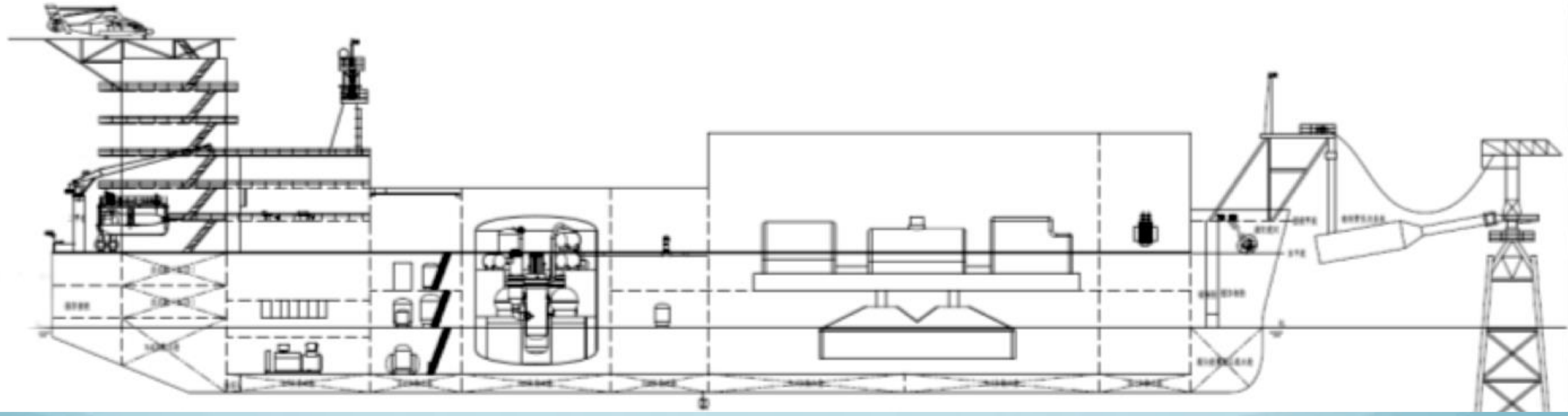
- Reactor power: 200 MWt
- 37 fuel elements (17 x 17 arrangement); average enrichment < 5%
- Refueling period: 2.5 years (30 months)
- 2 primary loops, each with one once-through steam generator (OTSG) and one vertical primary pump connected via co-axial piping.
- 1 x external pressurizer
- Key primary parameters:
  - Core coolant avg. temp: 310 °C (590 °F)
  - Primary pressure: 15.5 MPa (2,248 psig)
- Rated electric power output for a floating nuclear power plant: 50 MWe maximum; also capable of delivering process heat and drinking water.
- Design life: 40 years.

Source: adapted from https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-12-11-12-15-NPTDS50984/14_ACPR50S_JGuo_TM_SMR-Tunis_2-5Oct17.pdf

CGN ACPR50S

Shipboard arrangement for a floating nuclear power station





Source: https://www.iaea.org/INPRO/13th_Dialogue_Forum/026_ACPR_SMR_of_CGNPC.pdf

CGN ACPR50S

Onshore facilities for a floating nuclear power station

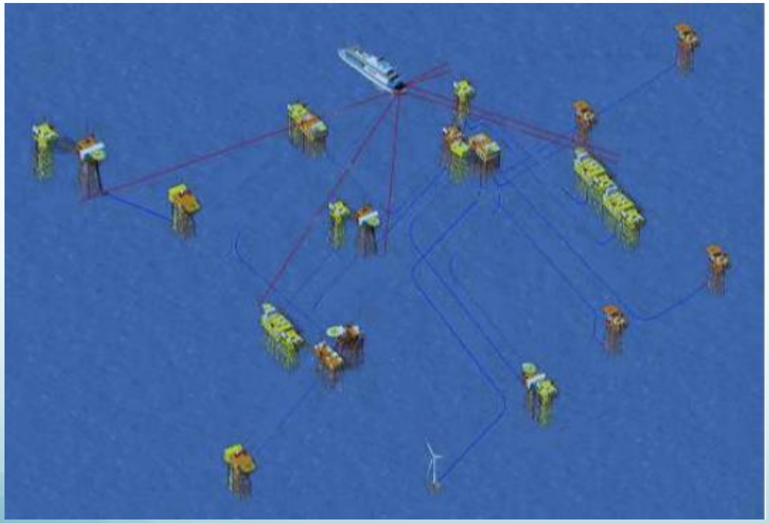
- The onshore base of ACPR50S houses a fuel building, a radioactive waste treatment building, and other balance of plant buildings
  - Refueling and temporary store of spent fuels
  - Disposal of nuclear waste
  - Maintenance

Source: https://www.iaea.org/INPRO/13th_Dialogue_Forum/026_ACPR_SMR_of_CGNPC.pdf

CGN ACPR50S

Floating nuclear power station for the oil & gas industry

- An FNPP is capable of replacing the existing power sources (typically gas turbine generators) used to power the isolated undersea electrical grids serving off-shore oil production platforms.
- The FNPP with desalination capabilities can provide drinking and domestic water. The FNPP also can provide process heat for use in lithium bromide absorption refrigeration or ammonia absorption refrigeration.
- Use of an FNPP greatly reduces the need to supply fossil fuel to the off-shore site. FNPP maximum annual generating capacity is about 440 million kWh/yr, which replaces about 721,000 barrels of fuel oil/yr (@ 578 kWh/bbl).



Source: https://www.iaea.org/NuclearPower/Downloadable/Meetings/2017/2017-12-11-12-15-NPTDS50984/14_ACPR50S_JGuo_TM_SMR-Tunis_2-5Oct17.pdf

Nuclear-powered surface ships

Future icebreaker,
Future aircraft carrier

Future nuclear-powered icebreaker

- China's interest for the Arctic has steadily increased over the last decade, and the country is now an observer to the Arctic Council. In northern Russia, Chinese investments are seen in both Yamal liquified natural gas (LNG) and other petroleum projects.
- China's currently operates a single ocean-going, diesel-electric powered icebreaker, the *Xue Long (Snow Dragon),* which is a 15,000 tonne icebreaking research vessel built in the Ukraine and put in service in 1994.
- In December 2016, construction of a new diesel-electric powered icebreaker *Xue Long 2*, jointly designed by China State Shipbuilding Corporation and Finland-based Aker Arctic Technology, started by Jiangnan Shipyard Group.

- *Xue Long 2* is expected to be completed in 2019. It will be 122.5 m (402 ft) long, displace 14,300 tonnes, and is classified as PC3; able to break through 1.5 m (4.9 ft)-thick ice at a maximum speed of 3 knots ahead or astern.

Xue Long diesel-powered icebreaker.
Source: https://www.scmp.com/news/china/diplomacy-defence/

Future nuclear-powered icebreaker

- On 21 June 2018, China National Nuclear Corporation announced that bids are welcome from domestic yards to build the country's first nuclear-powered icebreaker. The ship is said to be an "icebreaker support ship" indicating a multi-role purpose more than simply breaking the ice for other vessels in convoy.
- This icebreaker will be China's first nuclear-powered surface vessel. It is expected to have a displacement of about 30,000 tons, which is comparable to a Russian LK-60Ya-class nuclear-powered "universal icebreaker."
  - The Russian LK-60Ya icebreakers are powered by two RITM-200 integral PWRs, each rated at 175 MWt (350 MWt total) and delivering a combined 60 MW (80,460 shp) of propulsion power.
  - Comparable propulsion power should be expected on China's first nuclear-powered icebreaker.
- The experience from developing the powerful nuclear propulsion system for China's first indigenous nuclear-powered icebreaker will benefit plans for developing the propulsion system for a future nuclear-powered aircraft carrier.

Future nuclear-powered aircraft carrier

- China has built two indigenous, conventionally-powered Type 001 / 001A aircraft carriers with unassisted ski-jump ramps at the bow for launching aircraft. The first ship, *Liaoning*, is a large vessel with a full-load displacement of about 70,000 tons, a length of 315 m (1,033 ft), a beam of 75 m (246 ft), and a maximum speed of 31 knots.
- The follow-on Type 002 conventionally-powered aircraft carrier is expected to have aircraft catapult launchers and arrested recovery. At a displacement of about 85,000 tons and physical dimensions comparable to the *Liaoning*, the Type 002 carrier is approaching the size of US Nimitz-class carriers, which have a full-load displacement of over 100,000 tons, length of 332.8 m (1,092 ft) and beam of 76.8 m (252 ft).
  - In February 2016, Jiangnan Shipyard in Shanghai started construction on the first Type 002 aircraft carrier. It is expected to be commissioned by about 2023.
  - Steam and electromagnetic launch systems are being tested for use on the Type 002.
- The experience from developing the powerful nuclear propulsion system for China's first indigenous nuclear-powered icebreaker will benefit plans for developing the propulsion system for a future nuclear-powered aircraft carrier. However, aircraft carriers require much more powerful propulsion systems.
  - The propulsion systems on US Nimitz-class aircraft carriers deliver about 260,000 shp (194 MW) from two PWRs, each rated at about 1,100 MWt. The propulsion system on the earlier *USS Enterprise* (CVN-65) delivered 280,000 shp (210 MW) from eight smaller PWRs each rated at about 150 MWt.

Type 002 aircraft carrier

Speculative design, conventionally-powered aircraft carrier

Source: www.junshicg.com via https://www.sinodefenceforum.com/

China's decommissioned nuclear submarine status

- China's nuclear-powered fleet is still relatively young. As of mid-2018, only two SSNs have been decommissioned; these are the first two Type 091 Han-class "short hull" SSNs.
  - On 25 April 2017, the first Type 091 Han-class SSN, *Changzheng-1*, was opened to the general public as a museum ship at the Qingdao Naval Museum in Shandong Province.
  - At the time of its decommissioning, a member of the naval authorities told Global Times: "The submarine's release from military service and the safe, thorough and reliable handling of related nuclear waste, nuclear reactor and other devices showed China's life-cycle maintenance ability, ranging from a nuclear submarine's production, operation, management to disposal." *
- The current status of the other retired Type 091 SSN is not known.

* Source: http://www.dailymail.co.uk/news/article-4452198/China-turns-nuclear-submarine-museum.html

China's marine nuclear power current trends

China current trends

- **New build:**
  - Construction of the Type 093B multi-mission SSN / SSGN is continuing.
  - A special operations force (SOF) version of the Shang-class SSN, dubbed Type 093T, is expected, but has not yet been observed. Perhaps the SOF external dock can be added to any Type 093 / 093A SSN.
  - Construction status of the new Type 095 multi-mission SSN is not known, but construction is believed to be in progress. The first Type 095 SSN has not yet been observed. It is expected that there will be significant commonality between the Type 095 SSN and the Type 096 SSBN.
  - Construction status of the new Type 096 SSBN is not known. US Defense Department's 2017 Annual Report to Congress on China's military power claims that construction of China's Type 096 SSBN will likely begin in the early 2020s.
  - In June 2018, China National Nuclear Corporation announced plans to build a nuclear powered icebreaker, which will become China's first nuclear-powered surface ship.

China current trends

- **Phase-out / replacement:**
  - US Defense Intelligence Agency (DIA) lists the single Type 092 SSBN as "not operational." China's future plans for this boat are not known. It has been replaced by Type 094 SSBNs.
  - Three 1st-generation Type 091 "long hull" Han-class SSNs should be retired during the next decade and replaced by Type 093 or 095 SSNs.
- **Refurbishment / modifications:**
  - Type 094 / 094A SSBN fleet may be upgraded in the future to handle the new JL-3 SLBM when it enters service.
- **Operations:**
  - In 2016, the DIA reported that the Type 094 Jin-class SSBN, "when armed with the JL-2 SLBM, provides Beijing its first sea-based nuclear deterrent."
  - Chinese SSBN deterrent patrols should become regular occurrences.
  - The VLS missile system on the Type 093B multi-mission SSN/SSGN allows it to project power over long distances, including to targets on shore; capabilities not previously possessed by Chinese SSNs.
  - China' newer, quieter and more capable SSNs are operating further afield and have operated in the Indian Ocean since an initial patrol in that area by a Shang-class SSN between December 2013 – February 2014.
  - China has been building and/or leasing port facilities in the Indian Ocean. This is a definite sign of China's intent to permanently expand its naval presence in that area.

China current trends

- **Anti-access / area denial (A2/AD):**
  - China is deploying their SeaWeb undersea surveillance network to detect intruding vessels. The output from SeaWeb is integrated into a larger surveillance network that also uses airborne and space-based sensors to detect, correlate and alert shore-based, naval and airborne forces to protect naval bases and sea areas.
    - SeaWeb surveillance areas in China's littoral waters are believed to include the Bohai Sea, Yellow Sea, East China Sea, and South China Sea.
    - In January 2018, China revealed it had installed two deep-ocean listening devices (in the Challenger Deep of the Mariana Trench, as well as near the island of Yap) that were capable of monitoring US submarine activities near the naval submarine base in Guam.
  - The Type 093B, armed with long-range anti-ship and anti-submarine weapons in VLS launchers, could be a credible anti access / area denial (A2/AD) threat during future conflicts in China's in contested waters (i.e., in the South China Sea).
  - China's nuclear and conventional attack submarines are equipped for deploying a variety of mines, which can be an element of a comprehensive A2/AD strategy. Most Chinese submarine-launched torpedoes appear to have versions that can be modified for use as bottom-moored torpedo/mines, similar to the US Mark 60 CAPTOR mine (which no longer is used by the US).

China current trends

- **New submarine-launched weapons system development:**
  - The next-generation JL-3 SLBM development in progress.
  - A submarine-launched version of the CJ-10 land-attack cruise missile should be approaching IOC as a VLS weapon on the Type 93B SSN/SSGN. Previously, Chinese SSNs have not had a land-attack capability.
  - Development of a new long-range anti-submarine cruise missile armed with a homing torpedo is under development. It may be another weapon that can be deployed in the Type 093B VLS.
  - There is speculation that a version of the JL-2 SLBM with a conventional anti-satellite warhead is being developed.
  - The Yu-9 ASW / ASuW torpedo has a novel and very powerful sodium hydride chemical reaction warhead that has not been employed previously by any nation.
- **New nuclear-powered submarine development:**
  - Development of the designs and technologies for the new Type 095 SSN and Type 096 SSBN should be nearing completion as these boats transition into the new build phase.
  - In June 2015, a Chinese official announced completion of the "development" of the Type 098 fourth-generation SSBN. However, there has been no further information on this new class of SSBN.

China current trends

- **New nuclear-powered surface ship development:**
  - China National Nuclear Corporation (CNNC) and China General Nuclear Power Corporation (CGN) both have announced plans to develop floating nuclear power stations.
  - In July 2018, CNNC announced plans to build a nuclear-powered icebreaker, which will become China's first nuclear-powered surface ship. Completion of this ship could be expected by the mid 2020's.
  - China's development of modern, capable aircraft carriers is continuing with the construction of Type 002 conventionally-powered carrier. The Type 002 bears a strong resemblance to the large US conventionally-powered aircraft carriers (i.e., the Kitty Hawk-class carriers) that preceded the Nimitz-class nuclear-powered carriers. A Chinese nuclear-powered aircraft carrier is still a distant goal, likely more than a decade away.
- **New marine reactor development:**
  - China is likely developing one or more new naval reactors for the new classes of SSBNs and SSNs now being developed.
  - CNNC's ACP100 and CGN's ACPR50S marine reactors are being developed for use on floating nuclear power stations.
  - Nuclear propulsion plant development for the icebreaker will support longer-range plans for development of a propulsion system for a nuclear-powered aircraft carrier.
  - China has been rumored to be developing a high-temperature gas-cooled reactor for use in a naval propulsion system. Status is not known.

China current trends

- **Final disposition of retired nuclear vessels:**
  - As of mid-2018, only two nuclear vessels have been decommissioned; these are the first two Type 091 Han-class “short hull” SSNs. In 2017, the first Type 091, *Changzheng-1*, was opened as a museum ship at the Qingdao Naval Museum in Shandong Province. The disposition of the second Type 091 SSN is not known.
  - In the next decade, the remaining three 1st-generation Type 091 Han SSNs and the single Type 092 Xia SSBN will be decommissioned.
- **Technical support to other nations:**
  - China recently sold conventionally-powered submarines to Pakistan (up to eight modified Type 41 Yuan-class diesel-electric AIP submarines) and Bangladesh (two Type 035B Ming-class diesel-electric submarines). Planned delivery schedules are not known. Both sales will increase China’s influence in the region and likely will provide facilities for future Chinese submarine port visits.
  - It is not known if China is supporting North Korea (DPRK) in their development of an SLBM-firing conventional submarine or a nuclear submarine.

India

Naval nuclear submarines

Source: https://en.wikipedia.org/

India

Table of Contents

The beginning of India’s marine nuclear power program

India marine nuclear timeline

1940s

1944
India's nuclear program started with the founding of the Tata Institute of Fundamental Research
15 Aug 1947
Indian independence
1948
Atomic Energy Act focused on peaceful uses of nuclear energy

1950s

1954
Established Department of Atomic Energy (DAE)
3 Jan 1954
Established the Atomic Energy Establishment, Trombay (AEET)
4 Aug 1956
Initial criticality at India's 1st research reactor, *Apsara,* designed by AEET

1960s

10 Jul 1960
Initial criticality of India's 2nd reactor, CIRUS, which was used to make Pu for India's 1st nuclear test
1960s
Early discussions on the potential of nuclear powered submarines
1964
Plutonium Plant at AEET commssioned, reprocessed CIRUS reactor spent fuel
22 Jan 1967
AEET renamed Bhabha Atomic Research Center (BARC)

1970s

18 May 1974
India's 1st nuclear test: *Smiling Buddah (Pokhran I)*

1980s

1984
Beginning of India's Advanced Technology Vessel (ATV) program
1985
Pilot-scale uranium enrichment facility operational at BARC
1988
Charlie I SSN (*Chakra I*) SSN leased from Russia

1990s

1990
Centrifuge uranium enrichment plant at Rattehalli reported to be operational
1992
Charlie I SSN (*Chakra I*) SSN returned to Russia
1998
Started construction on the 1st indigenous SSBN
11 May 1998
India conducts 5 nuclear tests, collectively known as *Pokhran II*

2000s

11 Nov 2003
Initial criticality of naval reactor prototype at Kalpakkam
Sep 2005
Simulator training center for India's nuclear submariners opened at NITI, St. Petersburg, Russia
22 Sep 2006
Naval reactor prototype operational
26 Jul 2009
1st Indian indigenous SSBN *INS Arihant* (S2) launched

2010s

2012
Akula I SSN (*Chakra II*) 10-yr lease from Russia
10 Aug 2013
INS Arihant (S2) initial criticality
16 Dec 2014
INS Arihant first sea trials
Feb 2015
Indian government approved construction of 6 indigenous SSNs
19 Nov 2017
2nd Indian indigenous SSBN, *INS Arighat (S3).* launched
2018
INS Arihant likely to be operational with K-15 SLBMs.

The beginning of India’s marine nuclear power program

- **1944:** India started its own nuclear program when Homi J. Bhabha founded the Tata Institute of Fundamental Research in Mumbai.
- **1947:** Following India’s independence, basic infrastructure for the national nuclear program was established in the following decade:
  - **1954:** The Department of Atomic Energy (DAE) and the Atomic Energy Establishment, Trombay (AEET) were established.
  - **1956:** Initial criticality of India’s first research reactor, Apsara.
    - This reactor was designed by the AEET (which later became the Bhabha Atomic Research Center, BARC) and was built with assistance from the UK (which also provided the initial fuel supply consisting of 80% enriched HEU).
- **18 May 1974:** India's first successful nuclear bomb test, *Smiling Buddah.*
  - This was a plutonium implosion device similar to the US Fat Man bomb.
- **Early 1980s:** India began work on a uranium enrichment program.
- **1984:** Advanced Technology Vessel (ATV) project initiated
  - India discussed the potential of nuclear powered submarines as early as the 1960’s. The development of the Advanced Technology Vessel (ATV) submarine program didn't actually begin until 1984.
  - The main aim of the ATV program was to equip India with a second strike platform capable of launching retaliatory strikes against hostile states.
  - India’s indigenous Arihant-class SSBN was developed under the ATV program by the Defense Research and Development Organization (DRDO), which is accountable to the Defense Ministry.

The beginning of India's marine nuclear power program

- **1985:** A pilot-scale uranium enrichment facility became operational at BARC.
- **1988:** To gain experience with nuclear submarine design and operation, India leased a Charlie I SSN (Chakra I) SSN from Russia for four years (returned in 1992).
- **1990:** The centrifuge uranium enrichment plant at Rattehalli became operational. India's uranium enrichment program is believed to be oriented primarily toward production of HEU for the ATV nuclear submarine program.
- **1998:** Started construction on the 1st indigenous SSBN at the Hindustan Shipyard Limited (HSL) shipyard in Visakhapatnam (later named the Ship Building Center, SBC)
- **11 Nov 2003:** Initial criticality of the naval reactor prototype at Kalpakkam
- **Sep 2005:** A simulator training center for India's nuclear submariners opened at NITI in St. Petersburg, Russia.
- **22 Sep 2006:** The S1 naval reactor prototype was declared operational
- **26 Jul 2009:** India launched its first indigenous SSBN, *INS Arihant* (S2).
- India's ATV project is continuing with the production of additional Arihant-class SSBNs and is preparing for construction of a series of indigenous SSNs and a larger "S5"-class of SSBNs, which will be delivered during the 2020s.

India’s current nuclear vessel fleet

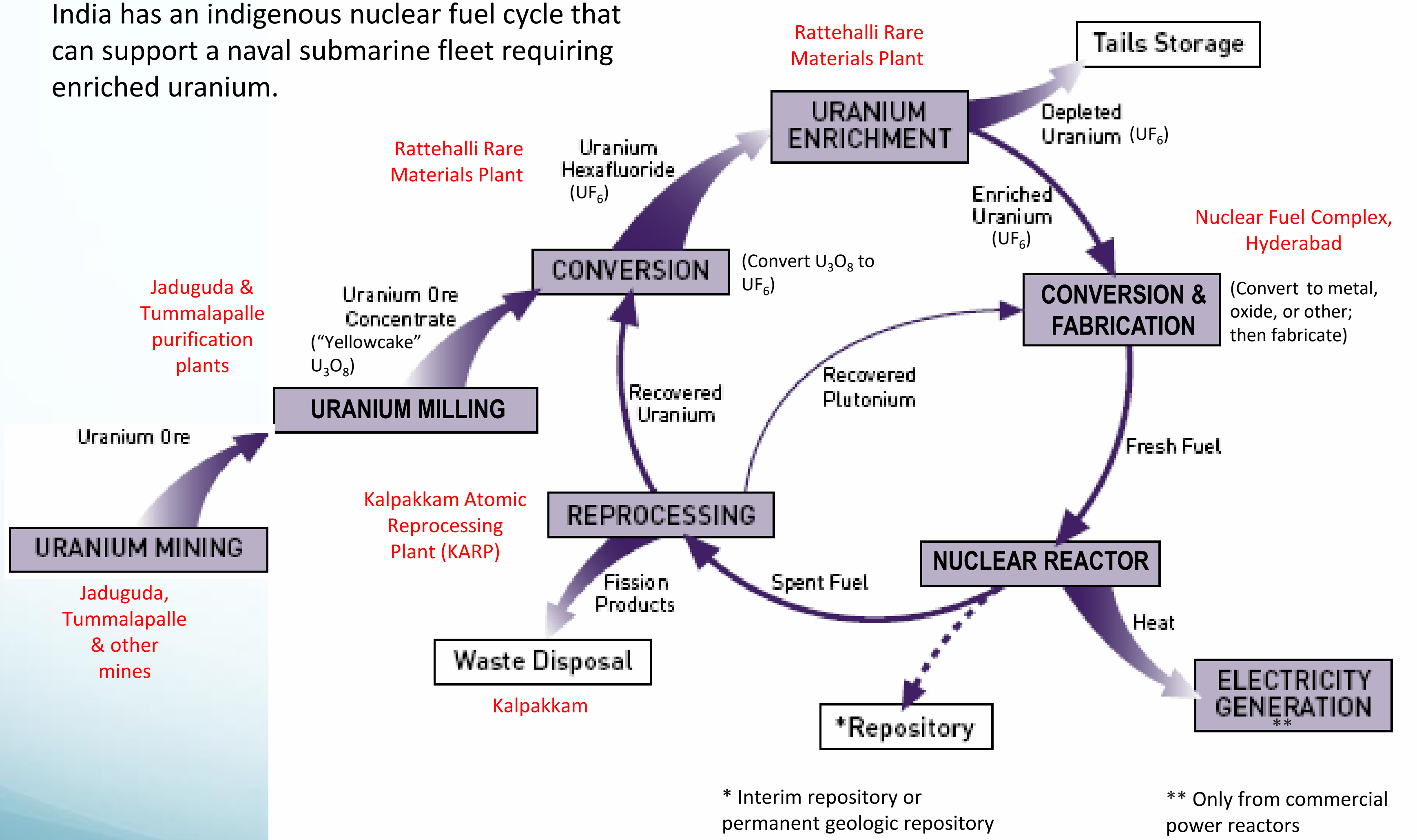
As of mid-2018

- India’s Navy operates a mixed fleet of conventional and nuclear submarines. The conventional submarine fleet is comprised of 16 attack submarines in several classes.
- The nuclear submarine fleet is comprised of three boats in the following classes:
  - Two indigenous Arihant-class SSBNs.
  - One Improved Akula-class SSN (*Chakra II*), leased from Russia until 2022.
- India does not operate any nuclear-powered naval or commercial surface vessels.

India’s naval nuclear infrastructure

India’s nuclear fuel cycle

India has an indigenous nuclear fuel cycle that can support a naval submarine fleet requiring enriched uranium.



Source: adapted from http://www.icnnd.org/reference/reports/ent/part-ii-5.html

India’s nuclear fuel cycle infrastructure

- Uranium mining & milling
  - Uranium Corporation of India, in Singhbhum, was founded in 1967 and is responsible for the mining and milling of uranium ore in India.
  - The firm operates mines at Jadugora (1st uranium mine in India), Bhatin, Narwapahar, Turamdih and Banduhurang.
  - A uranium purification (processing / milling) plant usually is located close to the mine to convert uranium ore to “yellow cake” (U_3O_8). Purification plants are located near the Jadugora and Turamdhi mines.
  - After purification of the ore, the yellow cake is shipped by heavy-duty vehicles to the Nuclear Fuel Complex in Hyderabad for use in natural uranium fuel, or to the Rattehalli Rare Materials Plant (RMP) for conversion to UF_6 and then enrichment.

India’s nuclear fuel cycle infrastructure

- Enrichment:
  - India's uranium enrichment program is believed to be oriented primarily toward production of HEU for the nuclear submarine program.
  - A pilot-scale enrichment plant in the Bhabha Atomic Research Center (BARC) Trombay complex was reported to begin operations in 1985.
  - A larger centrifuge plant, officially known as the Rattehalli Rare Materials Plant (RMP), near Mysore in southern India, reportedly has been operating since 1990.
    - Uranium Corporation of India Ltd (UCIL) delivers processed yellowcake to the RMP, where it is converted to uranium hexafluoride prior to enrichment.
    - A 2008 civil nuclear cooperation deal with the United States exempts India’s military facilities and stockpiles of nuclear fuel from scrutiny by the International Atomic Energy Agency. The RMP is not subject to IAEA safeguards.
    - In 2014, it was reported that the RMP being expanded.
  - The International Panel on Fissile Materials (IPFM) reported in February 2018 that HEU produced by India is assumed to be enriched to between 30% and 45% uranium-235 for use on India’s nuclear submarines. Assuming an enrichment level of 30%, India is estimated to have a stockpile of 4.0±1.4 tons of HEU as of the end of 2016.

India's nuclear fuel cycle infrastructure

- Nuclear Fuel Complex, Hyderabad, India:
  - Nuclear Fuel Complex (NFC) was established in 1971 as a major industrial unit of India's Department of Atomic Energy, for the supply of nuclear fuel bundles and reactor core components. It is a unique facility where natural and enriched uranium fuel, zirconium alloy cladding and reactor core components are manufactured under one roof.
- Kalpakkam Atomic Reprocessing Plant [KARP]
  - Situated about 80 km south of Chennai near the Madras Atomic Power Station (MAPS), KARP commissioned at in 1998.
  - One reprocessing line uses the PUREX process for spent fuel from MAPS. This line also should be able to reprocess spent naval fuel. There also is a separate reprocessing line for handling mixed-carbide fuels.
- Nuclear waste processing and interim storage
  - The Waste Immobilization Plant (WIP) at Kalpakkam started in 1983 and was commissioned in 1993.
  - An Interim Storage Facility (ISF) also is located in Kalpakkam.

India’s marine nuclear infrastructure

- Bhabha Atomic Research Centre (BARC), near Mumbai on India’s west coast
  - Nuclear engineering design and support facilities
  - Developer of the pressurized water reactor (PWR) for the Arihant-class SSBNs and the future indigenous SSNs and the “S5” SSBNs.
- Major naval reactor component manufacturers
  - Reactor vessel: Heavy Engineering Corporation, Ranchi
  - Steam generators: Bharat Heavy Electricals Limited (BHEL)
  - Valves: Audco India, Chennai and others
- Indian Navy’s Directorate of Naval Design
  - A new submarine design center opened in 2017 in Gurgaon, southwest of New Delhi in northern India
- Arihant hull fabrication facility in Gujarat, India's westernmost state
- Ship Building Center (SBC) at the Hindustan Shipyard Limited (HSL) shipyard, located in Visakhapatnam, on India’s east coast
  - In 2010, HSL was transferred from the Ministry of Shipping to the Ministry of Defense.
  - The yard is responsible for the final assembly of the *Arihant*-class SSBNs and the future indigenous SSN.
  - The yard also is capable of performing nuclear submarine maintenance and overhaul.

HSL Shipyard

Ship Building Center (SBC), Visakhapatnam

Source: Hslvizag - own work, via https://en.wikipedia.org/wiki/Hindustan_Shipyard#/media/File:HSL_view_2.jpg

HSL Shipyard

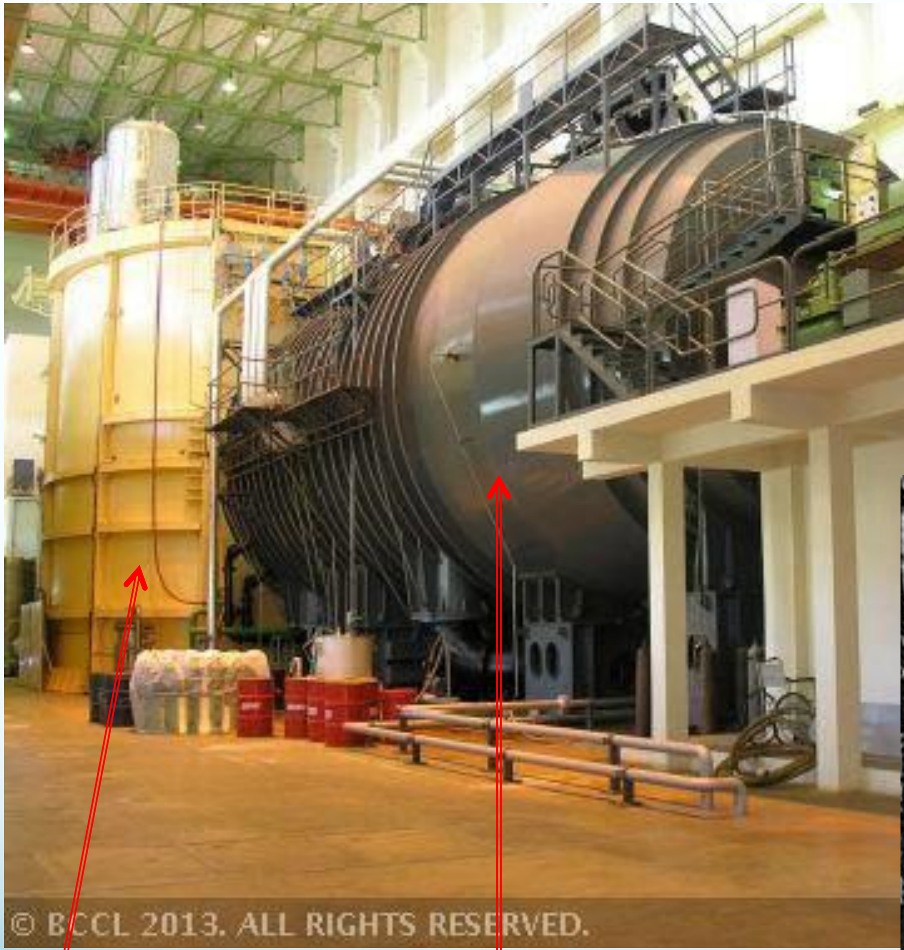
Ship Building Center (SBC), Visakhapatnam

Source: Hslvizag - own work, via https://en.wikipedia.org/wiki/Hindustan_Shipyard#/media/File:HSL_view_2.jpg

India’s S1 naval reactor prototype

- The S1 prototype naval nuclear propulsion plant is located in Kalpakkam, which is also home of several other nuclear facilities.
  - The prototype was developed by the Bhabha Atomic Research Center (BARC), specifically by a group called PRP Center.
    - PRP originally stood for “Plutonium Reprocessing Project”
    - It has been suggested that India received considerable assistance from the Russians for developing the prototype reactor.
  - The entire submarine propulsion plant with primary, secondary, electrical, propulsion systems and integrated control system was replicated in a land-based submarine hull.
    - Propulsion power (about 16,000 shaft horsepower, 11.9 MW) is absorbed by a dynamometer.
  - The prototype reactor is believed to be the same design as the *IHS Arihant* submarine reactor:
    - Power rating: 82.5 MWt
    - Fuel: uranium metallic fuel, enriched to about 30% U-235
    - 13 fuel assemblies with each assembly having 348 fuel pins.
- Key dates:
  - 11 Nov 2003: achieved initial criticality
  - 22 Sep 2006: declared operational and is used for both engineering development and training.

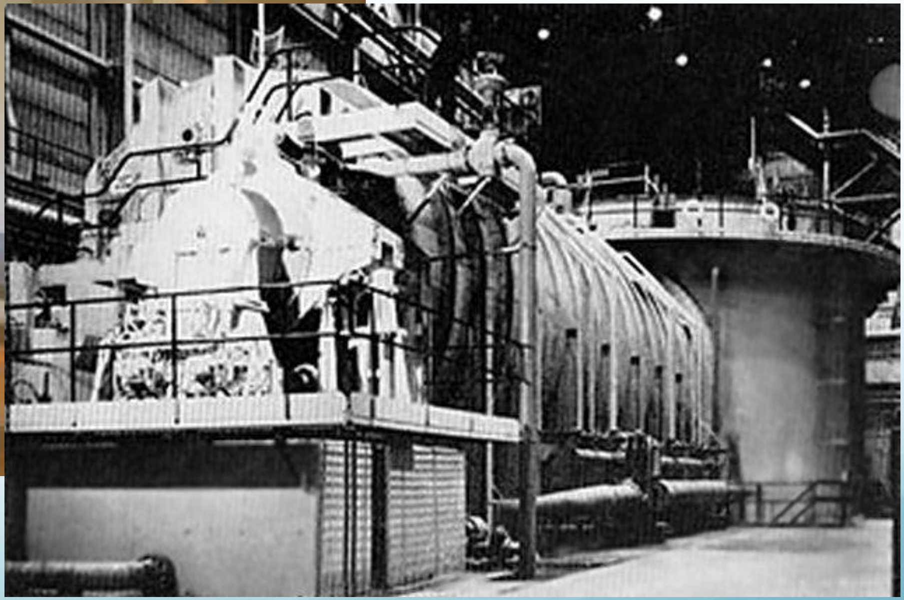
India's S1 naval reactor prototype



Left:
Indian naval reactor prototype.
Source: BCCL

Dynamometer to absorb propulsion power

Below: Very similar looking Westinghouse STR Mark 1 (S1W) prototype reactor, circa 1954



Reactor & primary coolant system in a hull section inside a shield water tank

Auxiliary systems and propulsion plant in unshielded hull section

Source: Westinghouse

Training India's nuclear submarine crews in Russia

- A simulator center for Indian nuclear submariners started operation in September 2005 at the A. P. Alexandrov Research Institute of Technologies (NITI) in Sosnovy Bor (80 km West of St. Petersburg).

Source: The Russian training center at Sosnovy Bor.
http://www.greenworld.org.ru/?q=ang_bv87

- Located next to the Russian training center for nuclear submarine officers.
- About 600 Indian officers together with their families will come to Sosnovy Bor for a long-term stay.

Naval Base *INS Varsha*

- This naval base is now being developed at Rambilli, on the east coast of India, about 50 km from Visakhapatnam.
  - Designed to support a fleet of 8 - 12 *Arihant*-class nuclear submarines, the Indian Navy's first indigenous aircraft carrier, *INS Vikrant*, and other naval vessels.
  - The submarines will be housed in underground pens.
  - The depth of water in the Bay of Bengal at *INS Varsha* will allow submarines to enter and leave the base without being detected by satellites.
  - A nearby facility of the Bhabha Atomic Research Centre (BARC) will provide nuclear engineering support facilities and crew accommodation.
- Visakhapatnam is the headquarters of the Indian Navy's Eastern Naval Command
  - Also, Hindustan Shipyard Limited (HSL), in Visakhapatnam, can support submarine maintenance & and overhauls.

Other naval infrastructure to support submarine operations

- VLF & ELF communications:
  - The Indian Navy has set up a new very low frequency (VLF) transmitting station at INS Kattabomman near the southern tip of mainland India. INS Kattabomman is an advancement over an existing VLF station located in its vicinity, which was established in the 1980s with US help, in terms of range and data transfer capability, among other aspects.
  - In 2014, extreme low frequency (ELF) transmitters were added, clearly indicative of a need to communicate with deeply submerged submarines.

India’s nuclear-powered submarines

Fast attack submarines

Strategic ballistic missile submarines

Nuclear-powered fast attack submarines (SSN)

India’s fast attack submarines (SSN)

Class	# in Class	Length	Beam	Displacement (tons)	Reactor	Shaft hp	Max speed (kts)	Years delivered	Years in service
Chakra I (leased Russian Charlie I SSN K-43)	1	95 m (312 ft)	10 m (32.8 ft)	4,000 (surf), 4,900 (sub)	1 x PWR 78 MWt	15,000 (est.)	24 kts	1988	1988 -1992
Chakra II (leased Russian Akula SSN K-152, ex-Nerpa)	1	110.3 m (362 ft)	13.6 m (45 ft)	8,140 (surf), 12,770 (sub)	1 x PWR 190 MWt (est.)	43,000 (est.)	>30 kts	2011	10 year lease 2011-2022
Chakra III (leased Russian Akula SSN)	1	110.3 m (362 ft)	13.6 m (45 ft)	8,140 (surf), 12,770 (sub)	1 x PWR 190 MWt (est.)	43,000 (est.)	>30 kts	2024 - 2025 (expected)	10 year lease planned
India’s indigenous SSN	6 (planned)	Not known	Not known	6,000 (est.)	1 x PWR 100 MWt (est)	Not known	Not known	Mid-2020s	

India’s leased Russian SSNs

- Leased Project 670 Charlie I SSN (*Chakra I*)
  - Former Russian designation was K-43.
  - Leased by India from Russia 1988–1992, then returned to Russia.
  - Introduced Indian crews to nuclear submarine operations.

- Leased Project 971I Improved Akula I SSN (*Chakra II*)
  - Former Russian designation was K-152, *Nerpa;* longest and heaviest of the Akulas, likely to be among the quietest.
  - 10-year lease from Russia, 2012 – 2022 at a reported price of $980 million.
  - Modified by Russia for export and does not include some features on Russian Akula counterparts:
    - No wake detection system (SOKS)
    - No counter-measure tubes located above the bow torpedo tubes
    - 8 x 533mm (21 inch) tubes (no 650 mm tubes)
  - *Chakra II* is expected to be armed with the Russian 3M-54 Klub (Club) cruise missile, which is available in anti-ship and land-attack versions.
  - Officially inducted into the Indian Navy on 4 April 2012.

India's leased Akula I SSN *Chakra II*

Source: http://nationalinterest.org/

India's leased Russian SSNs

- Second leased Project 971 Akula
  - In 2016, an agreement for a 10-year lease for a second Akula II SSN finally was formalized at an India-Russia summit meeting in Goa between President Vladimir Putin and Prime Minister Narendra Modi.
    - Candidate boats have been inspected by the Indian Navy, but a specific boat was not named in the agreement. It appears that the submarine in question is one of the Akula subs awaiting an overhaul at the "Zvezdochka" shipyard in Severodvinsk.
    - The project, which is funded by India, is expected to cost about $2.5 B and take about 78 month to complete.
  - After modernization, the 2nd Akula will be transferred to the Indian Navy.
    - This Akula will likely join the fleet before the first of India's indigenous SSNs is completed.
- In 2015, India reportedly raised the possibility of a future lease of a Project 885M Yasen-class multi-purpose SSN. Russia turned down this request.

India's indigenous SSN

- In February 2015, the India's government approved the construction of six (6) indigenous SSNs, which will benefit from experience gained building the first Arihant-class SSBN. IOC may be in the mid-2020s.
  - Designed by the Indian Navy's Directorate of Naval Design. Design work for the indigenous SSNs displacing around 6,000 tonnes is under way at the newly constructed submarine design center in Gurgaon,
  - Expected to be powered by a reactor developed by Bhabha Atomic Research Center. This reactor could be similar to the 100 MWt PWR used in the second-in-class *IHS Arighat* (S3) SSBN or a new design.
  - To be built by the Ship Building Center (SBC) in Visakhapatnam, on the east coast of India, where the Arihant-class SSBNs are being built.
- The six indigenous SSNs will join India's attack sub fleet currently comprised of one leased Russian Akula-class SSN and many conventional submarines.
- The indigenous SSNs are expected to have a maximum speed > 25 knots and an operating depth of about 500 m (1,640 ft).

India’s indigenous SSN

- Armament: Various weapons that can be launched from 533 mm (21 in) torpedo tubes, and possibly vertical launch systems (VLS). For example:
  - Torpedoes: The indigenous Varunastra heavyweight ASW torpedo or various international heavyweight torpedoes such as Black Shark manufactured by Italian firm Leonardo, the German-made SeaHake, and France’s F21 Artemis.
  - Missiles: The Russian 3M-54 Club-S anti-ship missile, a version of the Russian – Indian BrahMos medium-range, anti-ship cruise missile, and the indigenous Nirbhay long-range, land-attack cruise missile.
- Sonar: USHUS-2 is the likely choice for India’s indigenous SSN.
  - In 2017, India’s Naval Physical & Oceanographic Laboratory (NPOL) delivered the indigenous USHUS-2, which is an upgraded variant of the USHUS. According to NPOL USHUS-2 is an integrated sonar suite which constitutes an active sonar, passive sonar, intercept sonar, obstacle avoidance sonar and underwater communications. The system provides classification of targets, contact motion analysis and automatic torpedo detection capabilities.

INS Sindhudhvaj (S56) vs. *USS City of Corpus Christi* (SSN-705)

A case study of the performance of India's USHUS sonar suite on a very quiet and capable conventional submarine

- *INS Sindhudhvaj* is a 3,000 ton Russian-designed Kilo-class (Project 877EKM) diesel-electric submarine that was commissioned in 1987 and later modernized with the India's USHUS integrated sonar suite and tactical control system.
- *USS City of Corpus Christi* is a 6,900 ton Flight I Los Angeles-class SSN that was commissioned in 1983. Its modernized sonar suite included the BQQ 5D/E low frequency passive and active search and attack sonar, wide aperture flank array, thin line passive towed array, and close range high frequency active sonar.
- The October 2015 naval exercise *Malabar* was held in the Bay of Bengal (off India's east coast) and pitted vessels from the navies of India, US, and Japan against each other in mock combat. In one notable exercise, *INS Sindhudhvaj* defeated *Corpus Christi* with a simulated torpedo attack and was not detected by *Corpus Christi* before the exercise was terminated.
  - Apparently *INS Sindhudhvaj* captured the sound signature of *Corpus Christi* before the exercise started.
  - Later USHUS was able to locate and track *Corpus Christi* in the assigned exercise area in the open ocean. This enabled the very quiet *INS Sindhudhvaj* to close on its target and successfully conduct a simulated torpedo attack.

Submarine-launched tactical weapons

Torpedoes,
Tactical missiles

Varunastra ASW torpedo

- Varunastra, India's first indigenous heavy weight anti-submarine electric torpedo, was developed DRDO's Naval Science and Technological Laboratory (NSTL). It is manufactured under license from NSTL by by Bharat Dynamics Limited. This torpedo has > 95% indigenous content.
- This wire-guided torpedo is designed to target quiet and stealthy submarines, in deep or littoral waters, in intense counter-measure environments. Primary features include:
  - High speed and long endurance propulsion.
  - Conformal array for active / passive acoustic homing with wide look angle and advanced digital signal processing.
  - Advanced autonomous guidance algorithms with low drift navigational aids.
  - This currently is the only torpedo in the world with a satellite navigation location aid.
- Basic design parameters:
  - Weight: 1,500 kg (3,300 lb)
  - Diameter: 533 mm (21 in)
  - Length: 7 – 8 m (23 – 26 ft ft)
  - Propulsion: Electric motor; silver oxide – zinc batteries
  - Speed: 40 knots (75 kph, 46 mph)
  - Maximum range: 40 km (25 miles)
  - Operating depth: 400 m (1,300 ft)
  - Warhead: 250 kg (550 lb) high-explosive

Varunastra ASW torpedo

Source, above:
https://www.financialexpress.com/india-news/

IOC on Indian Navy surface ships was in 2016. Deployment of the submarine-launched version of the Varunastra torpedo began in 2017 on India's Sindhughosh-class diesel-electric submarines (Russian Kilo-class attack subs).

Source, above: https://www.indiatoday.in/india/

India’s submarine-launched tactical missiles

Cruise missile	Years in service	Weight	Length	Diam (D) /Span (S)	Speed	Range	Guidance	Warhead
3M-54 Club (SS-N-27 Sizzler) Anti-ship	Prior to 2015 on Kilo-class SS	1,780 kg (3,924 lb)	Club S: 6.2 m (20 ft)	D = 53 cm (21 in)	Subsonic cruise + Mach 2.5 - 2.9 terminal “sprint”	220 km (137 mi)	Inertial + active radar homing	Conventional, 200 kg (440 lb) penetrating high-explosive warhead
BrahMos Anti-ship	2015 on a surface ship; IOC on submarine expected 2019 - 2020	3,000 kg (6,614 lb)	8.4 m (27.6 ft)	D = 0.6 m (2.0 ft)	Mach 2.8 – 3.0	290 km (180 mi)	Inertial + satellite navigation + terminal active radar	200 kg (440 lb) warhead capability; conventional penetrating high-explosive warhead or nuclear
BrahMos II	IOC early - mid 2020s (est)	Not known	Not known	Not known	Mach 5 – 7	300 km (190 mi)	Not known	HE or nuclear
Nirbhay Land-attack	Still under development in mid-2018. IOC 2019 – 2020 (est)	1,500 kg (3,307 lb)	6.0 m (19.7 ft)	D = 52 cm (< 21 in) / S = 2.7 m (8.6 ft)	Mach 0.6 – 0,7	750 - 1,000 km (466 – 621 mi)	Inertial + satellite navigation + terminal active radar	200 - 300 kg (441 - 661 lb) warhead; wide range of conventional warheads or nuclear

Kalibr / Club / SS-N-24 Sizzler

Subsonic + terminal supersonic anti-ship cruise missile (aka 3M54E)

- The Kalibr 3M54E (aka Club and Klub) is a Russian-developed anti-ship cruise missile that is available in submarine-, surface ship-, and air-launched versions. The missile is used by Russian naval forces and and is available in export versions.
  - India is an export customer. The missiles were acquired prior to 2015 for use on India's Kilo-class (Sindhughosh-class) diesel-electric attack subs.
- Except in the air-launched version, a small rocket booster launches the weapon, then a turbojet engine powers the missile at subsonic speed until in the vicinity of the target. Then, a small, rocket-propelled "second stage" warhead separates from the subsonic airframe, accelerates to about Mach 2.5 - 2.9, and uses active radar to home in on the designated target.
- The 3M54E can be launched from a submarine via a standard 533 mm (21 in) torpedo tube or from VLS launcher at a launch depth of 30 - 40 m (98 – 131 ft).
- The missile carries a penetrating high-explosive warhead.
- Range is about 220 km (137 mi).

Kalibr / Club / SS-N-24 Sizzler

Subsonic + terminal supersonic anti-ship cruise missile (aka 3M54E)

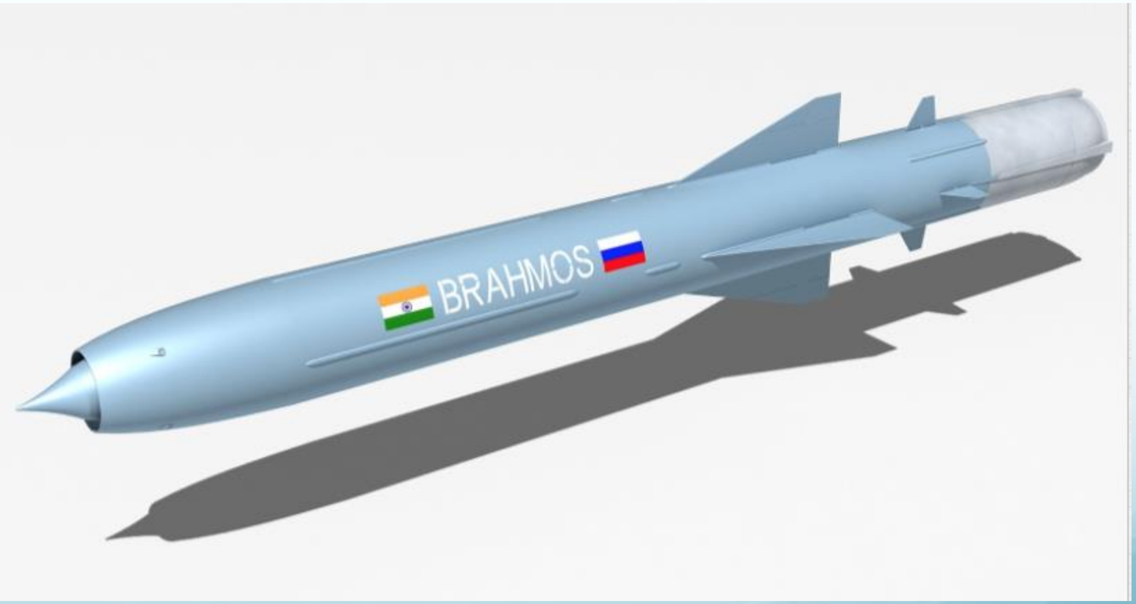
Source, above: Allocer via https://commons.wikimedia.org/wiki/File:3M-54E_missile_MAKS2009.jpg

Source: http://www.ausairpower.net/APA-Rus-Cruise-Missile

BrahMos

Supersonic medium-range, anti-ship cruise missile

- BrahMos (portmanteau of the rivers Brahmaputra and Moskva in India and Russia) is being developed by a Russian – Indian joint-venture, BrahMos Aerospace Private Limited (Russia's NPO Mashinostroeyenia and India's Defense Research and Development Organization).
- Design is similar to the Russian P-800 Oniks cruise missile developed by NPO Mashinostroeyenia.
- Intended as a "universal" anti-ship cruise missile with ship-, submarine-, land-, and air-launched versions.
  - Launched by a rocket booster; then flies to the target at Mach 2.8 – 3.0 powered by a ramjet engine.
  - Range limited to 300 km (190 mi) to comply with the Missile Technology Control Regime (MTCR).



Source: http://www.stlfinder.com/model/brahmos-pj10-missile

BrahMos

Supersonic medium-range, anti-ship cruise missile

- As of mid-2018, the ship- and land-launched versions have been deployed. The air-launched version was tested in 2016 and 2017 and is nearing deployment.
- Development of the submarine-launched version is continuing.
  - Capable of being launched from a submarine vertical launch system (VLS) tube at a depth of 40 – 50 meters (131 – 164 ft). The current version is too large to be launched from a 533 mm (21 inch) torpedo tube.
  - 1st submerged launch (from a platform) occurred on 20 March 2013..
  - After clearing the water, a protective nose cap is ejected and the missile turns toward the target, which may be up to 290 km (180 mi) away.

- In January 2016, NPO Mashinostroeyenia announced plans to develop a smaller version of BrahMos that can be launched from a 533 mm (21 inch) torpedo tube. This version will be used on future Indian subs that do not have a VLS.
- IOC for a submarine-launched version is likely to be in the early 2020s.

Brahmos submerged launch. Source: http://www.brahmos.com/

BrahMos II

Hypersonic medium-range cruise missile

- Like Brahmos, the more advanced BrahMos II is being developed by the Russian – Indian joint-venture, BrahMos Aerospace Private Limited.
- Technology likely is based on the Russian Zircon (3M22 Tsirkon) hypersonic cruise missile developed by NPO Mashinostroeyenia.
- Intended as a “universal” cruise missile with ship-, submarine-, land-, and air-launched versions.
  - Missile is launched with a rocket booster and then flies to the target at Mach 5 – 7 powered by a supersonic combustion ramjet (scramjet) engine.
  - Range will be limited to 300 km (190 mi) to comply with the Missile Technology Control Regime (MTCR).
- Expected to be ready for testing by 2020.

Source: Brahmos-II Hypersonic Cruise Missile on display at Aero India 2015. http://www.indiandefensenews.in

Nirbhay

Subsonic long-range, land-attack cruise missile

- This is India's first indigenously produced land-attack cruise missile; it is being developed in surface ship-, submarine-, land-, and air-launched versions.
  - All versions except the air-launched version include a solid rocket booster.
  - In cruise flight, Nirbhay has been powered by a Russian NPO Saturn 36MT mini turbofan engine. India plans to replace the 36MT with an indigenous small turbofan being developed by DRDO's engine laboratory GTRE (Gas Turbine Research Establishment), making Nirbhay > 95% indigenous.
  - The submarine-launched version of Nirbhay is designed to be launched from a standard 533 mm (21 in) torpedo tube.
- Range: 750-1,000 km (466-621 mi), with loiter capability en-route
- Speed: Subsonic, Mach 0.6 – 0.7
- Nirbhay may be a dual-capable (conventional or nuclear) missile.
- As of mid-2018, development testing was continuing at the Chandipur Integrated Test Range:
  - The 1st test flight was on 12 March 2013 was a partial success.
  - During the 2nd test flight on 17 October 2014, Nirbhay demonstrated the ability to fly a complex course and strike the intended target after flying for more than an hour.
  - By January 2018, a total of five test flights had been conducted.
- Initial Operating Capability (IOC) may occur in the 2019 – 2020.

Nirbhay

Subsonic long-range, land-attack cruise missile

Source, top: https://www.youtube.com/watch?v=JuVdtrqYyD4
Source, below left: http://missilethreat.com/missiles/nirbhay/

Source,below: http://www.rediff.com/news/report

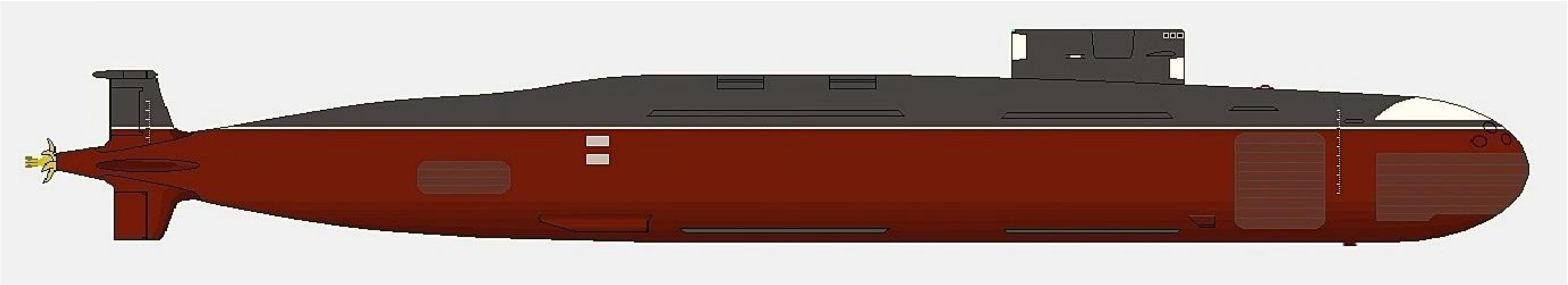
Nuclear-powered strategic ballistic missile submarines (SSBN)

India’s strategic missile submarines (SSBN)

Class *	# in Class	Length	Beam	Displacement (tons)	Reactor	Shaft hp	Max speed (kts)	Years delivered	Years in service
INS Arihant S73 / S2 (Arihant-class lead boat)	1	112 m (367 ft.)	11 m (36 ft.)	6,000 (surf)	1 x PWR 82.5 MWt	15,900 (est.)	24 – 25 (est.)	2014	2016 - present
INS Arighat S3	1	> *INS Arihant*	11 m (36 ft.)	> *INS Arihant*	1 x PWR 100 MWt	19,200 (est.)	24	2018	2020 - 2021 (est)
*S4 and S4**	2	> *INS Arihant*	11 m (36 ft.)	7,000 (surf) (est)	1 x PWR 100 MWt	19,200 (est.)	24 – 25 (est.)	2020 – 2022	Mid-2020s
S5	3 planned	Not known	Not known	14,881 (13,500 tonnes)	1 x PWR 190 MWt	35,000 – 37,000 (est)	About 25	Mid-2020s	

* The designation “S1” was applied to the naval reactor prototype at Kalpakkam.

INS Arihant (S2) SSBN



Source: adapted from defence.pk

- *INS Arihant* (originally S-73 / now S-2) is the 1st boat in what is expected to be a four boat class of indigenous SSBNs. *Arihant* is a Sanskrit word meaning *Slayer of Enemies*.
  - Based on the design of a Russian Akula I SSN, and originally intended to be an SSN.
  - Jointly developed by the Indian Navy, Bhabha Atomic Research Centre (BARC), and Defense Research and Development Organization (DRDO) with technical assistance from Russia's Rubin Central Design Bureau for Marine Engineering.
  - The Arihant-class eventually will constitute the sea leg of India's strategic deterrent triad. India maintains nuclear warfare policy centered on a No First-Use (NFU) doctrine.
- Propulsion:
  - *INS Arihant* is powered by one PWR developed by the Bhabha Atomic Research Centre (BARC). The reactor is rated at about 82.5 MWt, with a secondary steam plant delivering about 16,000 shaft horsepower (11.9 MW) to a single 7-bladed propeller.
  - Follow-on boats will have a more powerful reactor, with a rating of about 100 MWt.

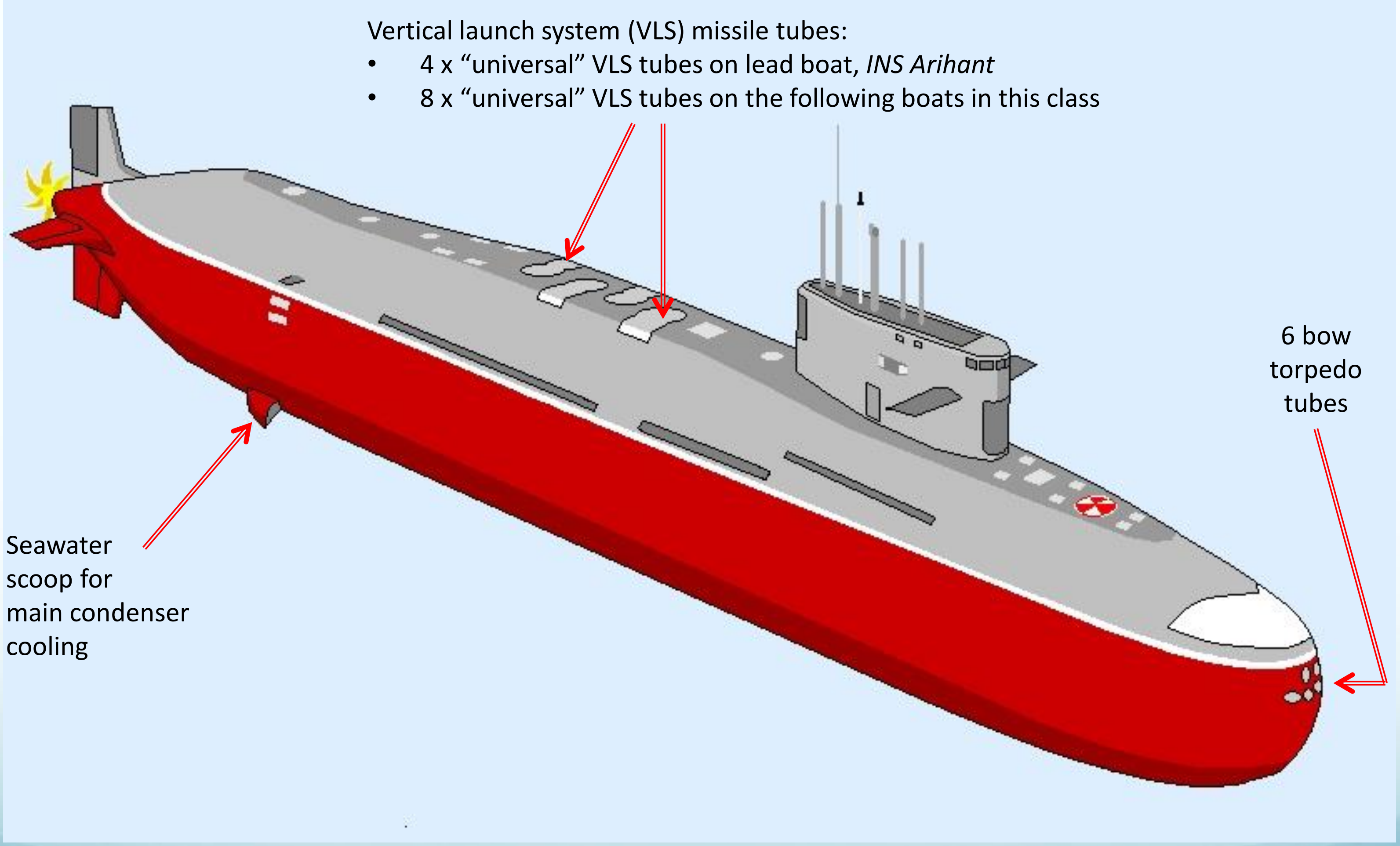
INS Arihant (S2) SSBN

- Armament:
  - 4 x "universal" (large) SLBM tubes amidships. Each tube is about 2 m in diameter and is capable of carrying:
    - 3 x K-15 Sagaril short-range SLBMs, or
    - 1 x K-4 long-range SLBM, or
    - Various combinations of smaller diameter missiles
  - Follow-on boats will have 8 x "universal" SLBM tubes, doubling their missile load.
  - Also armed with 6 x 533 mm (21 in) bow torpedo tubes; storage for 30 full-size weapons (heavyweight torpedoes or missiles) and mines.
- Sonar: USHUS
  - Arihant-class SSBNs will be fitted with an integrated sonar suite known as USHUS, which was developed in India by the Naval Physical and Oceanographic Laboratory (NPOL) of the Defense Research and Development Organization (DRDO), and built by Bharat Electronics Limited (BEL) in Bangalore.
  - USHUS is a unified submarine sonar and tactical control system, which includes passive, surveillance, ranging, intercept, obstacle avoidance and active sonar subsystems and included:
    - Twin flank passive sonar arrays are installed on the hull.
    - An underwater communications subsystem.
  - USHUS has been used operationally on India's modernized, Russian-designed, Kilo-class diesel-electric submarines, and likely will be installed on India's planned fleet of indigenous SSNs.

INS Arihant (S2) SSBN

- The hull is HY-80 steel. Test depth: 350 m (1,150 feet) (est.)
- Crew size: 95 -100
- Key milestones:
  - 1998: Start of construction
  - 26 Jul 2009: Launched
  - 10 Aug 2013: Initial criticality
  - 15 Dec 2014: Start sea trials
  - November 2015: 1st launch of a K-15 short-range SLBM from *IHS Arihant*
  - 31 Mar 2016: 1st launch of a K-4 long-range SLBM from *IHS Arihant*
  - Aug 2016: *IHS Arihant* Commissioned (but not yet ready for deterrent patrol)
  - Feb 2017: Flooding into the engine room occurred while *IHS Arihant* was in the harbor due to an external hatch not being properly secured. Sub was out of commission for about 10 months for restoration.
  - 2017: *IHS Arihant* completed trials of the K-15 short-range SLBM from the submarine.
  - 2018: K-4 long-range SLBM tests from *INS Arihant* continued.

INS Arihant (S2) SSBN



Source: Gagan / Wikimedia Commons

INS Arihant (S2) SSBN

Source: Indian Navy

Source: http://www.indiastrategic.in

INS Arihant (S2) SSBN

Sources top: https://www.thehindu.com/news/national/
bottom: https://www.ndtv.com/india-news/

INS Arihant (S2) SSBN

This may be a photo of a universal launch tube used on Arihant-class SSBNs.

Source: https://www.youtube.com/watch?v=kZ-DighKKKc

INS Arighat (S3) SSBN

- *INS Arighat* (originally named *INS Aridhaman*) is the 2nd boat in India's Arihant-class of SSBNs. The keel was laid in 2011. The ship was launched at the Ship Building Center in Visakhapatnam on 19 November 2017. Final outfitting and sea trials will be performed before commissioning in 2020 - 2021.
- *INS Arighat* has the following notable design changes:
  - 8 x "universal" (large) SLBM tubes (twice the number on *INS Arihant*), each capable of holding 3 x K-15 Sagaril short-range SLBMs or 1 x K-4 long-range SLBM.
  - Longer hull, greater displacement
  - A more powerful PWR rated at about 100 MWt.
  - More advanced sensors featuring the indigenous USHUS unified submarine sonar and tactical control system used for detecting and tracking submarines, torpedoes, as well as underwater obstacles. It can also be used for underwater communication.
  - The Rafael broadband expendable anti-torpedo counter-measures system is installed
- *INS Arighat* can achieve a maximum speed of 12–15 knots on the surface and 24 knots underwater.

S4 and S4* SSBNs

- The next two Arihant-class SSBNs, currently named the S4 and S4* (S4 'star’), will displace over 1,000 tonnes (1,102 tons) more than the *INS Arihant* and will be fitted with eight “universal” SLBM tubes amidships, like the *IHS Arighat*.
- Originally, S4 was to be the last Arihant-class SSBN before proceeding with construction of the larger S5-class SSBNs. The S-4* was approved in 2012 when it became clear that the S-5 would have a longer development cycle than originally planned and would result in the Advanced Technology Vessel (ATV) construction line at the Ship Building Centre (SBC) at Visakhapatnam being idle.
- The S4 and S4* are under construction at SDS in the drydocks vacated by the *INS Arihant* and *INS Arighat.*
- S4 and S4* are expected to be launched between 2020 - 2022.

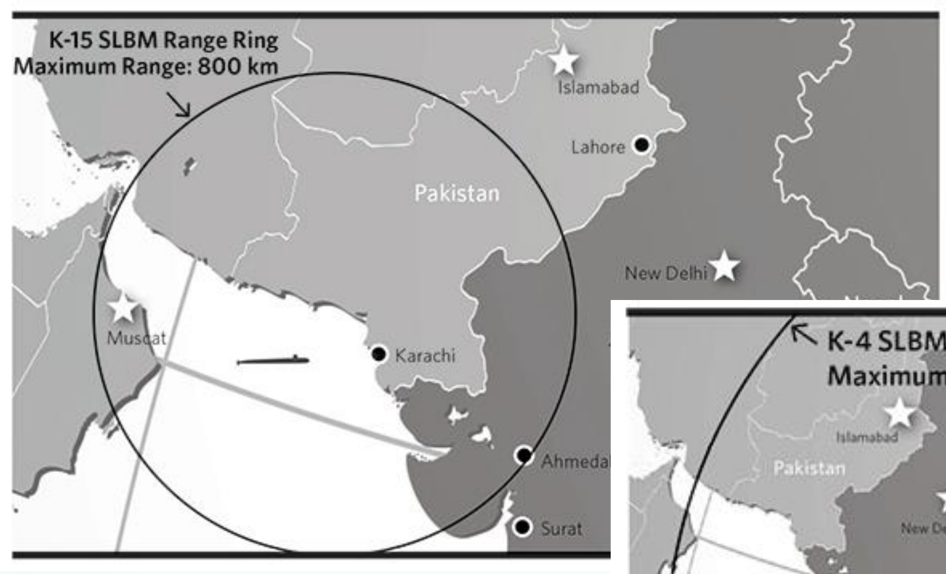
S5-*class* SSBNs

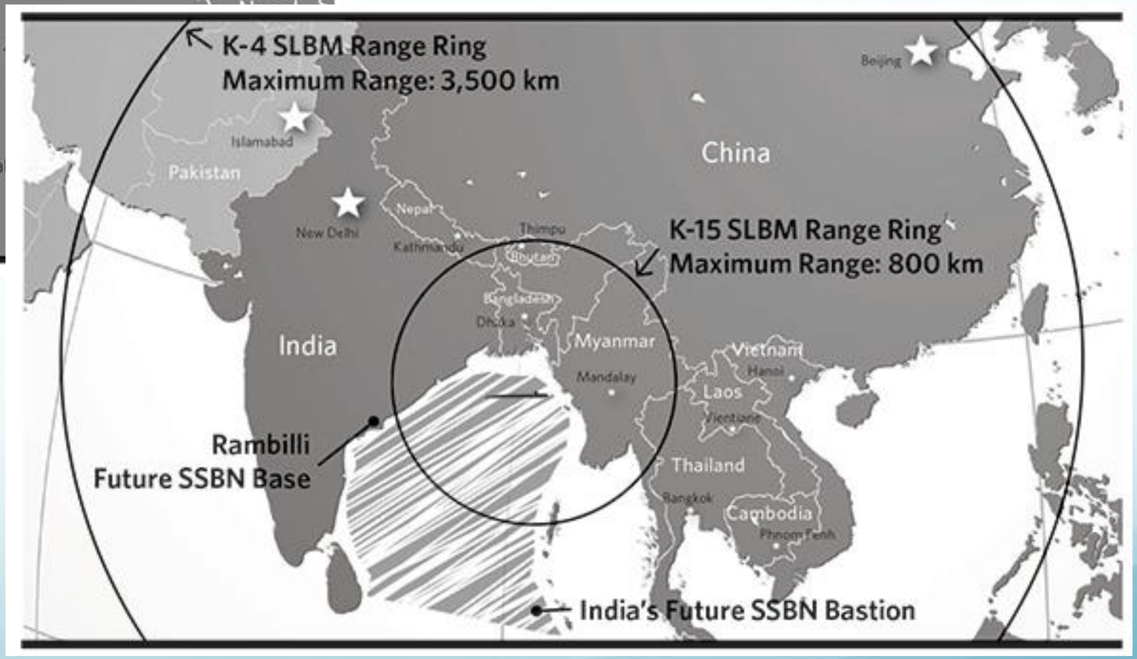
- The S5 SSBN concept evolved from a 2006 high-level committee led by Dr. R. Chidambaram, a principal scientific advisor to the government of India, which assessed India's ability to design and construct a new class of large SSBNs for delivery in the early 2020s.
- In 2015, BARC, DRDO and the ATV project were funded to start the S5 project.
- In 2017, it was reported * that final design work was under way on the S5 SSBNs. At 13,500-tonnes (14,881 tons), they will have twice the displacement of the Arihant-class SSBNs, will be powered by a reactor rated at about 190 MWt, and will be armed with 12 long-range K-6 SLBMs with nuclear warheads and a range of 6,000 km.
- In 2017 DRDO initiated the K-6 SLBM testing program.

Source: https://www.indiatoday.in/magazine/the-big-story/story/20171218-india-ballistic-missile-submarine-k-6-submarine-launched-drdo-1102085-2017-12-10

Example operating areas for India's SSBN deterrent patrols

K-15 short-range and K-4 long-range SLBMs





Source: http://carnegieendowment.org/2015/03/09/murky-waters-naval-nuclear-dynamics-in-indian-ocean

Example operating areas for India's SSBN deterrent patrols

K-4, K-5 and K-6 long-range SLBMs

Legend:

1 Visakhapatnam: Hindustan Shipyard, Ltd. (aka Ship Building Center, SBC), shipyard where India's nuclear subs are built and overhauled.
2 Rambilli: Naval Base *INS Varsha* will be the SSBN home port.
3 Andaman & Nicobar Islands: Test range for naval missiles.
4 SSBN patrol area (brown).

Source: https://www.indiatoday.in/magazine/the-big-story/story/20171218-india-ballistic-missile-submarine-k-6-submarine-launched-drdo-1102085-2017-12-10

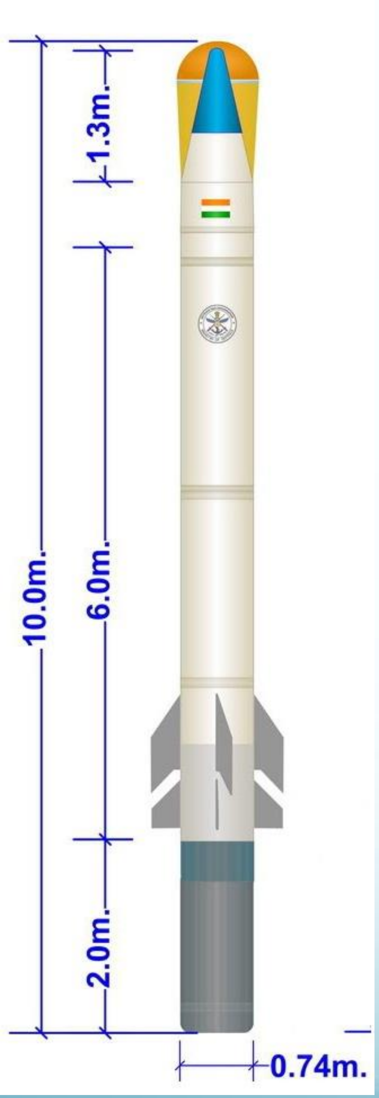
Submarine-launched ballistic missiles (SLBM)

India’s submarine-launched ballistic missiles (SLBMs)

SLBM	Years in service / platform	Weight	Length	Diameter	# of stages	Range / Guidance	Warhead
K-15 * (B-05) Sagarika	IOC probably in 2017 / Arihant-class SSBN	6,500 kg (13,860 lb)	10.0 m (32.8 ft)	0.74 m (2.42 ft)	2 solid	750 km (466 mi) / inertial + satellite nav update + terrain contour matching	Nuclear, 455 kg (1,000 lb)
K-4 Mk I *	In operational test phase / Arihant-class SSBN	17,000 kg (37,479 lb)	10.0 m (32.8 ft)	1.3 m (4.25 ft)	3 solid	3,500 km (2,175 mi)	Nuclear, 2,000 kg (4,400 lb) warhead
K-4 Mk II *	In development phase / S5 SSBN	17,000 kg (37,479 lb)	12.0 m (39.9 ft)	1.3 m (4.25 ft)	3 solid	5,000 km (3,110 mi)	Nuclear
K-5	In development phase / S5 SSBN	Not known	12.0 m (39.9 ft)	2 m (6.56 ft)	3 solid	5,000 km (3,110 mi)	Nuclear, 1,000 kg (2,204 lb) MIRV warhead
K-6	In design phase / S5 SSBN	Not known	Not known	2 m (6.56 ft)	3 solid	6,000 km (3,728 mi)	Nuclear, 2,000 – 3,000 kg (4,408 – 6,612 lb) MIRV warhead

* The K-15 and K-4 missiles are capable of flying a ballistic or a depressed (flat) trajectory. The K-15 and K-4 warhead sections are reported to be capable of 3-D maneuvering flight within the upper atmosphere, enroute to the target.

K-15 Sagarika SLBM (aka B-05)



- In the late 1990s, India's Defense Research and Development Organization (DRDO) initiated Project 420 to design and develop an SLBM for the planned Arihant-class SSBNs. Project 420 produced the K-15 SLBM.
- The K-15 is a two-stage, solid propellant, short-range SLBM. It has range of 750 km (466 miles) with a 1,000 kg (2,205 lb) payload, or 1,900 km with a 180 kg (397 lb) payload.
- *INS Arihant* can carry up to 12 K-15 SLBMs in its four universal SLBM launch tubes (three per tube).
- *INS Arighat* and the later two Arihant-class SSBNs can carry up to 24 K-15 SLBMs in their eight universal SLBM launch tubes.

This is a diagram of the land-based Shaurya, which is believed to be comparable to a K-15 SLBM. Source: https://defence.pk/pdf/threads/n-sub-ins-arihant-to-test-fire-missile.385145/

K-15 Sagarika SLBM (aka B-05)

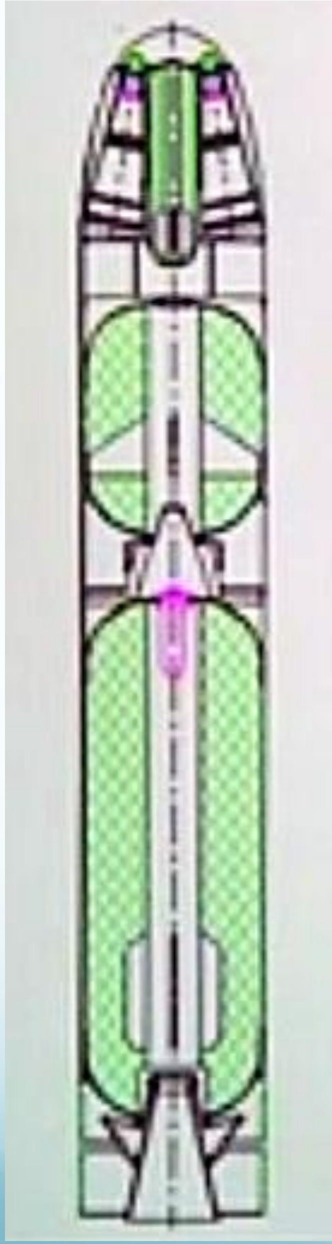
- The first fully-integrated test firing of the K-15/B-05 SLBM from an underwater pontoon was conducted in January 2010, followed by another test in January 2011, and another two tests in January 2012. The K-15's first-stage solid-fuel rocket booster was ignited inside a pontoon-based missile silo at a depth of 20 m (65.6 ft).
- In the tests from the underwater pontoon, the K-15 first demonstrated its ability to fly a depressed (non-ballistic) trajectory. The K-15's first-stage, solid-fuel rocket booster lifted the missile to an altitude of 7km (4.3 mi). Then the second-stage solid-fuel rocket ignited & lifted the missile to an altitude of 40km (24.8 mi), after which the missile flies at about Mach 7 on a depressed (flat, non-ballistic) trajectory to the target.
- 25 November 2015: 1st K-15 launched from *INS Arihant*.

K-15 pontoon missile launch tube.
Source: DRDO

K-15 Sagarika SLBM (aka B-05)

K-15 test launch and nose cap removal.
Source: https://defencelover.in/ins-aridhamanmore-deadly-ins-arihant/

Land-based Shaurya nose cap removed during launch.
Source: https://defenceforumindia.com



K-4 SLBM

Mark I and Mark II

- The K-4 is a three-stage, solid propellant, long-range SLBM with MIRV warheads
  - The Mark I version has range of 3,500 km (2,174 miles) with a 2,500 kg (5,512 lb) payload. This is the version that will be deployed first on Arihant-class SSBNs.
  - The Mark II version has range of 5,000 km (3,110 miles) with a 1,000 kg (2,204 lb) payload. It is in an earlier stage of development. The longer (12 m) Mark II version likely will require modifications to the Arihant-class SSBN missile tubes.
- *INS Arihant* can carry up to 1 x K-4 Mark I SLBMs in its four universal SLBM launch tubes (one per tube).
- *INS Arighat* and the later two Arihant-class SSBNs can carry up to 1 x K-4 Mark I SLBMs in their eight universal SLBM launch tubes.
- In 2010, the “cold-launch” gas-generator designed for launching the K-4 was successfully tested from a submerged pontoon.

Speculative K-4 SLBM general configuration.
Source: http://indiandefence.com/threads/

K-4 SLBM

Mark I and Mark II

- 24 March 2014: 1st successful underwater launch of a K-4 Mark I SLBM was conducted from a test platform at a depth of 30 m (98.4 ft). A gas generator ejected the K-4 from the missile silo on the submerged pontoon and the rocket motor ignited at the surface.
- 31 Mar 2016: 1st launch of a K-4 Mark I SLBM from *IHS Arihant*. The missile was launched with a dummy warhead, but otherwise in full operational configuration.
- As of mid-2018, the K-4 Mark I test program is still in progress, but should be approaching IOC. The K-4 Mark II is under development.

Source: http://idrw.org/india-issues-navarea-warnings-for-likely-test-of-k-4-slbm/

K-5 & K-6 SLBMs

- Development testing of the K-5 is in progress.
  - This SLBM will have a range of over 5,000 km (3,106 mi).
  - First missile test is expected later in 2018.
- Start of development of the K-6 SLBM was announced in 2017.
  - Range will be about 6,000 km (3,728 mi).
  - It will have a 2 – 3 tonne, multiple independently targetable re-entry vehicle (MIRV) warhead.

India’s marine nuclear power current trends

India current trends

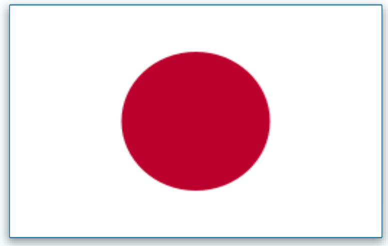
- **New build:**
  - Construction of the 3rd and 4th Arihant-class SSBNs, dubbed S4 and S4*, is in progress at the Ship Building Center (SBC) (Hindustan Shipyard Limited, HSL) at Visakhapatnam, with construction to be completed by about 2022.
  - The SBC likely will need to be expanded to support the planned construction of six indigenous SSNs that should be starting soon and the construction of the expected "S5"-class SSBNs later in the 2020s.
- **Additional leases:**
  - A 2nd Improved-Akula sub has been leased from Russia and is expected to join the fleet in 2018.
- **Operations:**
  - India has become increasingly concerned about Chinese submarine presence in the Indian Ocean since an initial patrol in the region by a Shang-class SSN between December 2013 – February 2014.
  - When completed in about 2022, Naval Base *INS Varsha* will support nuclear fleet operations from the east coast of India and permit easy access of SSBNs to patrol areas that can target both China and Pakistan with the long-range K-4 SLBMs.

India current trends

- **New weapons system development:**
  - SLBMs:
    - The long-range K-4 SLBM development program is continuing, and the SLBM should be approaching an initial operating capability (IOC) on *INS Arihant*.
    - Even longer range K-4 Mk II, K-5 and K-6 SLBMs are planned.
  - Cruise missiles:
    - Development of the indigenous Nirbhay long-range, land-attack cruise missile is continuing, with an IOC in 2019 – 2020 likely.
    - The Indian-Russian BrahMos joint venture plans to develop a smaller version of the supersonic BrahMos anti-ship cruise missile for submerged launch from submarine 533 mm (21 in) torpedo tubes.
    - The BrahMos II hypersonic cruise missile is under development. IOC in the mid-2020s may be possible.
- **New submarine development:**
  - Development of India’s indigenous SSN started in 2015 when the program was authorized by the Indian government. The first boat is expected to be delivered by the mid-2020s.
  - As a follow-on to the four Arihant-class SSBNs, India is planning a larger “S-5” SSBN, reportedly armed with 12 next-generation SLBMs. Delivery of the first boat before 2030 seems unlikely.

India current trends

- **New marine reactor development:**
  - The 2nd and later Arihant-class SSBNs are believed to have a more powerful 100 MWt PWR than the lead-ship. This may be the reactor that will be used on Indigenous SSNs.
  - The larger "S5"-class SSBNs will require a more powerful propulsion plant than the Arihant-class SSBNs. Development of this new reactor likely is in progress now.
  - India has expressed interest in adopting LEU naval reactor fuel (enrichment ≤20%) and has had discussions with France on their LEU naval fuel.
- **Nuclear aircraft carrier development:**
  - India is building two indigenous, conventionally-powered Vikrant-class aircraft carriers.
    - The first ship, *IHS Vikrant* is a modest-size carrier, with a displacement of 40,000 tonnes and an overall length of is 262 m (860 ft). It is designed for an air group of up to thirty aircraft. The ship has a ski-jump bow for launching aircraft and has an arrested recovery system. Sea trials are expected to begin in 2019, with commissioning in the 2022 – 2023 timeframe.
    - The second ship, *IHS Vishal*, will be significantly larger, with a displacement of 65,000 tons. This ship is expected to use catapult launch (possibly an electromagnetic catapult) to enable it to handle heavier aircraft, and arrested recovery.
  - While India is gaining experience building and operating modern, conventionally-powered aircraft carriers, it also is considering the use of nuclear propulsion for a future aircraft carrier. However, this remains a distant goal, possibly beyond 2030.



Japan

Civilian nuclear prototype cargo / research vessel
and advanced marine reactor concepts

Source: https://en.wikipedia.org/

Japan marine nuclear timeline

1963
Prototype boiling water reactor, the Japan Power Demonstration Reactor (JPDR) initial operation
Aug 1963
Japanese government established the Japan Nuclear Ship Research and Development Agency
12 Jun 1969
Mutsu launched

1978 – 1982
Mutsu was in the port of Sasebo for modifications
1983 – 1990
Mutsu remains in port, awaiting 1st voyage

2005
JNC and JAERI merged to create the Japan Atomic Energy Agency (JAEA)

1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s

1955
Atomic Energy Basic Law, which strictly limits the use of nuclear technology to peaceful purposes
1956
Atomic Energy Commission (JAEC), Nuclear Safety Commission (NSC), the Science & Technology Agency; Japan Atomic Energy Research Institute (JAERI) and the Atomic Fuel Corporation all were formed.

4 September 1972
Mutsu nuclear fuel loaded
1 Sep 1974
Mutsu towed to sea for 1st reactor test. High radiation detected. Test terminated
Mid-1970s
JAERI develops MRX (Marine Reactor X) concept

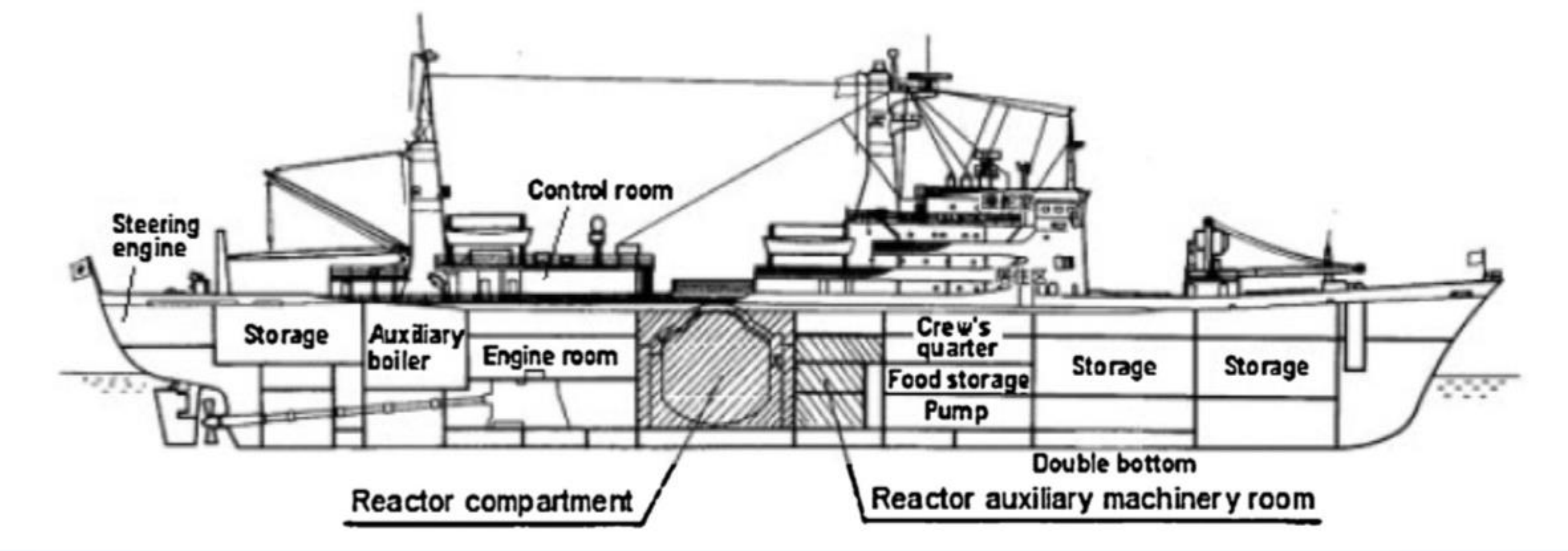
1990s
JAERI develops DRX (Deep-sea Reactor X) concept
February 1991
Mutsu first voyage on nuclear power
1992
Mutsu decommissioned
1996
Mutsu Science Museum opens

The beginning of Japan's marine nuclear power program

- **1955:** Japan's nuclear industry did not start for almost a decade after the end of WW II. In 1955, the Atomic Energy Basic Law was passed to strictly limit the use of nuclear technology to peaceful purposes.
- **1956:** Japan's basic nuclear industry started developing quickly with the establishment of the following organizations:
  - Atomic Energy Commission (JAEC)
  - Nuclear Safety Commission (NSC)
  - Science & Technology Agency
  - Japan Atomic Energy Research Institute (JAERI)
  - Atomic Fuel Corporation
- **Aug 1963:** The Japanese government established the Japan Nuclear Ship Research and Development Agency. Later, the Agency approved construction of a prototype nuclear-powered civilian cargo + research vessel design promoted by JAERI.
- **12 Jun 1969**: Six years after approval, Japan's first (and only) nuclear vessel, the prototype civilian cargo + research vessel *Mutsu* launched.
- **1 Sep 1974**: After a radiation streaming (shielding) design problem was found during the first reactor test, Mutsu was sidelined for the next 17 years.
- **February 1991**: *Mutsu* finally made its first voyage on nuclear power and was decommissioned the following year.
- After *Mutsu*, there were few significant opportunities to develop marine nuclear power in Japan beyond the interesting marine reactor concepts MRX and DRX.

Mutsu

Japan's prototype civilian cargo + research vessel



Source: L. O. Freire & D. Alves de Andrade, "Historic survey on nuclear merchant ships," Nuclear Engineering and Design 293 (2015), 176–186

- In August 1963, the Japanese government established the Japan Nuclear Ship Research and Development Agency and approved development of Japan's first nuclear-powered ship based on the "*Basic plan on the studies necessary for the research and development of nuclear powered ship*" prepared by Japan Atomic Energy Research Institute (JAERI).
- *Mutsu* was intended to serve as a prototype commercial nuclear-powered ship for transporting special cargos and training crews in nuclear ship operation.

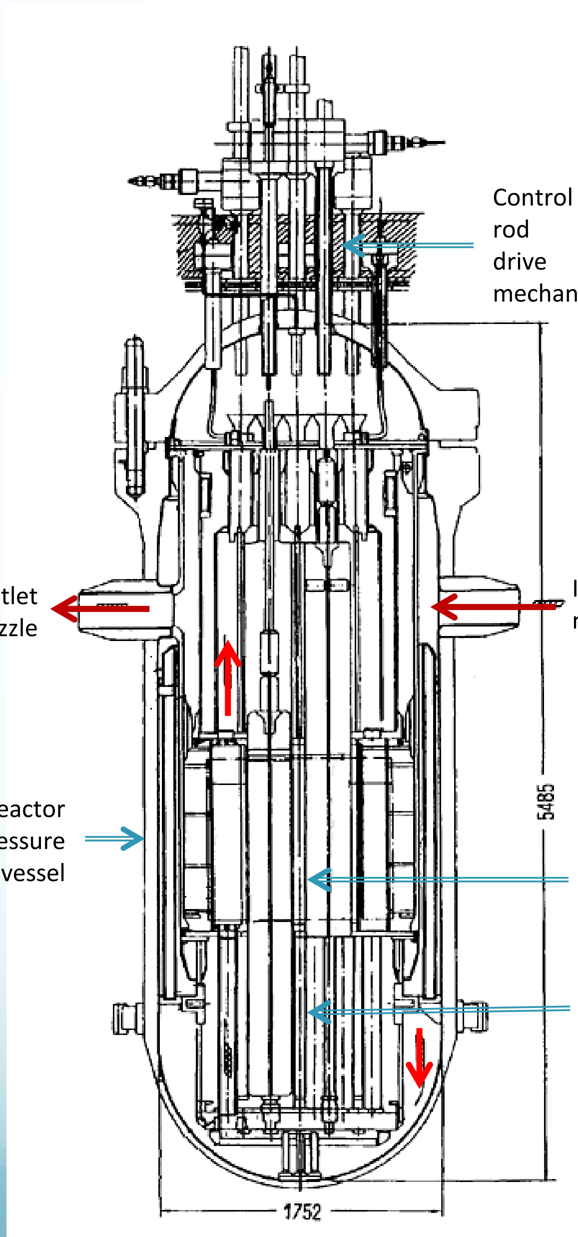
Mutsu

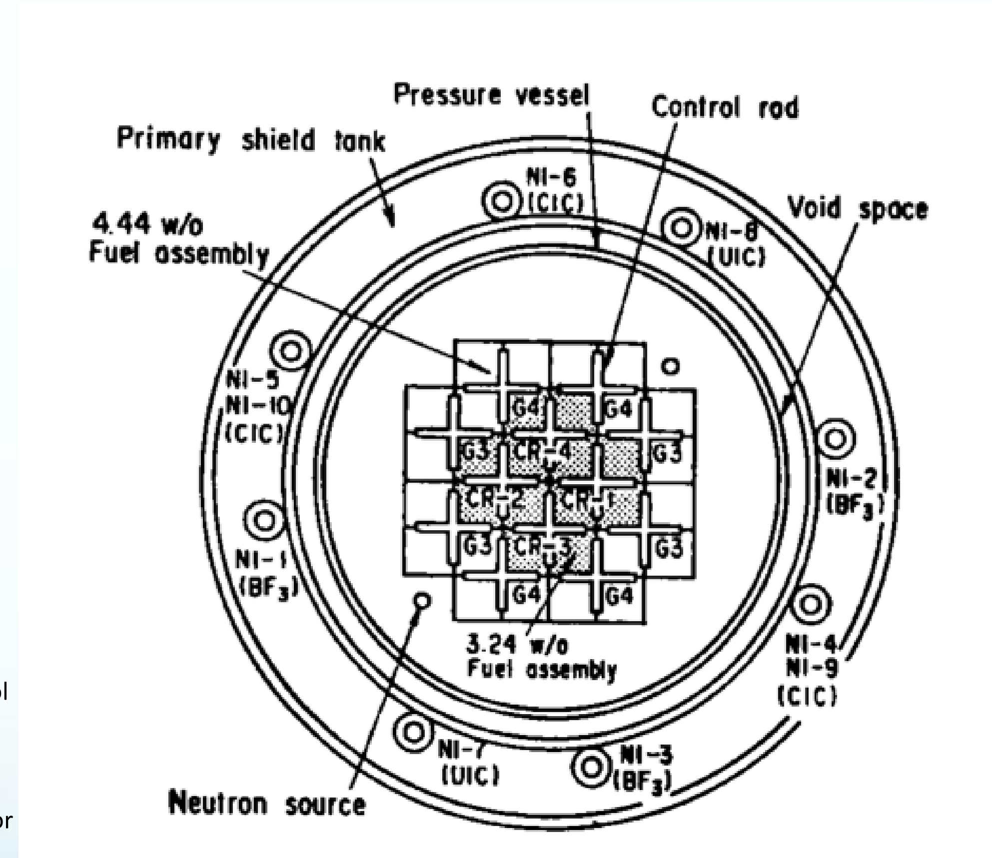
Japan's prototype civilian cargo + research vessel

- *Mutsu* was built by Ishikawajima-Harima Heavy Industries, which started construction at its Second Tokyo Factory on November 17, 1968. The hull was completed and launched 12 Jun 1969 without the reactor installed.
- Length: 130 m (426.5 ft); beam: 19 m (62 ft); full load displacement: 10,400 tons
- On 13 July 1970, the completed *Mutsu* hull was towed from the shipyard to the port of Ohminato on Mutsu Bay, where the reactor was installed and final ship outfitting was performed. Reactor installation was completed on 25 August 1972, and the nuclear fuel was loaded on 4 September 1972.
- Reactor: 2 x loop, 35 MWt PWR
  - Designed by Mitsubishi Atomic Power Industries
  - Fuel: UO_2 pellets in stainless steel rods in 11 x 11 fuel elements. The core consisted of 32 fuel elements in two enrichment zones: 3.24% in the inner fuel elements and 4.44% in the outer fuel elements.
  - Core life: 13,500 Megawatt-days (MWd); 9,257 equivalent full power hours (EFPH)
  - Located amidship, inside a steel containment vessel. Total volume of containment vessel: 3,149 m^3 (111,206 ft^3); total weight with reactor: about 3,200 tons
- Propulsion: Steam turbine, 10,000 shp, driving a single shaft. Maximum speed: 16.5 kts.

Mutsu

Reactor vessel & core layouts



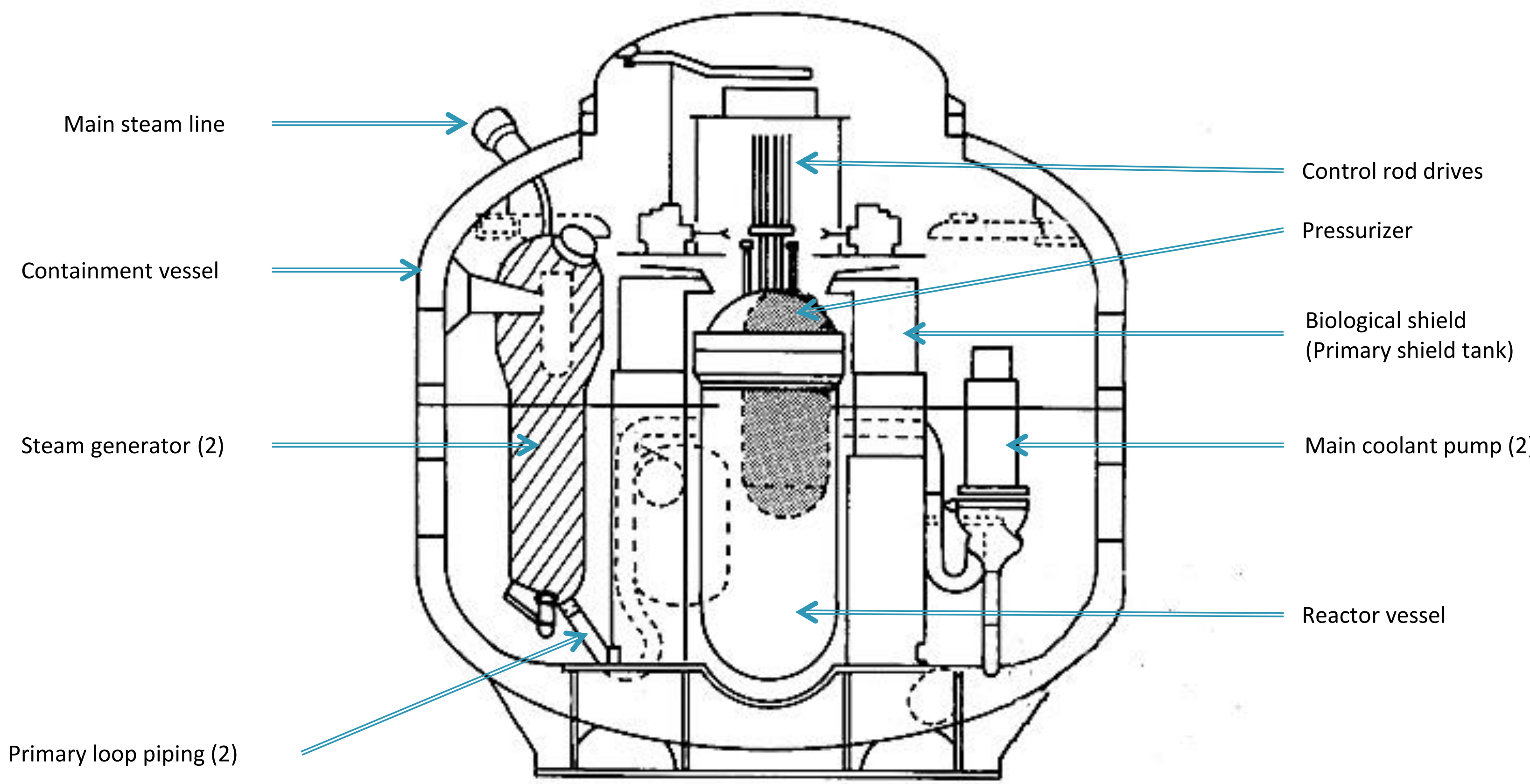


Mutsu reactor core cross-section

Source: adapted from http://www.rist.or.jp/atomica/data/dat_detail.php?Title_Key=07-04-01-02

Mutsu

Primary system layout inside the containment vessel

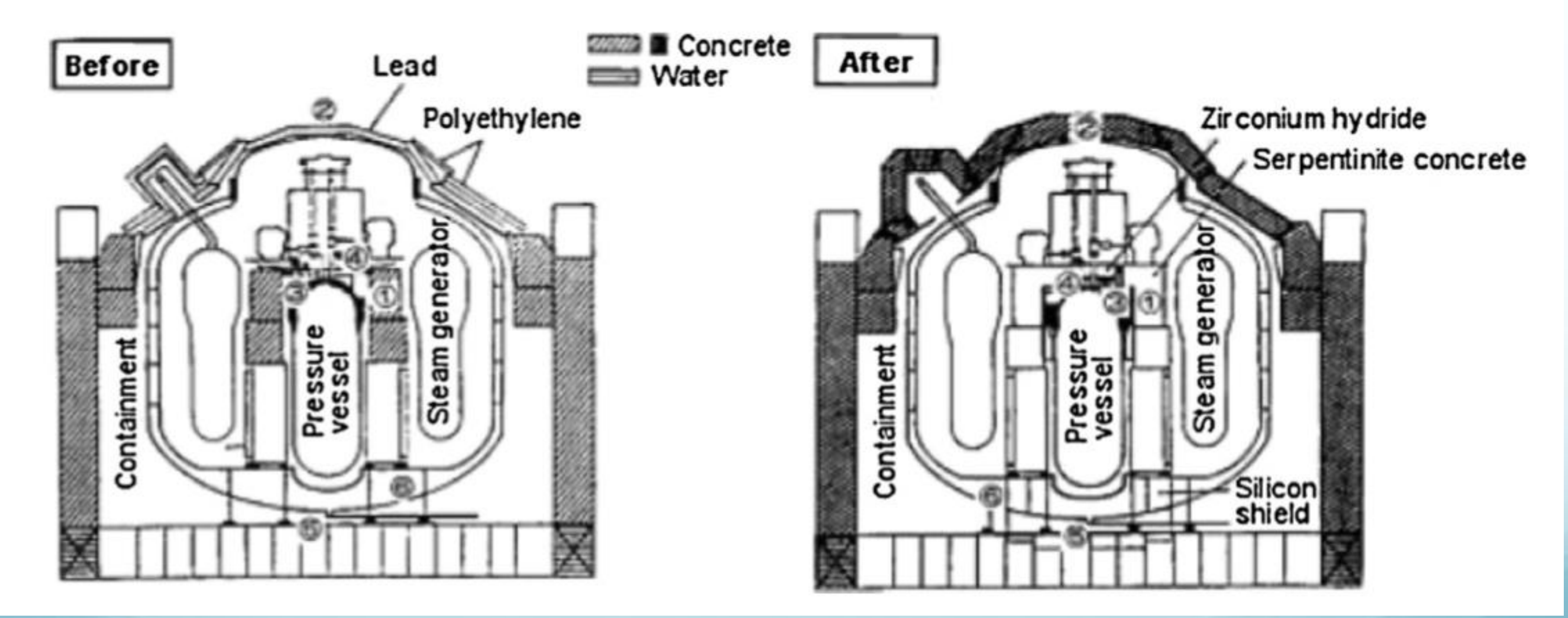


Source: adapted from http://www.rist.or.jp/atomica/data/dat_detail.php?Title_Key=07-04-01-02

Mutsu

Japan's prototype civilian cargo vessel + research vessel

- Operational matters (cont'd):
  - 1 Sep 1974: *Mutsu* was towed to sea for first reactor test. A shielding design defect led to significant radiation streaming observed after initial criticality and operation at only 1.4% power. The reactor was shutdown. *Mutsu* remained at sea for 45 days awaiting permission to return to port, which it did on 15 October 1974.
  - 1978 – 1982: *Mutsu* was in the port of Sasebo for modifications to correct deficiencies in the radiation shielding.

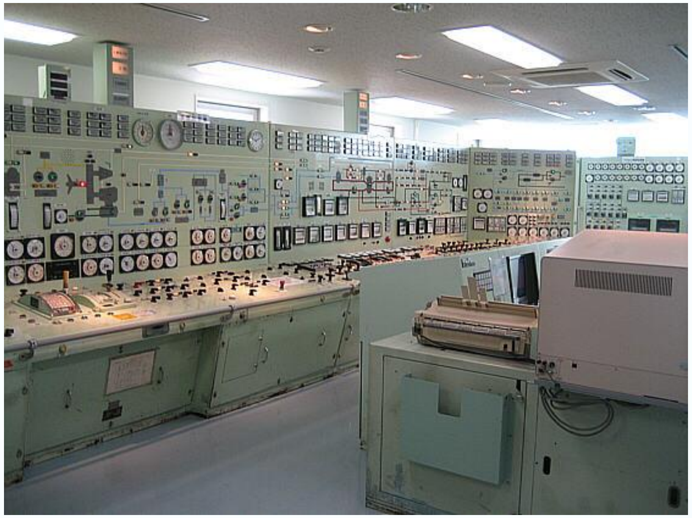


Source: L. O. Freire & D. Alves de Andrade, "Historic survey on nuclear merchant ships," Nuclear Engineering and Design 293 (2015), 176–186

Mutsu

Japan's prototype civilian cargo vessel + research vessel

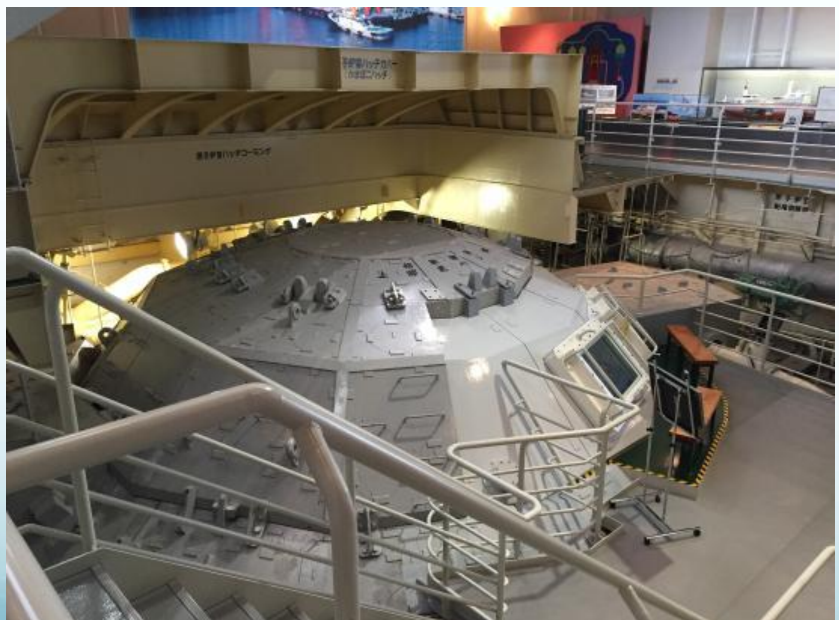
Mutsu underway. Source: JAEA



Mutsu reactor control room. Source: JAEA

- Operational matters (cont'd):
  - February 1991: After years of delays and more modifications, *Mutsu* finally made its first voyage on nuclear power, more than 16 years after initial criticality.
  - 1992: *Mutsu* was decommissioned after cruising 51,000 miles (82,076 km) on nuclear power. The reactor was defueled in 1993 and the spent fuel elements were transported to the Reactor Fuel Examination Facility (RFEF) in 2001. After examination, the fuel was "re-assembled" from 2002 – 2007 to meet the dimensional and enrichment acceptance criteria for the reprocessing plant.
  - Over 25 years the program had cost more than 120 billion yen (about US $1.2 B).
  - 1996: The former *Mutsu* hull was "re-born" as the non-nuclear research vessel *Mairi* operated by the Japan Marine Science Technology Center.

Mutsu Science Museum



Source, both photos: http://mutsu-kanko.jp/en/miru_05.html

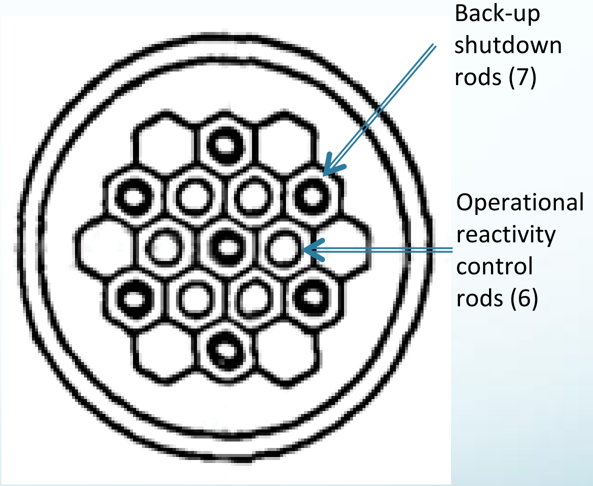
- This science museum, located on the Tsugaru Straits at the northern tip of Japan's main island, opened in 1996 and is built around a reproduction of the nuclear ship *Mutsu*.
- There is a section that presents the history of nuclear ship Mutsu, including an exhibition with the top of the reactor compartment.

Source: http://www.shipsonstamps.org/

MRX (Marine Reactor X)

Multi-purpose marine integral PWR

- MRX was the product of trade-off studies initiated in the mid-1970s by Japan Atomic Energy Research Institute (JAERI) to select a design for the next-generation Japanese marine reactor, factoring in lessons-learned from *Mutsu*.
  - The reactor was intended for surface ship propulsion for high speed container ships (around 30 knots), super high speed container ships (more than 50 knots) and ice-breakers.
  - It also was intended for non-propulsion marine applications, including electric power and process heat generation and seawater distillation.
- Reactor:
  - MRX was a 100 MWt integral PWR design that, according to JAERI, was scaleable to over 300 MWt without changing the design concept.
  - Fuel: UO_2 in zircaloy-clad fuel rods; average enrichment 4.3%
  - Core dimensions: 1.45 m (4.8 ft) equivalent diameter; 1.40 m (4.6 ft) height
  - 19 hexagonal fuel assemblies; 13 containing control rod clusters, 6 for reactivity control during operation and the other 7 for back-up reactor shutdown.



MRX core cross-section. Source: STUDSVIK/ES-96/29, http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/27/073/27073072.pdf

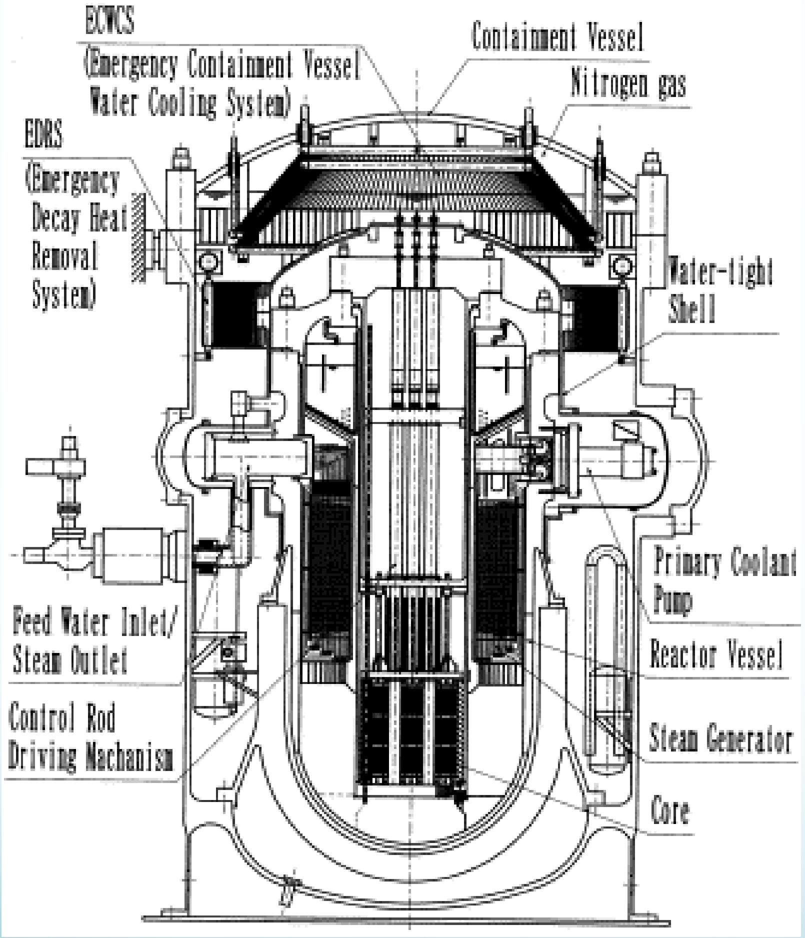
MRX (Marine Reactor X)

Multi-purpose marine integral PWR

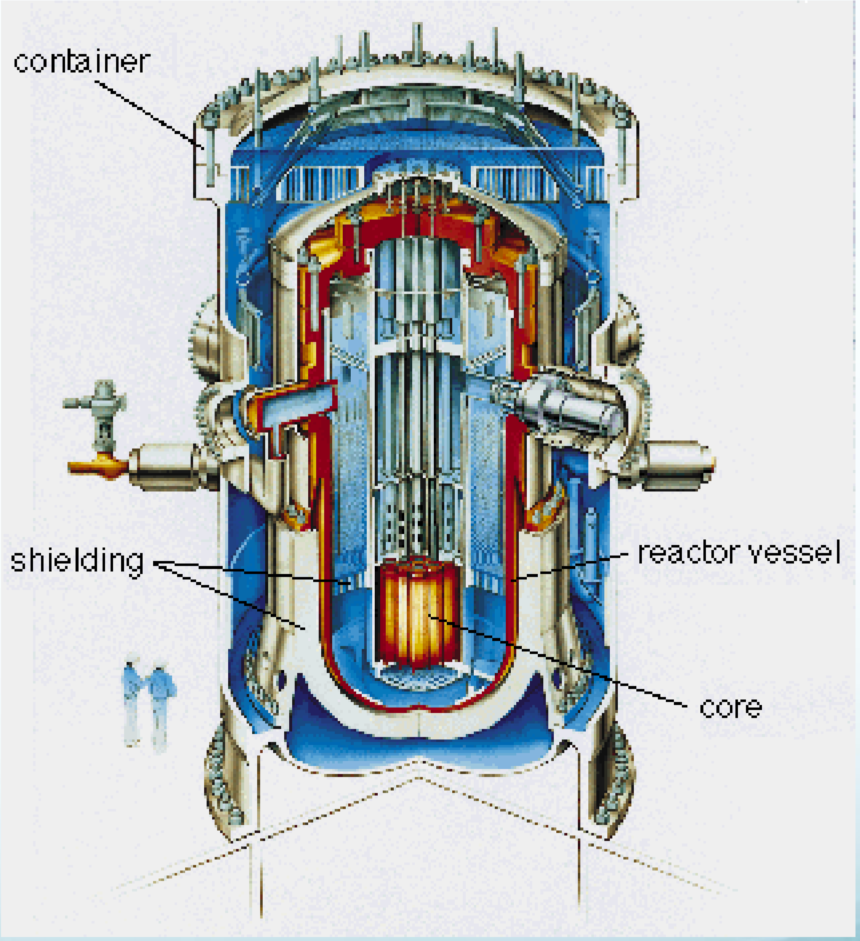
- Primary system:
  - The reactor core is in the lower part of an integral reactor vessel, the once-through, helical-coil steam generators are in the middle part, and the control rod drives are in the upper part, surrounded by an annular pressurizer. Two canned primary coolant pumps provide forced circulation. These pumps and the main steam and feedwater lines connect horizontally to the reactor vessel above the steam generators.
  - Reactor coolant temps: 282.5° C (540.5° F) core inlet; 297.5° C (567.5° F) core outlet
  - Primary system operating pressure: 12 MPa (1,740 psig)
- Secondary system:
  - The steam generators are once-through helical coil type.
  - Outlet steam conditions are: 289° C (552° F) / 4 MPa (580 psig)
- Emergency core cooling:
  - The emergency decay heat removal system transfers core decay heat from the primary system to the water-filled containment.
- Containment:
  - Dimensions: 6.8 m (22.3 ft) inner diameter; 13.0 m (42.7 ft) height
  - Containment maximum pressure: 4 MPa (580 psig)
  - A containment water cooling system uses redundant, passive heat pipe systems to complete the emergency heat transfer path to the ultimate heat sink (the ocean or the atmosphere, depending on application).

MRX (Marine Reactor X)

Multi-purpose marine integral PWR



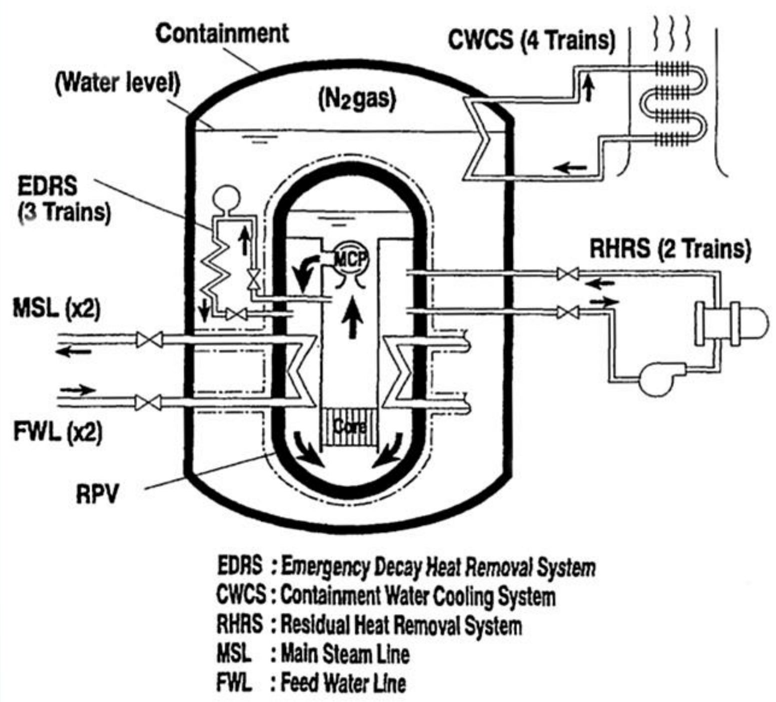
MRX installed within its compact containment vessel.
Source:
http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/31/058/31058473.pdf



Source:
https://rdreview.jaea.go.jp/fukyu/tayu/ACT95E/06/0603.htm

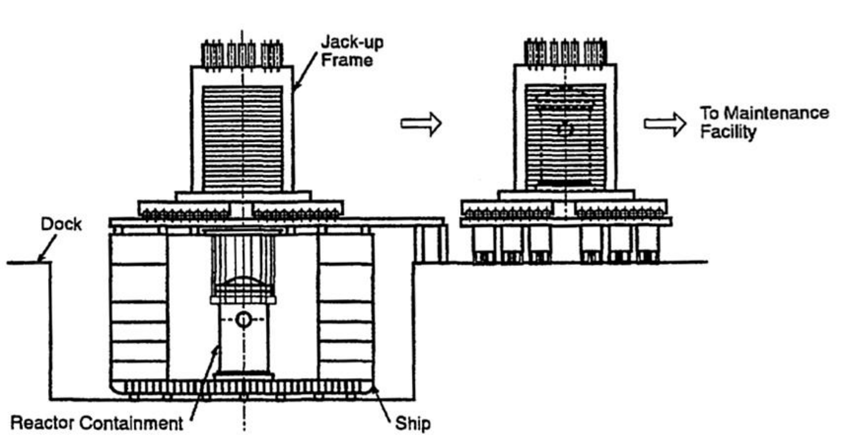
MRX (Marine Reactor X)

Compact containment vessel



- The MRX integral primary system is housed inside a water-filled containment vessel with an inert nitrogen cover gas. The containment includes a natural circulation emergency decay heat removal system (for post-accident core cooling) and a containment heat removal system.
- Total containment volume: 3,326 m^3 (117,457 ft^3); total weight of containment and reactor: 1,600 tons. This is about the same volume, but half the weight of *Mutsu.*

- The entire containment vessel, including the reactor, is designed to be installed on the ship and removed as a unit. A whole new or serviced/refueled unit would be re-installed on the ship.



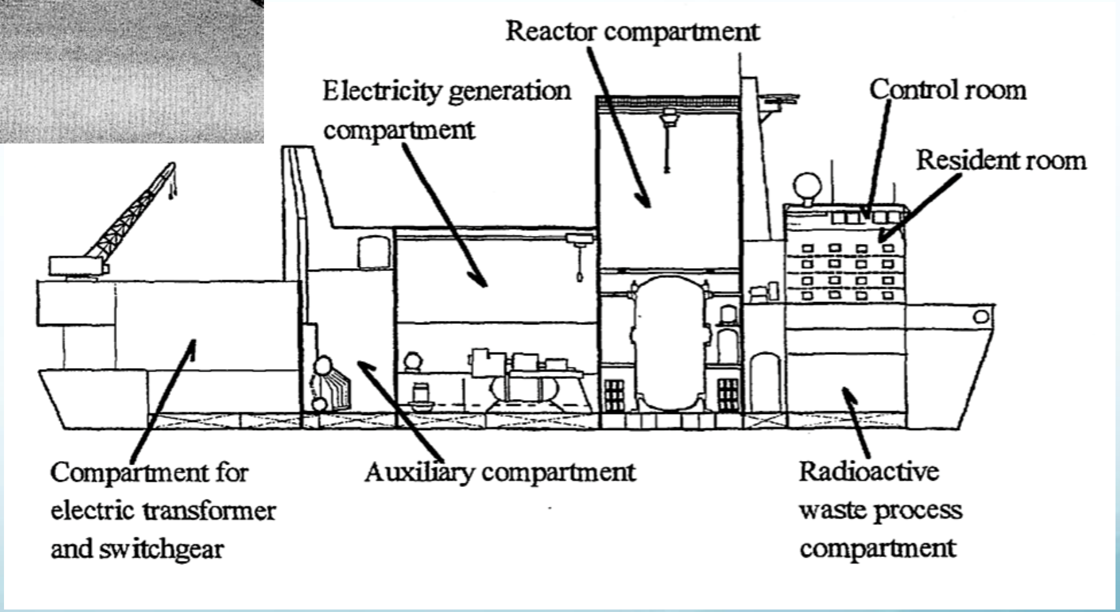
Source: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/31/058/31058473.pdf

MRX (Marine Reactor X)

Concept for a floating nuclear power plant

- JAERI developed a concept for an MRX-based floating nuclear power plant rated at 300 MWt and generating up to 100 MWe. This power output would be achieved with one uprated 300 MWt MRX or three 100 MWt MRX.

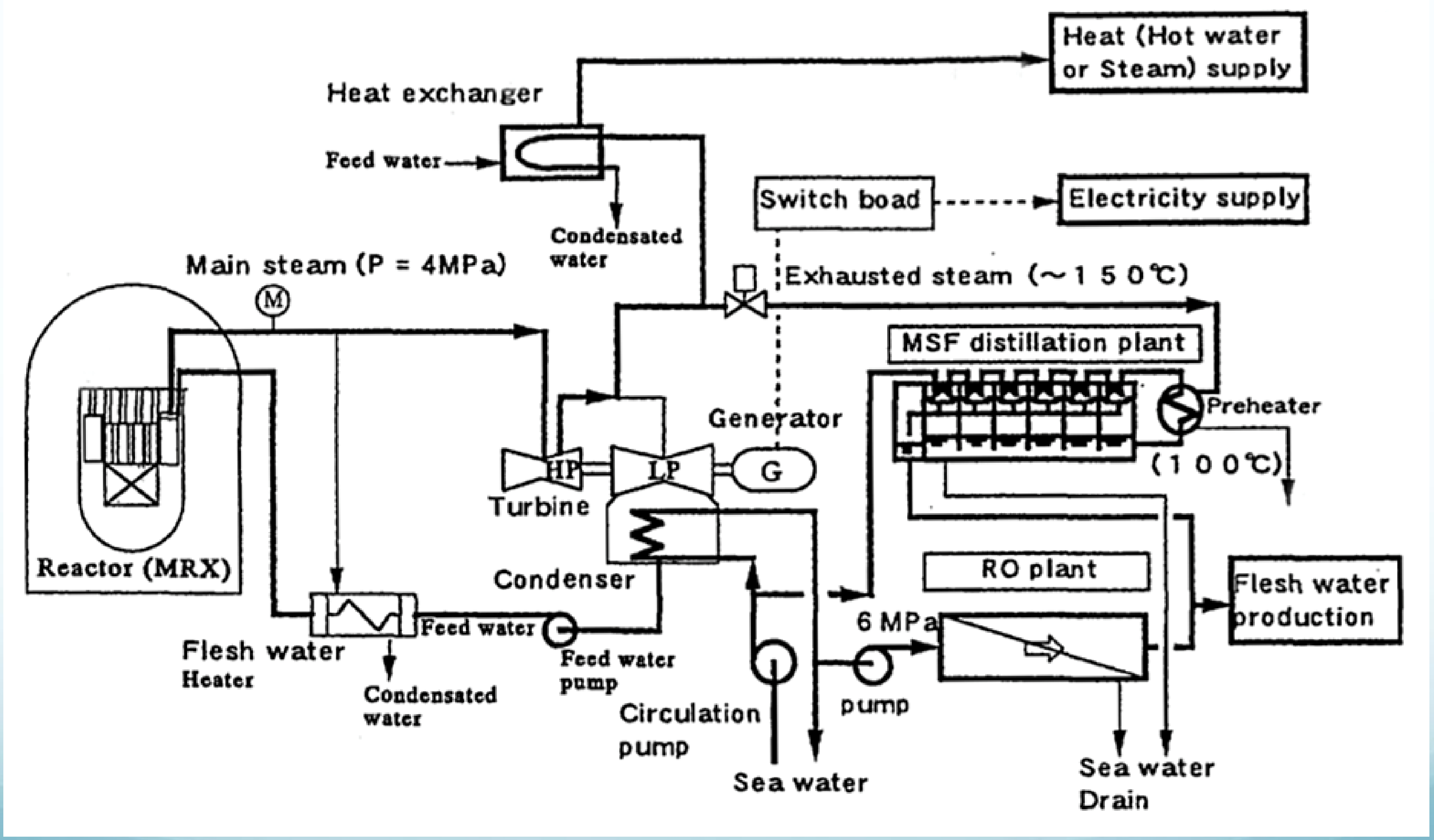
- Intended to supply electricity, fresh water and hot water for a population of 100,000 persons.
- Barge displacement: 13,000 tons.



Source: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/31/058/31058473.pdf

MRX (Marine Reactor X)

Floating nuclear power plant co-gen process diagram



Source:
http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/31/058/31058473.pdf

DRX (Deep-sea Reactor X)

Small, integral marine PWR

- DRX was a circa 1990s design by JAERI for a small, natural circulation integral PWR intended for use on a proposed small deep-sea research submarine.
- The operation of DRX was to be highly automated, requiring only a single reactor operator.
- Reactor:
  - Reactor power: 750 kWt.
  - Fuel: UO_2 with an average enrichment of 8.3%.
  - One group of control rods was used to adjust reactor power as needed to control primary coolant temperature and to make longer-term adjustments for fuel burn-up. A second group of control rods was fully withdrawn and used for backup reactor shutdown.
  - Designed for continuous operation at an average 30% load factor for four years without refueling.
- Primary system:
  - Natural circulation primary system, with the integral steam generator located above the elevation of the reactor core.
  - Designed for a maximum inclination of 60 degrees while maintaining natural circulation.
  - There was no pressurizer. The primary system was self-pressurized, with operating pressure being determined by primary coolant temperature (which was managed with the control rods).

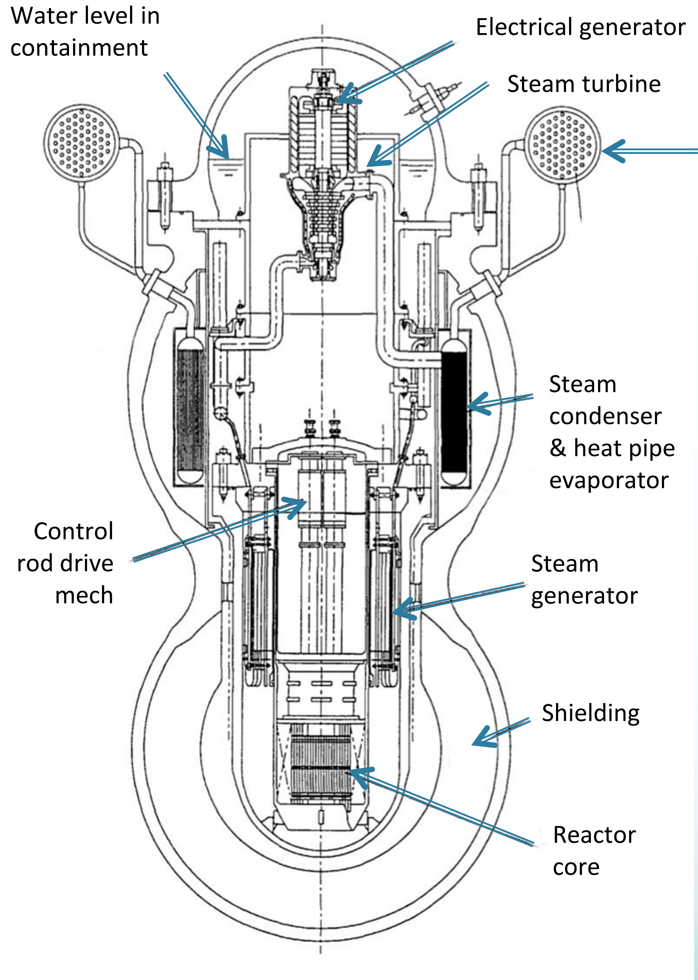
DRX (Deep-sea Reactor X)

Small, integral marine PWR

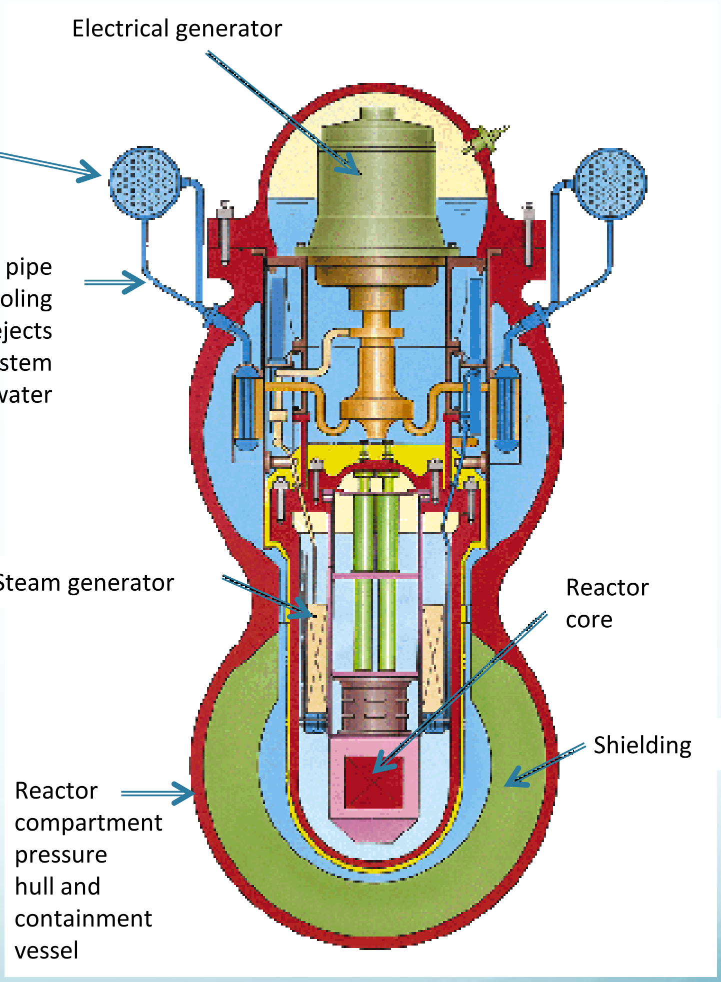
- Secondary and tertiary coolant systems:
  - Steam from the integral steam generator is delivered via a steam control valve to a single turbine-generator with a maximum electric power output of 150 kWe. A steam bypass valve matches electrical generation to electrical demand by diverting some steam from the inlet side of the turbine directly to the exhaust side.
  - Turbine exhaust steam enters two condenser / heat-pipe evaporator units that condense the steam by transferring heat to a tertiary, closed-loop, heat-pipe system. A feedwater pump returns the water to the integral steam generator.
  - In the tertiary cooling loop, the heat-pipe working fluid transfers heat from the evaporator section to the ocean via sea water-cooled condensers.
  - At a steam demand of < 15%, the turbine trips and the steam control valve closes. The steam bypass valve opens, ensuring continuity of core cooling via the condenser / evaporator units and the tertiary cooling loops.
- Containment:
  - The submarine pressure hull for the DRX integral reactor was to be created by vertically joining two 2.2 m (7.2 ft) diameter spherical pressure vessels. This compact pressure hull also served as the reactor containment vessel and gave the DRX its unique shape.

DRX (Deep-sea Reactor X)

Small, integral marine PWR



Source: adapted from JAERI-Research 2001-004, http://www.iaea.org/inis/collection/NCLCollectionStore/_Public /32/042/32042688.pdf



Source: adapted from https://rdreview.jaea.go.jp/fukyu/tayu/ACT95E/06/0603.htm

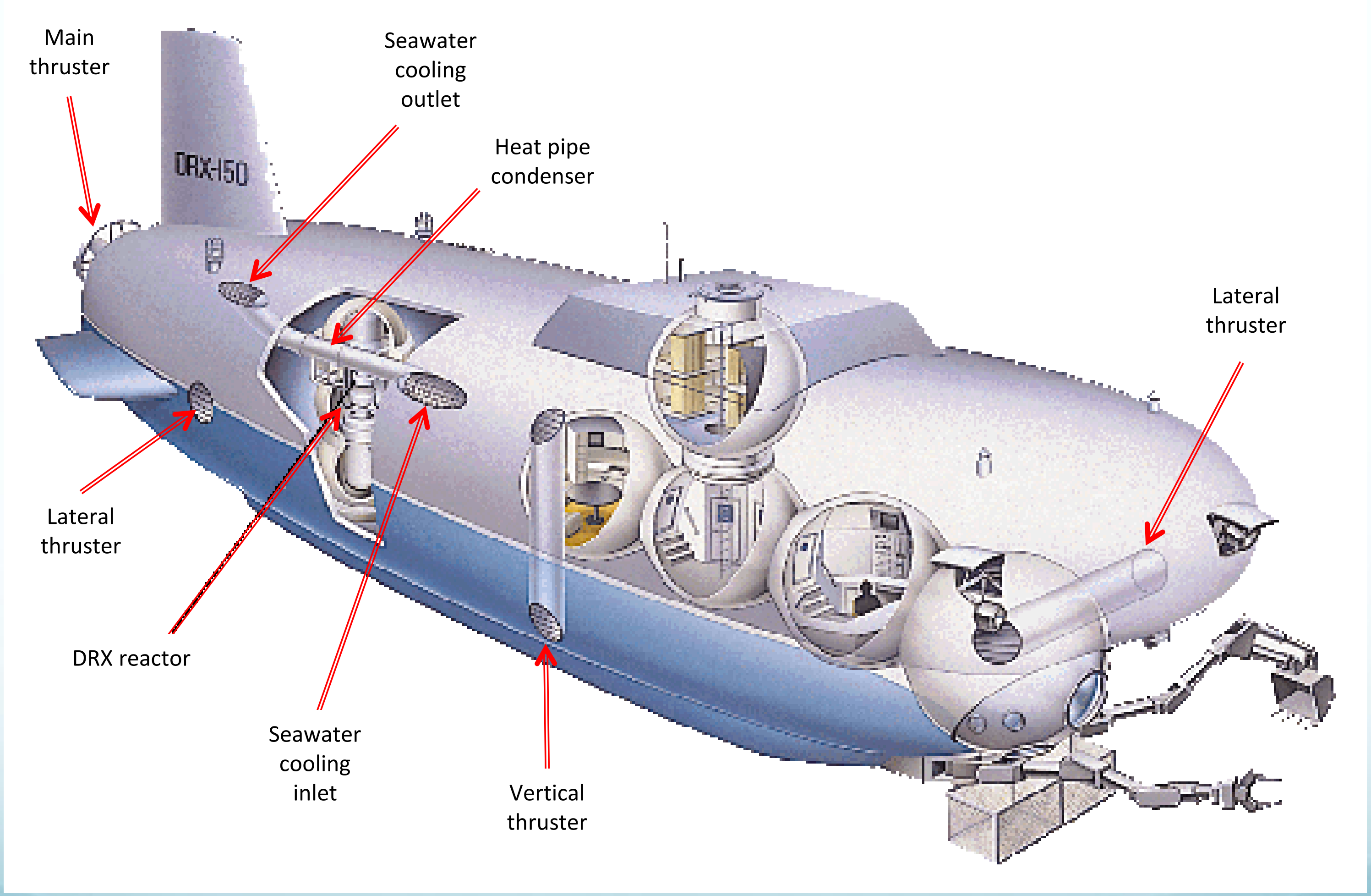
DRX-powered submarine

Concept for a deep-sea survey submarine

- The proposed deep-sea research submarine consisted of a series of interconnected spherical, titanium pressure vessels for a crew of eight, a separate pressure vessel for the unattended DRX reactor, and an outer hull.
- Basic submarine parameters:
  - Overall length: 24.5 m (80.4 ft)
  - Maximum beam: 4.5 m (14.8 ft)
  - Spherical pressure shell diameter for crew section: 2.8 m (9.2 ft)
  - Maximum speed: 3.5 knots
  - Maximum operating depth: 6,500 m (21,325 ft)
  - Continuous operating period: 30 days
  - Crew size: 8
- Assuming a 50 kWe house load, about 100 kW (134 shp) would be available for propulsion. Vessel maximum speed was only 3.5 knots.
- DRX and the proposed deep-sea research submarine were not built.

DRX-powered submarine

Concept for a deep-sea survey submarine



Source: adapted from https://rdreview.jaea.go.jp/fukyu/tayu/ACT95E/06/0603.htm

Brazil

Rapidly developing infrastructure to support manufacturing indigenous nuclear submarines

Source: https://en.wikipedia.org/

The beginning of Brazil’s marine nuclear power program

Brazil marine nuclear timeline

1950s

1957
Brazil's Comissão Nacional de Energia Nuclear (CNEN) commissioned its first US-supplied research reactor

1960s

1960s
Navy & Institute for Energy and Nuclear Research (IPEN) operated lab-scale centrifuge enrichment line

1964
Military regime assumes control of Brazil and its nuclear program

1970s

1978
SN-BR program was launched

1980s

1982
Navy program built its first gas centrifuge capable of enriching uranium

1985
Brazil's military regime replaced by civilian leadership. Secret military nuclear program became public knowledge

1988
Inaugurated the first cascade of centrifuges

1990s

1990
Brazil renounced its secret nuclear weapons program and began a series of steps toward binding non-proliferation commitments.

March 1993
Aramar director Admiral Othon Pinheiro da Silva declared that his center would not enrich uranium above 20 percent "because of a political decision"

1998
Brazil signed the Non-Proliferation Treaty (NPT)

2000s

January 2000
Navy's resumed its nuclear-powered submarine program

2007
President da Silva committed funds to complete the uranium enrichment project and enable production of nuclear fuel on an industrial scale

2010s

2008
General Coordination Program for the Development of a Nuclear-Powered Submarine (COGESN)

2008
PROSUB agreement between Brazil & France initiated for development of Itaguai shipyard and manufacturing 4 x conventional subs (SBR) and 1 x nuclear sub (SN-BR)

2020s

2019 - 2020
SN-BR keel laying expected

2029
SN-BR launch expected

2030
SN-BR delivery expected

The beginning of Brazil's marine nuclear power program

- **1947:** Admiral Alvaro Albero, who had been representing Brazil at the UN Atomic Energy Commission, presented the first proposal on Brazilian nuclear development to the Brazilian National Security Council (CSN).
- **1951:** National Research Council was established to coordinate the domestic development of nuclear energy
- **1952:** President Getulio Vargas approved a plan to cooperate with foreign countries to acquire all phases of nuclear energy production, to build power plants and to train nuclear scientists.
- **1957:** Under the US "Atoms for Peace" program, Brazil obtained its first research reactor in 1957 and built another, the "Argonauta," in 1962 with 93% indigenous content.
- **1964 – 1985**: Brazil was run by a military regime installed in 1964. The national nuclear program accelerated this under this regime.
- **1974:** The government adopted a policy to become fully self-sufficient in nuclear technology and called for the acquisition of technologies for uranium enrichment and fuel reprocessing for civilian nuclear power purposes. In parallel, a secret military program sought to leverage dual-use technologies for the construction of a reactor for naval propulsion, and the development of nuclear explosives.

The beginning of Brazil’s marine nuclear power program

- **1975:** The state-owned company Empresas Nucleares Brasileiras S.A. (Nuclebrás) was set up with a number of subsidiaries focused on particular aspects of engineering and the nuclear fuel cycle.
- **1985:** The parallel military program became public after the end of the military regime, in March 1985. Under this secret program Brazil had mastered two key fuel cycle technologies:
  - Yellow cake (U_3O_8) conversion into pure uranium hexafluoride (UF_6) gas suitable for use in enrichment operations.
  - Uranium enrichment, using ultracentrifuge technology developed by the Brazilian Navy (*Marinha do Brazil*).
- **1988:** A new company, Indústrias Nucleares do Brasil S.A. (INB) took over the front-end fuel cycle subsidiaries of Nuclebrás.
- **1989:** The former secret military nuclear program was integrated into the safeguarded civilian nuclear program.
- **1990:** Brazil renounced its secret nuclear weapons program and began a series of steps toward binding non-proliferation commitments.
- **Late 1980s – 1990s:** Brazil’s nuclear program slowed as a result of a continuing economic crisis. The weak economy contributed to the closure of the UF_6 conversion plant.

The beginning of Brazil's marine nuclear power program

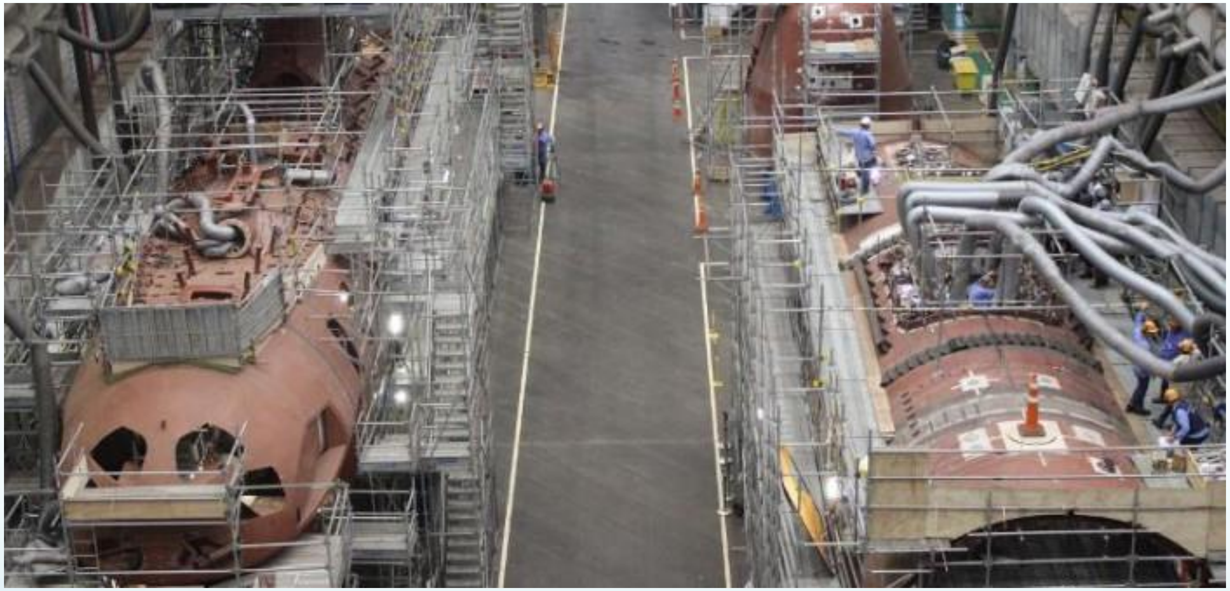
- **March 1993:** Aramar director Admiral Othon Pinheiro da Silva declared that his center would not enrich uranium above 20% "because of a political decision"
- **1998:** Brazil signed the Non-Proliferation Treaty (NPT)
- **2004:** INB started construction of an industrial-scale uranium enrichment plant using the ultracentrifuge technology developed and licensed to INB by the Brazilian Navy.
- **September 2008:** The General Coordination Program for the Development of a Nuclear-Powered Submarine (COGESN) was created with a projected annual budget of $250 million.
- **2008:** Brazil's submarine force was defined as a key part of the country's national armaments and defense strategy released in December 2008.
  - The strategy defines the plan to protect Brazil's 8,500 km (5,282 mile) coast.
  - At the time, Brazil operated a small fleet of five conventionally-powered subs built in Germany by Howaldtswerke-Deutsche Werft (HDW).
- **2008:** An agreement signed in December between the governments of Brazil and France aimed at preparing the Submarine Development Program for the Brazilian Navy (PROSUB). This agreement provides for:
  - Four new conventionally-powered submarines, derived from the French *Scorpene*, to be designated the SBR, plus
  - One nuclear powered submarine, to be designated the SN-BR (or SNBR)

The beginning of Brazil's marine nuclear power program

- **2009:** the Brazilian Navy contracted with French shipbuilder DCNS (*Direction des Constructions Navales*) for submarine technology transfer & construction assistance, as well as design and construction of a new shipyard and naval base for the submarines at Itaguai.
- **2010:** The Joint Plan for Marine Equipment of Brazil (*O Plano de Articulação e Equipamento da Marinha do Brasil - PAEMB*) provides a long-range plan for acquisition of 15 conventional subs (SBR) and 6 nuclear subs (SN-BR) by 2034.
- **2012:** the government set up Blue Amazon Defense Technologies (*Amazonia Azul*) to develop nuclear submarines using the Brazilian indigenous PWR with low-enriched uranium fuel (<20%)
- **2013:** In March, President Dilma Rousseff inaugurated the Metal Structures Manufacturing Unit (UFEM) at the shipyard Itaguaí Construções Navais (ICN). The UFEM will manufacture the submarine metal hull structures. At the time, the submarine construction schedule called for:
  - Four conventional SBRs to be delivered to the Navy in 2017, and
  - One SNBR to be delivered to the Navy in 2023

The beginning of Brazil's marine nuclear power program

- **2014:** In December, President Dilma Rousseff inaugurated the main assembly hall building at the ICN shipyard. Two submarines can be built in parallel in this building.



The first two SBR boats in the Assembly hall at Itaguai. Source: PROSUB

- **2018:** Construction of the first conventionally-powered attack sub (SBRs) at ICN, SBR-1 *Riachuelo* (S-40), is nearing completion, with an expected launch later in 2018 and delivery to the Navy in 2020.

The beginning of Brazil's marine nuclear power program

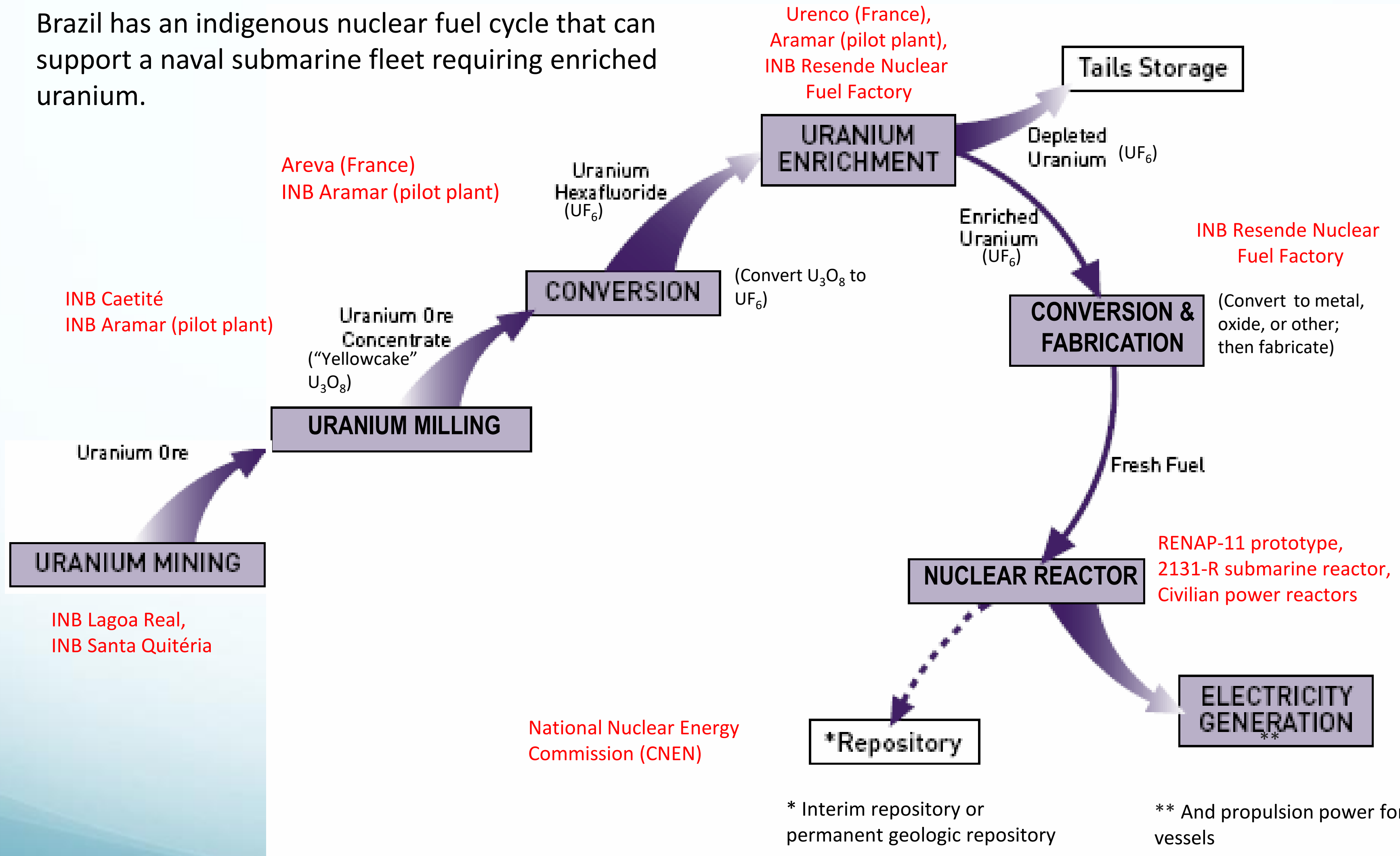
- **February 2018:** The president of Brazil, Michel Temer, reiterated his government's commitment to the construction of conventional submarines and a nuclear submarine.
  - The nuclear submarine, SN-BR *Alvaro Alberto* (SN-10), is still in the development phase. Construction has not yet started.
  - The SN-BR is expected to be completed by 2029.
- Brazil is the only non-nuclear-weapon state in which the military leases uranium enrichment technology to the civilian nuclear program, and the Navy drives technological advances in the nuclear field. Also Brazil is the only non-nuclear-weapon state developing a nuclear-powered submarine.

Sources: Carlo Patti, "Origins and Evolution of the Brazilian Nuclear Program (1947-2011)," 15 Nov 2012, https://www.wilsoncenter.org/
WANO, "Nuclcear Power in Brazil," June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/brazil.aspx
And others

Brazil's nuclear fuel cycle and naval nuclear infrastructure

Brazil’s nuclear fuel cycle

Brazil has an indigenous nuclear fuel cycle that can support a naval submarine fleet requiring enriched uranium.



Source: adapted from http://www.icnnd.org/reference/reports/ent/part-ii-5.html

Brazil's nuclear fuel cycle infrastructure

- Uranium mining
  - Systematic prospecting and exploration for radioactive minerals began in 1952.
  - Brazil has known resources of 278,000 tonnes of uranium, 5% of world total.
  - Two uranium mines currently are operated by Indústrias Nucleares do Brasil S.A. (INB). A third mine, Pocos de Caldas (Minas Gerais state) closed in 1997.
    - Lagoa Real (Bahia state; operating since 1999)
    - Itataia, now called Santa Quitéria (Ceará state) uranium recovery from existing phosphate mining operations; start of uranium recovery expected soon (later in 2018 or 2019).
- Yellowcake (U_3O_8) production
  - Brazilian uranium concentrate production capability is about 340 tU/year. The primary milling facility is at Caetité.
  - Uranium production in Brazil is only for domestic use. All uranium concentrate produced is shipped to other countries for conversion and enrichment and then returned to Brazil for fuel fabrication.
- Conversion
  - Brazil purchases most of its UF_6 conversion services from Areva (France).
  - There is a pilot-scale conversion facility at the Aramar Experimental Center.
  - A UF_6 conversion plant that was built under the secret military nuclear program. This plant was closed in the 1990s due to the weak economy in the late 1980s – 1990s.

Brazil's naval nuclear infrastructure

- Centro Tecnológico da Marinha em São Paulo (CTMSP)
  - Develops the nuclear program for Brazil's Navy (*Marinha do Brazil)*, including technological, industrial and operational processes of nuclear facilities applicable to naval propulsion.
  - This effort consists of two main projects:
    - Fuel Cycle Project:
      - Goal is to empower Brazil's Navy to design, deploy, commission, operate and maintain nuclear facilities applicable to naval propulsion
    - Infrastructure Project:
      - Provide all support facilities for the development of above nuclear projects
- Brazil Navy's Aramar Experimental Center (*Centro Experimental de Aramar,* CEA) near São Paulo, includes:
  - Isotopic Enrichment Laboratory; a pilot-scale centrifuge enrichment plant to enrich to < 20% U-235
  - A centrifuge manufacturing plant
  - A uranium purification facility
  - An experimental pressurized-water reactor (PWR)
  - A uranium conversion plant to convert yellowcake into uranium hexafluoride (UF_6) for use in the pilot-scale enrichment process at the site
  - Laboratorio de Geracao Nucleo-Eletrica – LABGENE (Nuclear-Electric Generation Laboratory) for the submarine prototype reactor is being developed at Aramar

Brazil's naval nuclear infrastructure

- Laboratorio de Geracao Nucleo-Eletrica – LABGENE (Nuclear-Electric Generation Laboratory) at Aramar
  - Facility consisting of 11 main buildings will be used to validate design conditions & test operating conditions for a naval nuclear propulsion plant.
    - Multi-purpose thermodynamic laboratory (LABTERMO), comprised of mock-ups, experimental test benches (i.e., for control rods drives mechanism tests) and test circuits (i.e., experimental thermo-hydraulic circuit operating at about 2200 psig)
    - Buildings that will house the naval reactor prototype, shown below.

Source, both graphics: www.mar.mil.br/ctmsp

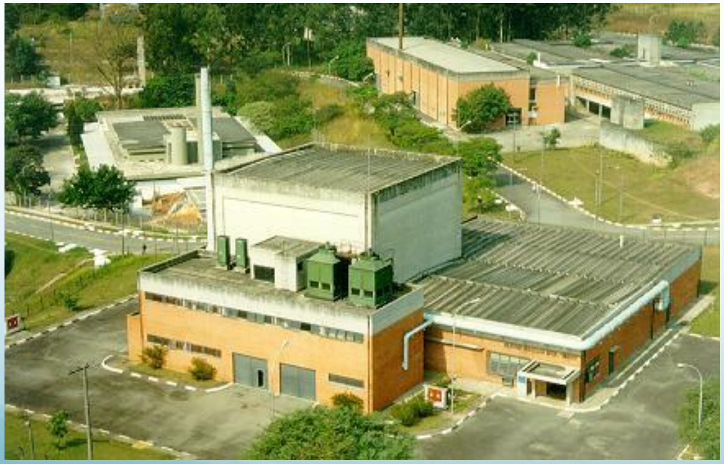
Brazil's naval nuclear infrastructure

- Instituto de Pesquisas Energéticas e Nucleares (IPEN)
(Institute of Nuclear and Energy Research, near São Paulo)

<u>IPEN/MB-01: zero-power (100 w) open pool-type critical facility</u>

Developed in 1988 by IPEN researchers in partnership with the Brazilian Navy.

An experimental program was carried out to validate the neutronic parameters of the Brazilian naval reactor core and to validate calculational methodologies and related nuclear data libraries.



IPEN/MB-01 Source: www.mar.mil.br/ctmsp

<u>IEA-R1: 5 MW swimming pool-type research reactor</u>

Moderated and cooled by light water with graphite and beryllium reflectors

Commissioned in 1957

Nuclear Fuel Irradiation Circuit is used to determine naval reactor fuel rod behavior under irradiation.

IEA-R1 Source: IAEA

Brazil’s naval nuclear infrastructure

- Resende Nuclear Fuel Factory, between Rio and São Paulo
  - An industrial-scale centrifuge enrichment plant was built based on the pilot plant technology developed at Aramar.
    - Centrifuges manufactured by Brazil’s Navy (at Aramar)
    - Operation of the Resende enrichment plant commenced in 2009.
    - The planned 2131-R naval reactor does not require uranium enriched to > 20%
  - A reconversion plant to make UO_2 powder
  - The Components and Assembly Unit produces fuel pellets, fuel rods, and fuel elements for Brazilian reactors.

- Sociedade de Proposito Especifico (SPE) will build Brazil’s nuclear submarines at the new shipyard being built at Itaguai
  - Consortium consists of Brazil’s Odebrecht (50%), France’s DCNS (49%) and the Brazilian Navy (1%)

Submarine base & shipyard at Itaguai

Main building of the construction shipyard, inaugurated Dec 2014; big enough to assemble two subs in parallel

Overhead imagery circa 2016 of Brazil’s Itaguai submarine base and shipyard located 70km south-west of Rio de Janeiro

Source, above: https://www.bellingcat.com/

Source: www.sinodefenceforum.com

Submarine base & shipyard at Itaguai circa 2017

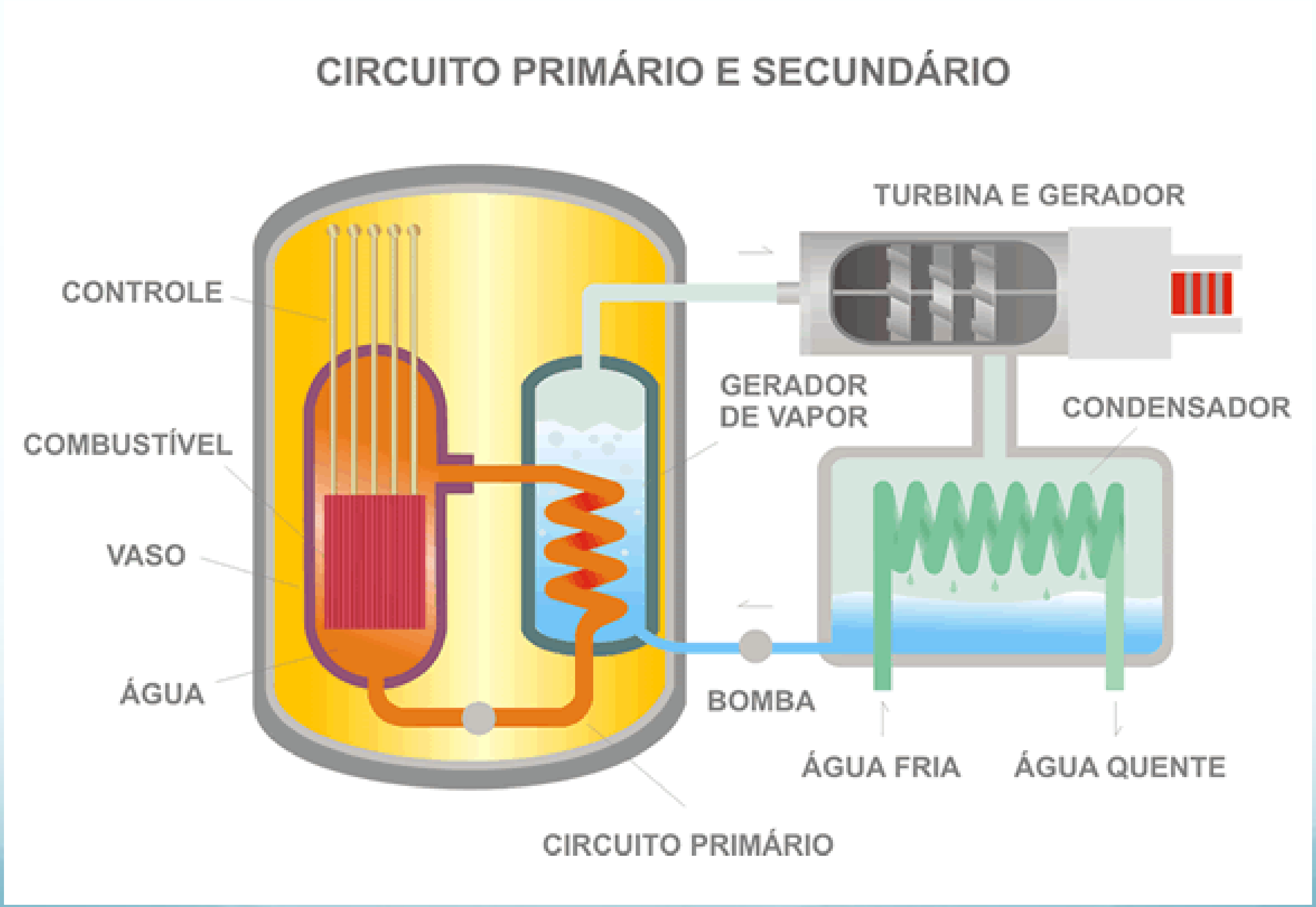
Source, both photos: Naval Group via https://www.meretmarine.com/fr/content/update-brazils-submarine-programme

Brazil's naval reactors

RENAP-11 prototype &
2131-R submarine reactor

RENAP-11 naval PWR prototype

(Reactor Naval de Potência (PWR) de 11 Megawatts)

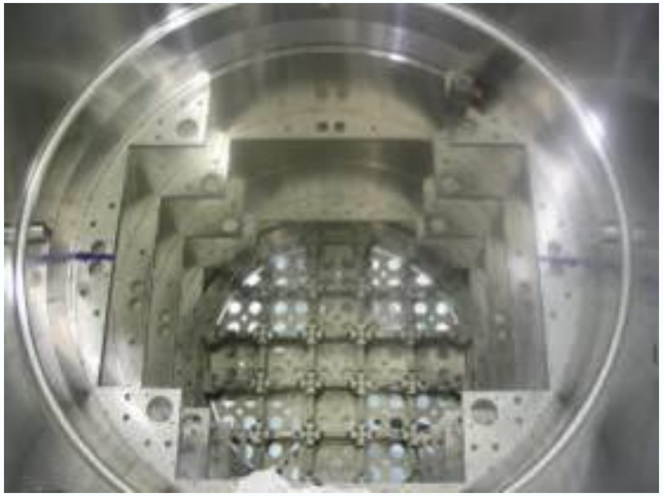


Source: www.zona-militar.com

RENAP-11 naval PWR prototype

(Reactor Naval de Potência (PWR) de 11 Megawatts)

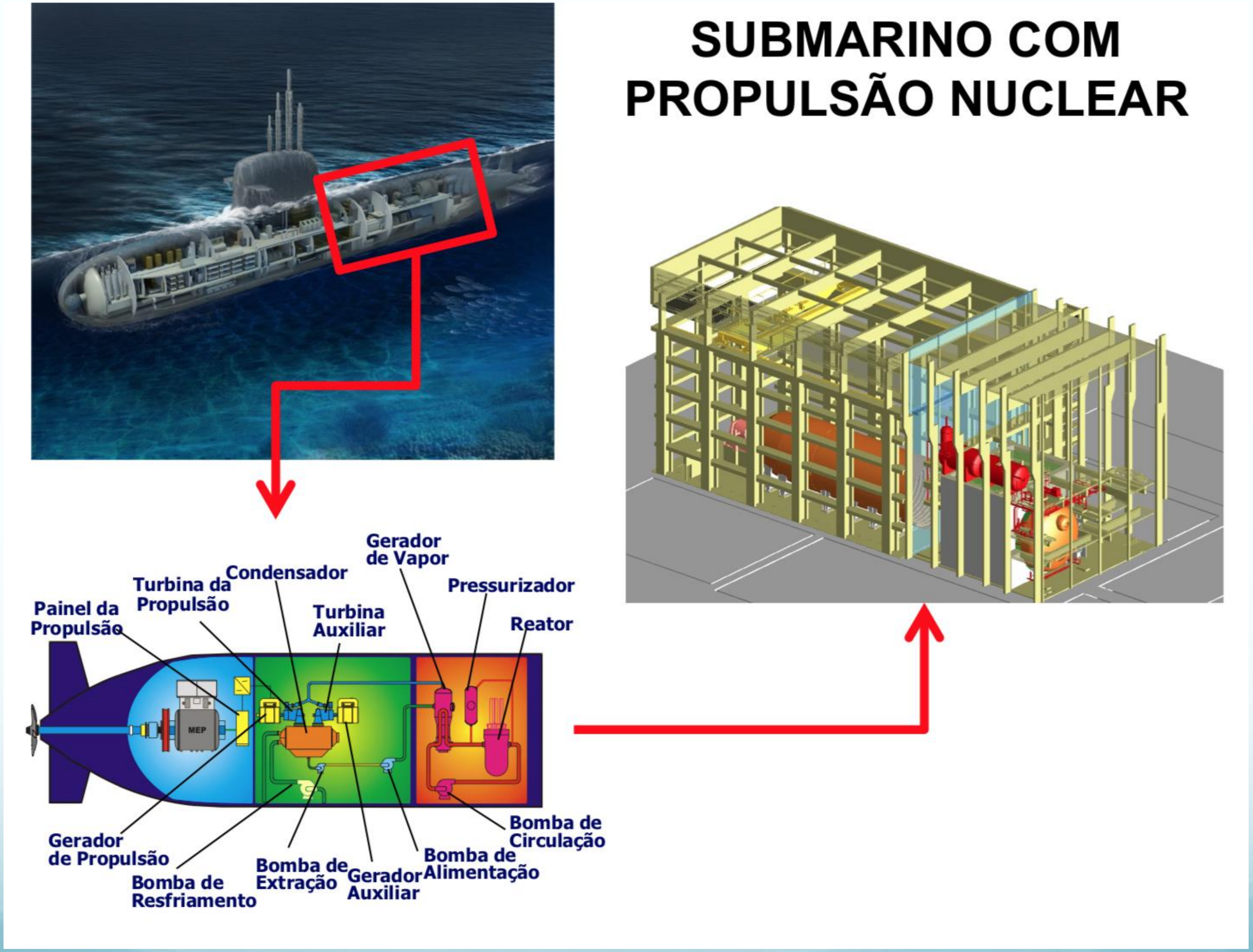
- 2-loop PWR rated, believed to be rated at 11 MWt
- Core comprised of 21 fuel elements (based on reactor grid plate in photo at right)
- Reactor systems are enclosed by a steel containment, surrounded by a water tank for shielding and, if needed, passive cooling.



Source: www.zona-militar.com

- Main components of the secondary circuit include turbo-generators, main condensers, condensate pumps & feedwater pumps.
- Most of the main equipment has been manufactured, delivered and is in storage awaiting further progress on building construction.
- Completion of the prototype reactor facility and commissioning the submarine prototype reactor seems possible in the 2016 – 2017 timeframe.
- The prototype reactor facility is licensed by *Comissão Nacional de Energia Nuclear* (CNEN), Directorate of Radiation Protection and Safety (DRS)

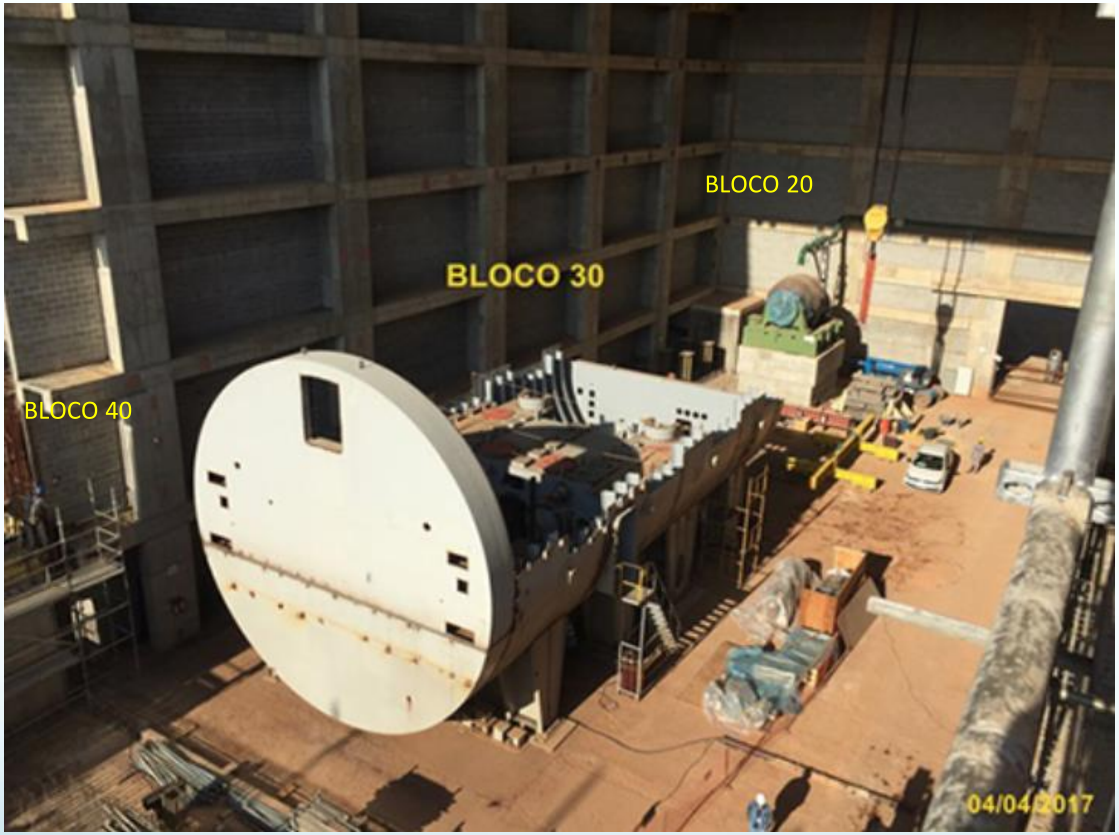
Scope of the naval prototype



Source: http://www.ibracon.org.br/eventos/56cbc/parte1.pdf

Naval prototype construction

Circa 2017

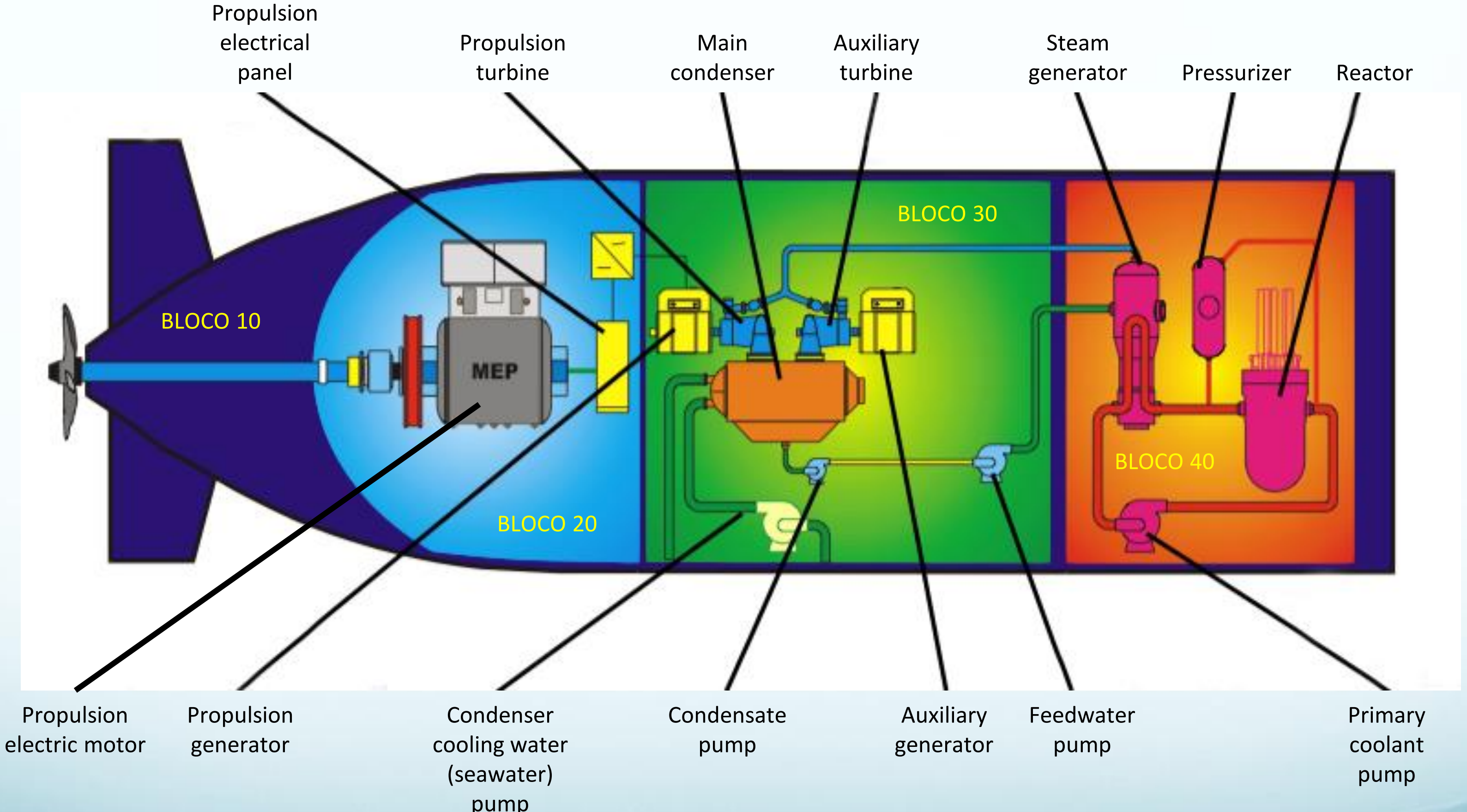


Assembly of the turbine compartment April 2017.
Source: adapted from http://www.defesaaereanaval.com.br/

- Bloco 40: Reactor compartment
- Bloco 30: Secondary steam plant (main turbines & generators, main condenser)
- Bloco 20: Propulsion motor
- Bloco 10: Stern and propeller

SSN propulsion system

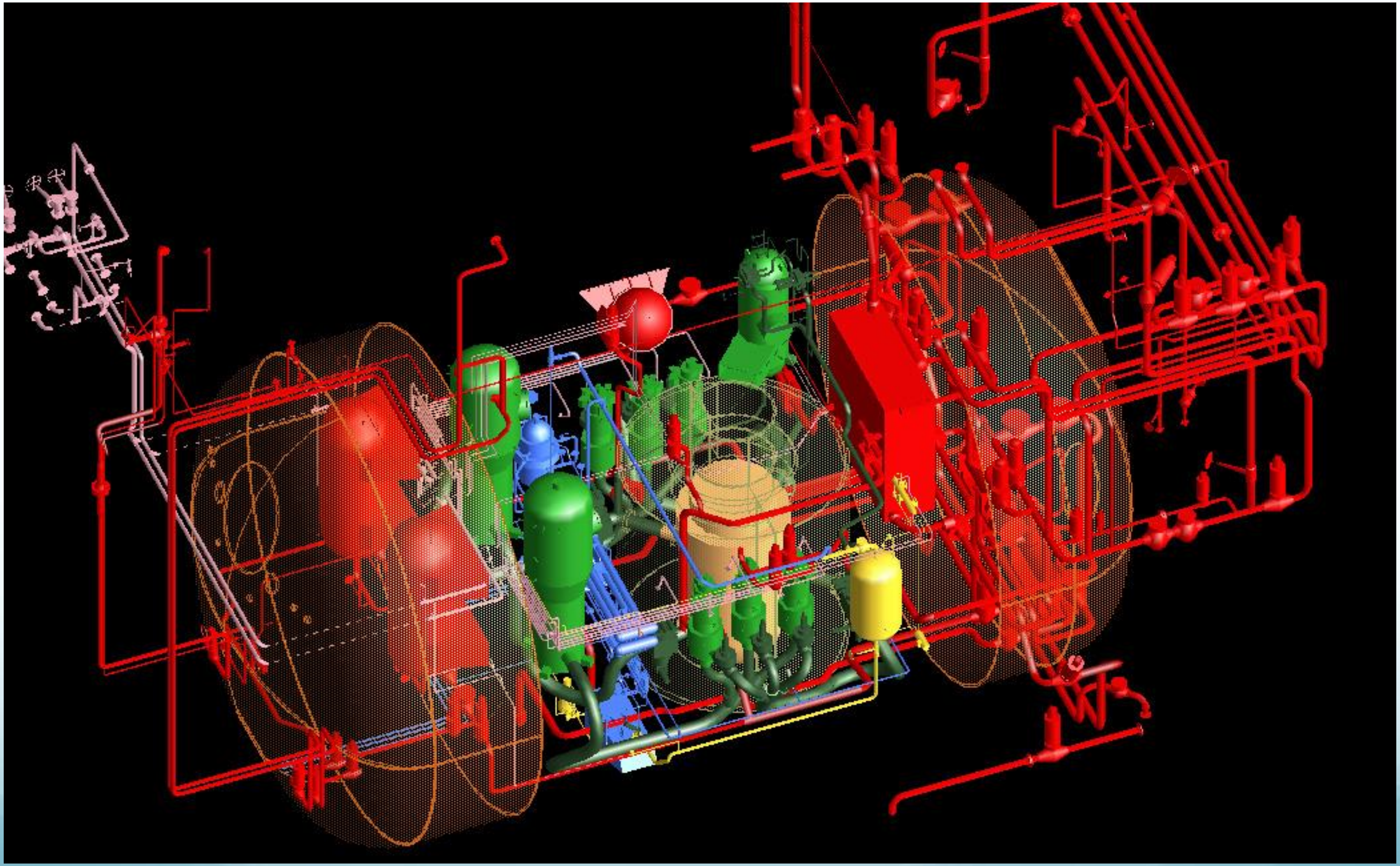
Process flow diagram



Source: http://www.ibracon.org.br/eventos/56cbc/parte1.pdf

SSN nuclear steam supply system

NSSS 3-D CAD layout of BLOCO 40



Source: http://www.ibracon.org.br/eventos/56cbc/parte1.pdf

Brazil’s 2131-R naval PWR

Models displayed at LAAD 2013 exhibition, Rio de Janeiro

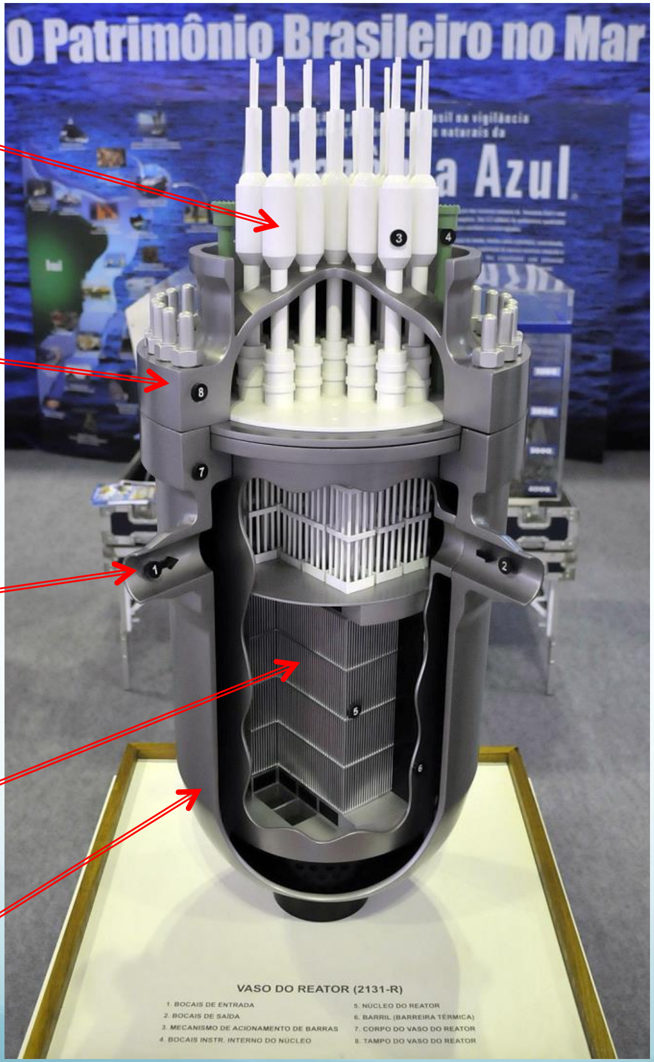
Control rod drive mechanisms

Reactor vessel head

Primary coolant loop piping nozzle (typ. of 4)

Reactor core

Reactor vessel



48 MWt

21 x 21 fuel element

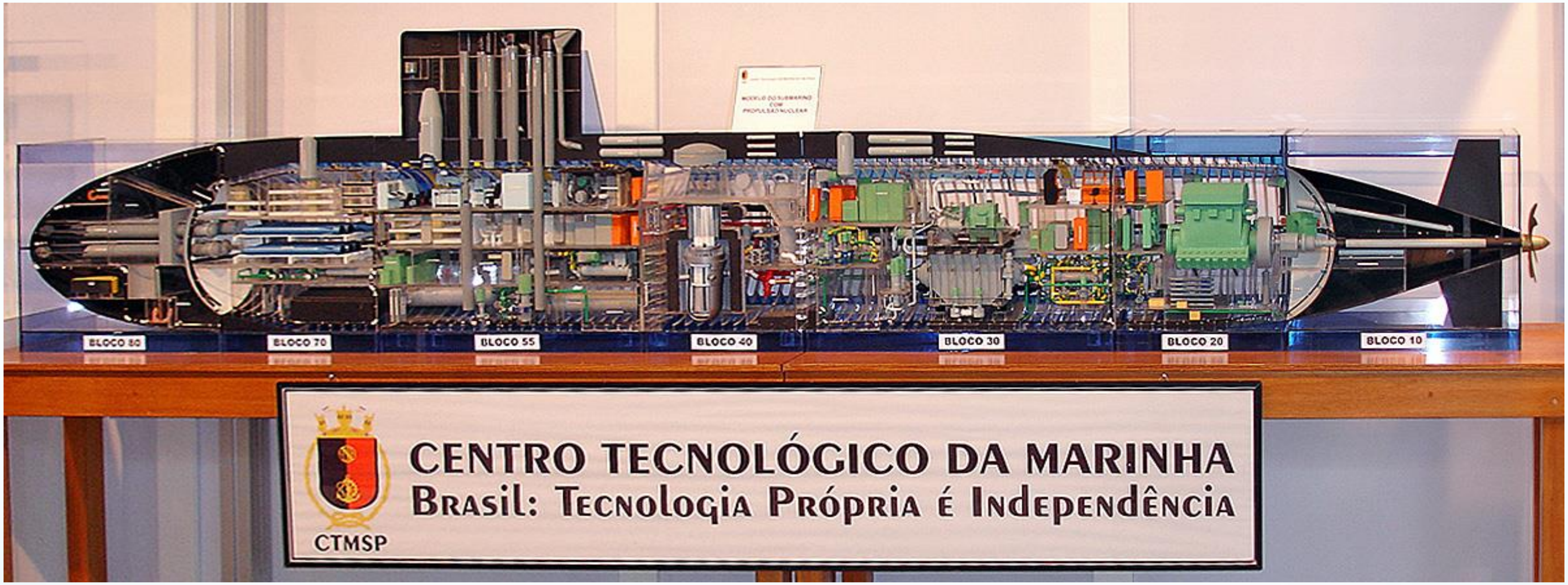
Individual fuel rods

Source: adapted from www.zona-militar.com

Brazil’s nuclear powered fast attack submarine (SSN / SN-BR)

Brazil’s nuclear sub – SN-BR

Model displayed at LAAD 2013 exhibition, Rio de Janeiro



Source: http://www.naval.com.br/blog/2018/06/15/snbr-cronograma-da-marinha-em-linha-com-o-cronograma-do-poder-naval/

Two SN-BR versions were revealed at LAAD 2013:

- One version with 8 x 533 mm (21 in) bow torpedo tubes
- A second version with 6 x bow vertical launch system (VLS) tubes and 2 x 533 mm bow torpedo tubes

Brazil’s nuclear sub – SN-BR

Model displayed at LAAD 2015 exhibition, Rio de Janeiro

SN-BR key design parameters:
Length: 100 m (328 ft); hull diameter 9.8m (32.2 ft)
Displacement: 4,000 tons submerge

Source: www.esdpa.org

Brazil's nuclear sub – SN-BR

Model circa 2018

Source: http://www.naval.com.br/blog/2018/06/15/

Brazil’s marine nuclear-power current trends

Brazil current trends

- **New build**
  - Construction on the 1st indigenous nuclear attack submarine (SB-BR) has not yet started. This sub is expected to be delivered in 2029.
  - The industrial consortium is in place and the new submarine construction facility at the Itaguai shipyard is manufacturing the first two conventionally-powered SBR attack subs. The first is expected to be launched later in 2018.
  - Progress on executing the new-build submarine program likely will be affected by Brazil's current weak economy, which could result in a stretch-out of submarine procurement.
- **Operations**
  - Only conventional submarine operations until delivery of the first indigenous nuclear submarine.
- **New weapons system development**
  - No indigenous weapons expected. Brazil's submarine force currently operates the US Mark 48 heavyweight torpedo and the French SM-39 Exocet submarine-launched anti-ship missile.
- **New submarine development**
  - Development of the SN-BR is in progress and should transition into the construction phase in the 2019 – 2020 timeframe.
- **New marine reactor development**
  - The RENAP-11 naval reactor prototype being built at the Brazil Navy's Aramar Experimental Center is not likely to be completed before about 2020.
  - The first indigenous submarine reactor is expected to be the 48 MWt 2131-R naval PWR as displayed in model form at the LAAD 2013 & 2015 exhibitions.

North Korea

Conventional submarine fleet
possibly with nuclear weapons

Source: https://en.wikipedia.org/

North Korea

Conventionally-powered submarine force

- North Korea currently operates a small fleet of conventionally-powered submarines, believed to include the following:
  - 4 former Soviet Whiskey-class diesel-electric subs (early Cold War-vintage)
  - 22 Soviet-designed Romeo-class (Chinese Type 033) diesel-electric subs
    - Seven imported from China, the others locally assembled from Chinese-supplied parts
  - Up to 40 Sang-O class coastal subs displacing 325 tons submerged
  - 10 midget submarines of the Yono class
- While North Korea has a program to develop nuclear-armed submarine launched ballistic missiles (SLBMs), it appears that their current focus is on installing these missiles on conventionally-powered submarines.

North Korea

Refurbished former Russian Golf II-class SSB

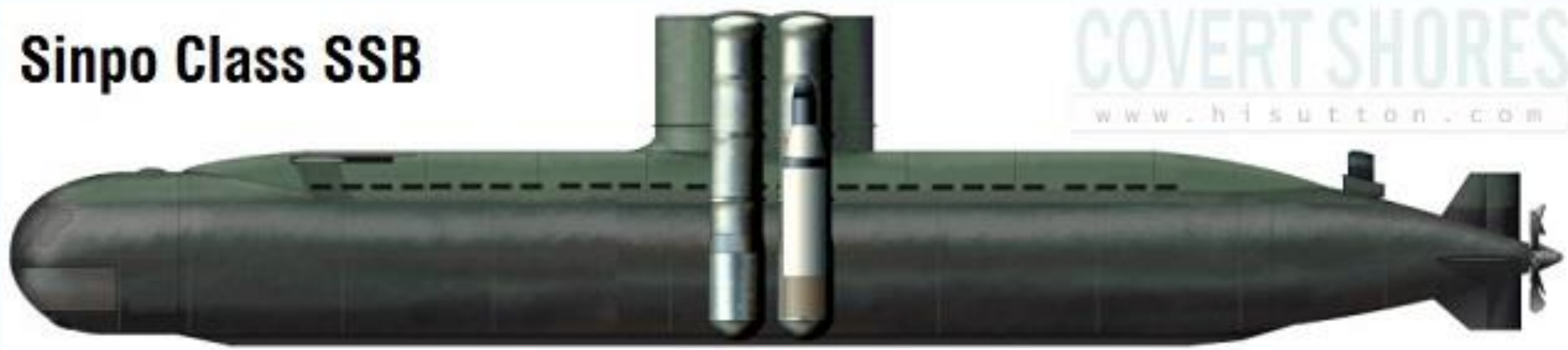
- By 1990, all Russian diesel-powered Golf-class ballistic missile submarines had been decommissioned.
  - These subs were capable of launching three R-21 liquid-propellant SLBMs.
  - Ten decommissioned Golf II submarines were sold to North Korea in 1993 – 94, to be dismantled under Russian military observation.
- On 1 Nov 2014, North Korea launched a refurbished Golf II sub, either for active service or as a testbed to support development of submarine launched ballistic missiles (SLBMs) for a similar indigenous sub.
  - First reported in October 2014 by the US- Korea Institute at the Johns Hopkins School of Advanced International Studies in the US
- On-going SLBM tests conducted on land and at sea are supporting development of a modern submarine missile launching capability.

Missile launch from a missile tube in the sail of a submerged Golf II submarine

Source: FAS.org

North Korea

Sinpo-class (aka Gorae- or Pongdae-class) indigenous SSB



- North Korea is developing a new ballistic missile submarine that likely is influenced by the design of the Yugoslavian Sava or Heroj-class diesel-electric submarines (built in the mid-1960s – mid-1970s), with provisions for two missile launch tubes extending through the sail, similar to the larger Soviet-era Golf II-class submarine (built in the late 1950s – early 1960s).
  - The Sinpo SSB was built at the Sinpo South Shipyard.
  - It is not known if this sub is intended as a testbed for for North Korea's SLBMs or as an the lead boat for a class of operational ballistic missile submarine (SSBs).
- Sinpo is a conventionally-powered sub with the following characteristics:
  - Length: 65.5 m (214.9 ft) overall; sail about 10 m (32.8 ft) long
  - Beam: 6.5 m (21.3 ft)
  - Displacement: 1,650 – 2,000 tons
- A speculative view of the missile tube installation in the sub is shown above.

North Korea

Sinpo-class (aka Gorae- or Pongdae-class) indigenous SSB

The commercial satellite photo below shows the suspected submarine at the Sinpo South Shipyard in December 2014.

Source: 38north.org

Source, above : https://militaryedge.org/armaments/sinpo-class-gorae/
Source, below: Reuters via http://dantri.com.vn/

North Korea

Sinpo South Shipyard, 21 September 2017

Source: https://www.38north.org/2017/10/sinpo101117/

North Korea

Pukkuksong-1 SLBM (KN-11)

- The KN-11 is a two-stage, solid propellant SLBM that uses grid fins at its base for flight stability.
- General characteristics of the missile:
  - Length: 9 m
  - Diameter: 1.5 m
  - Range: 1,200 km (746 mi) (est)
- Land-based testing began in 2014, moving to an underwater test platform in 2015 to validate the "cold-launch" process to be used for submarine launches.
  - A gas generator ejects the missile from the launch tube and the first-stage rocket engine ignites after the missile reaches the surface.

Source: Center for Nonproliferation Studies via https://commons.wikimedia.org/wiki/File:Pukkuksong-1.png

North Korea

Pukkuksong-1 SLBM (KN-11)

- An initial test launch from a submerged Sinpo-class SSB may have been conducted unsuccessfully in November 2015, with some damage to the submarine. The first successful cold launch test occurred on 23 April 2016.
- A successful test launch on a lofted trajectory with a range of about 500 km (311 mi) occurred on 24 August 2016. The CSIS Missile Defense Project estimates that this trajectory was comparable to a full-range test of 1,200 km (746 mi).
- The CSIS estimates that the KN-11 SLBM could become operational in 2020.

Source: https://missilethreat.csis.org/missile/kn-11/

North Korea

Fissile material inventory

- North Korea is a nuclear weapon state outside of the Nuclear Non-proliferation Treaty. As of the end of 2016, its nuclear arsenal is estimated to include about 10-20 warheads. It may have enough fissile material for as many as 60 warheads.
- North Korea operates a 5 MWe plutonium production reactor at Yongbyon and also is building a new facility named the Experimental Light Water Reactor (ELWR) at that site. The ELWR is expected to be rated at 25 – 30 MWe.
- The 5 MWe reactor was resurrected after having been shutdown in 2007 and having its cooling tower demolished as part of an agreed program to end plutonium production and disable the facility. The reactor resumed operation in August 2013 and site modifications have continued.
  - It is estimated that North Korea may have accumulated about 40 kg (88 lb) of separated plutonium as of the end of 2016.
- North Korea operates two uranium enrichment facilities:
  - The relatively small-scale centrifuge enrichment plant at Yongbyon was shown to visiting US nuclear experts in 2010.
  - A second enrichment plant at Kangson is situated just outside the capital city of Pyongyang. This site is older than the enrichment plant at Yongbyon and may have been in operation for 15 years or more. Its existence was publically revealed in July 2018 in an article in *The Diplomat*.

Source: International Panel on Fissile Materials, 12 Feb 2018, http://fissilematerials.org/countries/north_korea.html

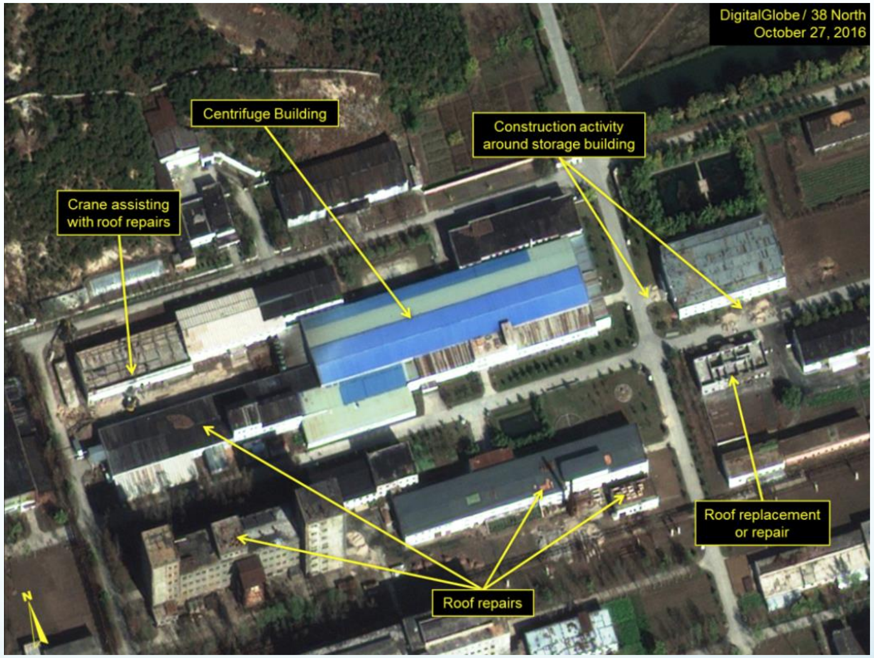
North Korea

Uranium enrichment facilities

Kangson enrichment plant

Source: Planet Labs, Inc. via The Diplomat

Yongbyon enrichment plant



Source: DigiGlobe via
https://www.38north.org/2017/01/yongbyon011817/

Pakistan

Conventional submarine fleet
possibly with nuclear weapons

Source: https://en.wikipedia.org/

Pakistan

Aging conventionally-powered submarine force

- Pakistan has a long-standing goal of acquiring a sea-based nuclear deterrent as part of its maritime strategy.
- Pakistan's Navy currently operates five French Agosta submarines (two older Agosta-70 boats & three modern Agosta-90B). The two 40 years old Agosta-70 boats are in need of replacement.
- An October 2013 article in *The Diplomat* by Haris Khan, a senior analyst at PakDef Military Consortium, reported that the Pakistan Atomic Energy Commission (PAEC) has a project known as KPC-3, "to design and manufacture a miniaturized nuclear power plant for a submarine."
- On 31 March 2015, *Daily Pakistan Global* reported that Pakistan Navy officials informed the National Assembly's standing committee for defense on plans for new submarine purchases:
  - France refused to sell six air independent propulsion (AIP)-equipped Scorpène submarines to Pakistan, citing technology transfer issues. However, France is selling Scorpène to India.
  - Pakistan announced plans to buy eight new Chinese Type 041 Yuan-class diesel-electric AIP submarines.
- PAEC and National Engineering and Scientific Commission (NESCOM) reportedly are developing a compact plutonium warhead, which could be used on the naval version of the indigenous Babur cruise missile (similar to the US Tomahawk).
  - Naval version, Babur 3, is launched from a standard 533 mm (21 in) torpedo tube.

Babur (Hatf VII)

Indigenous subsonic cruise missile family

- Basic design features are comparable to a US BGM-109 Tomahawk cruise missile.
- Turbojet or turbofan powered; speed about 550 mph (885 kph); range about 621 miles (1,000 km); can be armed with conventional or nuclear warheads.
- Ground-, surface ship- and submarine-launched versions. The submarine-launched cruise missile (SLCM) version, Babur 3, can be launched from a 533 mm (21 in) standard torpedo tube.

Babur. Source: http://www.terminalx.org

- January 2017: First test from a submerged platform
- March 2018: Second test from a submerged platform

Babur 3

Indigenous submarine-launched cruise missile

Source: https://www.hindustantimes.com/world-news/

Source: https://www.defensenews.com/naval/

Babur 3 in flight.   Source: Twitter, Maj Gen Asif Ghafoor@OfficialDGISPR, 29 Mar 2018

Pakistan

Fissile material inventory

- Pakistan is a nuclear weapon state outside of the Nuclear Non-proliferation Treaty. It is believed to have about 120 - 130 nuclear weapons. Pakistan continues production of fissile materials for weapons.
- As of the end of 2016, Pakistan had an accumulated stockpile of about 280 kg (617 lb) of plutonium. This plutonium was produced at the production reactors in Khushab. Four such reactors are now operational. This estimate assumes that in 2016 Pakistan separated plutonium from the spent fuel from Khushab-3 and Khushab-4 reactors, which began operating in 2013 and 2015, respectively.
- As of the end of 2016, Pakistan is estimated to have a stockpile of 3.4 ± 0.4 tons of HEU and continues to produce HEU for its nuclear weapon program. Uncertainty about Pakistan's uranium resources, and the operating history and enrichment capacity of its centrifuge plant at Kahuta and a second plant at Gadwal (which may be dedicated to HEU production) limits the reliability of the estimate.

Source: International Panel on Fissile Materials, 12 Feb 2018, http://fissilematerials.org/countries/pakistan.html

Pakistan nuclear fuel cycle timeline

1956
Pakistan established the Pakistan Atomic Energy Commission (PAEC)
1956
Iran-US agreement on cooperation in research on peaceful uses of atomic energy under Eisenhower's Atoms for Peace program

1971
Canada-supplied Karachi Nuclear Power Plant (KANUPP) initial criticality
1971
Indo-Pakistani War
1972
Pakistan initiated nuclear weapons program
21 Jan 1974
Indigenous PARR II reactor initial criticality
1976
Canada & US cut off supply of HEU fuel for PARR-I
Jul 1976
Engineering Research Laboratories (ERL) Kahuta established
Mar 1979
1st centrifuge enrichment cascade started at ERL

Mar 1996
Khushab-I production reactor operational
28 May 1998
Pakistan conducted five Simultaneous underground nuclear tests, code named Chagai-I

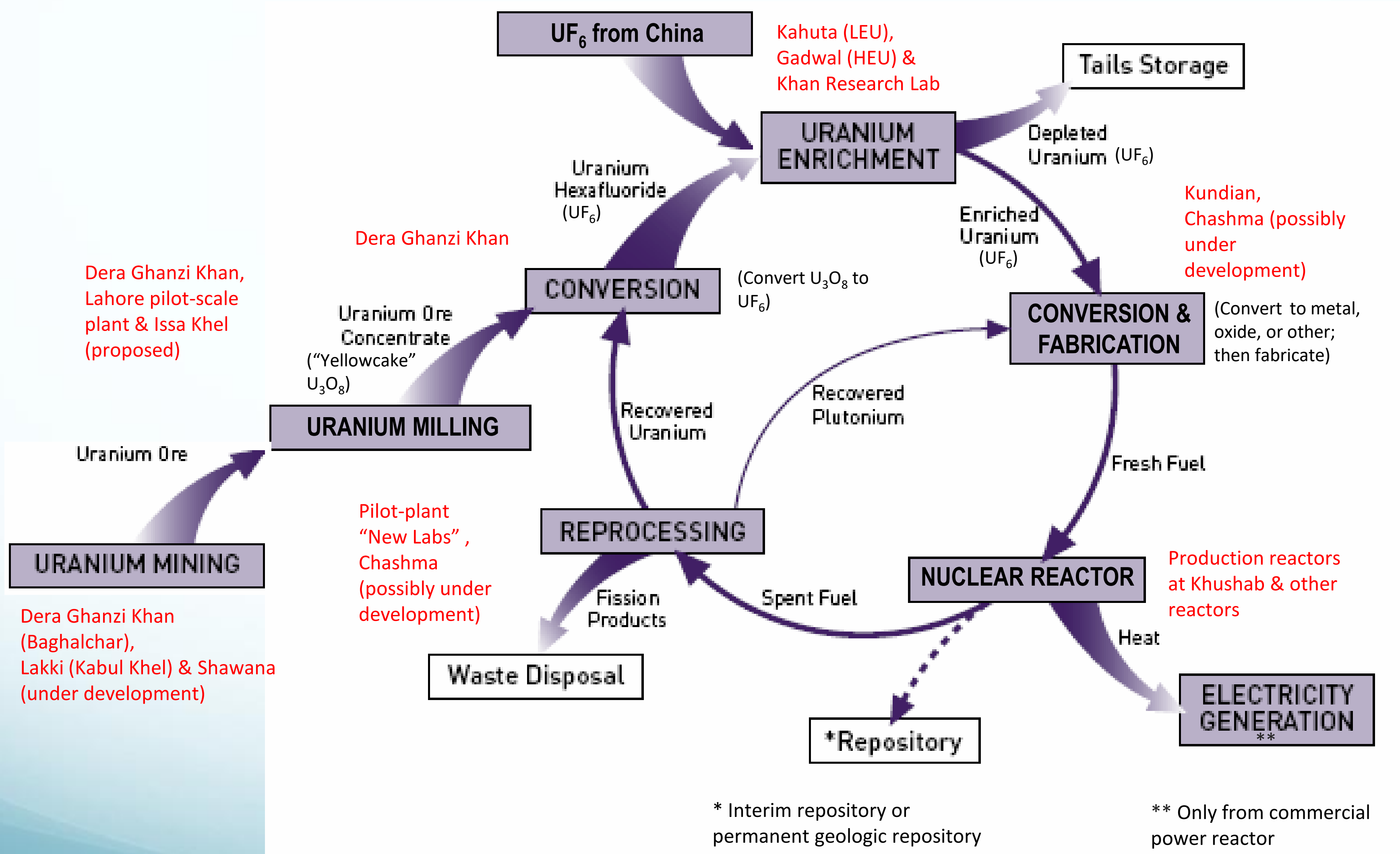
Jan 2015
Khushab-IV production reactor operational
Mar 2015
Pakistan Navy purchased eight Chinese Type 041 Yuan-class AIP subs
Jan 2017
1st submerged launch of a Babur 3 dual capable land-attack cruise missile
2018
New enrichment facility being developed at KRL

1950s	1960s	1970s	1980s	1990s	2000s	2010s	2020s

1965
Pakistan Atomic Research Reactor-1 (PARR-I) initial criticality with HEU fuel at the Pakistan Institute of Nuclear Science and Technology (PINSTECH)

May 1981
ERL renamed Kahn Research Laboratory (KRL) after A.Q. Kahn
1981
New Lab pilot reprocessing line completed at PINSTECH
1983
Pilot uranium enrichment line at KRL reached > 90% HEU

Pakistan's nuclear fuel cycle



Source: adapted from http://www.icnnd.org/reference/reports/ent/part-ii-5.html

Pakistan’s nuclear fuel cycle infrastructure

- Uranium mining
  - Beginning in 1972, the Pakistan Atomic Energy Commission launched geological surveys to find mineable deposits of uranium. The Atomic Energy Minerals Centre (AEMC) in Lahore was responsible for the exploration and mining operations. Initially, only low-grade ore was found.
  - In 1996, Pakistan launched a five-year effort to locate new uranium resources, primarily in the in the Dera Ghanzi Khan region in central Pakistan. A successful mine was established at Baghalchar.
  - Construction of the Shanawa Uranium Mine in northwest Pakistan began in 2009, but was temporarily suspended due to lack of funding in 2011. With funding restored in 2015, work is in progress on MPB-2, Shanawa Uranium Mining Project (Karak).
- Yellowcake (U_3O_8) production
  - Pakisani uranium extraction plant is located in the Dera Ghanzi Khan region.
  - Additional pilot-scale milling facilities exist in Lahore and a milling facility at Issa Khel (near the Lakki mine) has been proposed
- Conversion
  - There is a U_3O_8-to-UF_6 conversion facility at Dera Ghanzi Khan.
  - It appears that China supplied Pakistan with UF_6 as part of a nuclear development deal.

Pakistan's nuclear fuel cycle infrastructure

- Enrichment
  - Pakistan is believed to have two operational uranium enrichment facilities, Kahuta and Gadwal, both using gas centrifuge enrichment technology.
    - Kahuta (in Kahuta, Punjab province) is the older facility and may only produce LEU.
    - Gadwal (near Wah) appears to produce HEU from the LEU produced at Kahuta
  - A new uranium enrichment plant using the latest iteration of ultracentrifuge technology may be under construction at the Khan Research Laboratories at the Kahuta site, with an IOC as early as 2018.
  - Additional enrichment facilities may exist at Sihala (pilot ultracentrifuge) and Golra Sharif.
  - The total enrichment capacity that Pakistan can operate may be constrained by uranium resources, since domestic mining output is modest and Pakistan needs to fuel its four natural uranium-fueled plutonium production reactors at Khushab. The latest reactor was put in service in 2015.

Source: http://fissilematerials.org/blog/2016/09/pakistan_may_be_building_.html

Pakistan's nuclear fuel cycle infrastructure

- Reprocessing
  - A pilot-scale reprocessing plant known as "New Labs" was developed at PINSTECH based on technical data provided by Belgian firm named Belgonucleaire. New Labs plutonium output is thought to be sufficient to manufacture 2 – 4 plutonium bombs per year.
- Nuclear Power Fuel Complex (NPFC)
  - Pakistan reportedly is seeking to complete its nuclear fuel cycle for power reactors and is seeking assistance from China on the fuel technology for its future nuclear power plants.
  - The end product would be the creation of the NPFC, which is intended to give Pakistan the indigenous capability to support its own fleet of nuclear power plants. NPFC is expected to include:
    - National Fuel Enrichment Plant (NFEP)
    - Chemical Processing Plant (CPP)
    - Seamless Tube Plant-1 (STP-1)
    - Fuel Fabrication Plant (FFP)
    - Nuclear Power Fuel Testing Project (NPF-TP)
- Given the significant gaps in Pakistan's current nuclear fuel cycle for power reactors, it seems unlikely that Pakistan would be able to develop an indigenous naval nuclear propulsion plant in the next decade.

Iran

Conventional submarine fleet
with significant nuclear infrastructure and
possible aspirations for a nuclear submarine fleet

Iran

Conventionally-powered submarine force but possible aspirations for nuclear-powered submarines

- Iran is the only nation on the Persian Gulf possessing submarines. Their submarine force currently consists of three Russian-designed Kilo-class (4,000 ton) diesel-electric subs and several small (400 ton) and midget (150 ton) conventionally-powered subs.
  - The Kilo-class and small/midget submarines create a balance between littoral defensive operations and offensive operations further from the Persian Gulf.
  - The Kilo subs have been in service for about 20 years.
- Iran has a plan to develop one or more indigenous conventionally-powered submarine types.
- In June 2012, an Iranian official asserted that scientists were "at the initial phases of manufacturing atomic submarines."
  - Senior Iranian naval officers have said that they plan to use fuel enriched to 45 - 56% U-235.
  - Outside analysts stressed that manufacturing a nuclear reactor for use in submarines would be beyond Iran's current capabilities, suggesting that the announcement may have been meant as leverage in negotiations with the West.
- Iran's nuclear fuel cycle appears to have the basic uranium processing infrastructure for producing HEU at modest enrichment (i.e., 30 – 45% enrichment, like India) to support development of a nuclear reactor for an indigenous fleet of nuclear–powered vessels. This capability has been restricted by the 2015 *Joint Comprehensive Plan of Action.*

Iran nuclear fuel cycle timeline

1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s | 2020s

5 March 1957
Iran-US agreement on cooperation in research on peaceful uses of atomic energy under Eisenhower's Atoms for Peace program

1967
Tehran Nuclear Research Center (TNRC) established, run by Atomic Energy Organization of Iran (AEOI), equipped with a 5 MW research reactor supplied by the US

1968
Iran signed the Nuclear Non-Proliferation Treaty (NPT)

1979
After the 1979 Revolution, most international nuclear cooperation programs ended

Early-1980s
Iran purchased 450 tonnes of uranium (531 t U_3O_8) from South Africa.

2003
Pilot Fuel Enrichment Plant (PFEP) at Natanz started operation

2004
Uranium conversion plant (UCF) for UF_6 at Isfahan started operation

mid-2000s
Underground full-scale enrichment plants constructed at Natanz & Fordow

2006
Gchine U mine and Bandar Abbas Uranium (yellowcake) Production Plant (BUPP) started operation

2012
Fuel fabrication plant operational at Is Isfahan

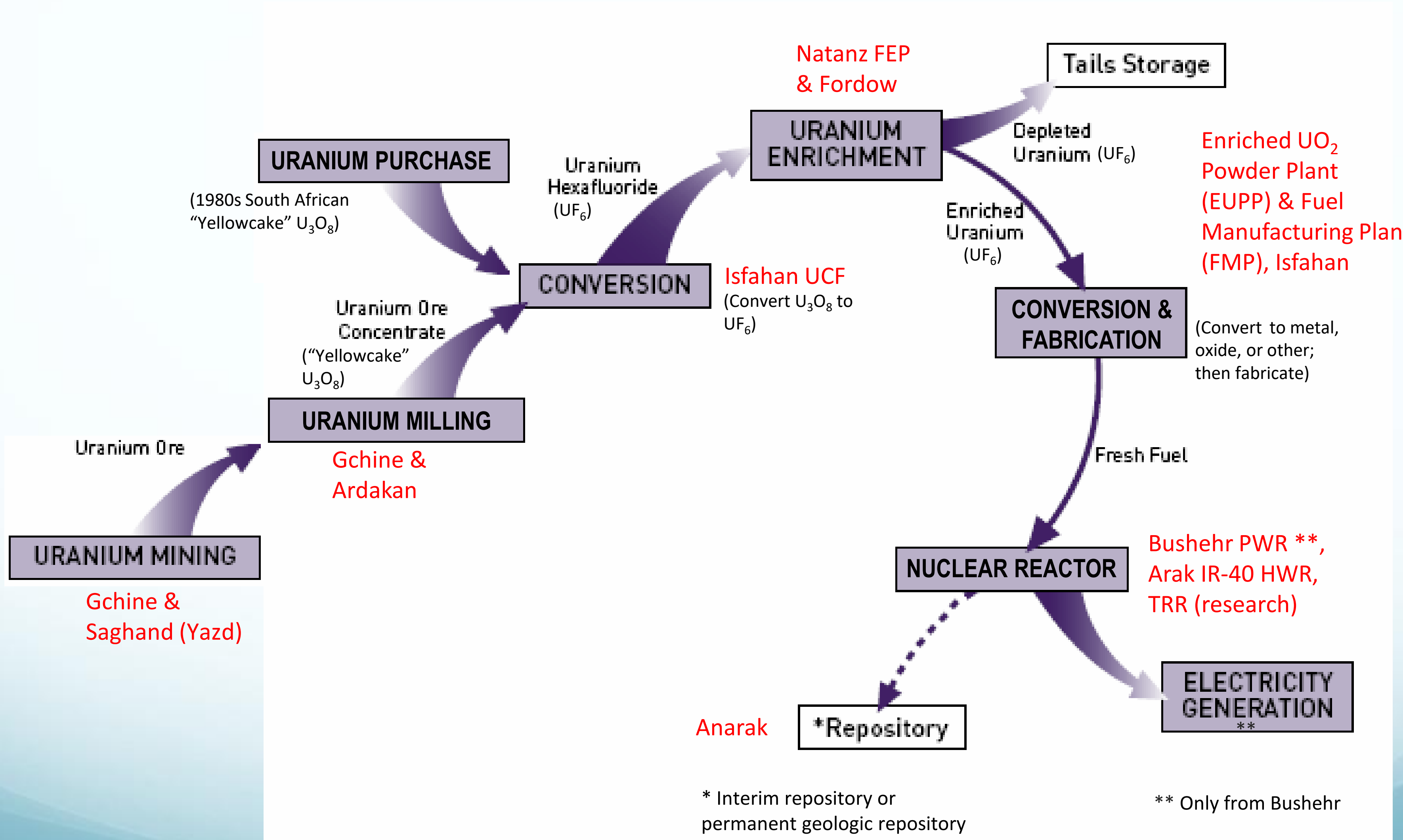
2013
Yellowcake Production Plant at Ardakan started operation

2014
Enriched UO_2 Powder Plant (EUPP) commissioned at Isfahan

2015
Saghand U mine started production

14 July 2015
Joint Comprehensive Plan of Action

Iran's nuclear fuel cycle



Source: adapted from http://www.icnnd.org/reference/reports/ent/part-ii-5.html

Iran’s nuclear fuel cycle

- A uranium conversion facility (UCF) at the Isfahan Nuclear Technology Centre converts “yellowcake” (U_3O_8) to uranium hexafluoride (UF_6). The UCF has 200 tonnes/yr capacity and started up in 2004. It is under IAEA safeguards and the IAEA reported that thru November 2014 it had produced 550 tonnes of natural UF_6, of which 163 tonnes had been moved to Natanz for enrichment.
- Prior to the 2015 *Joint Comprehensive Plan of Action,* Iran operated two uranium enrichment plants, both of which used gas centrifuge enrichment technology:
  - The Natanz FEP includes an above-ground Pilot Fuel Enrichment Plant (PFEP) and a hardened, underground Fuel Enrichment Plant (FEP).
  - Fordow is a hardened, underground enrichment plant.
- After enrichment, UF_6 is converted to oxide form at the Enriched UO_2 Powder Plant (EUPP) at Isfahan.
- The Fuel Manufacturing Plant (FMP) at Isfahan is the primary site for nuclear fuel production in Iran. The FMP was commissioned on 9 April 2009 but is thought to have been operational before this date.
  - FMP produces natural uranium fuel rods for the IR-40 research reactor at Arak.
  - FMP potentially could manufacture low-enriched uranium (LEU) fuel for Iran’s Bushehr power reactors, which were built by Russia. In practice, Iran used Russian-supplied nuclear fuel for Bushehr.
  - FMP probably would be the site where Iran would manufacture fuel for a future nuclear-powered vessel.

Natanz enrichment facilities

Natanz site circa 2010, after construction of the underground facilities.
Source: https://publicintelligence.net/iran-nuclear-site-natanz-uranium-enrichment-site/

Joint Comprehensive Plan of Action - 2015

- On 14 July 2015, the *Joint Comprehensive Plan of Action* between Iran and the P5+1 (the permanent members of the United Nations Security Council—the United States, the United Kingdom, Russia, France, and China—plus Germany) and the European Union, a comprehensive agreement based on the April 2015 framework agreements, was announced.
- Basic restrictions on fuel cycle operations include the following:
  - Restrictions on uranium enrichment
    - There will be no enrichment facilities other than Natanz and the number of centrifuges there will be limited. The level of enrichment will be limited to 3.67%
    - Fordow, the underground enrichment center, will be converted to a "nuclear, physics and technology center".
  - Restrictions on the Arak heavy water reactor
    - To be converted and modernized to become a heavy water research reactor with no plutonium production capability.
  - Restrictions on reprocessing
    - There will be no domestic reprocessing. Spent fuel will be exported for reprocessing.
  - Iran's uranium stockpile will be reduced by 98% to 300 kg (660 lbs) for 15 years.
- The restrictions on uranium enrichment should delay any plans Iran has for developing an indigenous nuclear-powered vessel.

Israel

Modern conventional submarine fleet
with weapons comparable to those found on
nuclear submarines

Source: https://en.wikipedia.org/

Israel

Modern conventionally-powered submarine force

- Israel's submarine force currently consists of three Type 800 Dolphin-class submarines and two Dolphin II submarines manufactured in Germany at the ThyssenKrupp's Howaldtswerke (HDW) shipyard in Kiel.
  - The first three boats are diesel-electric Type 800 Dolphin subs built in the 1990s
    - Basic parameters: Length: 57.3 meters (188 ft); displacement: 1,565 tons surfaced, 1,720 tons submerged.
  - 4th & 5th boats, the *INS Tannin*, and *INS Rahav*, are more advanced Dolphin II class submarines, capable of remaining submerged for long periods (weeks) using "air independent propulsion" (AIP) technology, which allows the engines of diesel-electric submarines to run without atmospheric oxygen.
    - Basic parameters: Length: 68.6 meters (225 ft); displacement: 2,050 tons surfaced, 2,400 tons submerged.
- March 2012: Israel and Germany signed a contract for a third Dolphin II submarine, the *INS Dakar*, that is expected to be delivered later in 2018.
- In June 2017, the German government approved the sale of three more Dolphin II submarines to Israel for a combined price of some $1.3 billion (about €1.1 billion). These subs are intended to replace the Type 800 Dolphin subs that were acquired in the 1990s.

Israel

Modern conventionally-powered submarine force

- Armament:
  - Ten torpedo tubes: 4 x 650 mm (25.6 in) diameter and 6 x 533 mm (21 in) diameter tubes for a variety of weapons, including DM-2A4 SeaHake wire-guided torpedoes, UGM-84C Harpoon anti-ship cruise missiles and Triton anti-helicopter missiles.
  - Also likely to carry Israel's indigenous Popeye Turbo cruise missile, which is believed to have a range of up to 1,500 km (932 mi) carrying a 200 kg (441 lb) payload.
- Operational matters:
  - Israeli subs have operated in the Persian Gulf
  - 2011: Israel invested about $27 million in a comprehensive structural overhaul and upgrade of the three Dolphin I submarines at a shipyard in Haifa, including addition of 650 mm (25.6 in) torpedo tubes and larger fuel tanks.
- Given the extensive capabilities of their modern fleet of conventionally-powered submarines, it is doubtful that Israel would make the great investment needed to develop an indigenous nuclear-powered submarine and the associated nuclear support infrastructure.

Israel

Dolphin II-class AIP submarine *IHS Tannin* prior to delivery

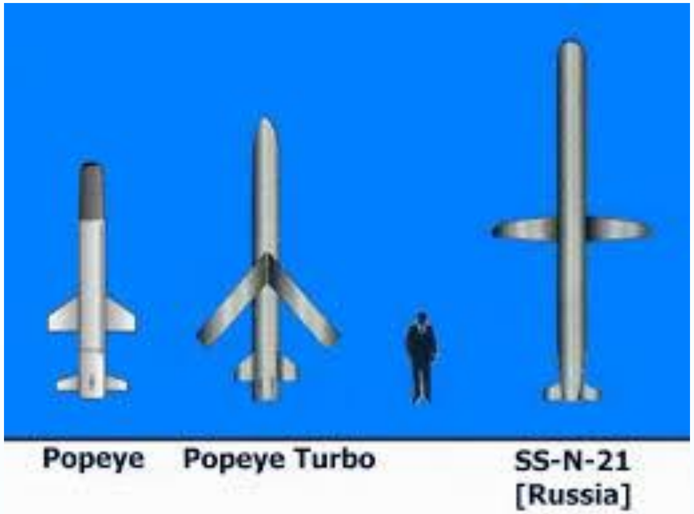
Source, all photos: http://intercepts.defensenews.com/2014/08/

Popeye

Indigenous subsonic cruise missile family

- 2000: Israel’s request for US Tomahawk cruise missiles was rejected by the Clinton administration on the grounds that the sale would violate the Missile Technology Control Regime (MTCR) restriction on missiles with ranges > 300 km (185 mi).
- Israel’s Navy operates shorter-range US Harpoon cruise missiles with anti-ship and land-attack capabilities.

Source: http://fas.org/nuke/guide/israel/missile/popeye-t.htm



- Popeye cruise missiles are produced in several versions (ship-, submarine-, and air-launched) and are sold to several nations, including the US
- 2002: 1^{st} long-range (1,500 km) test flight of a variant of the indigenous Popeye Turbo submarine-launched cruise missile (SLCM) occurred in the Indian Ocean.
- The long-range Popeye Turbo SLCM has the capability to serve as a strategic second-strike nuclear deterrent weapon.

Israel

Fissile material inventory

- Israel is a nuclear weapon state outside of the Nuclear Non-proliferation Treaty. As of the end of 2016, its nuclear arsenal was estimated to include about 80 plutonium warheads.
- Israel is believed to still be operating the now 50 year old Dimona plutonium production reactor, built for it by France, and an associated reprocessing plant in the Negev desert. The reactor may be operated now primarily for tritium production. As of the end of 2014, Israel may have had a stockpile of about 900 ± 130 kg (1,984 ± 287 lb) of plutonium.
- It appears that Israel does not have an indigenous uranium enrichment facility. However, Israel may have about 300 kg (661 lb) of HEU. The source of this HEU is subject to debate. There is speculation that the HEU was diverted from the NUMEC plant in the United States in the 1960s.

Source: International Panel on Fissile Materials, 12 Feb 2018, http://fissilematerials.org/countries/israel.html

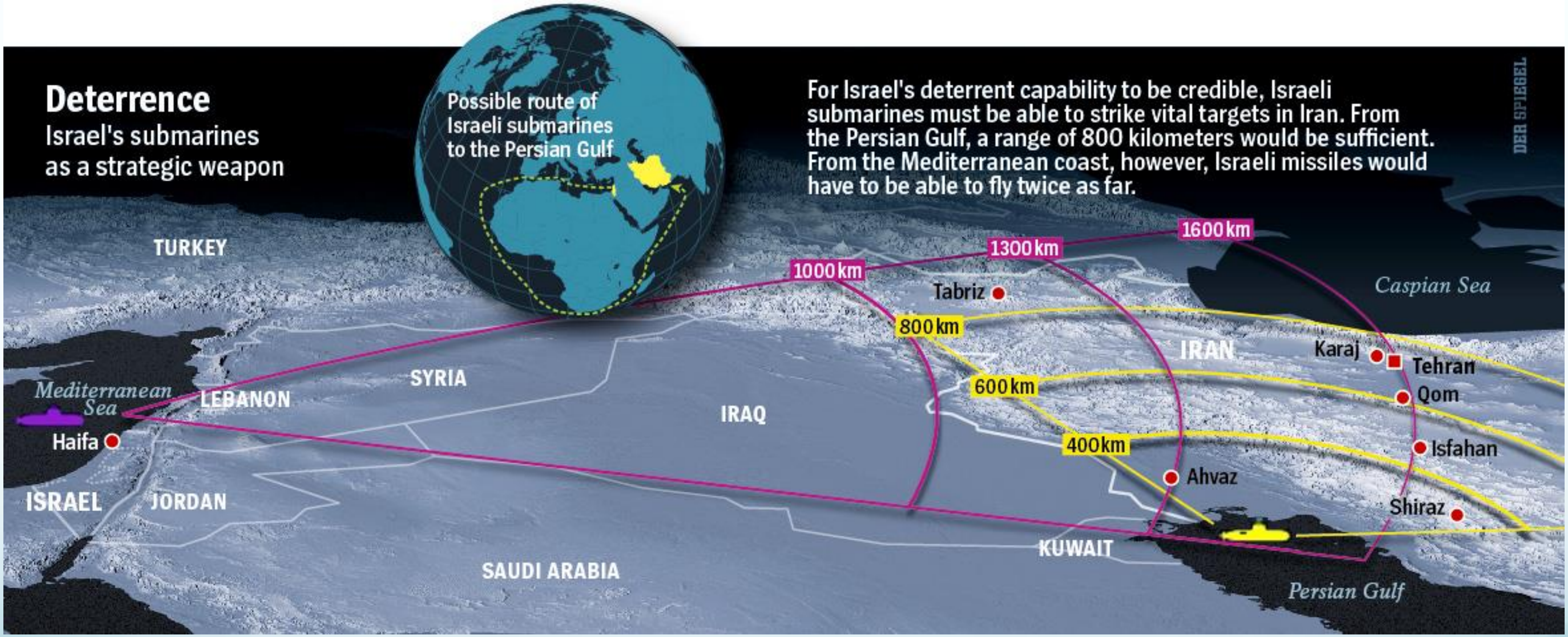
Israel

Dimona

Dimona shown in circa 2002 photo. Source: Arms Control Association, https://www.armscontrol.org/ACT/2015_12/Features/Building-on-the-Iran-Deal-Steps-Toward-a-Middle-Eastern-Nuclear-Weapon-Free-Zone

Israel

Deterrence capability with a long-range submarine-launched cruise missile



Source: http://www.supervideo.com/dolphin.htm

Australia

Passing interest in nuclear subs,
but will modernize its conventional submarine fleet

Australia

Modernization of the submarine force

- Royal Australian Navy submarine force is based in Western Australia with a small fleet of 6 x Collins-class diesel-electric subs.
  - These boats entered service between 1996 and 2003 and will begin to reach the end of their useful life in 2026
- SEA-1000 (Future Submarine Program) study evaluated Australia's options for a next-generation sub.
  - Finalists in the three-year selection process were DCNS (France), Thyssen-Krupp (Germany), and a Mitsubishi Heavy Industries – Kawasaki Shipbuilding Corp. consortium (Japan).
  - A nuclear powered submarine was considered, but was not a serious alternative for Australia because of their lack of an indigenous nuclear industry, lack of marine nuclear regulatory infrastructure, and adverse public opposition.
- French firm DCNS won the competition in April 2016 with their Shortfin Barracuda design, which is a conventionally-powered derivative of the French Barracuda nuclear attack submarine.
  - 12 Future Submarines are planned; A$50 billion (about US$36 B) contract.
  - All will be built in the ASC shipyard in Adelaide, Australia.
  - All will have US combat systems and will be armed with US weapons.

Australia

Choice for new submarine: the DCNS Shortfin Barracuda

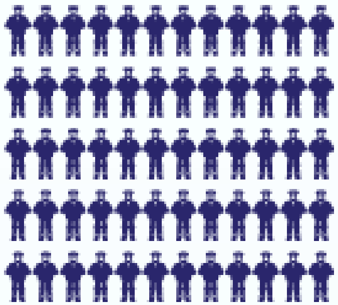
French Shortfin Barracuda

Manufacturer
DCNS

Technical specifications

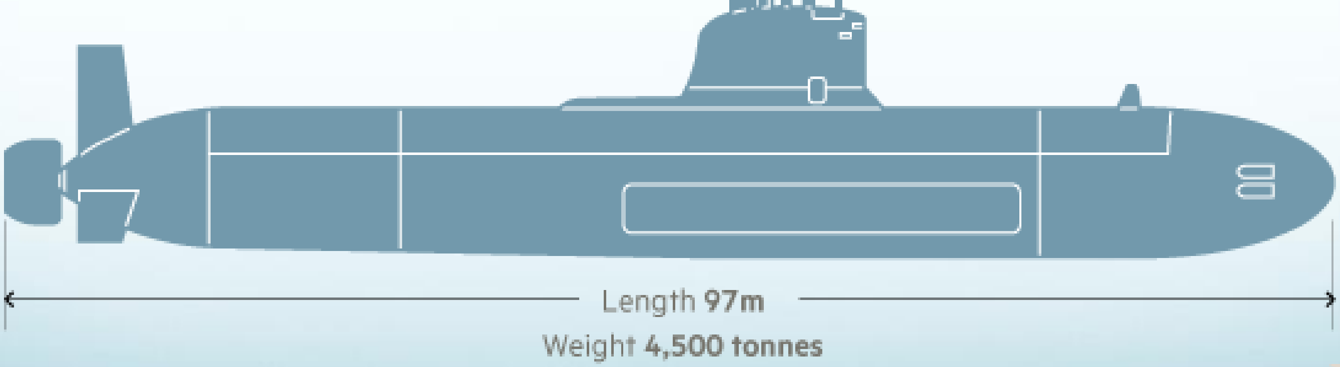
DCNS is adapting a nuclear design for a conventional model and will integrate a US weapons system.

Crew



Vessel will use latest jet-propulsion technology rather than traditional propellers, reducing noise.

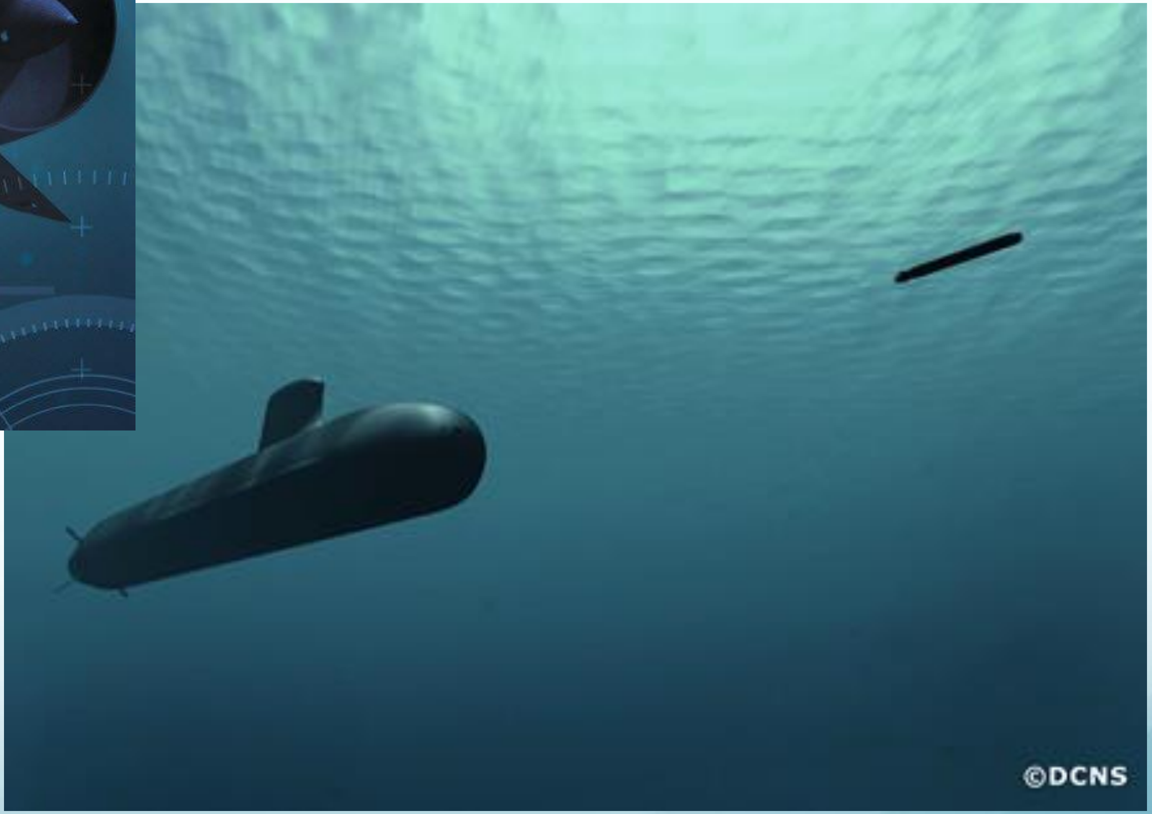
Battery storage will have enough power to meet Australia's very long-range requirements. Will be able to accommodate lithium battery technology developments.



Source: Note: actual length may be closer to 94 meters.
Financial Times, https://www.ft.com/content/4ab37572-0b4a-11e6-b0f1-61f222853ff3

Australia

Choice for new submarine: the DCNS Shortfin Barracuda



Short Fin Barracuda, right firing a Mark 48 torpedo. Source, both graphics: DCNS