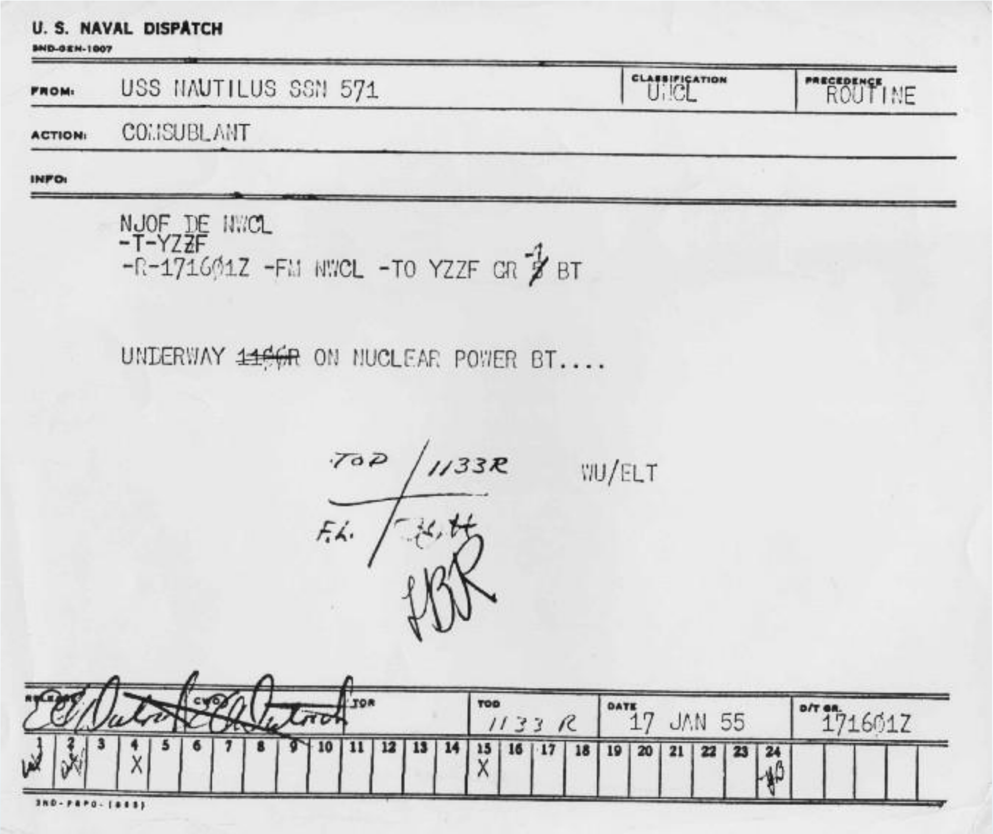
60 Years of Marine Nuclear Power: 1955 - 2015



U. S. NAVAL DISPATCH
SND-GEN-1907

FROM: USS NAUTILUS SSN 571
CLASSIFICATION: UNCL
PRECEDENCE: ROUTINE

ACTION: COMSUBLANT

INFO:

NJOF DE NWCL
-T-YZZF
-R-171601Z -FM NWCL -TO YZZF GR ~~3~~ 7 BT

UNDERWAY ~~1100R~~ ON NUCLEAR POWER BT....

TOD /1133R

WU/ELT

TOD: 1133 R
DATE: 17 JAN 55
D/T GR.: 171601Z

Peter Lobner

August 2015

Foreword

This rather lengthy presentation is my attempt to tell a complex story, starting from the early origins of the U.S. Navy's interest in marine nuclear propulsion in 1939, resetting the clock on 17 January 1955 with the world's first "underway on nuclear power" by the *USS Nautilus*, and then tracing the development and exploitation of nuclear propulsion over the next 60 years in a remarkable variety of military and civilian vessels created by eight nations.

I acknowledge the great amount of work done by others who have posted information on the internet on international marine nuclear propulsion programs, naval and civilian nuclear vessels and naval weapons systems. My presentation contains a great deal of graphics from many internet sources. Throughout the presentation, I have made an effort to identify all of the sources for these graphics.

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

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

Best regards,

Peter Lobner
August 2015

60 Years of Marine Nuclear Power: 1955 – 2015

Organization of this presentation

- Part 1: Introduction
- Part 2: United States
- Part 3: Former Soviet Union & Russia
- Part 4: Other Nuclear Marine Nations
  - UK, France, China, Germany, Japan & India
  - Other nations with an interest in marine nuclear power technology: Brazil, Italy, Canada, Australia, North Korea, Israel, Pakistan & Iran
- Part 5: Arctic Operations

60 Years of Marine Nuclear Power: 1955 – 2015

Part 1: Introduction

Peter Lobner
August 2015

Part 1: Introduction

- Quick look: Then and now
- State-of-the-art in 1955
- Marine nuclear propulsion system basics
- Timeline
  - Timeline highlights
  - Decade-by-decade
- Effects of nuclear weapons and missile treaties & conventions on the composition of naval nuclear fleets
- Prospects for 2015 - 2030

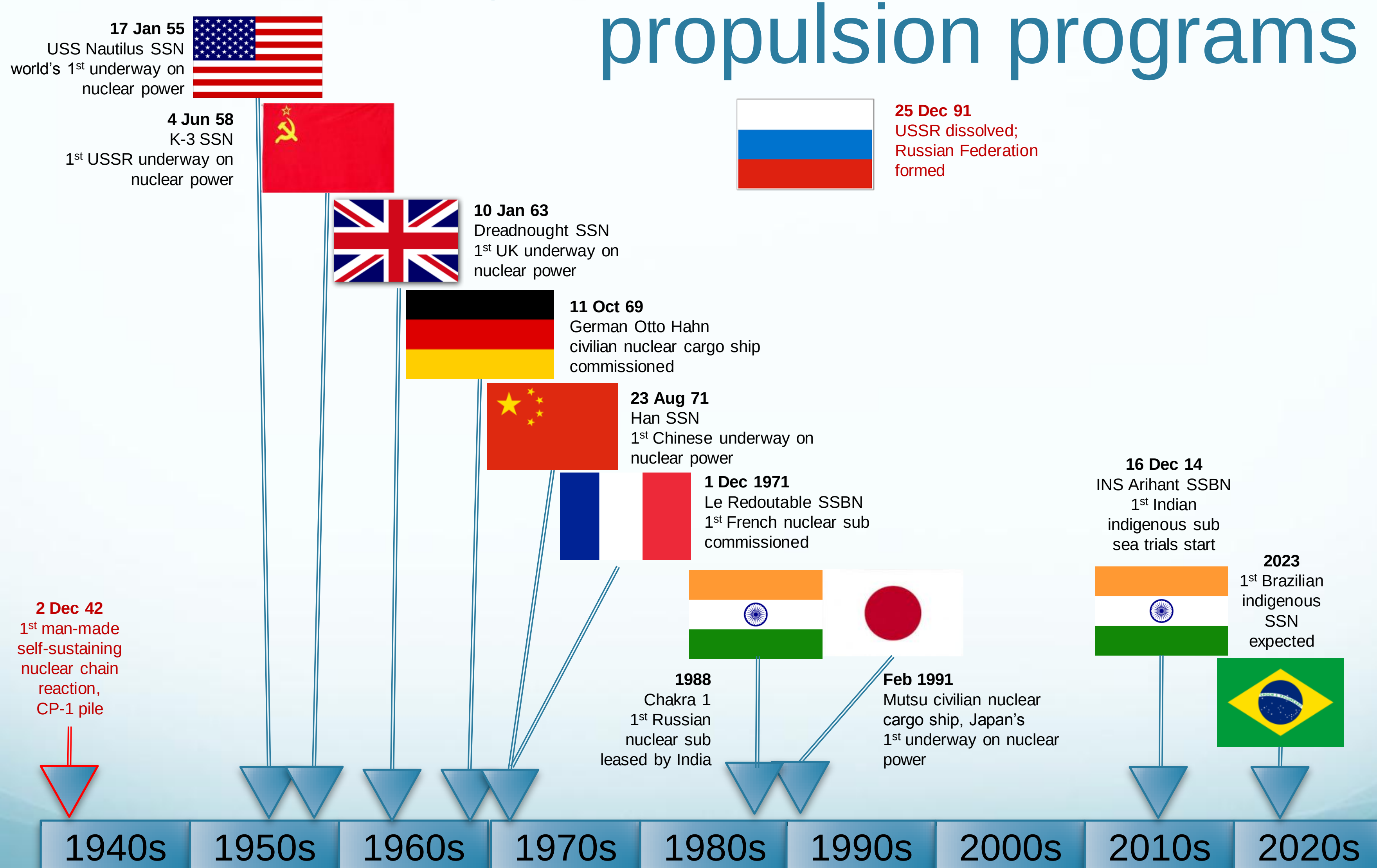
Quick look:
then and now

17 Jan 1955: *USS Nautilus* (SSN-571) made the first voyage of a nuclear-powered vessel

- Capt. Eugene P. Wilkinson was the first commanding officer of the *Nautilus* on that historic voyage, which was made from the U.S. Navy submarine base at New London, CT.
- The famous message, "UNDERWAY ON NUCLEAR POWER," was sent by flashing light signal to Commander Submarine Forces Atlantic.
- *Nautilus* was built by Electric Boat (a division of General Dynamics), Groton, CT.
- The reactor was a 70 MWt S2W pressurized water reactor (PWR) built by Westinghouse Electric Company.
- This was the start of a revolution in marine propulsion and naval technology that is continuing today.

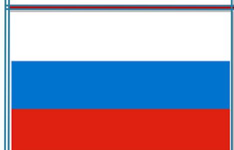
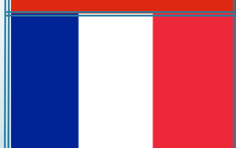
Capt. Eugene P. Wilkinson & *Nautilus* Source: U.S. Navy

60 years of marine nuclear propulsion programs



The world's marine nuclear fleets

Estimated total of 174 operating nuclear-powered vessels as of mid-2015

	Nuclear submarines				Nuclear surface ships		
	Attack sub (SSN)	Strategic missile sub (SSBN)	Cruise missile sub (SSGN)	Other special nuc subs	Naval surface combatants	Civilian surface vessels	Country totals
	54	14	4	2 MTS	10 CVN	0	84
	19	13	8	9	1 CGN	7	57
	7	4	0	0	0	0	11
	6	3	0	0	0	0	9
	6	4	0	0	1 CVN	0	11
	1 (leased)	1	0	0	0	0	2

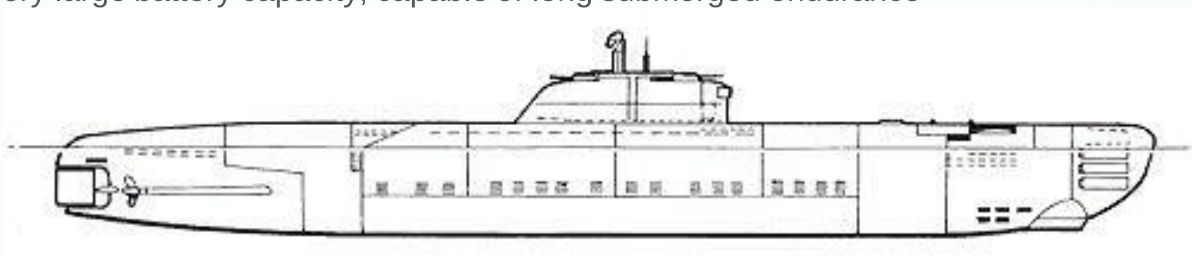
CVN = Nuclear-powered aircraft carrier; CGN = Nuclear-powered guided missile cruiser MTS = Moored Training Ship

State-of-the-art in 1955

State-of-the-art in 1955

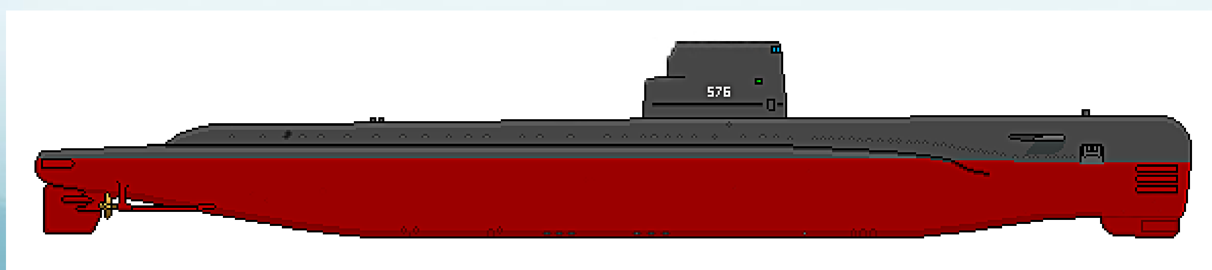
Submarine hull design

- WWII German Type XXI “Elektroboat” set the standard for post-war hydrodynamic hull design and underwater performance
  - Faster speed submerged (17.2 kts) than when running on the surface (15.7 kts)
  - Very large battery capacity; capable of long submerged endurance



Source: www.uboataces.com

- US Navy implemented the Greater Underwater Propulsion Power Program (GUPPY) program to improve WWII-era diesel submarines.
  - Key GUPPY features included removing the deck guns, streamlining the outer hull, replacing the conning tower with a sail, installing new propellers optimized for submerged operations, installing a snorkel mast and more air conditioning, and doubling the battery capacity.
  - USS Tang (SS-563) and USS Darter (SS-576) were the first new U.S. conventional submarines designed under the GUPPY program. Tang was commissioned in October 1951, and Darter in October 1956.
  - Their cleaner hull form is similar to the early U.S. nuclear submarines: Nautilus, Seawolf, Triton, and Skate-class



Source: www.shipbucket.com

USS Albacore (AGSS-569)

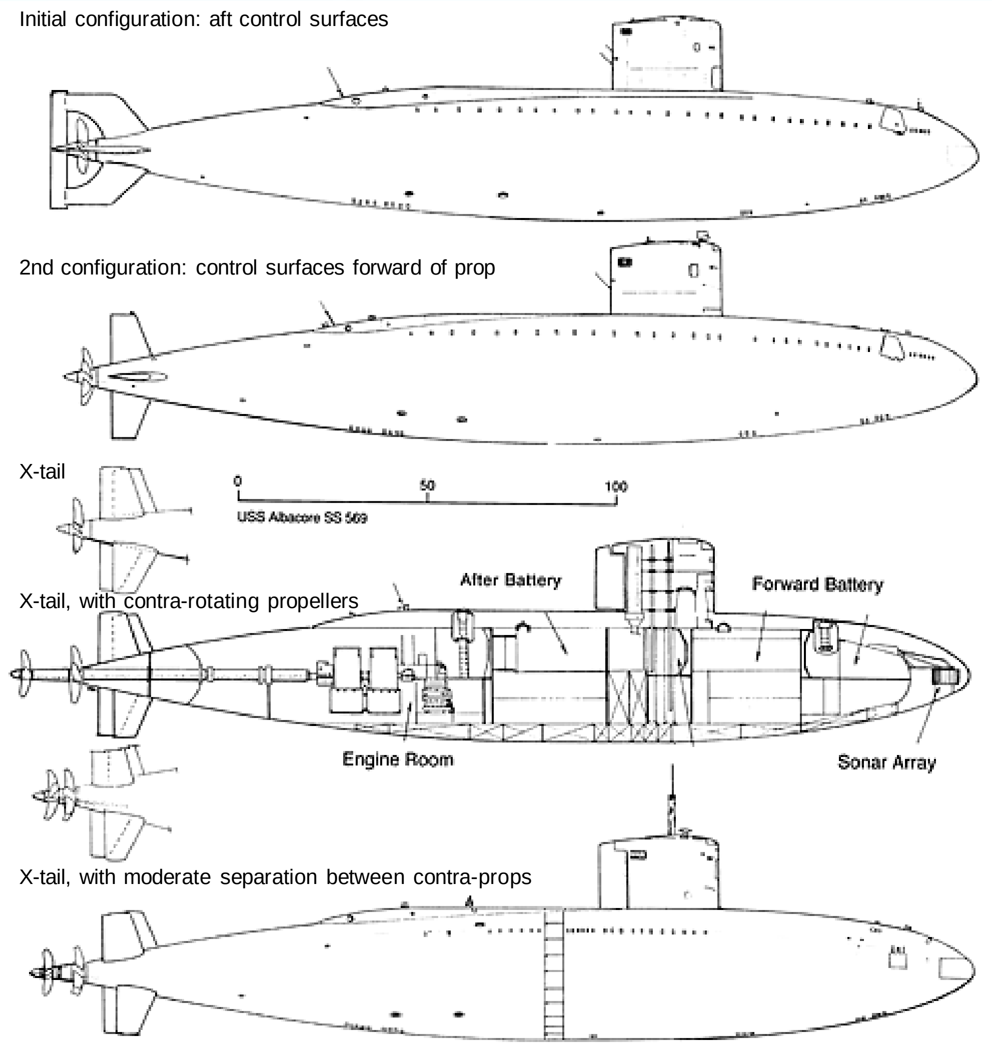
Revolutionary hull design

Source:www.princeton.edu

Class	# in Class	Length	Beam	Displacement (tons)	Engine	Shaft hp	Max speed	Years delivered	Years in service
Albacore	1	62.1 m (204 ft)	8.2 m (27 ft)	1240 (surf), 1540 (sub)	2 x GM 16-338 pancake diesels, 1 x electric motor	7,500	33 kts	Dec 1953	Dec 53 – Dec 72

- Albacore's advanced hull form was the result of a 1949 study by U.S. Navy Bureau of Ships (BuShips) and subsequent tests conducted by David Taylor Model Basin, Carderock, MD.
- Key characteristics: teardrop-shaped hull & single screw, which were incorporated immediately into the Skipjack-class SSN and all subsequent classes of U.S. nuclear subs. Also introduced HY-80 high-strength steel hull, which was the U.S. standard through the Los Angeles-class SSN.
- Construction authorized Nov 1950; built at Portsmouth Naval Shipyard; launched in Aug 1953.
- Tested various control surface and propeller configurations, including dorsal rudder on the sail, X-configured stern planes, contra-rotating propellers, and deployable speed brakes.

USS Albacore (AGSS-568)



Above: dorsal rudder on aft edge of the sail

Below: final X-tail configuration

Source: all from www.ussalbacore.org

State-of-the-art in 1955

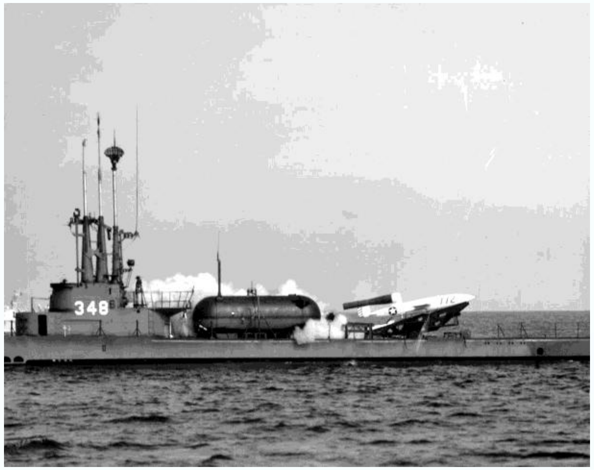
Submarine weaponry

- Various WWII-era torpedoes
  - Mk 14, 21” (533 mm) straight-running torpedo
    - Methanol fuel, 643 lb warhead, range: 4,500 yards @ 46 kts; 9,000 yards @ 31 kts
    - Service dates: 1931 – 1980
  - Mk 16, 21” (533 mm) straight or pattern-running torpedo
    - Concentrated hydrogen peroxide (Navol) fuel, 746 lb warhead, range: 11,000 – 13,700 yards @ 46 kts
    - Service dates: 1946 – 1975
  - Mk 27 Mod 4, 19” (483 mm) passive acoustic homing torpedo
    - Electric, 585 lb warhead, range: 4,000 yards @ 19.6 kts
    - Service dates: 1946 – 1960
  - Mk 28 21” 21” (533 mm) passive acoustic homing torpedo
    - Electric, 128 lb warhead, range: 6,200 yards @ 15.9 kts
    - Service dates: 1944 – 1960
- Various WWII-era mines
- No deck guns
  - All removed in an effort to streamline older submarines under the Navy’s GUPPY program.

State-of-the-art in 1955

Submarine weaponry

- 1st-generation submarine-launched land attack cruise missiles under development
  - 12 February 1947: First JB-2 Loon missile tested from a submarine, USS Cusk (SS-348)
  - July 1953: First Regulus I launched from a submarine, USS Tunny (SS-282)
- No anti-ship cruise missiles
- Submarine-launched ballistic missile development just starting
  - 9 September 1955: Joint program established to develop the Army's liquid-fuelled Jupiter IRBM for Navy use on submarines & surface ships.



Cusk launches JB-2 Loon Source: Wikipedia


Tunny launches Regulus I Source: Wikipedia

State-of-the-art in 1955

Nuclear weapons

- Small atomic weapons existed. W9 warhead for 280 mm “atomic cannon” was tested in 1953.
- Thermonuclear weapons were just being introduced to the military inventory and they were very large:
  - 28 Feb 1954: U.S. detonated its first “deliverable” (non-cryogenic) thermonuclear weapon, Bravo.
  - Mk-17 & Mk-24 bombs were the first operational thermonuclear weapons deployed by the U.S.:
    - 24.7 ft (7.52 m) long, 61.4 in (1.56 m) diameter, and weighed 21 tons (19,091 kg).
    - Yield: 10 – 15 MT
    - In production Oct 54 - Nov 1955
  - Mk-15 bomb was the first relatively lightweight thermonuclear bomb created by the U.S.:
    - 11.7 ft long (3.56 m) long, 35 in (0.89 m) diameter, and weighed 7,600 lb (3,450 kg)
    - Yield: 1.7 – 3.8 MT
    - First produced in 1955

Mk-17 Source: http://www.castleairmuseum.org


Mk-15 Source: Wikipedia

State-of-the-art in 1955

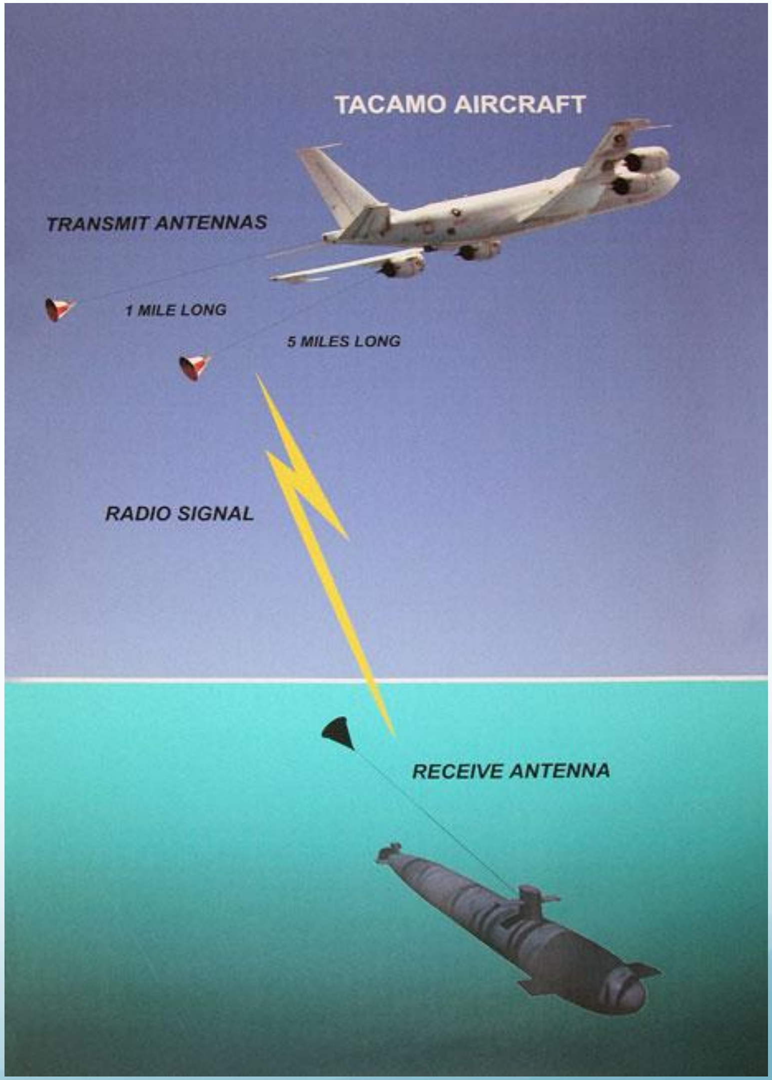
Communications

- WW-II-era HF & VHF radio communications were available for vessels on the surface, as was short-range signaling via flags or flashing light.
- The only operational means for communicating with a submerged submarine was the AN/WQC-2, "Gertrude", underwater telephone developed in 1945.
- Very Low Frequency (VLF) communications were not available
  - VLF radio waves (3 – 30 kHz) can penetrate seawater to a depth of about 20 meters.
  - Naval Research Laboratory (NRL) developed a VLF facsimile transmission system, known as "Bedrock", that was the first system to provide reliable command and control communication from a single high-power transmitting station in the U.S. to continuously submerged submarines operating in any region of the world.
  - Earliest demonstrations of this system were:
    - USS Skate (SSN-578) used the system successfully on its 1959 voyage to the North Pole.
    - USS Triton (SSN-586) used the system with good results throughout the first submerged circumnavigation of the globe, February-May 1960.
  - VLF communications systems were installed in all nuclear submarines, with communications via a VLF "crossed-loop" antenna and/or a floating wire antenna that trails behind the sub.

State-of-the-art in 1955

Communications

- No TACAMO aircraft to provide a backup VLF data and HF voice radio transmission capability to relay Emergency Action Messages from the President to submarines.
  - 1962: 1st TACAMO tests
  - 1969: System operationally deployed using EC-130Q Hercules cargo aircraft flying long-duration missions over the Atlantic and Pacific.
  - Modern TACAMO aircraft are E-6B.



Source: http://usnavymuseum.org/Ex2_TACAMO

State-of-the-art in 1955

Communications

- Extremely Low Frequency (ELF) communications not available
  - Project Sanguine was proposed in 1968 to create a hardened ELF transmitter facility in Wisconsin & Michigan to transmit tactical orders one-way to U.S. nuclear subs anywhere in the world, and survive a direct nuclear attack.
    - ELF radio waves can penetrate seawater to a depth of hundreds of feet.
    - Original design would have operated at 76 Hz and required about 800 MW of electric power
  - Project ELF was the scaled-back 76 Hz system actually built in Wisconsin & Michigan.
    - Operational from 1989 to 2004, then retired due to high operating cost and regional ecological opposition.

Submarine radio communications

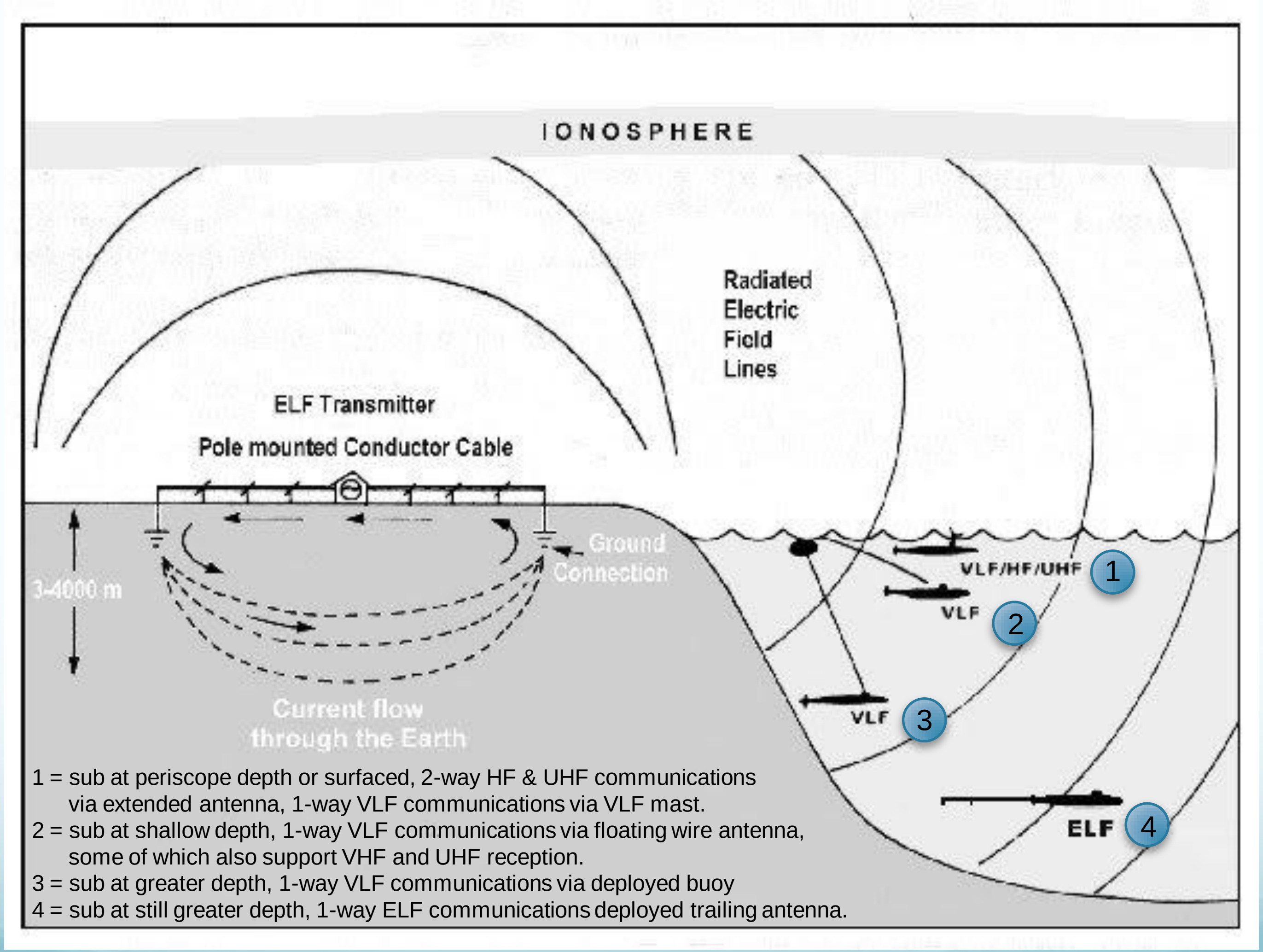


Image source: adapted from R. Romero and V. Lehtoranta, 22 November 1999.

State-of-the-art in 1955

Communications

- Satellite communications not available
  - 4 Oct 1957: 1st satellite, Sputnik 1, launched into orbit
  - Aug 1960: Echo 1 launched; the world's 1st communications satellite capable of passively relaying radio signals to other points on Earth.
    - Relayed 1st recorded voice message (from President Eisenhower) on 13 Aug 1960 from CA to NJ
  - Jul 1962: Telstar 1 launched; the 1st communications satellite capable of relaying television signals from Europe to North America.
  - Early 1970s: Initial Navy operational use of satellite communications during Vietnam War
  - 1978-89: Fleet Satellite Communications (FLTSATCOM) system launched; operational 1981
  - 1984-90: Leasat launched & leased by Navy to add capacity:
  - 1993-2003: Ultra-High Frequency Follow-On (UFO) system launched to replace FLTSATCOM
  - 2012: Mobile User Objective System (MUOS) 1st launch; provides smart-phone-like service to Navy forces. 4th launch Sep 2015.

State-of-the-art in 1955

Navigation

- Well-established manual navigation available
  - Charts & sightings
  - Sextant, marine chronometer & Nautical Almanac
  - Dead-reckoning
- Long-range HF radio navigation available
  - The long-range radio navigation system LORAN, LOng-range Aid to Navigation, later called LORAN-A, introduced in January 1943, was still the standard system in use in 1955.
  - LORAN-A range up to 1,500 miles, with accuracy of tens of miles
  - LORAN-C became operational along the U.S. east coast in 1957 and the system came under management of the U.S. Coast Guard in August 1958. LORAN-C fixes typically were accurate within hundreds of feet
  - LORAN-C coverage areas included the US coasts, Mediterranean, Norwegian Sea, Central Pacific, and Bearing Sea
  - 3 August 2010: all LORAN transmissions in North America from Canada and the U.S. ceased broadcasting
  - Loran-C was the underpinning of Enhanced Loran, or e-Loran, which some had envisioned as a backup system to satellite-based GPS.

State-of-the-art in 1955

Navigation

- No shipboard inertial navigation system
  - Autonetics Division of North American Aviation conducted the first airplane flight of an inertial Autonavigator (XN-1) in 1950.
    - The first flight of the all-solid-state Autonetics N6A inertial guidance system developed for the Navajo Navaho supersonic intercontinental cruise missiles occurred in 1955
  - In 1957 – 58, research ship USS Compass Island (AG-153) tested the Navy's first inertial navigation system, N6A-1 Autonavigator, which was a modification of the N6A.
    - The N6A-1 was installed on Nautilus, Skate and Sargo for their missions to the North Pole.
  - Ships Inertial Navigation System (SINS) originally was developed for the Fleet Ballistic Missile (FBM) submarine program
    - Developed by Sperry. One of the earliest transistorized systems introduced widely in Navy ships
    - First deployed in 1960 on USS Halibut and for USS Seadragon's Arctic cruise
    - Originally known as the N7, derived from the N6A-1. Re-designated Mk II SINS.
    - Manufactured from late 1950s to 2006
  - Dual Miniature Ships Inertial Navigation System (DMINS)
    - Developed by Rockwell
    - First deployed in Los Angeles-class SSNs in 1976 and retrofit on selected other subs and aircraft carriers

State-of-the-art in 1955

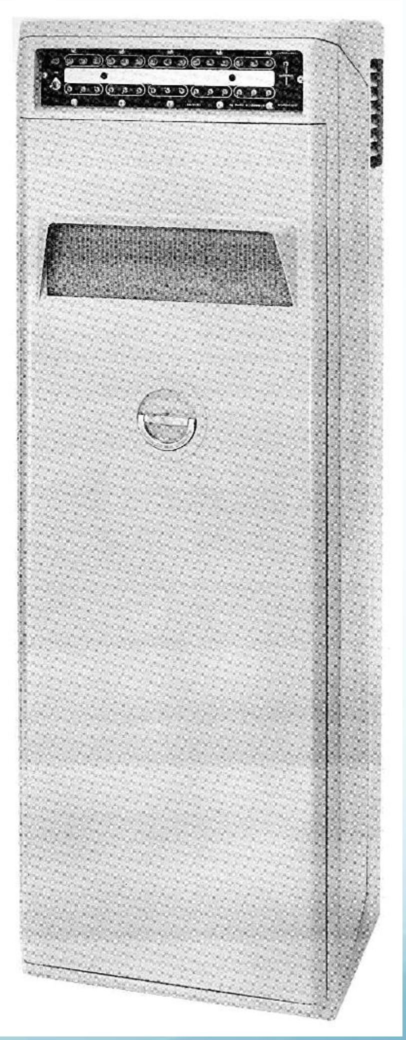
Navigation

- No long-range VLF radio navigation available
  - OMEGA was a global-range radio navigation system, operated by the U.S. and six partner nations, with a set of very low frequency (VLF) fixed terrestrial radio beacons transmitting at 10 to 14 kHz.
  - Became operational in 1971; shut down in 1997 in favor of GPS.
- No satellite navigation system available
  - TRANSIT
    - Development of the TRANSIT system began in 1958.
    - The first successful tests of the system were made in 1960, and the system entered Naval service in 1964.
    - TRANSIT provided continuous navigation satellite service initially for Polaris submarines and later for other military and civilian use.
    - Ceased navigation service in 1996; replaced by GPS.
  - Global Positioning System (GPS)
    - GPS project began in 1973.
    - 1st experimental Block-I GPS satellite was launched in 1978.
    - Achieved full operational capability in April 1995.

State-of-the-art in 1955

Shipboard Computers

- In 1955, no computer small enough to fit through a submarine's hatch existed.
- The 1st standard Navy shipboard computer, AN/UYK-1, was still years away.
  - This was the military designation of the Thompson Ramo Wooldridge TRW-130 computer introduced in 1961.
  - AN/UYK-1 was the processor in the AN/BRN-3 Submarine Navigation Subsystem developed by Westinghouse Electric Corporation (receiver) and TRW for Fleet Ballistic Missile (FBM) submarines.
    - AN/UYK-1 integrated TRANSIT satellite navigation and Ships Inertial Navigation System (SINS) data.
    - First installed in an FBM submarine on 31 December 1963, about two years after the start of Polaris submarine deterrent patrols in 1960.

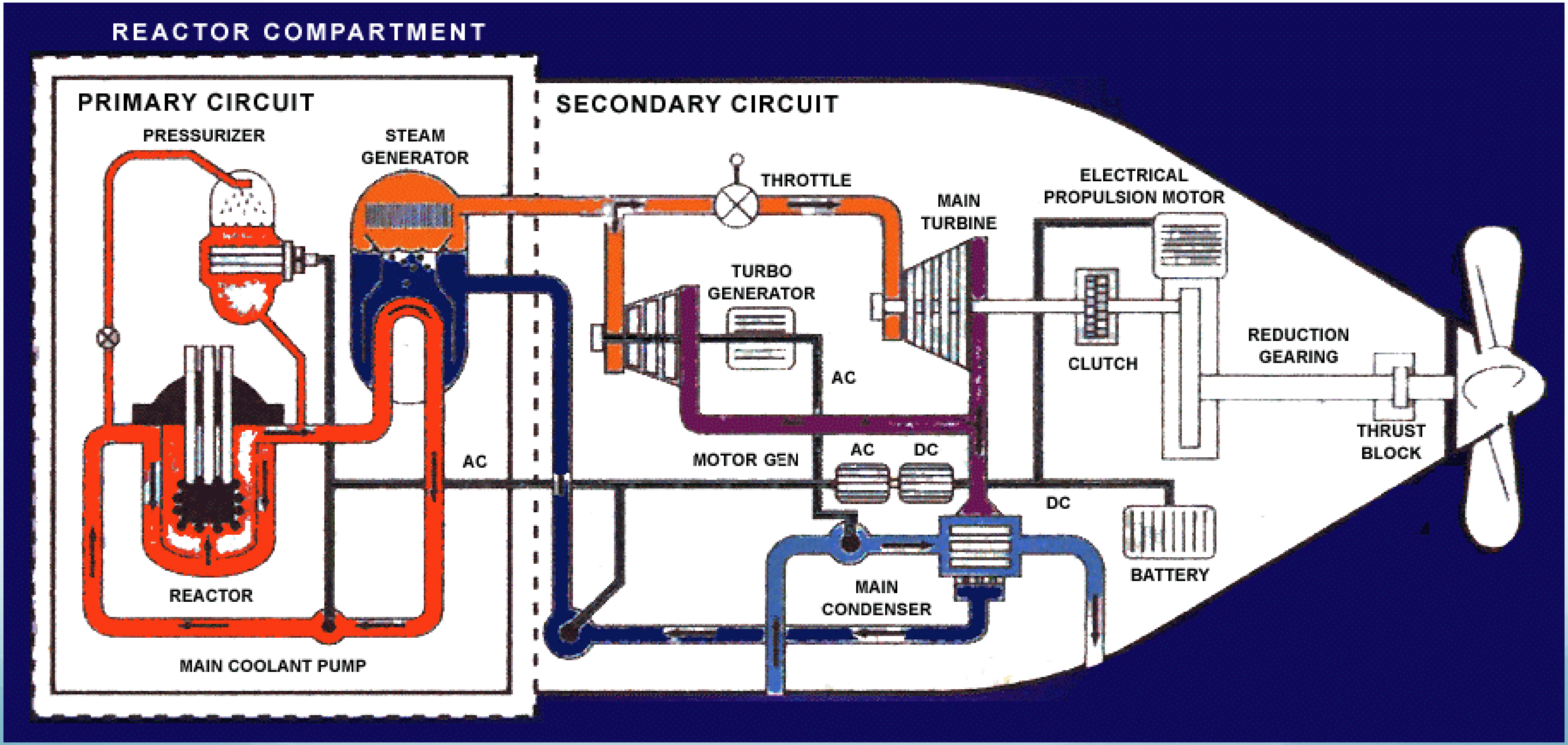


AN/UYK-1 computer
Source: TRW M250-2U19 Rev B Feb 63

Marine nuclear propulsion system basics

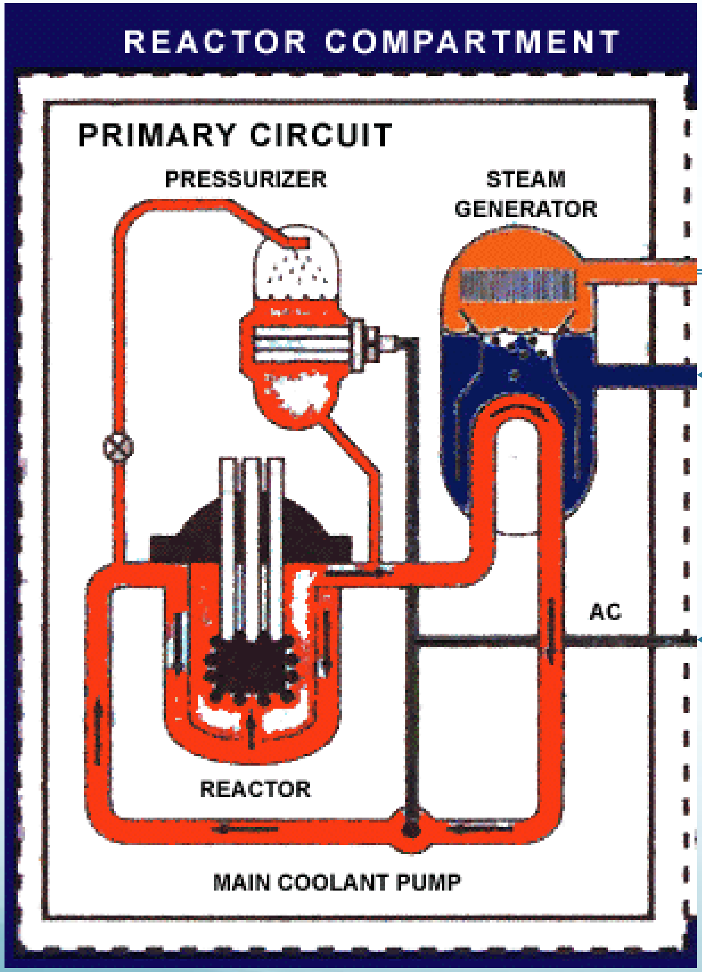
PWR propulsion plant basic process flow diagram

The pressurized water reactor is the dominant type of marine reactor today



Source: adapted from World Nuclear Association

How heat transfer in a PWR primary system works



Saturated steam is supplied to the secondary (power conversion) system to drive turbines

Feedwater returns from the secondary system

AC electric power for main coolant pumps & pressurizer heaters

Source: adapted from World Nuclear Association

- The primary system is a closed-loop heat transport system that circulates ordinary water to move thermal energy from the reactor core (the heat source) to the steam generators (the heat sink) where the thermal energy is transferred into the secondary coolant to produce steam.
- Intact steam generator tubes prevent leakage of primary coolant into the secondary system.
- The primary coolant returns to the reactor to be reheated and circulated again through the primary system.
- The pressurizer is a “surge volume” with heaters and sprays that are used to maintain the correct high pressure in the PWR primary system and prevent the primary coolant water from boiling in the reactor core.

How heat transfer in a PWR primary system works

- The reactor is the heat exchanger in the closed-loop primary system containing the heat source (the reactor fuel elements).
- The steam generator is the other heat exchanger in the closed-loop primary system containing the heat sink (the secondary coolant flowing through the steam generator tubes).
- The pressurizer maintains the PWR primary system at constant pressure.
- The continuous flow of the sub-cooled water primary coolant transfers heat from the reactor to the steam generators.
- In both heat exchangers, heat transfer in a sub-cooled liquid system at constant pressure is governed by:

  $Q = UA\,\Delta Tm$, where:

  Q = rate of heat transfer
  U = mean overall heat transfer coefficient
  A = heat transfer surface area of the heat exchanger

  ΔTm = logarithmic mean temperature difference across the heat exchanger

How heat transfer in a Rankine-cycle secondary system works

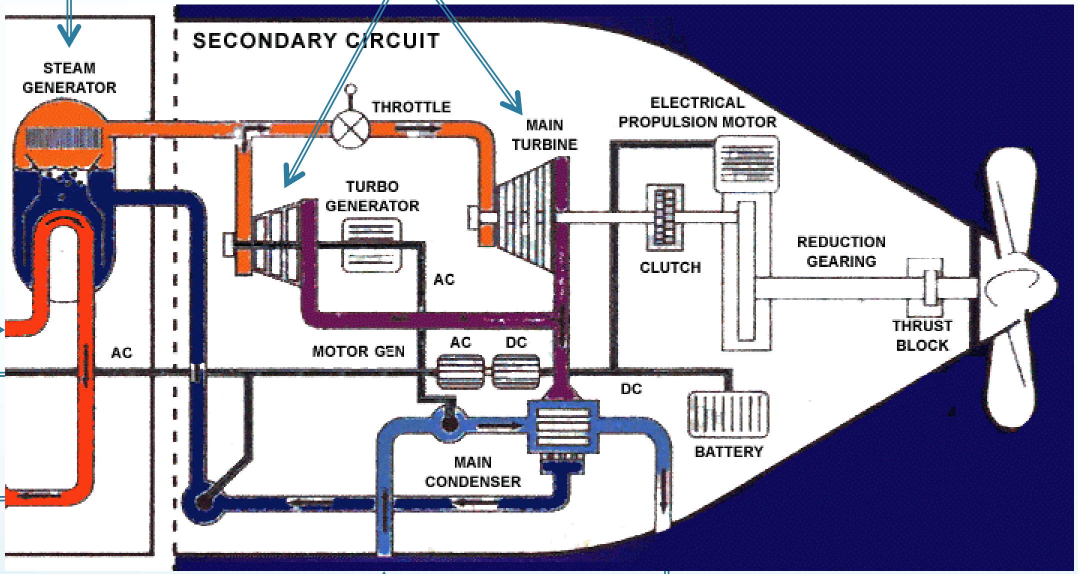
Thermal energy is transferred across the steam generator tubes and boils secondary coolant water to produce steam

Steam turbines expand the steam to extract energy to drive the propulsion machinery and to generate AC electric power via turbine generators

“Hot” water from the reactor core

Electric power

“Cold” water returned to the reactor core

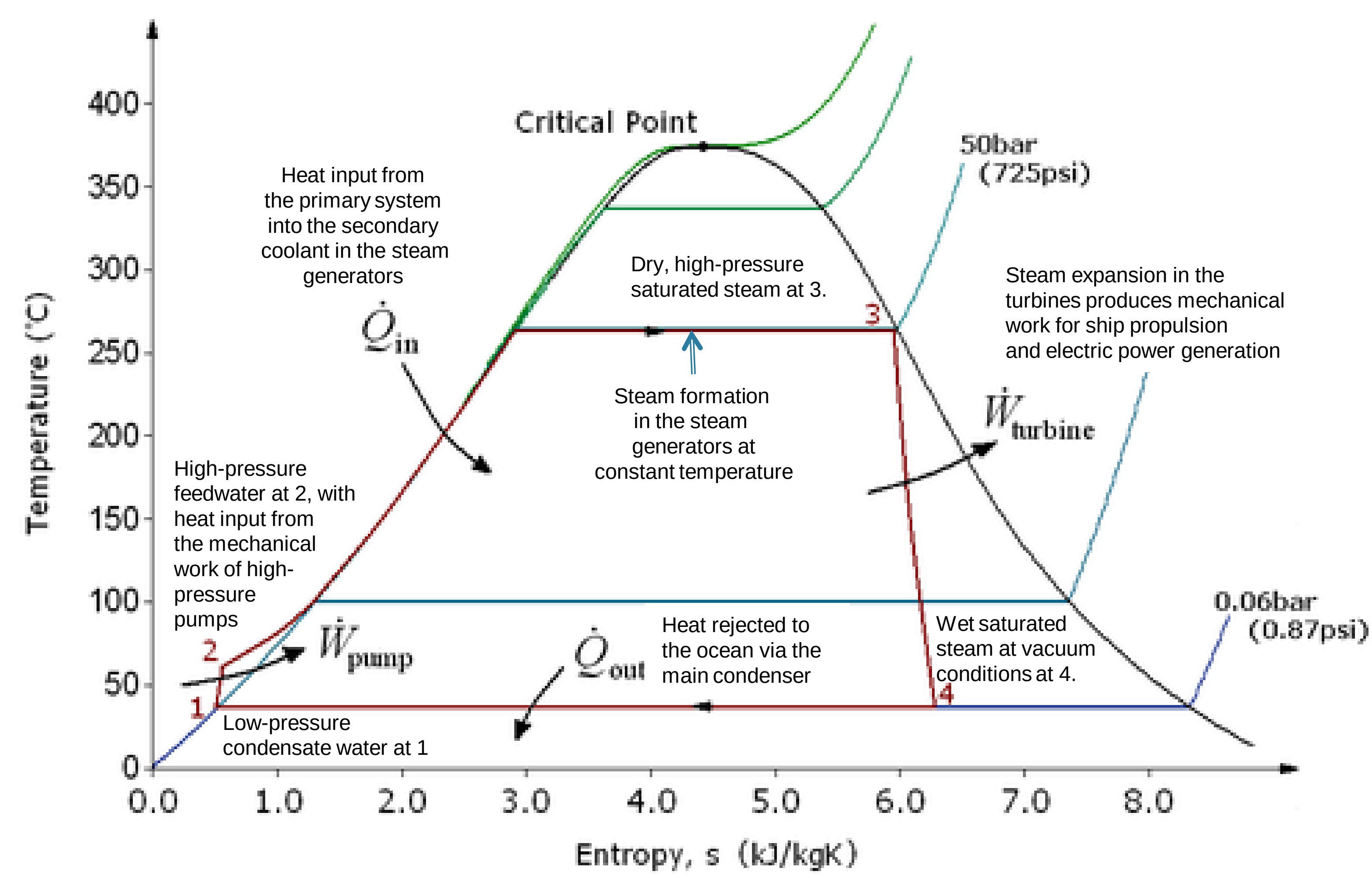


Circulating water from the ocean passes through tubes in the main condenser, condenses the steam exhaust from the turbines, and rejects waste heat to the ocean. Intact main condenser tubes prevent leakage of sea water into the secondary coolant.

- Turbine exhaust steam is condensed in the main condenser and this water is pumped back to the steam generator where it continues removing heat from the primary system to produce more steam.
- A motor-generator supplies DC loads (i.e., the ship’s battery and an emergency DC propulsion motor) and can supply AC loads in an emergency.
- Some subs use electric motors for main propulsion. These subs have large turbine generators and no mechanical propulsion train.

Source: adapted from World Nuclear Association

How heat transfer in a Rankine-cycle secondary system works



Source: adapted from https://en.wikipedia.org/wiki/Rankine_cycle

Timeline

Decade-by-decade

Timeline highlights

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

1940s

2 Dec 42
1st man-made self-sustaining nuclear chain reaction, CP-1 pile

Early 1946
Eight Naval officers, including Rickover, detailed to Oak Ridge for the start of the Naval Nuclear Program

Feb 49
Rickover assigned to AEC's Div of Reactor Development & Dir. Naval Reactors Branch of BuShips

1950s

17 Jan 55
USS Nautilus world's 1st underway on nuclear power

4 Jun 58
November- class SSN 1st USSR underway on nuclear power

3 Aug 58
USS Nautilus, 1st vessel to reach North Pole

15 Apr 59
USS Skipjack 1st sub combining Albacore hull & nuclear power commissioned

15 Sep 59
USSR icebreaker Lenin, world's 1st nuclear surface ship voyage

1960s

15 Nov 60
1st U.S Polaris SSBN deterrent patrol

25 Nov 61
1st nuclear aircraft carrier, USS Enterprise commissioned

10 Jan 63
Dreadnought SSN 1st UK underway on nuclear power

15 Jun 68
1st UK SSBN deterrent patrol

Jun 69
1st Russian Yankee SSBN deterrent patrol

1970s

1971
1st French sub (Le Redoutable SSBN) commissioned

23 Aug 71
1st Chinese sub (Han SSN) underway on nuclear power

31 Dec 71
1st USSR Alfa SSN commissioned

3 May 1975
1st Nimitz-class aircraft carrier commissioned

17 Aug 77
Russian icebreaker Arktika, 1st surface ship To reach North Pole

1980s

1981
1st Russian Typhoon-class SSBN commissioned

11 Nov 81
1st U.S. Ohio-c;ass SSBN commissioned

23 Feb 83
1st French SSN (Rubis) commissioned

1987
1st Chinese SSBN (Xia) operational

1988
Russian Charlie SSN leased by India

1990s

Dec 94
1st UK Vanguard-class SSBN deterrent patrol

9 Mar 95
Last of original 41 U.S. Polaris subs, decommissioned

19 Jul 97
1st U.S. Seawolf class SSN commissioned

1997
1st French Triomphant-class SSBN deterrent patrol

30 Jul 99
USS S Carolina, last U.S. nuclear cruiser, decommissioned.

2000s

23 Oct 04
1st U.S. Virginia-class SSN commissioned

7 Feb 06
1st U.S. Ohio-class SSGN conversion, re-joins the fleet

2007
300th UK SSBN deterrent patrol

2010s

1 Mar 13
Brazil inaugurates naval shipyard for building its 1st nuc sub

2013
Russia commissions 1st new-gen Borei SSBN & Yasen SSN

2014
1st Chinese 2nd-generation Jin SSBN operational

19 Sep 14
4000th U.S. SSBN deterrent patrol

16 Dec 14
1st Indian indigenous nuclear sub, SSBN INS Arihant sea trials

Marine nuclear power timeline – 1940s

17 Mar 39
Enrico Fermi makes presentation to Navy on prospects for nuclear weapons & propulsion.
Ross Gunn attended, became early Navy advocate for nuclear propulsion

19 Nov 45
Dr. Philip Abelson organizes Naval Research Laboratory (NRL) symposium on naval nuclear propulsion.
Proposes marriage of WW II German Walter (Type XXI) submarine hull form and a nuclear power plant

Early 1946
Eight Naval officers, including Rickover, detailed to Oak Ridge for the start of the Naval Nuclear Program

May 46
Rickover assigned Deputy Dir of Oak Ridge nuclear propulsion program

15 May 46
Contract signed with General Electric forming Knolls Atomic Power Laboratory (KAPL)

1947
Regulus missile program begins

April 1948
Submarine reactor program established at Argonne National Lab

Dec 1948
Original AEC-Westinghouse contract for developing STR

Feb 49
Rickover assigned to AEC's Div of Reactor Development & Dir. Naval Reactors Branch of BuShips

1949
Contract signed with Westinghouse forming Bettis Atomic Power Laboratory

1940	1941	1942	1943	1944	1945	1946	1947	1948	1949

2 Dec 42
1st man-made self-sustaining nuclear chain reaction, CP-1 pile

Nov 43
Y-12 electromagnetic separation plant begins operation at Oak Ridge, producing enriched U-235

4 Nov 43
X-10 reactor begins operation at Oak Ridge, rated @ 1 MWt, delivers 1st reactor-produced Pu

26 Sep 44, Dec 44 & Feb 45,
Initial criticality of Hanford B, D & F production reactors rated @ 250 MWt

Dec 44
Pu separation & refining begins at Hanford 221-T

16 Jul 45
Trinity a-bomb test, Alamogordo, NM

6 & 9 Aug 45
Hiroshima & Nagasaki atomic bombing

Aug 1945
Oak Ridge K-25 gaseous diffusion uranium enrichment plant begins operation

1 Aug 46
US Atomic Energy Act of 1946 signed into law. Establishes the civilian Atomic Energy Commission (AEC) to manage development of nuclear weapons and nuclear power technology

Aug 1949
CNO establishes a January 1955 "ready-for-sea" date for development of a submarine nuclear propulsion plant

Marine nuclear power timeline – 1950s

Aug 1950
President Harry Truman authorizes construction of 1st nuclear sub

Aug 1950
Construction starts on STR Mark 1 (S1W) reactor prototype

July 51
Congress approves funding for construction of 1st nuclear sub

Aug 1951
BuShips signs contract with Westinghouse & Electric Boat for Nautilus

Jun 52
Nautilus keel laid

30 Mar 53
S1W reactor prototype Initial criticality

July 53
1st surface launch of Regulus cruise missile from sub

1953
AEC approves Submarine Fleet Reactor Program for S3W, S4W

6 Dec 53
Teardrop hull USS Albacore (AGSS-569) commissioned

21 Jan 54
Nautilus launched

17 Jan 55
Nautilus world's 1st underway on nuclear power

9 Sep 55
Army-Navy joint Jupiter missile program starts

8 Dec 56
Joint program terminated, Navy starts Polaris program

23 Dec 57
Skate (SSN-578) 1st in class commissioned

1958 US-UK Mutual Defense Agreement included export of a complete S5W power plant & fuel for 1st UK nuc sub.

3 Aug 58
Nautilus 1st vessel to reach North Pole
11 Aug 58
Skate 1st to cross North Pole E-W

17 Mar 59
Skate 1st to surface at North Pole

15 Apr 59
USS Skipjack commissioned, 1st sub combining Albacore hull & nuclear power

Sep 59
1st Regulus deterrent patrol (by diesel sub)

1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959

20 Dec 1951
EBR-1, 1st nuclear-generated electricity (4 lightbulbs) at Idaho Natn'l Lab

Sep 52
Stalin approves building Project 627 nuclear sub

20 Nov 53
USSR decision to build Lenin icebreaker

27 Jun 54
1st NPP in the world, Russian Obninsk NPP, AM-1, commissioned, generated 5 MWe

30 Aug 54
US Atomic Energy Act of 1954 signed into law, enables commercial nuclear development

17 Jul 55
Arco, ID is 1st US community powered by nuclear electricity (from BORAX III)

16 Sep1955
1st SLBM, USSR R-11FM, fired from surfaced Zulu-V (diesel) sub B-67

27 Aug 56
1st UK NPP, Calder Hall, connected to grid, delivering 50 MWe

12 Jul 57
SRE is 1st US reactor to deliver power to a commercial power grid (SoCal Edison, serving Moorpark, CA, 6.5 MWe)

5 Dec 57
Lenin icebreaker launched

18 Dec 57
1st US NPP, Shippingport, delivered power to Duquesne Light Co grid, 60 MWe

4 Jun 58
USSR Project 627 sub K-3 1st underway on nuclear power

1958
Initial USSR Golf I (diesel) SSB deterrent patrols

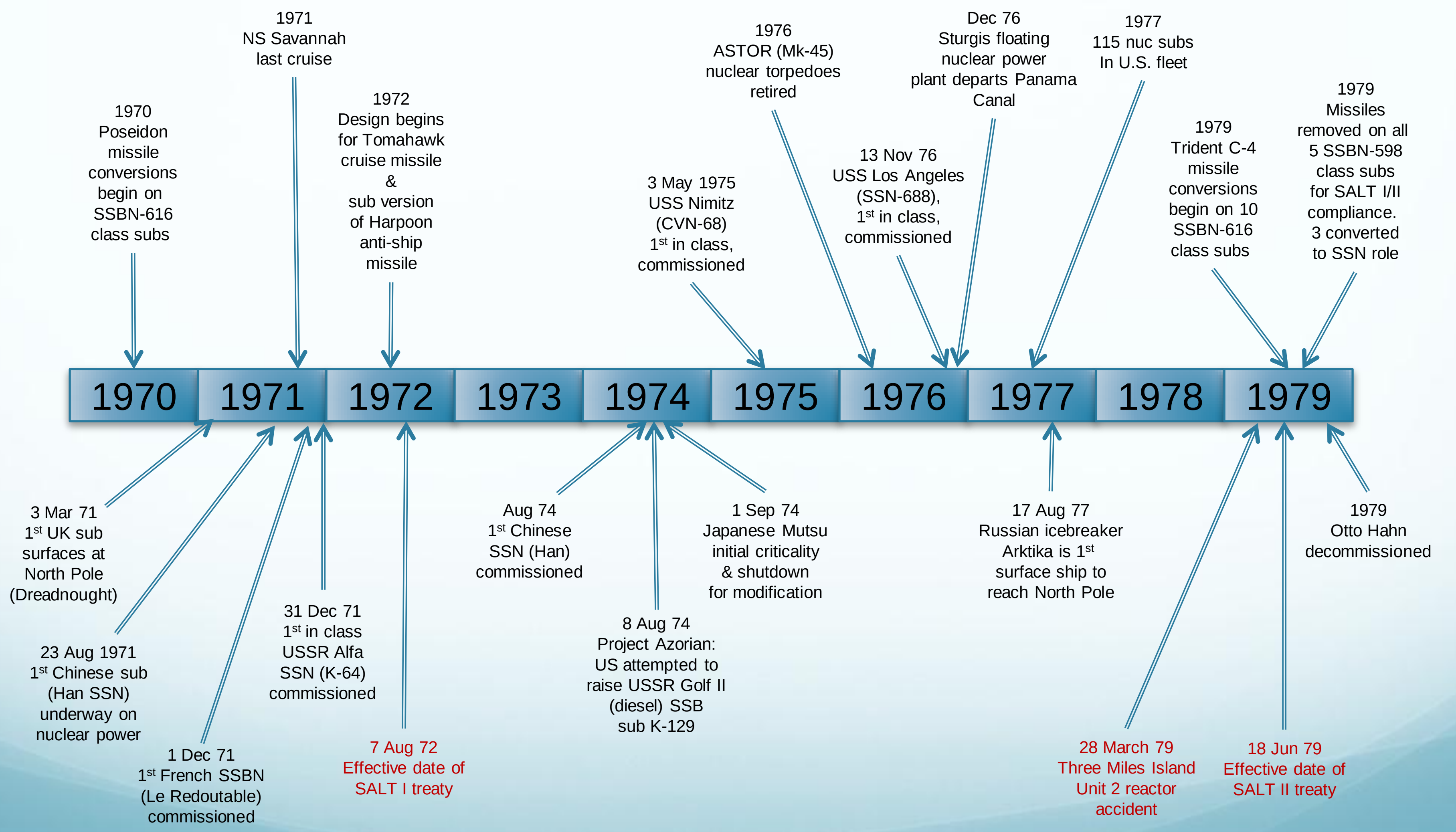
15 Sep 59
USSR icebreaker Lenin 1st nuclear surface ship voyage

Marine nuclear power timeline – 1960s

1960 1961 1962 1963 1964 1965 1966 1967 1968 1969

- 24 Feb – 25 Apr 60: 1st submerged circumnavigation of the globe by USS Triton
- 25 Mar 60: 1st surfaced launch of a Regulus by a nuclear sub (USS Halibut)
- 20 Jul 60: 1st submerged launch of a Polaris (A1) by USS George Washington
- 15 Nov 60: 1st FBM deterrent patrol started by USS George Washington
- Jun 61: USS Sculpin 1st nuclear sub based in San Diego
- 5 Jul 61: USS Long Beach 1st US surface ship underway on nuclear power
- 1961: 1st Russian Hotel I missile sub deterrent patrol
- 25 Nov 61: USS Enterprise 1st nuclear aircraft carrier commissioned
- 6 May 62: 1st submerged launch of a nuclear-armed Polaris (A2) by USS Ethan Allen (Operation Dominic, Shot Frigate Bird)
- 17 Jul 62: 1st Russian sub, K-3, surfaces at North Pole
- 20 Aug 62: NS Savannah maiden voyage
- 16 Sep 62: Indian Point 1 NPP began operation, 275 MWe
- 11 Dec 62: Polaris Sales Agreement with UK
- 10 Jan 63: Dreadnought SSN 1st UK underway on nuclear power
- 10 Apr 63: USS Thresher sank in Atlantic
- 1963: IOC for nuclear-armed SUBROC (UUM-44) missile & ASTOR (Mk-45) torpedo
- Sep 63: 1st Russian E-W & W-E sub Arctic transits
- July 64: Last Regulus deterrent patrol completed (USS Halibut)
- 31 Jul – 3 Oct 64: Operation Sea Orbit
- 1964: 1st Russian Yankee SSBN commissioned
- Feb-Mar 66: 1st Russian “circumnavigation”, 2 subs, Barents to Kamchatka
- 3 Mar 67: 1st in class USS Sturgeon (SSN-637) commissioned
- 1967: Lenin OK-150 reactor accident
- 2 Oct 67: 1st UK SSBN Resolution commissioned
- 8 Mar 68: Russian Golf II SSB (diesel) K-129 sank in the Pacific
- 22 May 68: USS Scorpion sank in Atlantic
- 24 May 68: Russian sub K-27 reactor accident
- 15 Jun 68: 1st UK SSBN deterrent patrol
- Aug 68: Sturgis floating nuclear power plant arrives at Panama Canal
- 1 Jan 69: San Onofre 1 NPP began operation, 465 MWe
- 3 May 69: 1st nuc sub decommissioned, USS Triton
- Jun 69: 1st Russian Yankee FBM deterrent patrol
- 11 Oct 69: German Otto Hahn commissioned
- 27 Oct 69: NR-1 deep submergence nuc sub enters service

Marine nuclear power timeline – 1970s



Marine nuclear power timeline – 1980s

1980 1981 1982 1983 1984 1985 1986 1987 1988 1989

1981
1st in class
Russian Typhoon
SSBN
commissioned

27 Jun 81
2000th FBM
deterrent
patrol

11 Nov 81
USS Ohio
(SSBN-726),
1st in class,
commissioned

1 Feb 82
ADM Rickover
relieved by
ADM McKee
as head of
Naval Reactors;
Executive Order
12344 preserves
NR org, roles &
responsibilities

2 May 82
In Falklands War
UK nuclear sub
HMS Conqueror
sank Argentine
cruiser Gen. Belgrano

6 Sep 82
K-27 scuttled
near
Novaya Zemlya

23 Feb 83
1st French SSN
(S601 Rubis)
commissioned

8 Aug 83
San Onofre 2
commissioned,
1127 MWe
(typical large
modern PWR)

1986
IOC for
nuclear-armed
Tomahawk
cruise
missile
(TLAM-N)

16 Apr 86
Chernobyl unit 4
reactor accident

6 Oct 86
Soviet Yankee
SSBN K-291
sank in
Atlantic

1987
136 nuc subs
In U.S. fleet

1987
1st Chinese
SSBN (Xia)
operational

1988
USS San Juan
(SSN-751)
1st of Improved
688i class
commissioned

1 Jun 88
Effective date of
INF Treaty

1988
Russian
Charlie I K-43
leased by India

1989
Navy retired
nuclear-armed
SUBROC
(UUM-44)
missiles

7 Apr 89
Soviet sub
Komsomolets
sank in
Norwegian Sea

Marine nuclear power timeline – 1990s

1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999

March 1990
Trident II D-5
IOC

19 Jan 91
USS Louisville
(SSN-724) fired
1st sub-launched
Tomahawk
cruise missile
in combat

Sep 91
GHW Bush
Presidential
Nuclear
Initiative:
Orders all tactical
nuclear weapons
removed
from Navy ships

1991
121 nuc subs
in U.S. fleet

1993
SCICEX
feasibility
Arctic cruise

9 Mar 95
Last of original
41 FBM subs,
Mariano Vallejo
(SSBN-658)
decommissioned

1 May 95
USS Long Beach
(CGN-9),
1st US nuclear
surface ship,
decommissioned

19 Jul 97
USS Seawolf
(SSN-21)
1st in class,
commissioned

1997
91 nuc subs
in U.S. fleet

1999
Last dedicated
SCICEX
Arctic cruise,
USS Hawkbill
(SSN-666)

30 Jul 99
USS S Carolina
(CGN-37),
last US nuclear
cruiser,
decommissioned.
US Navy nuclear
fleet comprised
of subs &
aircraft carriers

Feb 91
Japanese
Mutsu
1st voyage on
nuclear power

6 Aug 91
Russian
Delta IV test
launches an
"all-missile" salvo
(16 x R-29RM
SLBMs)

25 Dec 91
USSR dissolved
into 15 post-Soviet
states.
Russian Federation
formed

1992
Japanese
Mutsu
decommissioned

1992
Russian
partially-complete
nuclear aircraft
carrier
scrapped

14 Aug 93
1st in class
UK SSBN
Vanguard
commissioned

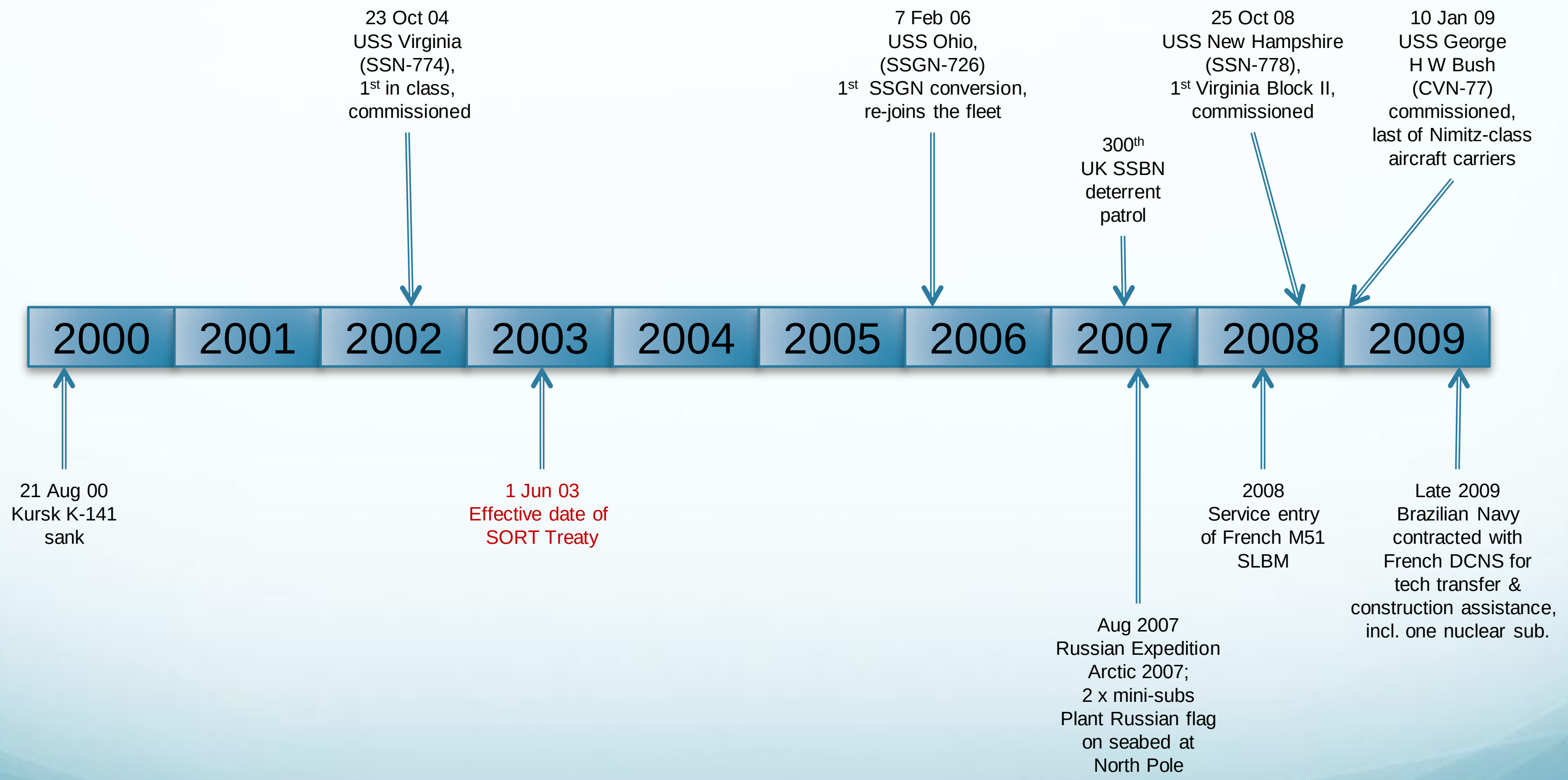
Dec 94
UK SSBN
Vanguard
1st deterrent
Patrol

5 Dec 94
Effective date of
START I treaty

21 Mar 97
1st in class
French SSBN
Triomphant
commissioned

1997
French SSBN
Triomphant
1st deterrent
patrol with
M45 missiles

Marine nuclear power timeline – 2000s



Marine nuclear power timeline – 2010s

2010 - 2013
Navy retires
nuclear-armed
Tomahawk cruise
missiles

1 Dec 12
USS Enterprise
(CVN-65),
1st nuclear
aircraft carrier,
decommissioned
after 51 years
of service

19 Nov 13
1st new-gen
aircraft carrier,
Gerald R Ford
(CVN-78),
launched

19 Sep 14
4000th FBM
deterrent patrol

25 Oct 14
USS N Dakota
(SSN-784),
1st Virginia
Block III,
commissioned

2015
71 nuc subs
In U.S. fleet

2016
Aircraft carrier
Gerald R Ford,
(CVN-78)
expected to be
commissioned

2020 - 21
Expected start of
construction on 1st
Ohio-replacement
SSBN

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

5 Feb 2011
Effective date of
New START
treaty

11 Mar 11
Fukushima
Daiichi
nuclear disaster

4 Apr 12
India's
1st leased
Akula II
from Russia
commissioned
as INS Chakra

Aug-Oct 12
Russian
Expedition
Arctic
2012

1 Mar 13
Brazil
inaugurates
Sepetiba Bay
naval shipyard
for building subs,
incl Brazil's
1st nuc sub

2013
Russia
Commissions
1st new-gen
Borey SSBN &
1st new-gen
multi-purpose
Yasen SSN

2014
Chinese
Jin-class
SSBN
operational

16 Dec 14
1st Indian
indigenous
nuclear sub,
INS Arihant
SSBN
sea trials
&
Dec 14
India agrees
to lease
2nd Akula II
from Russia

2016
1st Russian
floating nuclear
power station
expected to be
operational

2017
1st French
new gen
Barracuda SSN
expected to be
operational

2020
1st Russian
new gen
LK-60 icebreaker
expected to be
operational

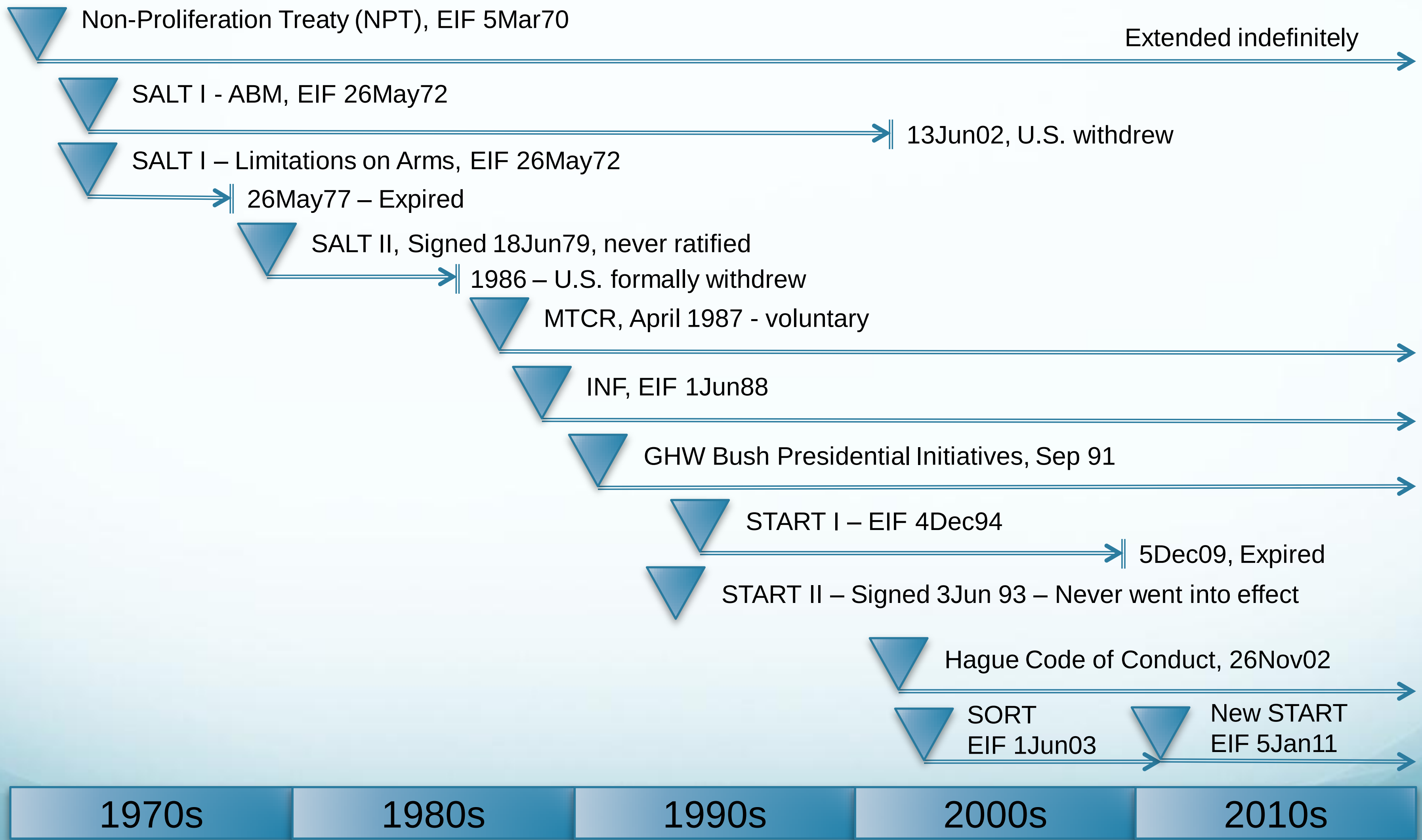
2023
Expected
completion of
1st Brazilian
Indigenous SSN

Effects of nuclear weapons and missile treaties & conventions on the composition of naval nuclear fleets

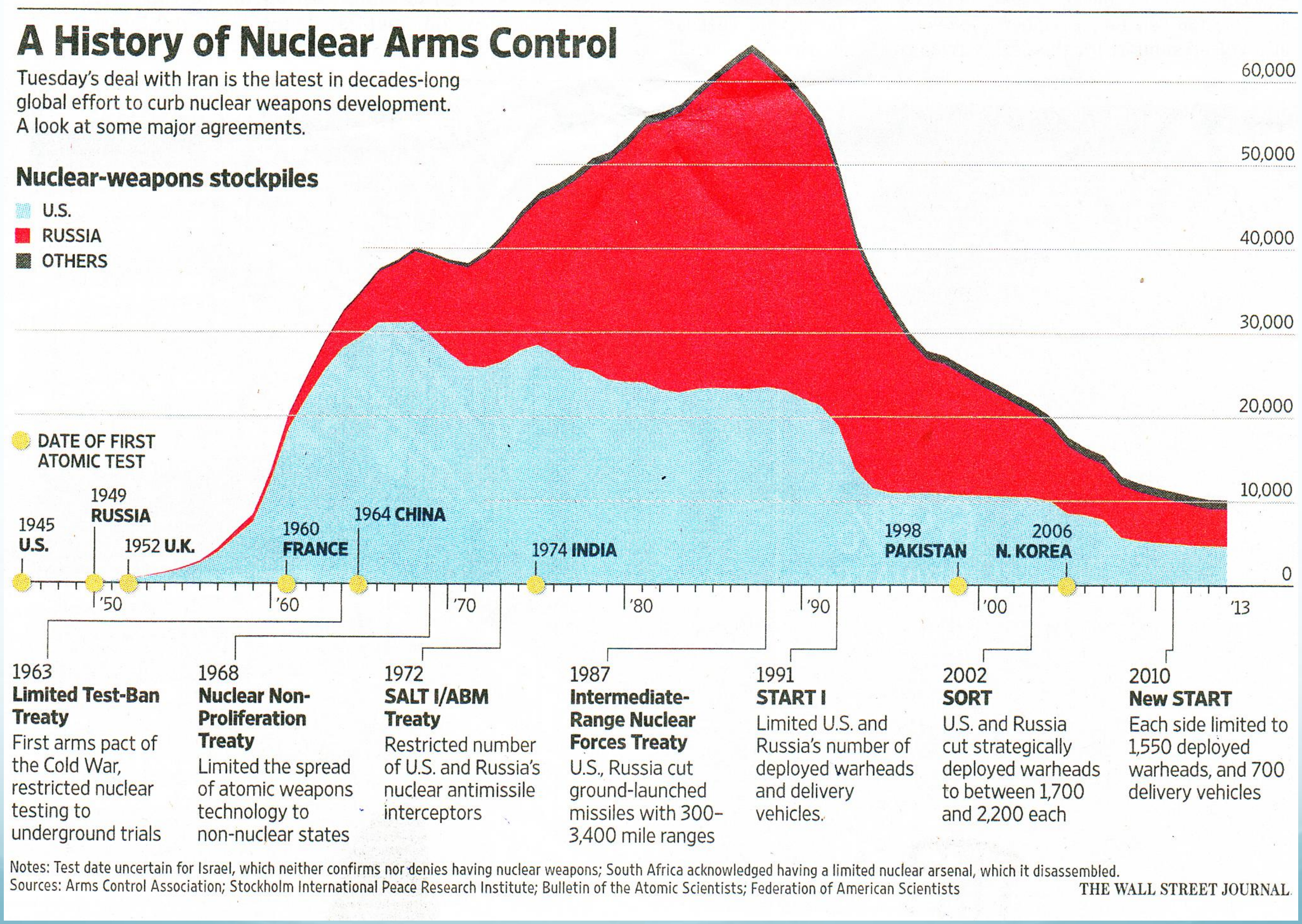
Treaties & conventions

- 1963: Limited Test Ban Treaty (no effect on naval nuclear fleets)
- 1970: Treaty on the Non-Proliferation of Nuclear Weapons (NPT, aka Non-Proliferation Treaty)
- 1972: Strategic Arms Limitation Treaty (SALT I)
- 1979: Strategic Arms Limitation Treaty II (SALT II)
- 1987: Missile Technology Control Regime (MTCR)
- 1988: Intermediate-range Nuclear Forces (INF) Treaty
- 1991: GHW Bush Presidential Nuclear Initiatives
- 1994: Strategic Arms Reduction Treaty (START I)
- 1993: Strategic Arms Reduction Treaty II (START II, never implemented)
- 2002: International Code of Conduct Against Ballistic Missile Proliferation (ICOC, Hague Code of Conduct)
- 2003: Strategic Offensive Reductions Treaty (SORT, aka Treaty of Moscow)
- 2011: New START (formally known as Measures for the Further Reduction and Limitation of Strategic Offensive Arms)
- Future: Fissile Material Cutoff Treaty (FMCT)

Timeline


Non-Proliferation Treaty (NPT), EIF 5Mar70
Extended indefinitely
SALT I - ABM, EIF 26May72
13Jun02, U.S. withdrew
SALT I – Limitations on Arms, EIF 26May72
26May77 – Expired
SALT II, Signed 18Jun79, never ratified
1986 – U.S. formally withdrew
MTCR, April 1987 - voluntary
INF, EIF 1Jun88
GHW Bush Presidential Initiatives, Sep 91
START I – EIF 4Dec94
5Dec09, Expired
START II – Signed 3Jun 93 – Never went into effect
Hague Code of Conduct, 26Nov02
SORT
EIF 1Jun03
New START
EIF 5Jan11
1970s
1980s
1990s
2000s
2010s

Timeline



Source: Wall Street Journal

Signatories of NPT & international missile control conventions

Country	NPT	MTCR	ICOC
USA	Signed, weapons state	Member	Subscribing state
Russia	Signed, weapons state	Member	Subscribing state
UK	Signed, weapons state	Member	Subscribing state
France	Signed, weapons state	Member	Subscribing state
China	Signed, weapons state	Non-member, agreed partial compliance	Not subscribing
Germany	Signed, non-weapons state	Member	Subscribing state
Japan	Signed, non-weapons state	Member	Subscribing state
India	Not signed, weapons state	Non-member	Not subscribing
Brazil	Signed, non-weapons state	Member	Not subscribing
Italy	Signed, non-weapons state	Member	Subscribing state
Canada	Signed, non-weapons state	Member	Subscribing state
Australia	Signed, non-weapons state	Member	Subscribing state
North Korea	Withdrew, weapons state	Non-member	Not subscribing
Israel	Not signed, weapons state?	Non-member, agreed partial compliance	Not subscribing
Pakistan	Not signed, weapons state	Non-member	Not subscribing
Iran	Signed, non-weapons state	Non-member	Not subscribing

Marine nuclear propulsion state

Interest in marine nuclear propulsion

Treaty on the Non-Proliferation of Nuclear Weapons

aka Non-Proliferation Treaty (NPT)

- NPT is an international treaty intended to:
  - Limit the spread of nuclear weapons and weapons technology,
  - Support the goal of achieving nuclear disarmament
  - Recognize the right to peacefully use nuclear technology
- The NPT entered into force on 5 Mar 1970; effective period 25 years.
  - The NPT is reviewed at 5-year intervals in meetings called "Review Conferences of the Parties to the Treaty of Non-Proliferation of Nuclear Weapons."
  - On 11 May 1995, a consensus of the Review Conference agreed to extend the NPT indefinitely.
- A total of 191 states joined the NPT with North Korea withdrawing in 2003.
  - Non-signators are India, Israel, North Korea, Pakistan and South Sudan
- The NPT consists of a preamble and eleven articles.
  - Article IV affirms, "…the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes…"
- Application of the NPT is guided by IAEA document INFCIRC/153 (Corrected), June 1972, *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons*

Treaty on the Non-Proliferation of Nuclear Weapons

aka Non-Proliferation Treaty (NPT)

- The NPT does not explicitly regulate the production, use, and disposition of highly-enriched uranium (HEU) for naval nuclear reactors.
  - Paragraph 14 of *INFCIRC/153 (Corrected), June 1972* allows a state to withdraw nuclear material from safeguards if it is being used for a "nonproscribed military activity" (i.e., for use in naval reactor fuel), and , "…the nuclear material will not be used for the production of nuclear weapons or other nuclear explosive devices."
  - This is viewed by some as a legal loophole in the NPT, which allows fissile material to be removed from IAEA monitoring for use in non-weapons military applications.
  - On 21 Mar 2014, the *New York Times* reported that U.S. naval reactors use about 4,500 pounds (2,041 kg) of HEU per year. Other worldwide naval reactor programs combined use about 1,500 pounds (680 kg) of HEU per year.
    - The *New York Times* article claims that the U.S. has 150 tons (136,078 kg) of weapons-grade uranium set aside for use in naval fuel.

Treaty on the Non-Proliferation of Nuclear Weapons

aka Non-Proliferation Treaty (NPT)

- NPT and the NATO Multilateral Force (MLF)
  - MLF was a U.S. proposal, supported by the Eisenhower, Kennedy and Johnson administrations, to create a NATO fleet of nuclear-armed ballistic missile submarines (SSBNs) and surface warships armed with Polaris missiles.
    - The Italian cruiser *Guiseppe Garibaldi* was the only vessel refitted with four launchers for Polaris missiles
  - The vessels in the fleet would have been manned by NATO crews and under NATO command, thereby increasing European control over their own nuclear defense in the event of a war with the Soviet Union
    - MLF also was seen as a way to preclude independent nuclear weapons development by some European nations.
  - MLF failed in the 1965 – 66 timeframe because the U.S. and the European NATO members could not agree on many key factors that would govern international nuclear collaboration under MLF, including: vessel type (submarine and/or surface ship launch platforms), basing, and financing.
  - The extent of dysfunction within NATO was punctuated on 21 June 1966 by France’s withdrawal from NATO.
  - It has been reported that the Soviet Union made elimination of the NATO MLF a pre-condition to their signing the NPT on 1 July 1968. By that date, the MLF no longer was an issue.

Use of HEU in naval reactors is permitted by Paragraph 14 of *INFCIRC/153 (Corrected), June 1972*

NON-APPLICATION OF SAFEGUARDS TO NUCLEAR MATERIAL TO BE USED IN NON-PEACEFUL ACTIVITIES

14. The Agreement should provide that if the State intends to exercise its discretion to use nuclear material which is required to be safeguarded thereunder in a nuclear activity which does not require the application of safeguards under the Agreement, the following procedures will apply:

(a) The State shall inform the Agency of the activity, making it clear:

(i) That the use of the *nuclear material* in a non-proscribed military activity will not be in conflict with an undertaking the State may have given and in respect of which Agency safeguards apply, that the *nuclear material* will be used only in a peaceful nuclear activity; and (ii) That during the period of non-application of safeguards the *nuclear material* will not be used for the production of nuclear weapons or other nuclear explosive devices;

(b) The Agency and the State shall make an arrangement so that, only while the *nuclear material* is in such an activity, the safeguards provided for in the Agreement will not be applied. The arrangement shall identify, to the extent possible, the period or circumstances during which safeguards will not be applied. In any event, the safeguards provided for in the Agreement shall again apply as soon as the *nuclear material* is reintroduced into a peaceful nuclear activity. The Agency shall be kept informed of the total quantity and composition of such unsafeguarded *nuclear material* in the State and of any exports of such material; and

(c) Each arrangement shall be made in agreement with the Agency. The Agency's agreement shall be given as promptly as possible; it shall only relate to the temporal and procedural provisions, reporting arrangements, etc., but shall not involve any approval or classified knowledge of the military activity or relate to the use of the *nuclear material* therein.

Strategic Arms Limitation Treaty
(SALT I)

- President Richard Nixon & Soviet General Secretary Leonid Brezhnev signed SALT I 26 May 72. The treaty was ratified by Congress 3 Aug 72
- SALT I was comprised of two major parts
  - Anti-ballistic Missile (ABM) Treaty
    - Allowed one ABM site with 100 ABM launchers
    - U.S. withdrew from ABM treaty 13 Jun 2002
  - Interim Agreement on the Limitation of Strategic Offensive Arms
    - Set quantitative limits on ICBM and submarine-launched ballistic missile (SLBM) launchers (higher than either side possessed at the time), but no limit on the number of warheads.
      - Freeze the number of strategic ballistic missiles at 1972 levels
    - Limits included:
      - U.S. could have a maximum of 44 SSBN subs with 710 SLBM launchers; Russia could have a maximum of 62 SSBN subs with 950 SLBM launchers.
      - NATO and the U.S. could operate a maximum of 50 SSBNs with a maximum of 800 SLBM launchers among them
        - U.S had 41 Polaris SSBNs and the UK had 4 SSBNs.
        - France was not a NATO member between 1966 and 2009
    - This part of SALT had a 5 year duration and expired in 1977. It was intended to be superseded by SALT II, which was not ratified.

Strategic Arms Limitation Treaty II
(SALT II)

- President Jimmy Carter & Soviet General Secretary Leonid Brezhnev signed SALT II on 18 Jun 1979 by the treaty was not ratified by Congress
- Limits: Each side was limited to 2,400 (dropping to 2,250 in Jan 1981) deployed launchers for strategic nuclear delivery vehicles, including ICBMs, SLBMs, heavy bombers, and air-launched missiles with ranges > 600 km (373 mi)
  - Various ceilings on missiles carrying multiple, independently-targeted reentry vehicles (MIRVs)
  - Ban until Dec 1981 on deployment of sea-launched cruise missiles with range > 600 km (373 mi)
- While not being ratified, some of the SALT II limits were voluntarily observed by the U.S. and the Soviet Union
- U.S. formally withdrew in 1986

Missile Technology Control Regime (MTCR)

- MTCR is an informal and voluntary partnership among member states that originally was created to prevent the proliferation of delivery systems for nuclear weapons; specifically delivery systems capable of carrying a 500 kg (1,102 lb) payload for at least 300 km (186 mi).
  - Applies to ballistic missiles, cruise missile, and other unmanned aerial vehicles (UAVs)
- Established in April 1987 by Canada, France, Germany, Italy, Japan, Great Britain, and the U.S. MTCR functions primarily as an export control group.
  - In 1992, MTCR expanded to apply to all weapons of mass destruction, not just nuclear weapons
  - In 2015 there are 34 member states.
  - Not all members have agreed to the same level of compliance
- The MTCR "no undercut" policy means that if one member denies the sale of some missile technology to another country, then all members must adhere.
- In 2002, the MTCR was supplemented by the *International Code of Conduct Against Ballistic Missile Proliferation* (Hague Code of Conduct).
- MTCR has been successful in stopping some international missile programs and limiting the export of others.
- However, MCTR has its limitations; India, Iran, Israel, North Korea, and Pakistan continue to advance their indigenous missile programs.
  - Israel's Popeye Turbo and India's Nirbhay long-range submarine-launched subsonic cruise missiles
  - The Russia – India BrahMos joint-venture that developed the BrahMos family of medium-range anti-ship supersonic cruise missiles.

Intermediate-range Nuclear Forces (INF) Treaty

- President Ronald Reagan & General Secretary Mikhail Gorbachev signed the INF treaty on 8 Dec 1987. It was ratified by Congress in May 1988. Entry into force date: 1 Jun 1988
  - Eliminated nuclear and conventional intermediate range (500 – 5,500 km; 311 – 3,418 mi) ground launched ballistic and cruise missiles.
    - Focus was on eliminating all U.S. Pershing II ballistic missiles and ground-launched cruise missiles (Gryphon GLCMs) and all Soviet SS-4, SS-5 and SS-20 ballistic missiles.
  - INF did not directly affect submarine-launched nuclear weapons. However, it did raise their importance.
    - Nuclear-armed submarine-launched Tomahawk cruise missile (TLAM-N, BGM-109A) entered service in 1986, with a range of 2,494 km (1,550 mi).
- Current Issues:
  - Since 2005, Russia repeatedly has reported that it was considering withdrawing from the INF treaty,
  - In July 2014, the U.S. formally notified Russia that it considers them in breach of the treaty for developing and possessing prohibited weapons:
    - The R-500 ground-launched cruise missile and a short-range “ICBM”.
    - Russia argues that similar weapons have been developed by Asian nations that are not constrained by the INF treaty.

Presidential Nuclear Initiatives

- Issued by President George H. W. Bush in September 1991
  - Not a treaty. This was a unilateral action by the U.S.
  - The President ordered the Navy to “withdraw all tactical nuclear weapons from it’s surface ships and submarines,” including:
    - Carrier Air Wing aircraft-delivered nuclear weapons
    - Tomahawk nuclear land attack cruise missiles (TLAM-N), which were carried by some Los Angeles-class SSNs and some surface ships.
    - The withdrawal was completed in early 1992.
    - An U.S. aircraft carrier battle group and all U.S. SSNs / SSGNs now have no nuclear weapons.
  - Several Navy tactical nuclear weapons already had been retired:
    - ASTOR (Mark 45) nuclear torpedo retired in 1976
    - SUBROC (UUM-44) anti-sub missile with nuclear depth charge retired in 1989
    - ASROC (RUR-5) surface ship-launched anti-sub nuclear depth charge retired in 1989.
  - Did not affect the strategic submarine-launched ballistic missiles (SLBMs) carried by the SSBN fleet, which now are the only nuclear weapons in the Navy’s fleet.

Strategic Arms Reduction Treaty
(START 1)

- Signed by President George H. W. Bush & Soviet President Mikhail Gorbachev on 31 July 1991
- Break-up of the Soviet Union in December 1991 contributed to a three year delay between signing the treaty and its entry into force.
  - The Lisbon Protocol, which adapted the original signed treaty to the political situation in the new Russian Federation, was signed on 23 May 1992
    - Four post-Soviet states, Russia, Belarus, Kazakhstan & Ukraine, were recognized as parties to START I in place of the Soviet Union, but only Russia was designated a nuclear weapon state.
    - Belarus, Kazakhstan, and Ukraine assumed an obligation to join the NPT as non-nuclear states and eliminate all START I accountable weapons and associated facilities within 7 years.
- EIF 5 Dec 1994; effective for 15 years; expired 5 Dec 2009; superseded by New START.
- Basic limits:
  - Each side limited to 1,600 operational delivery vehicles, including ICBMs, SLBMs and nuclear-capable bombers
  - Maximum of 6,000 deployed strategic nuclear warheads + other warhead limits
  - Maximum “throw weight” of 3,600 metric tons.
- Treaty bans testing of missiles with more warheads than established in the treaty, and bans any new ballistic missiles with more than 10 warheads.

Strategic Arms Reduction Treaty II
(START II)

- Signed by President George H. W. Bush and Russian Federation President Boris Yeltsin on 3 Jan 1993.
- This treaty never went into effect (entered force):
  - Ratified by the U.S. Senate on on 26 January 1996
  - After a long delay, during which the treaty became less relevant, Russia ratified the treaty on 14 April 2000.
  - On 14 June 2002, Russia withdrew from START II in response to U.S. withdrawal from the SALT I Anti-Ballistic Missile (ABM) Treaty on 13 June 2002.
  - START II was replaced by SORT on 1 June 2003
- Intended limits:
  - Banned use of multiple, independently-targetable re-entry vehicles (MIRVs) on ICBMs
  - SLBMs were not affected by START II
- While not done to comply with START II, the U.S. unilaterally deactivated all MIRV’d LGM-118A Peacekeeper ICBMs by 2005 and converted all LGM-30G Minuteman III ICBMs to single re-entry vehicle per missile.

International Code of Conduct Against Ballistic Missile Proliferation

(ICOC, Hague Code of Conduct)

- Established on 25 November 2002; today with 119 member countries.
- Calls for restraint and care in the proliferation of ballistic missile systems capable of delivering weapons of mass destruction.
  - It is the only normative instrument to verify the spread of ballistic missiles.
- Operates in parallel with Missile Technology Control Regime (MTCR).

Strategic Offensive Reductions Treaty

(SORT, aka *Treaty of Moscow*)

- Signed by President G.W. Bush & Russian President Vladimir Putin on 24 May 2002 and ratified by the U.S. Senate and Russian Duma; EIF 1 Jun 2003
- Limits:
  - In a key departure from START I, SORT limited operationally deployed warheads, whereas START I limited warheads through declared attribution to their means of delivery (ICBMs, SLBMs, and heavy bombers).
  - Each side agreed to reduce operationally deployed strategic nuclear warheads from 2,200 to 1,700 by 31 December 2012 (the date SORT was scheduled to expire).
- Implementation:
  - Warheads are not required to be destroyed and may therefore be placed in storage and later redeployed.
  - U.S. deactivated all 50 LGM-118A Peacekeeper ICBMs by 2005, each of which was equipped with 10 MIRVs. The remaining U.S. fleet of 450 LGM-30G Minuteman III ICBMs were converted from 3 MIRV warheads to a single re-entry vehicle per missile.
  - The U.S. SLBM fleet retained its MIRV warheads, but with fewer than the maximum number of re-entry vehicles per missile.
- Superseded by New START on EIF date: 5 Feb 2011.

New START

- Formally known as *Measures for the Further Reduction and Limitation of Strategic Offensive Arms*
- Signed by President Barack Obama and Russian President Dimitry Medvedev on 8 April 2010
- EIF 5 Feb 2011; replaces START I and SORT; expires 5 Feb 2021
- Limits applicable to both sides commencing 5 Feb 2018
  - Maximum of 700 deployed (operational) launchers, including ICBMs, SLBMs and nuclear-capable bombers
  - Maximum of 800 deployed and non-deployed (nuclear capable) launchers
  - 1,550 (or somewhat more*) deployed strategic nuclear warheads
    - Actual number of re-entry vehicles per missile are counted; one warhead per re-entry vehicle.
    - * Only one warhead is counted per bomber regardless of how many warheads it actually carries. The actual number of free-fall nuclear bombs and/or air-launched cruise missiles can be 16 – 20 per bomber.
- Limits on total deployed + non-deployed launchers are intended to prevent each side from maintaining a stockpile of non-deployed launchers that could be made operational in a relatively short period of time.

Comparison of Treaty Limits

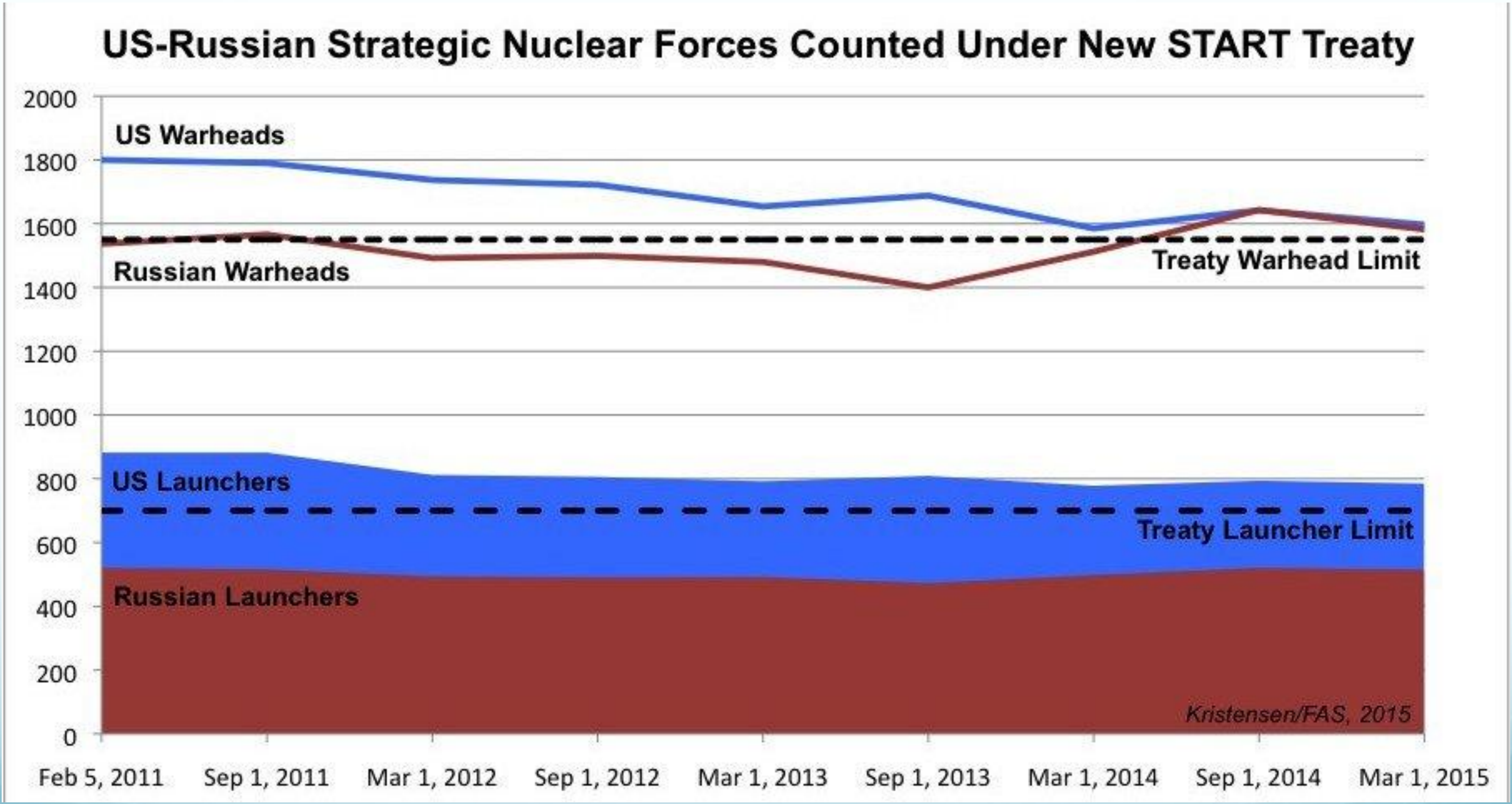
Treaty	START (1991)	Moscow Treaty (2002)	New START (2010)
Limits on Delivery Vehicles	1,600 strategic nuclear delivery vehicles	No limits	800 deployed and nondeployed ICBM launchers, SLBM launchers and heavy bombers equipped to carry nuclear weapons Within the 800 limit, 700 deployed ICBMs, SLBMs, and heavy bombers equipped to carry nuclear weapons
Limits on Warheads	6,000 warheads attributed to ICBMs, SLBMs, and heavy bombers 4,900 warheads attributed to ICBMs and SLBMs 1,100 warheads attributed to mobile ICBMs 1,540 warheads attributed to heavy ICBMs	1,700-2,200 deployed strategic warheads No sublimits	1,550 deployed warheads No sublimits
Limits on Throwweight	3,600 metric tons	No limit	No limit

Source: The New START Treaty: Central Limits and Key Provisions, Congressional Research Service, February 2015

New START implementation

- Each side has the flexibility to structure its nuclear forces as it wishes, within the limits of the treaty.
- U.S. actions to reduce its number of operational launchers and deployed warheads include:
  - No later than 5 Feb 2013, the U.S. was required to exhibit four Ohio-class submarines converted permanently from SSBN to SSGN role, eliminating 96 strategic launchers
  - In 2015 the U.S. Navy began reducing the number of missile tubes in Ohio-class SSBNs from 24 to 20. This work will be completed by 5 Feb 2018, eliminating 40 strategic launchers for Trident II (D-5) MIRV'd SLBMs.
  - By 5 Feb 2018, the single-warhead Minuteman III ICBM fleet will be reduced from 450 armed missiles to 400 armed missiles, with 50 unarmed missiles in reserve.
- The treaty does not limit the number of operationally inactive stockpiled nuclear warheads. The Federation of American Scientists has estimated that, as of 1 Mar 2015, the U.S. and Russia have the following inventories.
  - U.S.: 7,100 total warheads; 4,760 in the military stockpile (1,597 deployed, 3,163 inactive stockpile), 2,340 awaiting dismantling
  - Russia: 7,500 total warheads; 4,500 in the military stockpile (1,582 deployed, 2,918 inactive stockpile), 3,000 awaiting dismantling

Progress toward meeting New START limits



Source: https://fas.org/blogs/security/2015/04/newstart2015/

New START implementation

- The treaty does not prohibit either side from deploying conventional warheads on strategic missiles.
  - These strategic missiles would be counted against the treaty limits.
  - The treaty cautions that both sides are, “mindful of the impact of conventionally-armed IRBMs and SLBMs on strategic stability.”
  - The U.S. is planning a weapon of this type called Prompt Global Strike (PGS), which is intended to deliver a precision conventional warhead to strike any point in the world within 1 hour of launch.
    - In Feb 2014, the Navy solicited bids for a 2-year industry trade study for a submarine-launched, intermediate-range, hypersonic, conventional warhead PGS weapon.

Fissile Material Cutoff Treaty
(FMCT)

- FMCT is a proposed international treaty intended to prohibit the production of highly-enriched uranium (HEU) and weapons-grade plutonium.
  - HEU = enrichment > 20%
  - LEU = enrichment ≤ 20%
- Preliminary FMCT discussions have been held by the UN Conference on Disarmament (CD), which is a body of 65 member nations established as the sole multilateral negotiating forum on disarmament.
- Nations that joined the NPT as non-weapon states already are prohibited from producing or acquiring fissile material for weapons.
- If FMCT is ever passed, it could put at risk the continued use of HEU as naval reactor fuel.
  - Large HEU inventories exist in the U.S., Russia, UK and France
  - Long operating lives of modern HEU naval reactors will make their phase-out difficult.

Fissile Material Cutoff Treaty (FMCT)

- According to the International Panel on Fissile Material (IPFM) *Global Fissile Material Report 2015*, the global stockpile of HEU is about 1,345 tons.
- IPFM estimates the global stockpile of separated plutonium at about 499 tons.

Fissile Material Production End Dates

Country	Highly-enriched Uranium HEU	Weapons-grade Plutonium
USA	Stopped 1992 (since 1964 for naval fuel only)	Stopped 1988
Russia	Stopped 1989; May have restarted in 2012 for export	Stopped 1994
UK	Stopped 1962 (imports from USA)	Stopped 1995
France	Stopped 1996	Stopped 1992
China	Stopped 1987 (unofficial)	Stopped 1991 (unofficial)
India	Ongoing	Ongoing
Pakistan	Ongoing	Ongoing
Israel	Status unknown	Status unknown
North Korea	Status unknown	Status unknown
Brazil	Claims not to enrich >20%	None

Source: https://www.armscontrol.org/factsheets/fmct

Marine reactor fuel enrichments in use in mid-2015

- U.S and UK:
  - The U.S. Navy is known to operate with reactor cores fueled by very highly enriched uranium, either 97% produced specifically for naval reactors, or 93% extracted from surplus nuclear weapons.
  - UK naval reactor fuel uses the same enrichment. UK imports some HEU for naval fuel from the U.S.
- Russia:
  - Russian naval reactors typically use HEU fuel. For example, the most commonly used submarine reactor, the OK-650, uses a fuel enrichment of 20 – 45%.
  - Russia's current-generation Arktika-class icebreakers with OK-900A reactors use HEU fuel enriched to 55 - 90%.
  - Russia's *Sevmorput* ice-breaking cargo ship and the Taimyr-class icebreakers respectively have KLT-40 and KLT-40M nuclear power plants that operate on HEU fuel enriched to 30 – 40%.
  - Russian new civilian marine reactors for the LK-60-class icebreakers (RITM-200 PWR) and a floating nuclear power plant (KLT-40S PWR) are designed to operate with LEU fuel.

Marine reactor fuel enrichments in use in mid-2015

- France:
  - Except for their 1st-generation PWR/SNLE PWRs, which have been retired, all operating French naval reactors have been designed to operate with LEU fuel.
  - The newest reactor for the Barracuda SSN is designed to operate with the same LEU enrichment as commercial nuclear power plants (about 3.5%).
- China
  - Chinese naval reactors are believed to operate with LEU fuel enriched to about 5%.
- India:
  - India's PWR naval reactor prototype operates with HEU fuel enriched to 30%.
  - The fuel enrichment for India's first submarine, *Arihant,* is not known.
- Brazil:
  - Brazil claims it's 2131-R PWR naval reactor will use LEU fuel.

Prospects for 2015 - 2030

Prospects for 2015 - 2030

- The number of nuclear marine nations will increase.
  - Brazil is expected to launch its indigenous SSN by about 2023.
    - This will give Brazil’s Navy the capability to more effectively patrol that nation’s 7,491 km (4,655 mi) coastline and protect national interests in the exclusive economic zone (EEZ).
    - Brazil’s current poor economic condition could delay their indigenous nuclear submarine program.
  - No additional nations are expected to develop their own nuclear submarine or surface vessel within the next 5 – 10 years.
    - Iran and North Korea may have the political motivation to develop a global reach, but are unlikely to be capable of deploying an indigenous nuclear submarine in the next decade.

Prospects for 2015 - 2030

- The number of nuclear marine nations will increase (continued).
  - Based on the precedent of leasing SSNs to India, the possibility exists that Russia will lease a nuclear submarine to one or more other nations that previously had no nuclear fleet.
  - Successful demonstration of the Russian floating nuclear power plant, *Akademik Lomonosov,* later in this decade should lead to international orders from other nations for similar floating nuclear power plants.

Prospects for 2015 - 2030

- The number of nuclear marine vessels in the worldwide nuclear fleet will increase.
  - 2030 will be an important milestone year because it is near the date when several major submarine classes are scheduled to retire:
    - U.S. Ohio-class SSBNs & SSGNs, Russian Delta IV SSBNs, and UK Vanguard SSBNs all will be retiring near 2030.
    - The investment needed to replace these weapons systems will put a strain on other naval nuclear new construction budgets.
  - The U.S. fleet will get smaller.
    - There will be about 41 SSNs by 2028, Ohio-class SSBNs & SSGNs will start retiring near that date, and the Ohio-replacement SSBN will not enter service until about 2031. Aircraft carriers will hold steady at 11.
    - U.S. nuclear fleet size could decline by about 15 subs to a total of 69 vessels by 2030.

Prospects for 2015 - 2030

- The number of nuclear marine vessels in the worldwide nuclear fleet will increase (continued).
  - The Russian fleet will start growing back slowly after two decades of under-funding.
    - New-build multi-purpose Yasen-M SSNs, Borei II SSBNs and modernized Sierra and Akula SSNs and Oscar SSGNs will strengthen and expand the submarine force.
    - LK-60 icebreakers will allow retirement of the oldest nuclear icebreakers and may slightly expand the polar icebreaker fleet.
    - Modernization of two or more Kirov-class CGNs should be completed by 2020, complemented by new-construction Leader-class nuclear-powered destroyers that may start entering the fleet in the mid-2020s.
    - Deployment of additional floating nuclear power plants in remote Arctic ports is likely.
    - Russian nuclear fleet size could grow by 5 – 10 vessels to a total of 62 – 67 by 2030.

Prospects for 2015 - 2030

- The number of nuclear marine vessels in the worldwide nuclear fleet will increase (continued).
  - The UK nuclear submarine fleet size will be constant.
    - Astute SSNs will replace Trafalger SSNs on a one-for-one basis.
    - Successor SSBNs will replace Vanguard SSBNs on a one-for-one basis.
    - The number of SLBMs and warheads in the SSBN fleet will continue to decrease as a result of the UK's 2010 Strategic Defense and Security Review (SDSR).
  - The French nuclear vessel fleet size will be constant.
    - Barracuda SSNs will replace Rubis SSNs on a one-for-one basis
    - Le Triomphant-class SSBNs will remain operational beyond 2030, but a program to develop the replacement SSBN will have to start in the early 2020s.

Prospects for 2015 - 2030

- The number of nuclear marine vessels in the worldwide nuclear fleet will increase (continued).
  - China's nuclear vessel fleet size will grow:
    - Improved Type 93 and multi-mission Type 95 SSNs will be added to the fleet
    - Type 94 and new Type 96 SSBNs will be added to the fleet
    - Next-generation subs will be under construction before 2020s
    - The earliest Type 91 SSNs and the one Type 92 SSBN will be retired
    - The intent to build a nuclear powered aircraft carrier has been raised by China, but deployment within the next 10 – 15 years is very unlikely because of the lead time to design and construct a CVN.
    - China could add 20 or more nuclear submarines to its fleet by 2030 (at a new-build rate of about two per year minus retirements)

Prospects for 2015 - 2030

- The number of nuclear marine vessels in the worldwide nuclear fleet will increase (continued).
  - India's nuclear fleet will grow:
    - India will continue construction of it's indigenous SSBN fleet to strengthen it's national nuclear deterrent force.
    - India will lease additional SSNs from Russia, perhaps even a current-generation Yasen-class SSN.
    - By 2030, India could add seven or more nuclear submarines to it's fleet (at an assumed rate of one per two years)
  - Brazil will have one or more indigenous SSNs by 2030.
    - Current plans are for the first SSN to enter the fleet in 2023.
    - The 2010 Joint Plan for Marine Equipment of Brazil calls for six SSNs by 2034.
    - By 2030, Brazil could have three or more indigenous SSNs (at an assumed rate of one per three years), but this will be highly dependent on the state of Brazil's currently-weak economy.

Prospects for 2015 - 2030

- The number of nuclear marine vessels in the worldwide nuclear fleet will increase (continued).
  - The worldwide nuclear fleet could grow to 189 – 194 vessels by 2030.
    - Most of the real growth will be attributable to the newer nuclear marine nations: China, India & Brazil.
    - The older nuclear marine nations, U.S., Russia, UK & France, will be making major investments to replace or extend the operating lives of aging submarines and surface ships. Being able to replace older vessels, even on a one-for-one basis, will be a significant economic challenge.

Prospects for 2015 - 2030

- The ability to operate underwater at high speed for long durations is no longer the sole domain of the nuclear-powered submarine.
  - Nuclear submarines and naval surface forces will be increasingly challenged by the latest generation of non-nuclear submarines using various types of air-independent propulsion (AIP) systems.
  - A well-equipped modern "conventional" submarine has the ability to operate effectively, and silently, at relatively long range against all adversary forces.
  - Armament is comparable to SSNs and SSGNs operated by the U.S. or Russia.

Prospects for 2015 - 2030

- The “attack submarine” has evolved into a multi-purpose platform capable of a wide variety of missions
  - The newest generation of SSNs has blurred the distinction between SSNs and SSGNs by carrying a large arsenal of missiles in vertical launch system (VLS) tubes, while retaining the weaponry in the traditional torpedo room. Examples are:
    - U.S. Virginia-class Block V SSNs
    - Russian Yasen / Yasen-M-class SSNs
    - Chinese improved Type 93G SSNs
  - The ability for submarines to host, deploy and recover special operations forces (SOF) and their equipment has become commonplace.
  - The use of unmanned underwater vehicles (UUVs) launched from submarines is increasing and will greatly expand the capabilities of submarines equipped to use them.
    - UUVs will be a “force multiplier”

Prospects for 2015 - 2030

- Many nations now have the capability to raise a significant anti-access/area denial (A2/AD) challenge to U.S. nuclear-powered aircraft carriers and their battle groups, or to any other surface fleet.
  - Examples of A2/AD weaponry include:
    - Chinese DF-21D anti-ship ballistic missiles with a range of 900 miles (1,448 km)
    - Long-range, high-speed, anti-ship cruise missiles, like India's Brahmos Mach 3 cruise missile with a range of 180 mi (290 km), or Russia's similar P-800 Oniks.
  - Some individual submarines can salvo-launch a very large quantity of cruise missiles that may be able to overwhelm the defense capabilities of a carrier battle group.
    - Russian Oscar SSGNs currently carry 24 x P-700 Granit (SS-N-19) and soon will be modified to carry 72 x P-800 (SS-N-26) Oniks.
    - Russian Yasen SSN can carry 24 x P-800 Oniks, or a larger number of smaller missiles.

Prospects for 2015 - 2030

- Prospects for new commercial nuclear marine propulsion applications remains uncertain.
  - Other than new Russian icebreakers and floating nuclear power plants, it is unlikely that any nation or firm will develop and license a nuclear-powered commercial vessel before 2030.
  - Lloyd's Register updated its 'rules' for nuclear ships, which concern the integration of a reactor certified by a land-based regulator with the rest of the ship.
    - Lloyd's claims this was done in response to its members' interest in commercial marine nuclear propulsion.
    - Interest is driven primarily by market-based measures for controlling carbon dioxide emissions from maritime operations.

Prospects for 2015 - 2030

- Prospects for new commercial nuclear marine propulsion applications remains uncertain (continued).
  - Practical considerations may limit the primary market for new commercial nuclear-powered ships to point-to-point heavy cargo ships, or single port heavy tugs.
    - These applications minimize the number of different national nuclear regulatory organizations that need to be involved in licensing and providing nuclear safety / operational oversight of commercial nuclear marine activities.
    - It also minimizes the investment in nuclear power port infrastructure needed to support a commercial nuclear vessel.
      - Few nations have the in-place regulatory and nuclear service infrastructure needed to support the operation of a commercial nuclear-powered vessel.
      - Developing that infrastructure at the ports of interest could take a decade or more and require significant investment.

Prospects for 2015 - 2030

- The role of nuclear vessels in the Arctic will increase, and most of them will be Russian vessels.
  - Russia’s nuclear-powered polar icebreaker fleet and soon-to-be-deployed floating nuclear power plant give that nation unmatched capabilities to explore and commercialize the Arctic by:
    - Establishing reliable open sea lanes for other vessels in ice-covered regions along the Northern Sea Route
    - Enabling the exploration for, and exploitation of, petroleum, mineral and natural resources along the Russian Arctic coast and in off-shore waters.
  - If Russia’s 2015 Extended Continental Shelf (ECS) claim is upheld by the Commission on the Limits of the Continental Shelf, Russia will have the resources and the means to enforce it’s expanded exclusive economic zone (EEZ).
    - No other Arctic nation has comparable means to operate in the Arctic region.
    - The general decline of the U.S. and Canadian conventional icebreaker fleets opens great opportunities for Russia to dominate the Arctic region.

Prospects for 2015 - 2030

- The role of nuclear vessels in the Arctic will increase, and most of them will be Russian vessels (continued).
  - Nuclear submarines will continue to have greater freedom of navigation in the Arctic than any other class of vessel.
    - Russia's large number of small, deep-diving, nuclear-powered submarines and associated "motherships" gives them unique capabilities for underwater exploration and other activities in the Arctic and worldwide.
- Progress will be made in cleaning up radioactive contamination in the Arctic
  - Continued political pressure, plus economic incentives related to Arctic resource development in the region, will encourage Russia to remediate marine some nuclear waste sites and sunken nuclear submarine sites in the Kara Sea and the Barents Sea.

Prospects for 2015 - 2030

- Retired naval nuclear vessel decontamination and processing will improve:
  - The UK must resolve the current nuclear regulatory impasse that is preventing the de-fueling of some retired subs and the decontamination and scrapping of others that have been de-fueled.
  - New facilities near Vladivostok, in the Russian Far East, will enable a more effective decontamination and decommissioning processing of retired Pacific Fleet nuclear vessels and will provide for storage of sealed reactor compartments on land.
  - U.S. is modernizing the Expended Core Facility at the Idaho National Lab, and will be moving all spent fuel into dry storage.
- Increasing international pressure for a Fissile Material Cutoff Treaty (FMCT) could have an impact in the long-term on use of HEU in naval reactors.
  - Only the U.S. and the UK continue to use HEU enriched to ≥ 93% U-235, and would be most impacted by an FMCT.