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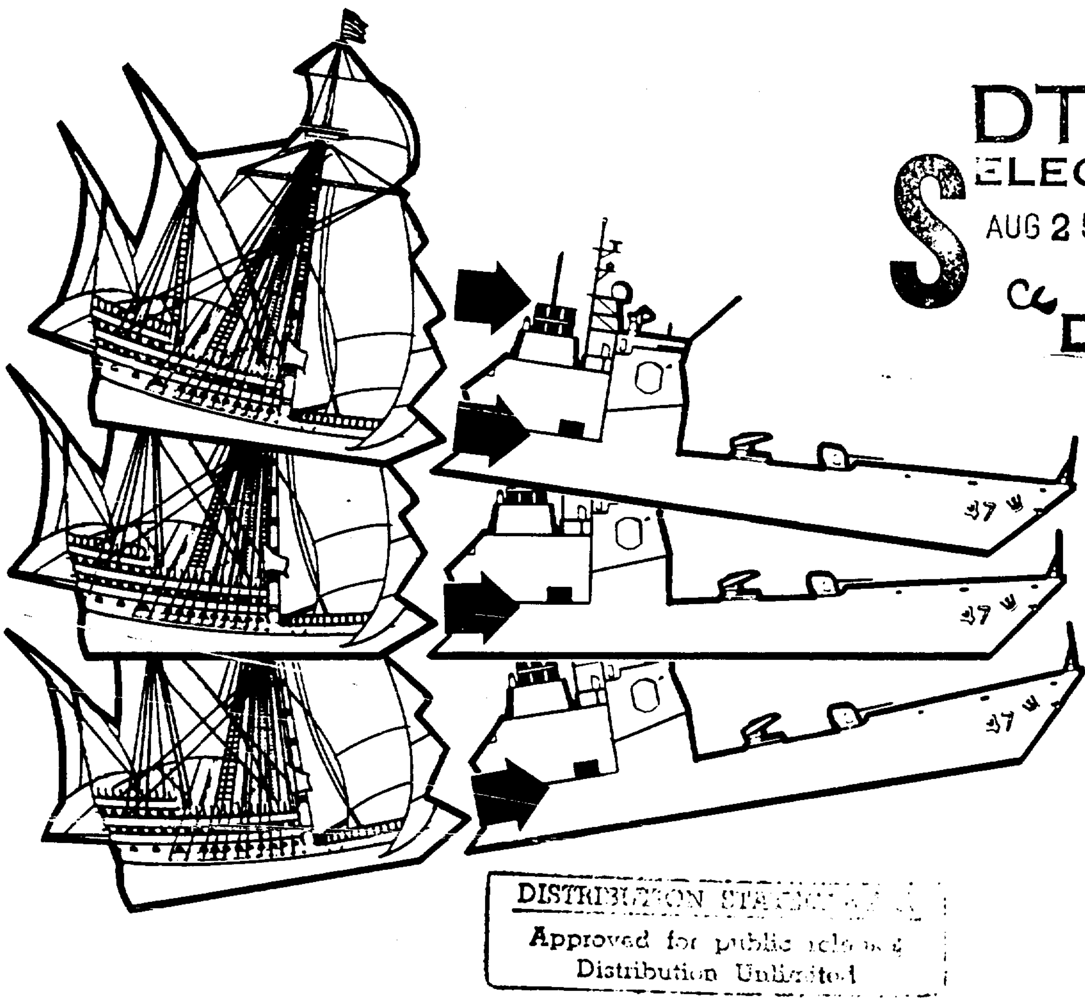

REACTIVATION OF 16-INCH THREE GUN TURRETS IN THE BATTLESHIP

by: Art Romano

ASSOCIATION OF SCIENTISTS AND ENGINEERS OF THE NAVAL SEA SYSTEMS COMMAND • DEPARTMENT OF THE NAVY • WASHINGTON, D.C. 20362

Reactivation of 16-Inch Three Gun Turrets

In the Battleships

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Abstract

According to Jane's Fighting Ships, the IOWA class are the most heavily armored United States war ships ever constructed.

As a part of the program to increase U. S. Naval power, the four BB-61 class ships in the inactive reserve fleet commenced reactivation and modernization beginning with BB-62 in 1981.

The 16-inch guns carried by the ships are the largest guns ever put to sea by the U. S. Navy and are the largest in existence in the world today. For a listing of all Battleships ever built by the United States see Appendix A.

Reactivation of the 16-inch turrets was accomplished with few major problems because of the care with which they were preserved when deactivated. The reactivation effort basically involved cleaning, reassembling, adjusting, and testing each component of the turret individually until all components were operating and then testing the entire gun as a unit.

Reactivation of the 16-inch guns rekindled thinking about basic major caliber gun system operation. Studies and design improvements have been completed on measuring the muzzle velocity of the projectile, and reducing the wear of the gun barrel through addition of a wear reducing jacket on the propellant charge. Additional longer range programs are underway to extend the range and accuracy of the 16-inch gun.

With the reactivation of the 16"/50 Three Gun Turrets the U. S. Navy has gained a unique major weapon system at a fraction of the cost to design and build a comparable system.

REACTIVATION OF
16"/50 THREE GUN TURRET

I INTRODUCTION

Since 1981 when the U.S. Navy began reactivation of the USS NEW JERSEY, controversy has surrounded this program. However, controversy has surrounded battleships since the first battleship was built. Controversy can be traced to the definition of "battleship". According to the Third New International Dictionary, Unabridged Edition, dated 1981, a battleship is defined as:

> "a warship of the largest and most heavily armed and armored class usually having at least 10-inch armor and carrying in the main battery, guns of 12-inch or larger caliber."

However, this definition implies that the battleship is superior to all other ships, which is probably the cause of most of the controversy. It is the larger caliber guns and heavy armor on a battleship which makes them unique an asset to the Fleet.

The USS IOWA (BB-61) class battleships have nine 16-inch guns in three turrets, see Figure I-1. These are the largest guns every placed in service by the U.S. Navy. (An 18 inch prototype gun was built by the Naval Gun Factory in Washington D.C. and proof fired at the Naval Proving Grounds in Dahlgren, VA but never put into the fleet except as ballast material in the USS REPOSE.)

Even though there has been a lot of questions concerning the battleship reactivation program reactivation of the 16"/50 Three Gun Turrets was accomplished with no major problems and no controversy.

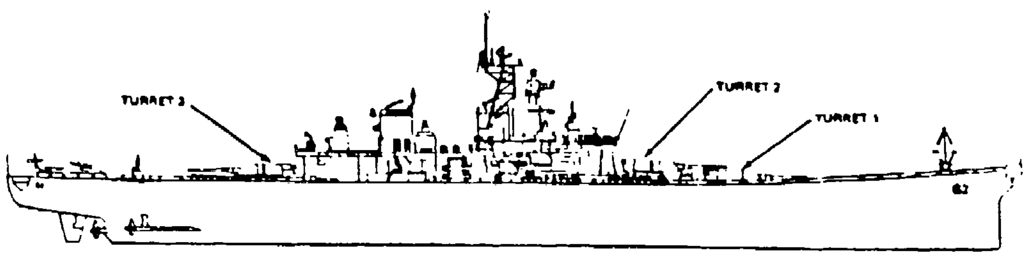

Figure I-1. BB-61 Class 16-Inch Turret Locations.

History

Guns have been on ships for centuries but it wasn't until the 1800's that they became useful for anything but shooting at point blank range. The British fired the first rifled gun in the 1850's.

Rifling is a series of spirally formed grooves and lands cut in the inside of the barrel from the chamber to the muzzle. It induces a spin to the projectile along its longitudinal axis when it leaves the barrel. Longitudinal rotation of the projectile provides stability in flight which permits the use of longer and heavier projectiles. This allowed guns to obtain vastly increased range, accuracy, and projectile penetration of the target. Old smoothbore cannons could fire only round shot. The weight of the old spherical projectile was limited by size thus making them more affected by wind and air resistance than more massive ones.

Ramming large caliber ammunition from the muzzle was excessively difficult if the projectile fit the rifled bore closely, and the rifling was useless if it didn't.

The key to making effective and practical rifled guns lay in development of effective mechanisms to permit loading from breech end rather than the muzzle end. The first breech loaded gun was built in 1859.

Large caliber gun development then progressed rapidly. A 16"/50 caliber gun was first designed and proof fired by the U.S. Navy in 1918. Due to the London Naval Agreement (Arms Limitation), further development and construction was set aside. Work on a new 16"/50 caliber gun began in 1938 after the Arms Limitation Agreement had expired. These guns were to be installed in six IOWA class and five MONTANA class ships to be built in the 1940's. USS IOWA, (BB61), USS NEW JERSEY, (BB62), USS MISSOURI, (BB63), and USS WISCONSIN, (BB64), were the only ships built. After World War II, these ships were decommissioned briefly, then reactivated for the Korean War. In the late 1950s, these ships were again mothballed. During the Vietnam War, the USS NEW JERSEY was reactivated in 1967 and deactivated in 1969. In 1981 the current battleship reactivation program began. The USS NEW JERSEY, BB62 was recommissioned in 1983; USS IOWA, BB61 in 1984; and USS MISSOURI, BB63 in 1986. USS WISCONSIN, BB64 is scheduled to be recommissioned in August 1988.

Description of 16-Inch Turrets

Turrets I, II and III of each ship are closely similar. Each has a gun house mounted above a conical and cylindrical structure (greatest dia. 35 ft. 1.0 in.). Each such rotating assembly is protected by heavy armor plate on the front, sides, rear, and roof

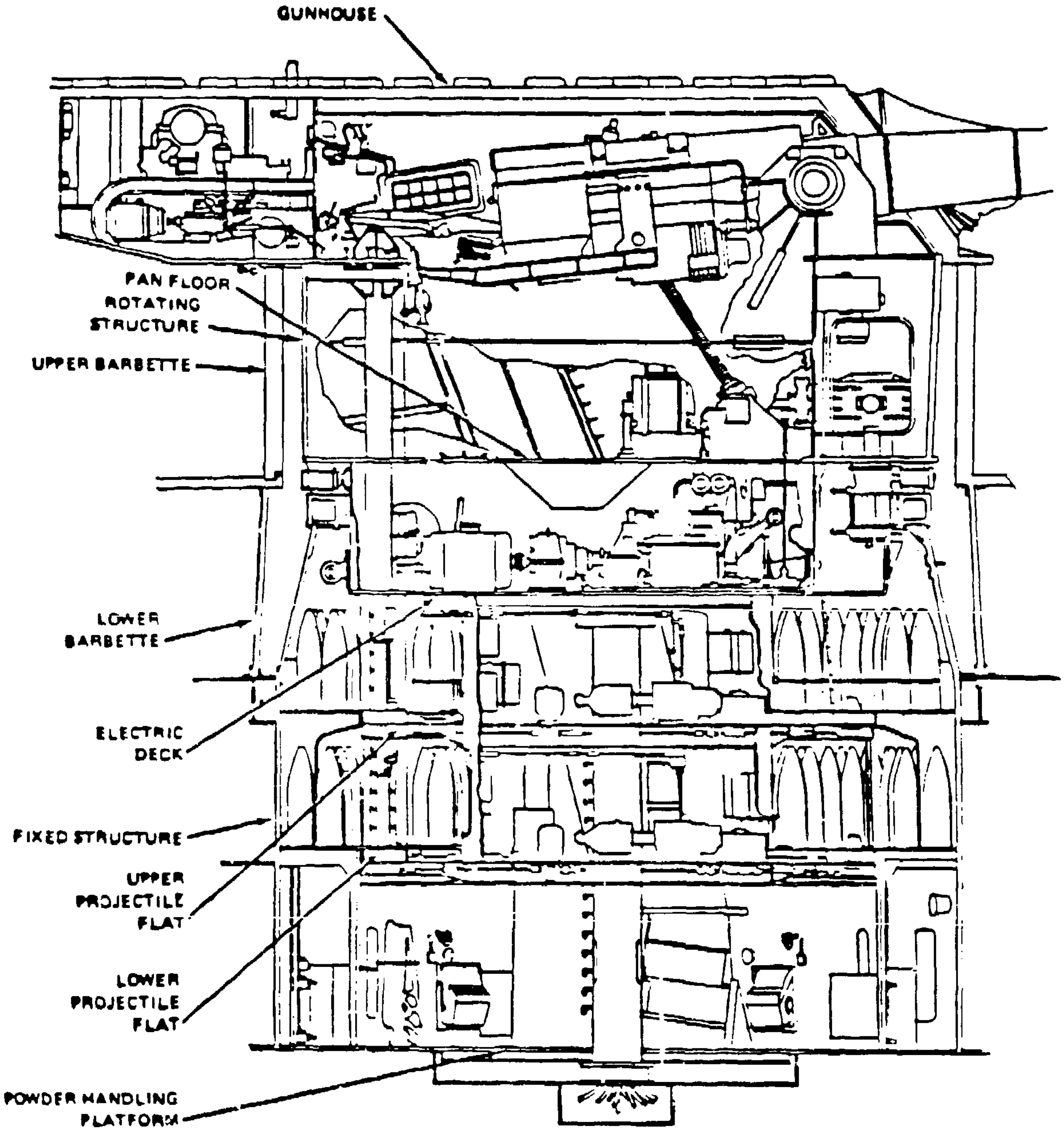

Figure I-2. 16"/50 Three Gun Turret.

of the gun house, and below the shelf plate (gun house floor) is enclosed within fixed barbette of heavy plate of cylindrical form. The barbette and armor deck plates enclose and protect the roller path and its cylindrical-conical foundation (37 1/4 ft. dia., max.). The rotating structural is supported from the roller path by a roller carriage composed of 60 large steel rollers mounted in 12 cage sectors of five rollers each. The carriage is located immediately below the pan floor (bottom of gun pockets) and thus the electric equipment deck, projectile handling levels and powder handling floor are suspended from the carriage. Differences in height of structures result in varying space allotments for projectile stowage and differing heights of lift for powder service. All other space divisions are virtually the same in all turrets. Turret subdivisions provide separate flameproofed compartments for the three guns, two sight stations, and the range finder turret officer's station; gun compartment subdivisions extend to the pan floor.

The 16"/50 caliber turret consists of equipment on six separate levels, see Figure I-2. These are (1) gunhouse, (2) pan floor, (3) electric deck, (4) upper projectile flat, (5) lower projectile flat and (6) powder handling platform.

1. The gunhouse is 50.63 feet long with a maximum width of 36 feet which is mounted above and attached to the rotating structure. The armor plates of the gunhouse range in thickness from 7.25 inches to 17 inches. The gunhouse is comprised of the turret officer control booth, the gun compartments, and the sight station. All of these compartments are separated by flametight bulkheads. The aft overhang of the gun house contains the only entrance hatches to the turret officer's booth from the weather deck. Located in the booth are the auxillary computer, rangefinder, turret communications and powered equipment for the rammer. The three separate gun compartments have separate controls and equipment for servicing the individual guns. The two sight stations contain duplicate equipment for the operation of the turret optical sights by the pointers, trainers and sight setters.

2. The pan floor contains the pockets into which the breeches of the guns are depressed as the guns are elevated. It also contains part of the elevation machinery.

3. The electrical deck is the third level below the gunhouse in which are located the three gun layers and the turret trainer stations, and the electric-hydraulic machinery necessary to move the guns in elevation and the turret in train.

4. The next two levels are the upper and lower projectiles flats where projectiles are stored. Here the projectiles are taken from stowages, loaded into hoists and lifted up into the gun rooms. Turret 2 only, has a third level that does not rotate where projectiles are stored.

5. The bottom level is the powder handling platform. Surrounding this flat, outside of the turret, are the powder stowage magazines. The bags of powder are passed from the magazines through flameproof scuttles into the handling platforms. Here six bags are loaded into one of three elevator type powder hoist cars for delivery to one of the gun rooms.

Operation of 16-Inch Turrets Onboard BB-61 Class

Ships and turret design arrangements permit two separate routes per turret to be utilized for moving ammunition from the main deck outside the turret to stowed positions in the magazine and projectile flats. Each projectile is lowered through hatch openings in the ammunition loading trunk to an annular handling space, then hoisted into the lower or upper projectiles flat level where it is lashed in vertical stowage. Similarly, the powder can is striked down into the powder magazine and stored in cordwood style racks.

During firing, the 16-inch 3-gun turret is operated with a minimum crew of 77 men inside the turret. Station assignments for the turret crew are ordinarily as listed in Table I-1.

Table I-1. Turret Crew Station Assignments

Station	Location	Station	Location
Turret officer.........		Powder-hoist	Top, powder
Turret officer's talker.		operators (3).....	trunks
Turret captain..........	Rangefinder		
Computer operators (2)..	and Turret	Gun layers (3).....	Machinery
Rangefinder operator....	Officer's	Gun train operator.	floor
Rangefinder pointer.....	compartment		
Rangefinder trainer.....		Projectile-hoist	
Talker.................		operators (3).....	
		Projectile-ring	
Sight trainer, right....		operator..........	Projectile-
Sight pointer, right....	Right sight	Shellmen (9).......	handling
Sight setter, right.....	station	Electrician........	floor (each
		Shell-deck P.O.....	level)
Sight trainer, left.....			
Sight pointer, left.....	Left sight	Powder-door	Powder-
Sight Setter, left......	station	operators (3).....	handling
		Powder passers (9).	floor
Plugmen (gun captains)(3)		Handling-room P.O..	
Cradle operators (3)....			
Rammer operators (3)....	Gun rooms		
Primermen(3)............			

In addition, there are 6 powder passers in the annular space between the powder-handling room and the magazines, and 12 powder passers in the magazines.

With the turret in all respects ready to fire and the power machinery in operation, the first command is: "Fill the powder train; fill the projectile hoists." At this command the necessary powder tanks in the magazines are opened using specially designed wrenches; powder is passed through the scuttles to the lower handling room; the powder cars are filled and raised to the top of the hoists. Ordnance safety precautions require that in each flametight stage of the ammunition train, not more than one charge per gun (for the guns being supplied through that stage) shall be exposed or allowed to accumulate. Simultaneously the projectile-handling room crews are loading the projectile hoists with the required type of projectiles.

This command further implies that whenever an empty powder car is returned to the lower handling room, or that whenever an empty stage in the projectile hoist appears, the crew reloads immediately.

The first command to the gunroom crew is "Load." The gun captain, on the loading platform, unlatches the breech-operating lever and pushes it down. The primerman, under the breech, assists the gun captain in locking the breech down. The gun captain wipes the mushroom and inspects to see that the bore is clear. As soon as the "Bore clear" signal is given, the gun captain shuts off the gas ejector valve and signals the cradle operator to span the tray (lower it to loading position).

At the same time the primerman inserts a primer into the open firing lock. The rammer operator rams the projectile until it is seated and withdraws the rammer as he opens the powder hoist door. The powder-car operator tilts one of the powder-car trays, and 3 bags of powder roll across the door onto the spanning tray. The gun captain and cradle operator guide the powder bags across the door and space them out on the spanning tray. The powder car lowers about 23 inches and stops automatically, and the remaining three bags of powder are rolled onto the spanning tray.

The rammerman closes the powder-car door and carefully rams the six powder bags to place the rear-most bag not more than 4 inches from the mushroom when the breech is closed. The cradle operator folds the spanning tray as soon as the rammer is withdrawn. The gun captain releases the breech hold-down latch and opens the air valve to the closing cylinder. He then latches the operating lever as the plug rotates to the closed position. The gun captain steps off the loading platform and operates the "ready" switch to signal that the gun is loaded and to bring the gun to gun order position. The gun is then fired either by a remote signal or in local control. The operational characteristics of the 16"/50 Three Gun Turrets on the BB-61 class Battleships are given in Table I-2.

Table I-2. 16"/50 Three Gun Turret Operational Characteristcs.

Characteristic	Limit
Weight	
Total Rotating Assembly	4,030,000 lbs
Oscillating Assembly	387,900 lbs
Recoiling Mass	292,000 lbs
Elevation	
Maximum	45°
Minimum	-2° (0° turret 2)
Rate	7° to 8° per sec
Train	
Turrets 1 and 2	150° either side of center line
Turret 3	150° stbd or 125° port of centerline
Rate	4° per sec
Rate of fire	2 rounds per min
Muzzle Velocity (AP projectile)	2500 feet/sec
Muzzle Velocity (HC projectile)	2700 feet/sec
Range (AP projectile)	40,000 yards
Range (HC projectile)	41,000 yards

II REACTIVATION

Basic Reactivation Method Used for 16-Inch Turret

The turrets had been deactivated in accordance with OP 1208 when the ships were placed in inactive reserve fleet. Periodic inspections had provided assurance that the preservation system was doing its job.

Prior to reactivation, each turret was inspected and all visible deficencies recorded. The turret preservation on all four battleships held up very well while the ships were decommissioned. Based upon the inspection report, work packages were developed to delineate the effort required to reactivate the turrets. As each ship was reactivated lessons were learned which improved the inspections and work packages for the next ship.

Because of the massive size of the equipment and the interrelated construction of the turret being built into the ships, the actual reactivation techniques used on the turrets were unlike those used on most ordnance equipment. The system could not be removed and sent to a depot for complete overhaul nor could the assemblies be completely torn down aboard ship. The piece parts removed during reactivation were cleaned and reinstalled. The assemblies were then cleaned and repaired as necessary and operated individually.

After all assemblies and components were individually operated the actual testing of the components began. After each component was individually tested the major assemblies of the turret and then the entire turret was operated and tested in accordance with prescribed total ship test packages.

Oscillation of Elevation Drive

While reactivating the turrets on USS IOWA (BB-61), it was discovered that two of the 16" gun elevation power drives had oscillation problems. These problems existed in both "Hand" and "Automatic" control modes. Neither gun would synchronize to a stationary signal when operated in automatic and when matched to a stationary signal the guns would oscillate continually about that signal. See figure II-1 for a general arrangement of the 16-inch elevation drive system.

An investigation revealed that this problem had existed in both guns at the time the IOWA was last decommissioned. Historical records of that period showed that major repair efforts were being taken by the Norfolk Naval Yard up until the decommissioning to correct the problem on one gun. Their last attempt to repair involved the disassembly of the elevating gear A-end pump assembly and remachining of internal components to minimize internal fluid leakage.

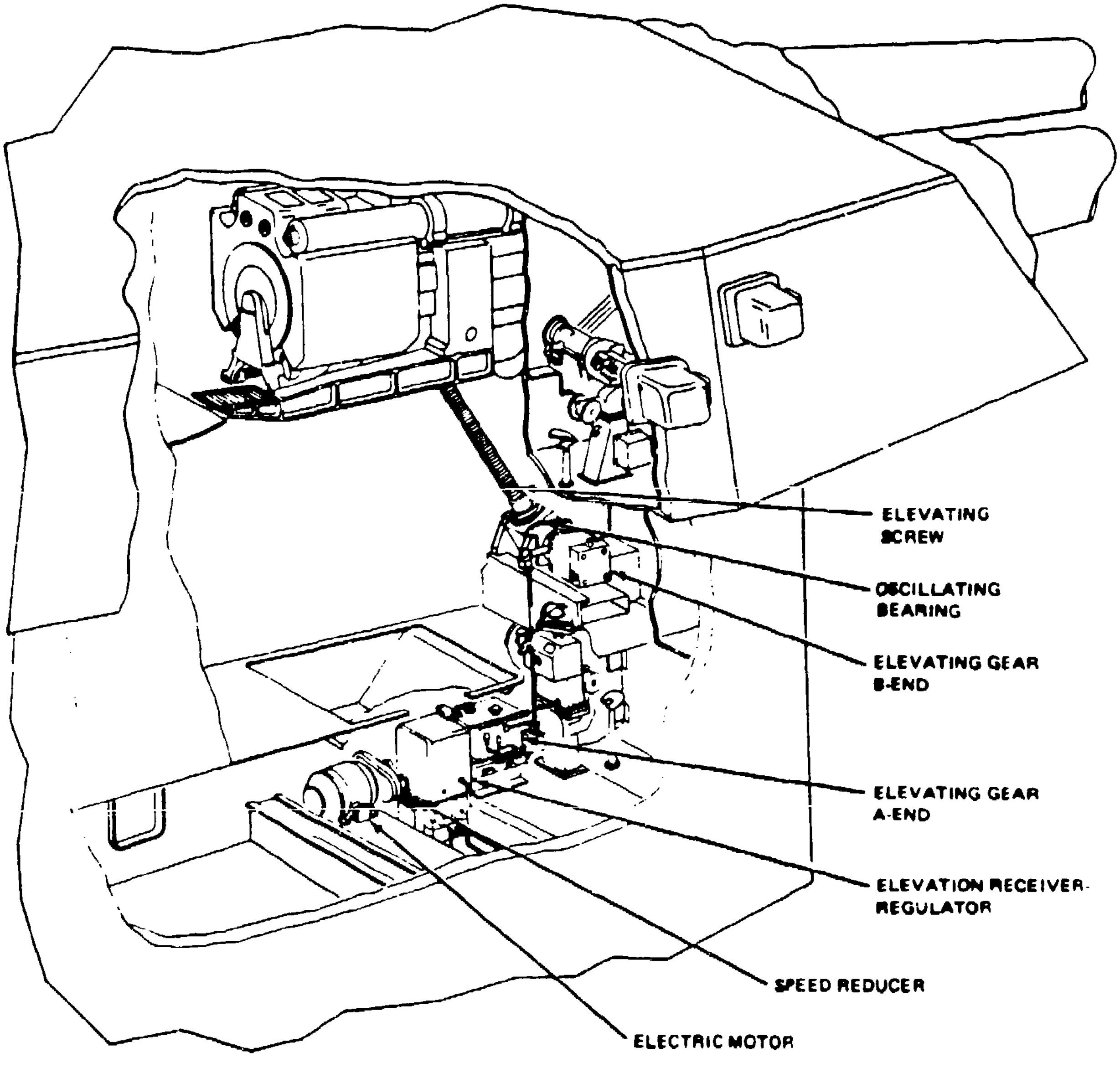

Figure II-1. 16-Inch Elevating Gear Mk 5 Mod 0, General Arrangement.

The effects of long term deactivation made these problems even more difficult to solve. First, although there were experienced technicians to work the problems, only a few had past work experience on this gun system and most of these people hadn't been near this equipment for over thirty years. Accordingly, there was no one who had a complete understanding of the total interrelationship associated with this equipment's operation. Prior to beginning work on the problem, engineering data had to be gathered i.e., main system and control system pressure data, system internal leakage data, and system operating response data, to fully evaluate the effects of the many adjustments required to set up the equipment. In addition, many volumes of technical manuals, old weapon specifications, etc. were researched in the process of this investigation. Accordingly, there was a necessary "learning period". Secondly, a preservative (cosmoline), which was used to preserve the equipment during deactivation, was a major problem that hindered the investigative work. The preservative, because of the long term deactivation period, had become hardened, making it difficult to remove. As the systems were reactivated and operated, this preservative would continually work loose. This material would then clog orifices, etc., in the Servo Control System causing erratic equipment operation which complicated the investigative process.

Eventually, the source of the problem was pinpointed on both guns. For one of these guns, it meant the replacement of a major assembly - the A-end pump. (The other gun was corrected by replacing a major sub-assembly and the fine adjustment of the regulator assy.)

The replacement of this major assembly was an enormous evolution. This unit is installed inside the turret on what is called the "electric deck". This is a compartment directly below the gun pit.

In this area are housed the Power Drive Assemblies for ELEVATION (3), TRAIN (1) and PROJECTILE HOIST (3) systems. It is a very congested area. There are three access holes through which equipment can be removed from this area. These holes are covered with a one inch steel plate. In all cases these plates have equipment that is mounted or routed over them. Therefore, before the plates can be removed, a substantial amount of equipment disassembly was required to clear a path for the removal of these access plates.

On the center gun of turret two, the major assembly to be replaced was the elevating gear A-end pump. The assembled size of this unit is approximately 55 inches high by 30 inches deep by 36 inches wide. The access hole used to remove this unit from the electric deck was only 25 inches by 30 inches in size. Therefore to remove the A-end assembly, the exterior mounted sub components had to be removed and the A-end disassembled into two components: (1) Pump and (2) Control Box. From the upper projectile shell deck the units were lowered through the turret ammunition storage trunks to an outer annular powder handling space at the base of the turret. From there the units were moved aft to the ship's stern via the monorail through the main "Broadway" passageway. There the units were hoisted onto the fantail and then off the ship. This same procedure can be used to remove many of the other equipment (except turret train components) should the need arise.

A final report of the gun oscillation problem which documents the actions taken to repair these problems and the lessons learned while working the problem was published by NAVORDSTA Lousiville (NOSL R-378).

Hydraulic System

When the battleships were originally deactivated, the hydraulic systems in the turrets were preserved by filling them with corrosion preventive compound MIL-C-16173 Grade 2 and then drained. This left a preservative coating on all internal surfaces in the hundreds of pipes and hydraulic components of each turret. Because of the 30 years storage since these systems were originally preserved, a significant amount of the preservative adhering to the internal surfaces had hardened and remains within the system even after repeated flushings. Even today this residual material continues to be broken loose as the systems are operated. The residue causes problems when it lodges in the small orifices and ports in the train and elevation control systems.

To correct this problem a large capacity 0.5 micron filter system with an integral motor/pump assembly was installed on each train and elevation unit during reactivation to continuously filter the fluid during train and elevation operation. These units are off-line low pressure filters mounted in a recirculating loop on the reservoir. The filtration system can operate independent of train and elevation operation since it can filter sump tank oil when the drives are shut down. Fluid is drawn from the existing drain port in the tanks and the filtered fluid returned into the top of the tank.

An off-line low pressure filter mounted in a recirculating loop avoids the problems caused by system flow and pressure surges by placing the filter on a separate loop with its own constant flow, low pressure pump to recirculate fluid from the reservoir. This arrangement provides an ideal, steady-state environment for the filter by isolating it from system flow-and-pressure variations. In addition, filtration in this location will not impede system flow under any circumstances, because flow through the filter is provided by a separate pump, and is totally independent of system flow. Consequently, continuous filtration can be provided by recirculation of the reservoir even when the hydraulic system is not in operation. More efficient contamination control can also be provided in this location, since very fine filtration can be achieved without any restriction on system flow. Since the system fluid ultimately passes through the filter many times, 0.5 micrometer cartridges in this location provide a high level of fluid cleanliness.

Breech Operating Valve

In reactivation of a complex forty-five year old weapon system like the 16"/50 Three Gun Turret you might expect a lot of things not to operate within original design specifications. However, there was only one item on the 16"/50 turret which did not operate as required after being reactivated.

This was a commercial pressure reduction air valve installed on the 16-inch Breech Mechanism to regulate the air pressure to the breech closing control valve. Because of deterioration from age and use, all of the original valves were not able to operate reliably after reactivation. The old valve would not hold the pressure adjustment for a long time.

To eliminate this problem a new commercial pressure reducing valve was found which was a direct replacement for the old valve. The new valve is being installed on the 16-inch turrets by ORDALT 15515. Repair kits are commercially available to repair the new valves. These repair kits are being added to the supply system to assure logistic support for the new valve.

Velocimeter

Because of the desire to increase the accuracy of 16"/50 guns, velocimeters were installed on the battleships. A velocimeter was placed on the top of each turret in line with the center gun. From that position the velocimeter determines the velocity of the projectile when it leaves the barrel. The exit velocity of the last projectile is then transmitted to the fire control computer. The fire control solution is corrected based upon this data thus improving the accuracy of the gun. Prior to installation of the velocimeter the initial velocity of the round was determined by barrel wear measurement and getting a corresponding correction factor from a table. The old method was much less accurate and therefore the gunfire from the turrets was less accurate.

The velocimeter works by emitting a continuous radar beam which is reflected by the projectile. By mixing the reflected signal with part of the transmitter signal, a continuous signal, called a doppler signal is created. The frequency of the doppler signal is directly proportional to the velocity of the projectile.

The first and last part of the trajectory cannot be used for measuring velocity since the radar signal is affected by muzzle flash ionization in the first part, and the signal to noise ratio is not adequate during the last part. Figure II-1 shows the useable part of a trajectory on a graph of velocity vs. distance from an actual radar return.

Therefore, theoretically, a velocimeter does not measure the actual velocity but deduces the muzzle velocity from the velocity data measured on the useable part of the trajectory. Further, the velocity is measured at many evenly spaced points on the useable part of the trajectory to enable the use of extrapolation techniques that accurately calculate what the velocity was at muzzle exit.

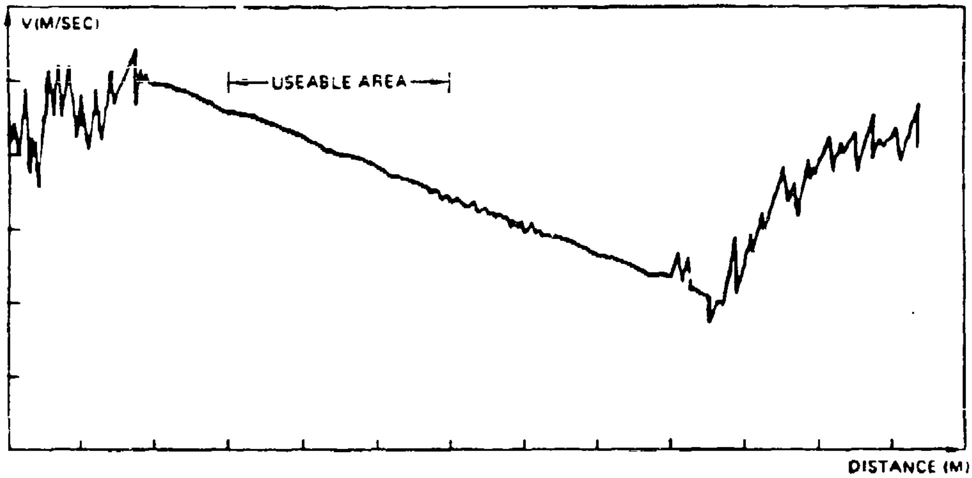

Figure II-1. Usable Part of Trajectory

Sequencial Firing of Guns in a Turret

The preparation for return of the BB-61 class battleships to the fleet included the installation of new modern weapon systems topside. The placements of these was controlled to some degree by the overpressures generated by the 16" inch turrets when they fired.

The placement of equipment on the forward part of the ship was the most critical. The highest dynamic pressure some equipment had previously experienced aboard ship was from a 5-inch gun Based upon available test data, calculations predicted some forward mounted equipment would see a reflective pressure from surrounding bulkheads up to 16.7 psi from one 16-inch gun. This pressure was far in excess of that for which some equipment had been designed and tested.

The problem was further complicated by the fact that overpressure from multiple guns in a turret is additive.

Since the equipment could not withstand the overpressure from the 16"/50 guns, the following options were available:

a. Modify the equipment to withstand the overpressure.
b. Relocate the equipment.
c. Modify the firing sequence of the three guns in a turret.
d. Restrict the 16"/50 turret firing arc.
e. Do not install the equipment in the areas of the ship which receive a high overpressure when the guns fire

A combination of options "c" and "d" were done. The firing arcs of the turrets were reduced by relocating the train limit stops.

Modifying the firing sequence of the three guns in each turret required the development of an ORDALT. ORDALT 15034 added agastat time delay relays and attendant rewiring of the firing circuits for the two outbound guns, while also removing the firing delay coil from the firing circuit for the center gun. The ORDALT was installed on each battleship during reactivation.

III 16-INCH GUN BARREL

Existing 16-Inch Gun Barrel Design

Design of gun barrels are based upon interior ballistics. Interior ballistics is the science of the motion of the projectile and state of the propellant while inside the gun barrel. Studies i this science include the combustion of the powder, pressure developed inside the gun, velocity of the projectile, bore erosion and how these are affected by varying loading conditions.

The relationships of interior ballistics are determined by solving simultaneously equations of motion of the projectile, state of the powder gases and an energy balance equation. A fundamental ballistic equation is derived from the energy equation by substituting the equation of state to express the temperature of the powder gases in terms of pressure and travel of the projectile. Then, the equation of motion for the projectile is used to eliminate the pressure (see Table III-1). With these equations, a program can be developed to produce interior ballistic data.

Table III-1. Interior Ballastic Equations.

EQUATION OF MOTION FOR THE PROJECTILE

$$P = \frac{m}{A} V \frac{dV}{dX}$$

EQUATION OF STATE OF THE POWDER GASES

$$\frac{NFT}{T} = PV_c \left(\frac{X}{X_o} - \frac{\Delta_o}{P} - \frac{\alpha \Delta_o N}{C} \right)$$

ENERGY EQUATION

$$(\bar{\gamma}-1) \frac{1}{2} mV^2 = F\left(N - \frac{NT}{T_o}\right)$$

FUNDAMENTAL BALLISTIC EQUATION

$$\frac{1}{2} mV^2 = \frac{FN}{\bar{\gamma}-1} - \frac{V_c}{\bar{\gamma}-1} \left(\frac{X}{X_o} - \frac{\Delta_o}{P} - \frac{\alpha \Delta_o N}{C} \right) \frac{m}{A} V \frac{dV}{dX}$$

- A - CROSS-SECTIONAL AREA OF THE BORE
- m - EFFECTIVE MASS OF THE PROJECTILE
- P - AVERAGE PRESSURE BEHIND PROJECTILE
- V - PROJECTILE VELOCITY
- X - EFFECTIVE DISTANCE FROM BREECH TO PROJECTILE
- F - POWDER IMPETUS
- N - WEIGHT OF POWDER BURNED
- T - ABSOLUTE TEMPERATURE OF THE GAS
- T_o - ADIABATIC FLAME OR EXPLOSION TEMPERATURE
- V_c - POWDER CHAMBER VOLUME
- P - SOLID POWDER DENSITY
- X_o - EFFECTIVE LENGTH OF THE POWDER CHAMBER
- Δ_o - POWDER LOADING DENSITY
- C - POWDER WEIGHT
- α - CONSTANT BASED ON THE COVOLUME OF POWDER AND GAS

The U.S. Navy has different types of propelling charges for the 16 inch projectiles. To achieve maximum projectile velocity without excessive heat, pressure, or erosion; propellant burning rate must be controlled. The greater the surface area per unit weight of propellant, the faster the burning. The 16 inch gun barrel requires the projectile to travel further than small caliber guns and the powder must burn proportionally longer. To create more surface area, the 16 inch propellant has seven perforations compared to one or no perforations for guns 40-mm or smaller (see Figure III-1). Powder grain size, charge weight, and loading density are also varied to achieve optimum loading conditions for firing.

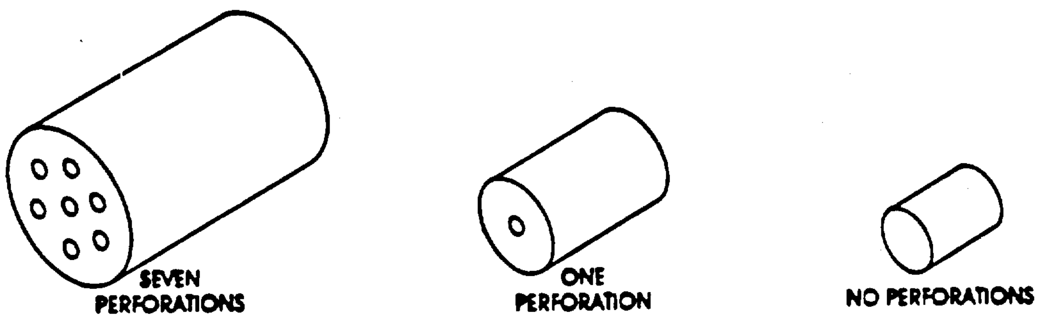

Figure III-1. Types of Propellants.

Varying loading conditions directly affects the interior ballistics of the 16 inch gun. An increase in the propellant burning rate, charge weight, or loading density causes an increase in pressure and velocity and a decrease in the amount of projectile travel before maximum pressure is reached (see Figure III-2). Erosion of the gun barrel chamber and bore lowers pressure and projectile velocity.

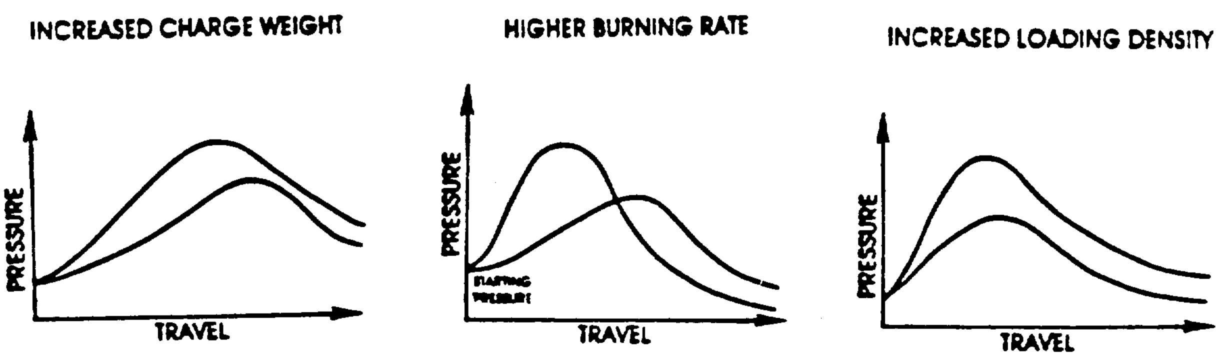

Figure III-2. Typical Pressure vs Travel Curves.

There are two different weights for projectiles being used in the 16 inch guns. They are the high capacity (HC) and armor piercing (AP) projectiles (1900 lbs and 2700 lbs respectively). These projectiles are normally fired with a full charge weight of 660 lbs. Since they are lighter, HC projectiles have a higher muzzle velocity than the AP projectiles. Depending on loading conditions, normal projectile muzzle velocity is around 2500 ft/s for the AP projectile and 2700 ft/s for the HC projectile. Interior ballistic programs can be used to predict data for various conditions (see Figures III-3,4,5). Research is currently underway on a proposed 13 inch sabot projectile with an estimated weight of 1200 lbs and a new propellant charge resulting in increased muzzle velocity.

Using the same weight of charge, a faster powder burning rate produces a higher maximum pressure than a slow rate, and reaches this maximum sooner in the travel of the projectile. Increasing the weight of the charge of a given powder and grain size increases the maximum pressure and causes this maximum to occur earlier in the travel of the projectile. These increases generally cause a velocity increase depending on gun barrel wear and weight of the projectile. Erosion of the gun barrel and increasing the weight of a projectile reduces muzzle velocity.

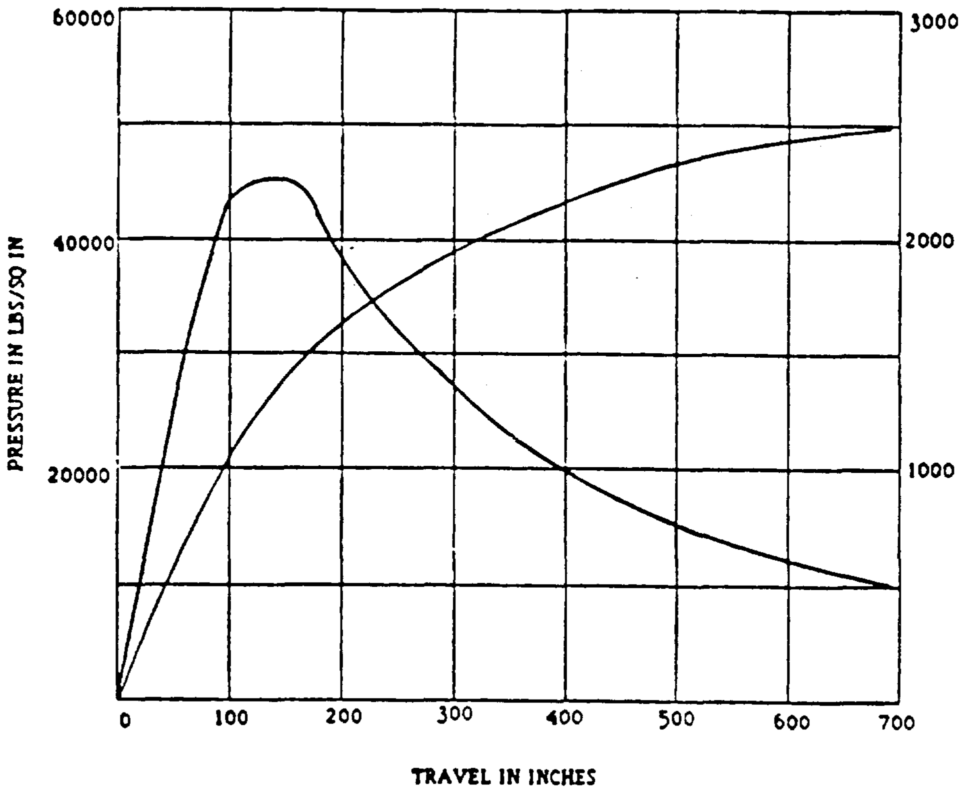

Figure III-3. Pressure and Velocity as Functions of Travel for the 16"/50 Gun Barrel (AP Projectile)

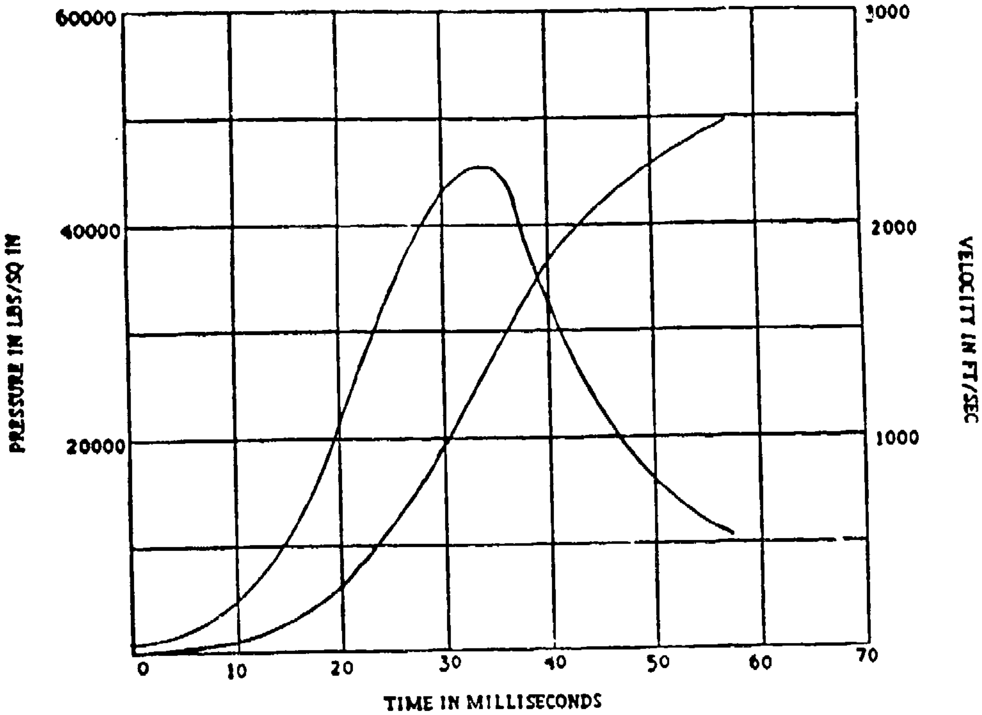

Figure III-4. Pressure ıd Velocity as Functions of Time for the 16"/50 Gun Barrel (AP Projectile)

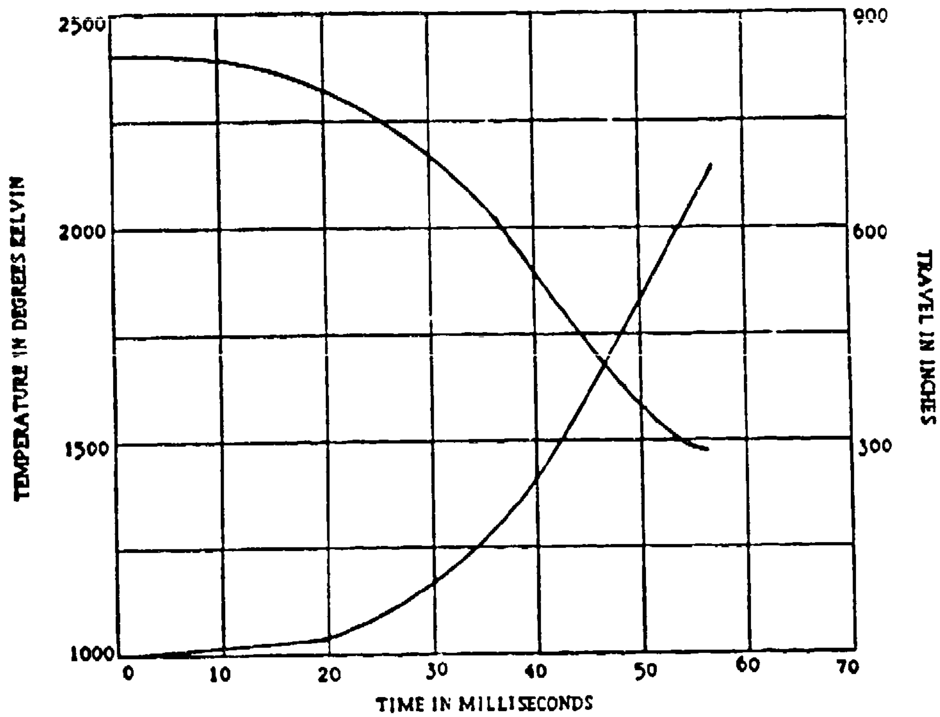

Figure III-5. Gas Temperature and Travel as Functions of Time for the 16"/50 Gun Barrel (AP Projectile).

Table III-2 lists the physical characteristics of the 16"/50 Mark 7 Gun Barrel used in the 16-Inch Three Gun Turrets on the BB-61 class.

Table III-2. 16"/50 Gun Barrel Data.

Component	Dimensions
Gun	Length 816 inches Weight 239,156 lbs (with screw box liner) 292,000 lbs (with recoiling parts)
Rear cylinder	Outside diameter 49 inches
Slide cylinder	Outside diameter 23 inches
Muzzle	Outside diameter 23.5 inches
Liner at muzzle	Outside diameter 18.46 inches
Liner at rear	Outside diameter 22.10 inches
Slide cylinder	Length 337 inches
Bore	Diameter 16.00 inches Length 800.00 inches
Powder chamber	Length 105.82 inches Volume 27,000 cubic inches Choke diameter 17.50 inches Bore diameter 18.35 inches
Rifling	Length 682.46 inches Plating length 690 inches Groove depth 0.15 inches Number of grooves 96 Uniform right-hand twist

Existing 16-Inch Gun Barrel Design

A gun barrel according to OP1A, Naval Ordnance Glossary, 22 OCT 1952, obsolete, is "a tubular structure in which ammunition is fired and which controls initial direction of the projectile." This simple definition contains no hint of the difficulties involved in gun barrel manufacture.

Manufacture of large caliber naval gun barrels in the 1930's and 40's was a technological challenge. Because of low grade steels and the limitations of available forging capabilities, gun barrels were constructed of a series of concentric layers of metal - liner, tube, jacket, and hoops shrunk fit together. Figure III-6 depicts the construction of 16"/50 Gun Barrel.

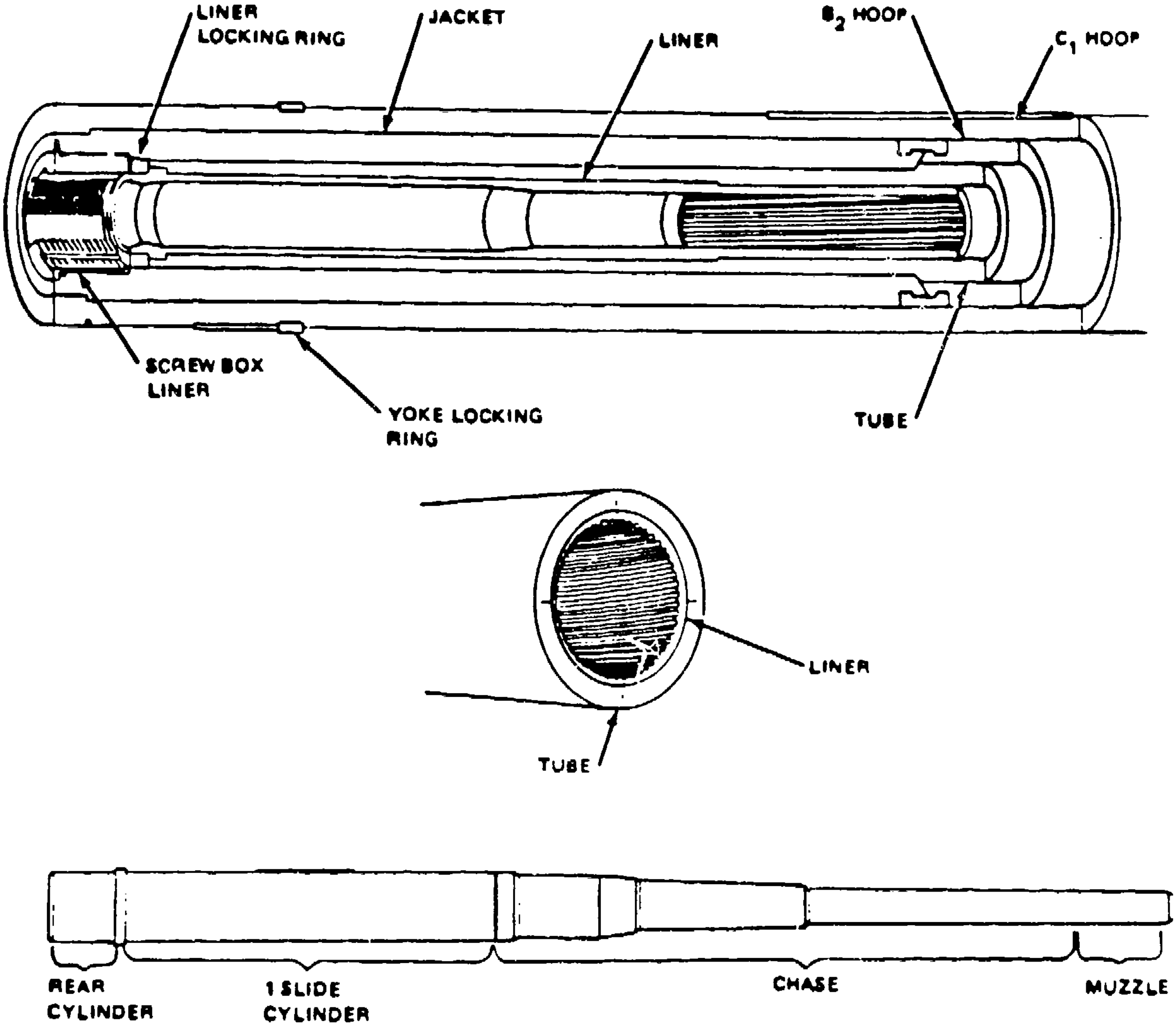

Figure III-6. 16"/50 Gun Barrel.

The shrunk fit asembly was accomplished in a deep electrically heated pit. First the jacket was heated to cause expansion. A tube was then placed in the pit, breech end down, with a centering mandril extending up into the bore for support. Cold circulating water cooled the tube and prevented it from expanding. The jacket, which had expanded in diameter, was then slipped on over the tube. Cooled, the jacket contracted and gripped the tube firmly and evenly, imparting extra strength through what is now known as autofrettage. Autofrettage is the creation of internal stresses in a tube by internal pressures. In the built-up barrel assemblies these internal stresses were created by not allowing the pieces to return to their original diameter after being expanded by heat during assembly. Before the assembly process began the outside diameter of the inside cylinder and the inside diameter of the cylinder being placed over it were machined so that there would be an interference fit after assembly. The addition of hoops on the outside of the assembly completed the first stage of the gun barrel construction. The assembled gun was then ready for conical boring of the tube which preceded the insertion of the liner. In the meantime the liner was turned, bored, measured, and inspected. The same process used in the first assembly stage was employed to insert the liner. The tube with its jacket was placed in the pit, muzzle end down, and expanded under high temperatures. The liner, filled with water and suspended above the gun, was slowly lowered into place. The gun gradually cooled and contracted about the liner. With this process completed, the built-up mass which was to become a gun barrel was finished.

This shrink fit assembly technique used to make large caliber gun barrels is a very critical process. It is an art requiring a well coordinated crew. The heat input and the flow of the cooling water had to be controlled exactly to assure the assembly went together properly and as the two mating pieces reached a uniform temperature mating surfaces did not pull apart longitudinally weakening the strength of the gun barrel.

Other important operations had to be performed, such as machining of the bore of the liner to final diameter, and chambering of the breech end of the bore for the powder chamber.

The only remaining operations included machining of the exterior to final dimensions and machining of the rifling in the liner. Some 750 separate cuts are required to machine the rifling in a 16-inch gun barrel.

<u>16-Inch Gun Barrel Installation/Exchange</u>

Just as manufacturing a 16-inch gun barrel is considerably more complex and difficult, the regunning of a 16-inch gun barrel aboard a ship is more difficult than any other gun barrel in the fleet today.

Before a regunning can be started, shoring must be placed between the two decks below the main deck. Then on the top of the main deck shoring must be built up to hold two rails paralleled to the barrel. Next the barrel is disassembled from the breech and yoke and slowly pulled out of the turret while riding on three specially made cars on the rails. When the barrel is all the way out of the turret, it is lifted off of the cars and the new barrel placed on the cars and the process reversed.

Relining of a 16-Inch Gun Barrel

A 16-inch gun barrel does not have to be scrapped when it is worn out in service because of its built-up type construction. After the barrel is removed from service it is shipped back to a manufacturing facility. There the complete assembly is placed in the furnace pits used to heat the barrel during assembly. Cooling water is then piped through the interior of the barrel. While the assembly is being heated large jacks pull on the liner until it is broken loose from the assembly. The liner is then removed from the assembly and a new liner placed into the old assembly. The new assembly is machined internally to become a new gun barrel ready for proof-firing and issue to the fleet.

New 16-Inch Gun Barrel Design

Because of the superior steels now available and the increased capabilities of the forging industry, a much simpler 16-inch gun barrel design is now possible. The new 16-inch gun barrel would be made from a one piece forging of high strength steel in accordance with MIL-S-46119 with an elastic limit of 160,000 psi to 180,000 psi used in all gun barrels currently being manufactured. The monoblock 16-inch gun barrel would have an adapter for interface with the existing recoil system, slide assembly and yoke assembly, and to assure proper operation of the turret elevation drive systems.

As an alternative to an all new gun barrel, some additional strength and wear life can be gained by relining existing worn 16-inch gun barrels with liners made from MIL-S-46119 steel.

IV RELATED PROGRAMS

Three major changes to the 16-inch ammunition used by the BB-61 class ships have either been completed or are in the design phase as a result of the reactivation program.

To reduce the wear of the gun barrel, which originally had a life of only 300 rounds, a wear reducing jacket is being attached to all full charge propellant bags. The wear reducing agent reduces the heat input to the barrel which is the major cause of wear of the barrel.

Tests conducted at the beginning of the battleships reactivation program determined that the powder for the 16"/45 guns did not deteriorate in storage as much as the 16"/50 powder and gave more consistent muzzle velocities which meant improved accuracy. Therefore, 16"/45 powder was loaded for use by the battleships when firing the 1900 pound projectiles. The heavy 2700 pound armor piercing projectile can not be fired with the 16'/45 powder because the faster burning rate of that powder would result in too high of pressure inside the gun barrel.

Longer range improvements are also in work for the 16-inch gun system. These improvements include 16-inch projectiles, a longer range 13-inch sabot projectile and improved fire control system components.

V SUMMARY

All twelve 16"/50 turrets on the BB-61 class ships were in excellent conditions when inspected pricr to reactivation. The reactivation of these turrets have been accomplished to date with no major problems. The biggest effort required to reactivate the turrets have been the cleaning of the preservative from the inside of the hydraulic systems. The equipment had not rusted or deteriorated since deactivation. Generally a systematic cleaning, reassembling, adjustment and testing was all that was needed to reactivate the turrets.

The 16-inch turret is operated by a 77 man crew who properly trained can fire two rounds a minute from each of the three guns in a turret. While this firing rate may seem slow compared to modern gun systems, it must be realized that two rounds per minute from the three guns of a turret can put over 16,000 pounds of ordnance on a target in a minute. A single HC round was able to clear a helicopter landing zone 200 yards in diameter out of dense, triple-canopy jungle and defoliate trees and undergrowth for another 300-400 yards in Vietnam. The rounds created craters 50 feet across and over 20 feet deep. A broadside from an IOWA class ship can level almost anything standing within a one square mile area. These guns were never intended to be fired rapidly but are to be aimed deliberately at targets.

By reactivating the 16-inch turrets the Navy has obtained a highly capable weapon system which can engage a wide range of surface targets in all weather conditions for a long period of time better than any other system the Navy has in the Fleet. Even in peace time the 16-inch turrets on the battleships provide an impressive naval presence.

APPENDIX

Table A-1. United States Navy Battleships

NAME	COMMISSIONED(1)	MAIN BATTERY	SECONDARY BATTERY
BB1 INDIANA	11/20/95	(4) 13"/35 (8) 8"/35 (4) 6"/40	(20) 6 Pdr (6) 1 Pdr
BB2 MASSACHUSETTS	6/10/96	(4) 13"/35 (8) 8"/35 (4) 6"/40	(20) 6 Pdr (6) 1 Pdr
BB3 OREGON	7/15/96	(4) 13"/35 (8) 8"/35 (4) 6"/40	(20) 6 Pdr (6) 1 Pdr
BB4 IOWA	6/16/97	(4) 12"/35 (8) 8"/35 (4) 4"/40	(20) 6 Pdr (4) 1 Pdr (4) .30 cal mg
BB5 KEARSARGE	2/20/00	(4) 13"/35 (4) 8"/35 (14) 5"/40	(20) 6 Pdr (19) 1 Pdr (2) 6mm mg
BB6 KENTUCKY	5/15/00	(4) 13"/35 (4) 8"/35 (14) 5"/40	(20) 6 Pdr (8) 1 Pdr (8) 6mm mg
BB7 ILLINOIS	9/16/01	(4) 13"/35 (14) 6"/40	(16) 6 Pdr (7) 1 Pdr (4) .30 cal mg
BB8 ALABAMA	10/16/00	(4) 13"/35 (14) 6"/40	(16) 6 Pdr (4) 1 Pdr
BB9 WISCONSIN	2/04/01	(4) 13"/35 (14) 6"/40	(16) 6 Pdr (6) 1 Pdr (4) .30 cal mg
BB10 MAINE	12/28/02	(4) 12"/40 (16) 6"/50	(6) 3"/50 (8) 3 Pdr (6) 1 Pdr (2) .30 cal mg
BB11 MISSOURI	12/01/03	(4) 12"/40 (16) 6"/50	(6) 3"/50 (8) 3 Pdr
BB12 OHIO	10/04/04	(4) 12"/40 (16) 6"/50	(6) 3"/50 (8) 3 Pdr (14) 1 Pdr (2) .30 cal mg
BB13 VIRGINIA	5/07/06	(4) 12"/40 (8) 8"/45 (12) 6"/50	(12) 3"/50 (24) 1 Pdr (4) .30 cal mg
BB14 NEBRASKA (EX-PENNSYLVANIA)	7/01/07	(4) 12"/40 (8) 8"/45 (12) 6"/50	(12) 3"/50 (2) 1 Pdr (2) .30 cal mg (2) .30 gatling
BB15 GEORGIA	9/24/06	(4) 12"/40 (8) 8"/45 (12) 6"/50	(12) 3"/50 (4) 3 Pdr (2) 1 Pdr
BB16 NEW JERSEY	5/12/06	(4) 12"/40 (8) 8"/45 (12) 6"/50	(12) 3"/50 (12) 3 Pdr (2) 1 Pdr (4) .30 cal mg
BB17 RHODE ISALND	2/19/06	(4) 12"/40 (8) 8"/45 (12) 6"/50	(12) 3"/50 (2) 1 Pdr
BB18 CONNECTICUT	9/29/06	(4) 12"/45 (8) 8"/45 (12) 7"/45	(20) 3"/50 (8) 3 Pdr (4) 1 Pdr (4) .30 mg (2) .30 gatling
BB19 LOUISIANA	6/02/06	(4) 12"/45 (8) 8"/45 (12) 7"/45	(20) 3"/50 (2) 1 Pdr
BB20 VERMONT	3/04/07	(4) 12"/45 (8) 8"/45 (12) 7"/45	(20) 3"/50 (2) 1 Pdr (6) .30 gatling
BB21 KANSAS	4/18/07	(4) 12"/45 (8) 8"/45 (12) 7"/45	(20) 3"/50 (2) 1 Pdr (2) .30 mg
BB22 MINNESOTA	3/09/07	(4) 12"/45 (8) 8"/45 (12) 7"/45	(20) 3"/50 (2) .30 mg
BB23 MISSISSIPPI	2/01/08	(4) 12"/45 (8) 8"/45 (8) 7"/45	(12) 3"/50 (2) 3 Pdr (2) 1 Pdr
BB24 IDAHO	4/01/08	(4) 12"/45 (8) 8"/45 (8) 7"/45	(12) 3"/50 (2) 1 Pdr (6) .30 mg
BB25 NEW HAMPSHIRE	3/09/08	(4) 12"/45 (8) 8"/45 (12) 7"/45	(20) 3"/50
BB26 SOUTH CAROLINA	3/01/10	(8) 12"/45	(22) 3"/50
BB27 MICHIGAN	1/04/10	(8) 12"/45	(22) 3"/50
BB28 DELAWARE	4/04/10	(10) 12"/45	(14) 5"/50
BB29 NORTH DAKOTA	4/11/10	(10) 12"/45	(14) 5"/50
BB30 FLORIDA	9/15/11	(10) 12"/45	(16) 5"/51
BB31 UTAH	8/31/11	(10) 12"/45	(16) 5"/51
BB32 WYOMING	9/25/12	(12) 12"/50	(21) 5"/51
BB33 ARKANSAS	9/17/12	(12) 12"/50	(21) 5"/51
BB34 NEW YORK	4/15/14	(10) 14"/45	(21) 5"/51
BB35 TEXAS	3/12/14	(10) 14"/45	(21) 5"/51
BB36 NEVADA	3/11/16	(10) 14"/45	(21) 5"/51
BB37 OKLAHOMA	5/02/16	(10) 14"/45	(21) 5"/51
BB38 PENNSYLVANIA	6/12/16	(12) 14"/45	(22) 5"/51
BB39 ARIZONA	10/17/16	(12) 14"/45	(22) 5"/51
BB40 NEW MEXICO (EX-CALIFORNIA)	5/20/18	(12) 14"/50	(14) 5"/51 (4) 3"/50
BB41 MISSISSIPPI	12/18/17	(12) 14"/50	(14) 5"/51 (4) 3"/50
BB42 IDAHO	3/24/19	(12) 14"/50	(14) 5"/51 (4) 3"/50
BB43 TENNESSEE	6/03/20	(12) 14"/50	(14) 5"/51 (4) 3"/50AA
BB44 CALIFORNIA	8/10/21	(12) 14"/50	(14) 5"/51 (4) 3"/50AA
BB45 COLORADO	8/30/23	(8) 16"/45	(12) 5"/51 (8) 3"/50AA
BB46 MARYLAND	7/21/21	(8) 16"/45	(14) 5"/51 (4) 3"/50AA
BB47 WASHINGTON	Cancelled		
BB48 WEST VIRGINIA	12/01/23	(8) 16"/45	(12) 5"/51 (8) 3"/50AA
BB49 SOUTH DAKOTA	Cancelled		

APPENDIX

Table A-1. United States Navy Battleships
(continued)

NAME	COMMISSIONED(1)	MAIN BATTERY	SECONDARY BATTERY
BB50 INDIANA	Cancelled		
BB51 MONTANA	Cancelled		
BB52 NORTH CAROLINA	Cancelled		
BB53 IOWA	Cancelled		
BB54 MASSACHUSETTS	Cancelled		
BB55 NORTH CAROLINA	4/09/41	(9) 16"/45	(20) 5"/38 (4) quad 1.1" (12) .50 cal AA mg
BB56 WASHINGTON	5/15/41	(9) 16"/45	(20) 5"/38 (4) quad 1.1" (12) .50 cal AA mg
BB57 SOUTH DAKOTA	3/20/42	(9) 16"/45	(16) 5"/38 (8) quad 1.1"
BB58 INDIANA	4/30/42	(9) 16"/45	(20) 5"/38 (6) quad 40mm (16) 20mm
BB59 MASSACHUSETTS	5/12/42	(9) 16"/45	(20) 5"/38 (6) quad 40mm (35) 20mm
BB60 ALABAMA	8/16/42	(9) 16"/45	(20) 5"/38 (6) quad 40mm (22) 20mm
BB61 IOWA	2/22/43	(9) 16"/50	(20) 5"/38 (15) quad 40mm (60) 20mm
BB62 NEW JERSEY	5/23/43	(9) 16"/50	(20) 5"/38 (16) quad 40mm (60) 20mm
BB63 MISSOURI	6/11/44	(9) 16"/50	(20) 5"/38 (20) quad 40mm (49) 20mm
BB64 WISCONSIN	4/16/44	(9) 16"/50	(20) 5"/38 (20) quad 40mm (49) 20mm
BB65 ILLINOIS	Cancelled	(9) 16"/50	(20) 5"/38 (20) quad 40mm (49) 20mm
BB66 KENTUCKY	Suspended[2]	(9) 16"/50	(20) 5"/38 (20) quad 40mm (49) 20mm
BB67 MONTANA	Cancelled	(12) 16"/50	(20) 5"/54 (8) quad 40mm
BB68 OHIO	Cancelled	(12) 16"/50	(20) 5"/54 (8) quad 40mm
BB69 MAINE	Cancelled	(12) 16"/50	(20) 5"/54 (8) quad 40mm
BB70 NEW HAMPSHIRE	Cancelled	(12) 16"/50	(20) 5"/54 (8) quad 40mm
BB71 LOUISIANA	Cancelled	(12) 16"/50	(20) 5"/54 (8) quad 40mm

[1]Commissioned date is date ship was originally commissioned.
[2]Construction was started but suspended with ship approximately 60 percent complete.