Hit-by-Hit Analysis

Hit 1 – Starboard 20 mm Gun Shield

The first hit listed in the BuShips report is an estimated 6-inch projectile that nicked the top of the starboard 20 mm gun shield near Frame 17 without detonating.[11]

Analysis of impact

There is no photograph of this damage in the damage report and a search of the USN archives did not find one. There are no inconsistencies with BuShip's estimate and, from the shell trajectory; this damage may have been caused by *Kirishima*'s secondary battery during the 0101 to 0110 time period.

Hit 2 – Frame 30 on Starboard Bow

From the BuShips damage report:

> 14. This projectile detonated upon impact at Frame 30 starboard blowing a 5 by 4-foot hole in the sheer strake about four feet below the main deck. The force of the detonation passes inboard and aft and blew an 8 by 6-foot hole in bulkhead 31 just below the main deck and 2 feet 6-inches inboard of the starboard side. The main deck was bulged up about 2-1/2 inches over a 5 by 4-foot area just inboard of the starboard shell and forward of bulkhead 31. The half deck was dished down about 4-inches over an 8 by 6-foot area adjacent to the starboard shell and forward side of bulkhead 31. The 42-inch ventilation duct on exhaust system H2-33-1 was blown out. Expanded metal partitions, doors, shelves and bins in AH-219-L were demolished. It is estimated that this was an 8-inch AP projectile.
>
> 15. Six holes occurred in the starboard shell plating between frames 29 and 32 just below hit 2 (photograph 1) [Ed's note – this is reproduced in this essay as Figure 8]. A seam in the shell about 1 foot above the second deck was opened between frames 30-1/2 and 32; lockers, ventilation ducts, insulation and sheathing were damaged in A-207-L; and fragments ignited a bedding bag in A-206-L and clothes in two lockers in A-207-L. Although there was no area within the ship where the reported extent of damage would indicate a point of detonation and there were no exit holes, *South Dakota* reported that the holes in the shell had been made by six 6-inch hits. However, from their location, the extent and nature of the damage and knowledge of the characteristics of Japanese projectiles, it is believed that these holes were made by the cap head and fragments of the windshield of the projectile of hit No. 2.[12]

Damage from Hit 2 as described in *South Dakota*'s Action Report:

> **AH-219L – Ward Room Cigar Mess Stores**
>
> Exhaust system H2-33-1 – 16' ventilation duct blown out, seams torn, and all metal distorted
> Gaping hole 8' through 30 lb. plate extending from main deck to 6' below main deck.

[11] BuShips War Damage Report # 57, page 4
[12] BuShips War Damage Report # 57, page 4

One section 4’ by 8’ of main deck was blown upward 4”.
One Transverse 6” by 14” I beam severed and blown out from shell plating starboard to a point 8’ inboard.
All intake and exhaust ventilation ducts demolished.
All metal partitions, doors, boundary angles, shelving and bins demolished.
One section of deck 4’ by 6’ between frames 29 and 31 starboard badly distorted.

A-206L

16” x 24” hole.
14” x 14” hole.
10” x 12” hole.
All above in shell plating 5’ above deck level between frames 29 and 31 starboard.
Top seam in shell plating 1’ above deck level frame 30½ blown open and rivets sheared.
3 36” x 7’ panels of sheathing and insulation were blown out.
1¼” fuel ventilation line severed at shell plating.

A-207L

6’ of lapped seam blown open and all rivets sheared 1’ above deck [level].
3’ of lapped seam blown open and rivets sheared 8’ above deck.
Upper section of watertight bulkhead 31 blown open leaving a hole 9’ by 6’ from starboard shell plating to centerline.
2 4” by 5” T bar bulkhead stiffeners were severed 9’ above deck plating.
Intake 36” circular ventilation duct system demolished.
1 12’ section of exhaust ventilation duct and watertight closure demolished.
18’ of 8’ supply ventilation duct and brackets demolished.
4 panels of 12’ by 12’ insulation and sheathing demolished.
1 8’ section of 3/8” x 6” x 10” I beam supporting deck overhead severely twisted, distorted between frames 31 and 33.
1 12’ section of 2” fuel oil air escape piping twisted and broken.
Pea coat locker demolished.
Longitudinal I beam supporting main deck overhead fractured between frames 32 and 33.
8” by 14” hole in starboard longitudinal 10’ inboard blower room, bulkhead stiffener fractured 4’ above deck level.
4 triple units C clothing lockers blown open by shrapnel.[13]

[13] USS *South Dakota* Action Report, Enclosure D, pages 8 and 9

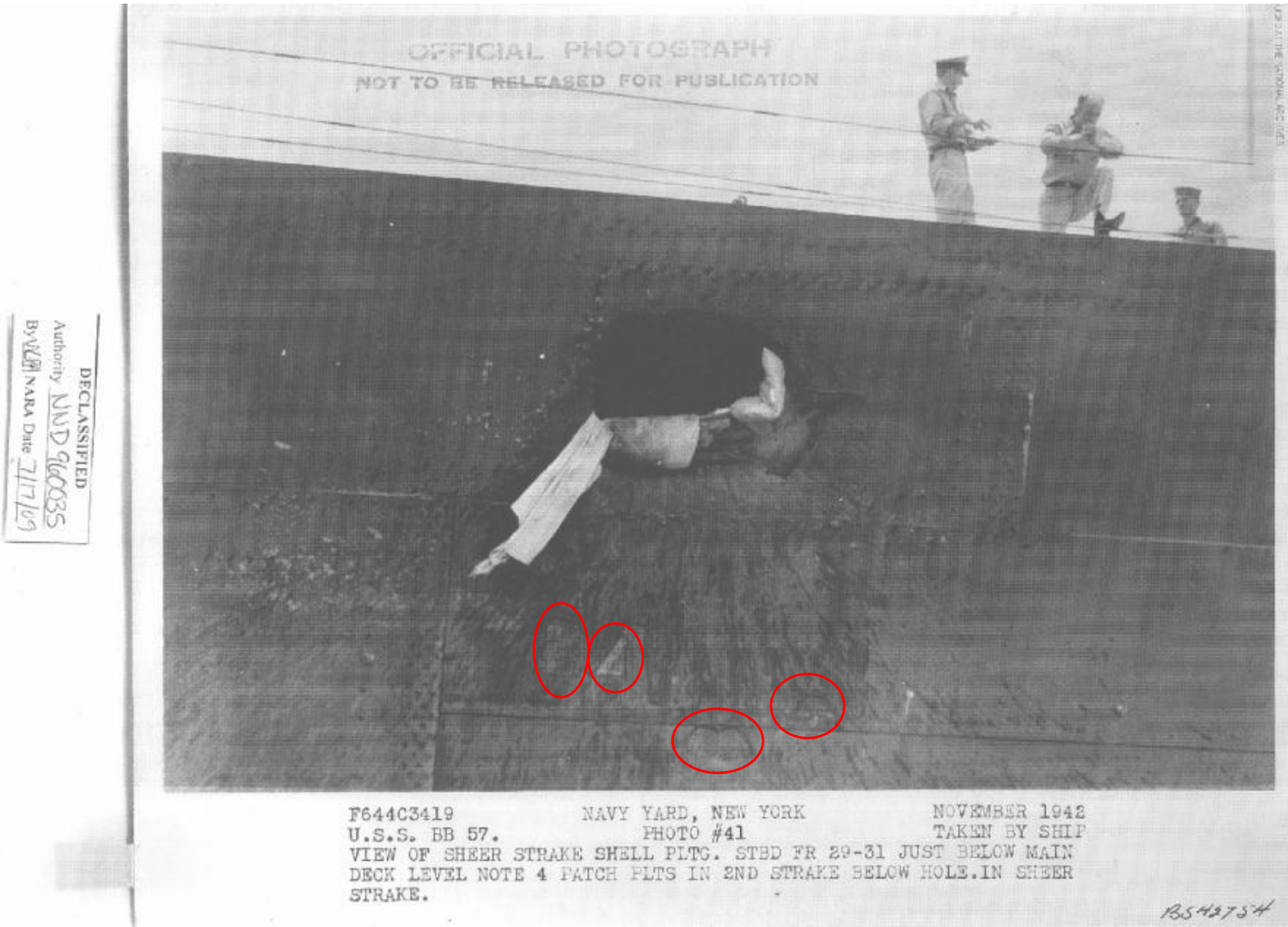

Figure 8 – Hit 2 – Starboard Bow at Frame 30

It is difficult to make them out in this photograph, but the original caption on this photograph notes that there are four patches on the hull below the large hole caused by Hit 2 and these have been highlighted by the addition of red ovals to this photograph. From comparing Plate 1 in the BuShips' report (shown as Figure 118 in this essay) with this photograph, it appears that one additional hole is covered up by the canvas hanging out of the left side of the Hit 2 hole. The sixth hole mentioned in BuShips' report is not shown here as it is below the lower edge of this photograph.

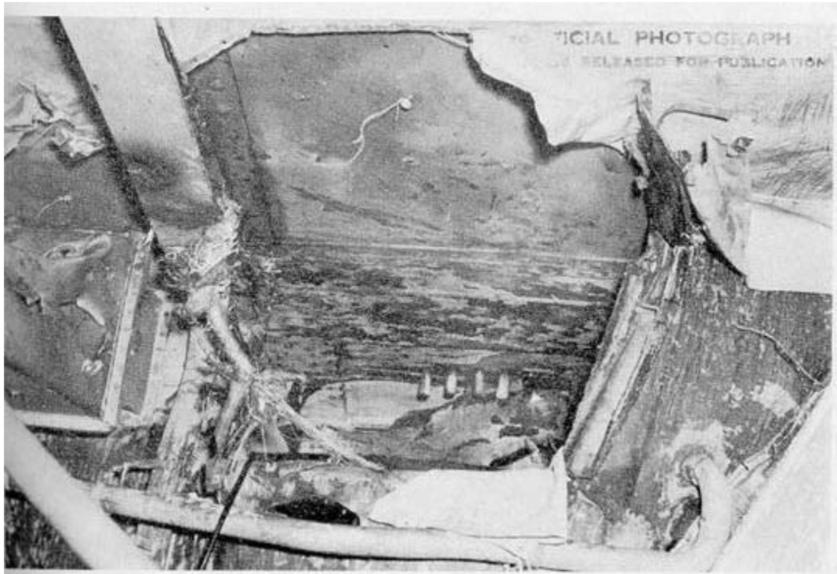

Photo 2: Hit No. 2. Looking forward at underside of main deck through hole in starboard side of bulkhead 31.

Figure 9 – Hit 2 – Interior Damage

Analysis of impact

The first inconsistency in BuShips' report for this hit is that it concludes that the hit was made by an 8-inch AP projectile, yet the shell actually detonated on impact, which would normally indicate a nose-fuzed projectile. There is no evidence in any Japanese or USN document that the authors have found that would support a conclusion that Japanese AP projectiles of any caliber would detonate on impact on light plates. In fact, with their long fuze delay of 0.4 seconds and very small burster charge (6.85 lbs TNA), the Japanese 8-inch Type 91 AP projectile was incapable of producing the amount of damage that is documented for this impact. For these reasons, the authors of this essay have concluded that the hit must have actually been from an HE projectile.

The next inconsistency in BuShip's original report is that it has Hit 2 striking on 0.75-inches of STS steel with the six lower holes being made in HTS steel (see Figure 118). However, the Builder Plans for *South Dakota* show that the sheer strake where Hit 2 landed was made from HTS steel. In order to have a complete analysis in case the Builder Plans are in error, we will consider both types of steel in our damage calculations below.

The first step is to determine the caliber of the projectile that made this hit. During the battle, *Atago* fired six 8-inch HE shells and *Kirishima* fired twenty-two 14-inch HE shells.[14] Both of these used instantaneous nose fuzes, which mean that both would have exploded on impact against plates as thin as 0.25 inches thick. This means that the 0.75-inch thick outer shell of *South Dakota* would have been more than enough to detonate these shells on impact, regardless of whether the plate was made with HTS or STS steel.

[14] *Atago* Direct Action Report and *Shikikan-tachi no Taiheiyō Sensō* [The Pacific War as Described by the Senior Officers]

Nathan Okun has developed an equation for nose-fuzed HE projectiles that detonate on impact with thin plates that can be used to determine the approximate amount of damage that the projectile caused to the plate:

$$\mathbf{Tphe(noADF) = (2.576 \times 10^{-20})(D)V^{5.6084}COS[2(Ob2 - 45^{o})] + (0.156)(D)} \qquad (\textit{Equation 1})$$

This equation computes for US Navy World War II STS and Class "B" armor plate[15] a thickness "T" where a hole of roughly caliber width will be punched entirely through by all "typical" instantaneous-impact-nose-fuzed HE projectiles that do not have an Auxiliary Detonating Fuze (ADF, used only in most World War II-era US Navy nose-fuzed HE projectiles); hence the "(noADF)" part of the label to separate it from another formula for T sometimes used with ADF-equipped shells.

This equation also applies to those World War II time-nose-fuze or VT-fuzed HE shells when the nose fuze gets crushed by a plate impact prior to the fuze setting off the shell in its normal manner (high-order detonation), as well as even applying to ADF-equipped shells under some impact conditions.

The "phe" label in this equation stands for "Penetration by HE Shell." In addition to the shell's minimum explosive filler detonation and fragmentation effects part, "(0.156)(D)," it uses the shell's impact velocity (V), angle of impact (Ob2, the impact angle Ob limited as to the values that can be used in this formula), and diameter ("caliber," D). These formulae only apply as-is to the plate directly in front of the shell that is impacted by the shell's nose. It can be used for nearby plates to the side by setting V to zero and only using the "(0.156)(D)" blast/fragmentation component.

All units in this formula are English units: T (thickness of plate) & D (diameter of projectile) are in inches, V (Striking Velocity) is in feet per second, and Ob2 (Obliquity or impact angle with zero meaning right angles to the plate face) is in degrees.

Ob2 is set equal to 45 degrees (PI/4 radians in most computer languages) whenever Ob2 is less than or equal to 45 degrees. That is, under 45 degrees from normal (right angles), obliquity has no effect whatsoever and the COSINE term is always set to 1.00. Only over 45 degrees does obliquity start to have any effect. This is because if you look at the typical explosion pattern of a HE shell, there is a narrow jet coming out the nose aligned with the centerline of the shell when it goes off, made up of somewhat larger, but still small, pieces, compared to the sideways spray. This can assist in punching a small hole in the center of the impact site, but since it is pushed into the dent of the impact when the shell detonates, the angle of impact doesn't mean much. Then there is a kind of "dead area" over a conical arc to about 45 degrees to each side surrounding the nose, with almost no fragments whatsoever in it – just a few tiny fragments of the pointed nose region. These have little damage-causing effect into the blast-induced 0.156-caliber-thick-or-less plate hole. From the 45 degree angle to roughly 135 degrees (tilted forward due to the speed of the shell a little bit), there are the mass of the small, very high speed fragments created by the detonation, most in the 70-110-degree arc ring around the projectile middle (if the projectile is stationary, otherwise tilted forward a little). This is why you have to have the obliquity change to at least 45 degrees to begin to see any difference in the effects on a plate in front of the shell nose. However, this side spray effect does not make the hole larger than the 0.156-caliber stationary projectile value, since the blast/spray effect is what was calculated to give the 0.156-caliber non-moving projectile value in the first place. Increasing the obliquity over 45 degrees rapidly causes the velocity effect on increasing the depth

[15] US Class "B" armor, STS and HTS are all "homogeneous" types, that is, they have a uniform quality throughout their thicknesses. By contrast, US Class "A" armor is Face Hardened.

to go away until at angles near 90 degrees obliquity (shallow glance just barely able to set off the nose fuze) the velocity has no effect at all and the shell acts like it is standing still when it detonates, as far as penetration of the hit plate is concerned.

Weaker plates with lower quality factors – HTS has a Q(armor) quotient of 0.85 – allow deeper penetrations, inversely proportional in depth to the quality factor of that material (if there were plates BETTER than STS, then the thickness T penetrated would go down by dividing by a value larger than 1.00 (= World War II STS Q(armor)). We call this value **Tmod**, and it is equal to T/[Q(armor)]. Thus, if an STS plate of T = 1 inch would just give a caliber-wide hole under the impact conditions involved, then a plate made with the lower-quality HTS steel would have Tmod = 1 / 0.85 = 1.176, which means that the HTS plate would need to be 1.176 inches thick in order to have the same size hole made in it.

After calculating Tmod per the Plate Quality factor as described in the above paragraph, the diameter of the hole created by a particular HE shell when the Plate Actual Thickness is less than Tmod can be calculated with the following equation:

HOLE DIAMETER = D x [Tmod/(Plate Actual Thickness)] (*Equation 2*)

This formula shows that the largest possible hole is approximately 40 calibers in width for foil-thick plates of very large size. The formula shows that an 8-inch HE shell can blow a hole 319.2 inches or 26.6 feet wide in a 30 x 30 foot aluminum-foil-thickness STS steel membrane that is supported tightly around the edges, assuming that the shell hits in the center.

As plates get thicker than Tmod, the hole size created goes down rapidly, with zero hole size (merely a large dent with cracks) occurring at a plate thickness of 1.2 x Tmod. For plates thicker than Tmod, we use the following equation:

HOLE DIAMETER = D x [(1.2 x Tmod) - Plate Actual Thickness]/Tmod (*Equation 3*)

The minimum hole diameter for this equation is zero.

These equations are valid for the filler weights of typical World War II HE shells which were in the range of 6.0% to 8.99% of the total weight of the shell.[16] The Japanese 8-inch Type 0 HE shell was a modern, long, streamlined design with a length of 4.33 calibers and had a filler weight of 6.5% of the total weight which was up to 283 lbs. Therefore, this projectile falls within the valid range for these equations.[17]

Turning now to the damage caused by Hit 2; the BuShips' reports states that this shell made a 5 by 4 foot hole in a STS plate that was 0.75 inches thick. To determine if this damage was caused by an 8-inch HE shell fired with a muzzle velocity of 2,330 fps which at 6,000 yards would have a striking velocity of

[16] For Nathan Okun's equations to work correctly; projectiles with 6.0 to 8.99% filler percentages are considered to be normal World War II HE shells; projectiles with fillers of 4.0 to 5.99% are considered to be normal World War II SAP shells; and rounds with fillers of 1.4 to 2.99% are considered to be normal World War II AP shells. This will be further developed later in this essay. Bombs have fillers of 9.0% and larger and these use a different equation that Nathan is in the process of developing.

[17] It should be understood that Equations of this type were not available to BuShips in 1947 and could only be developed by using modern, high-speed computing methods.

2,103 fps, we use the following intermediate steps which together make up the calculations for Equation 1:[18]

Step 1: $(2.576 \times 10^{-20})(D) = 2.576 \times 10^{-20} \times 8 = 2.06 \times 10^{-19}$

Step 2: $V^{5.6084}COS[2(Ob2 - 45^{o})] = 2103^{5.6084} \times COS[2(45 - 45)] = 4.32 \times 10^{18}$

Step 3: $(0.156)(D) = 0.156 \times 8 = 1.25$ inches

Step 4: $2.06 \times 10^{-19} \times 4.32 \times 10^{18} = 0.89$ inches

Step 5: Tphe (noADF) = 0.89 + 1.25 = 2.14 inch thickness of STS which will result in a caliber-width hole

To find the minimum thickness of STS that ensures that no crack will be made in the plate (just a dent), we multiply 2.14 x 1.2 = 2.57 inches.

These calculations show that an 8-inch Type 0 HE shell would produce an 8-inch hole (caliber width) in a 2.14-inch thick STS plate and that a 2.57-inch thick plate would defeat this size shell, achieving only a dent. Intermediate thicknesses of STS between the 2.14 inch and 2.57 inch limits would have progressively smaller holes and shorter cracks in the plate.

Now that we have these numbers, we can calculate for the actual plate where Hit 2 struck, which was 0.75 inches thick. As we are calculating for STS plate, this means that T = Tmod which in this case was calculated above as 2.14 inches. As the actual plate thickness of 0.75 inches is less than Tmod, we use Equation 2 to determine the created hole diameter. Filling in the values for this formula:

Hole Diameter = 8 x [2.14 / 0.75] = 22.80 inches.

This is the approximate size hole that an 8-inch HE projectile would produce in a 0.75-inch thick STS plate. As can be easily seen, this estimated hole size of less than 2 feet is inconsistent with the BuShips reported hole size of 5 by 4 feet.

The above calculations were for a plate made of STS. What if the plate was actually HTS as in the Builders Plans? As HTS is 0.85% as strong as STS plating, we need to adjust Tmod per this lower quality factor:

Tmod = 2.14 / 0.85 = 2.52 inches

This means that an 8-inch HE projectile would blow an 8-inch hole (caliber width) in 2.52 inches of HTS plating (for reference, the thickness of HTS plate that would result in only a dent can also be calculated using this same quality factor: 2.57 / 0.85 = 3.02 inches).

Using the HTS value of Tmod in Equation 2:

[18] The range from *Kirishima*, *Takao* and *Atago* to *South Dakota* is estimated to have been as far as 7,500 yards to as close as 4,700 yards during the time of 0100-0106 when the Japanese ships when firing during this phase. As the exact time of impact for most hits is unknown, we have used an average range of 6,000 yards and the associated striking velocities for this range in the damage calculations for the 8-inch and 14-inch projectiles that are judged to have hit during this time.

Hole Diameter = 8 x [2.52 / 0.75] = 26.88 inches

So again, the results of the calculations for an 8-inch caliber HE projectile are inconsistent with the documented damage.

Moving now to the next larger size HE projectile that was present for the battle, the 14-inch Type 0 HE, this projectile is only 3.38 calibers long, weighs circa 1,378 lbs[19] and has a relatively small filler of 63.4 lbs of TNA (4.6%). This low filler percentage means that the Japanese 14-inch Type 0 HE shell design has an explosive burster that falls below the normal World War II HE Shell filler range mentioned above of 6.0 to 8.99% of total weight (see Footnote 16), which means that this projectile instead falls under Nathan Okun's formula for Semi-Armor Piercing (SAP) projectile types. The first step in determining the hole size that can be made by a 14-inch Type 0 projectile is to calculate what a normal World War II HE projectile would produce and then modify that result based on the ratio between the normal HE projectile and a SAP projectile.

What Nathan Okun has discovered is that a normal World War II HE projectile can blow a caliber-wide hole at a distance of 5-calibers or less from a 0.11-caliber-thick STS plate. This 0.11 figure can be used for all normal World War II HE shells, including US World War II HC projectiles that have filler percentages between 6.0 and 8.99%. This is the blast effect's only minimum distance and below this distance the still-accelerating fragments will have more hole-punching power and the caliber-wide hole in STS plate thickness steps up instantly to a constant 0.156-caliber size for a regular HE round.[20] For all SAP projectiles in the 4.0 to 5.99% filler range; these will produce a caliber-wide hole at a distance of 5-calibers from a 0.095-caliber thick STS plate. The ratio between a normal HE and a SAP round is thus 0.095/0.11 = 0.864.[21] Multiplying the results for a normal HE projectile by 0.864 will thus give the correct hole size for a SAP projectile and thus the hole size for the Japanese 14-inch Type 0 projectile.[22]

As a last piece of data; at 6,000 yards, the striking velocity of a Japanese 14-inch HE projectile fired with full charges would be 2,131 fps (see Footnote 18).

With all the above information, we can now make the following calculations using the same intermediate steps for Equation 1 that were used above:

Step 1: $2.576 \times 10^{-20} \times 14 = 3.61 \times 10^{-19}$

Step 2: $2131^{5.6084} \times \mathrm{COS}\ [2(45 - 45)] = 4.66 \times 10^{18}$

Step 3: 0.156 x 14 = 2.18 inches

Step 4: $3.61 \times 10^{-19} \times 4.66 \times 10^{18} = 1.68$

[19] Sectional density of this projectile would be (W/D^3) = 1,378 / 2,744 = 0.5.

[20] Nathan Okun also uses this same multiplier for the contact-hit, all-distances-under-5-calibers 0.156-caliber-STS-plate-thickness-for-a-caliber-wide-hole HE shell computation too, since filler blast punching power is what is changing, not the fragments, as filler size steps down to the SAP range and then to the AP range (thus, 0.156 becomes 0.135 for an SAP round, and 0.113 for an AP round).

[21] For an AP projectile that uses a 1.4 to 2.99% filler charge, the caliber wide hole at a distance of 5-calibers is reduced to 0.08 calibers thick STS plate. The ratio would then be 0.08 / 0.11 = 0.727 for an AP projectile.

[22] For a simple first approximation, Nathan Okun uses this 0.864 multiplier for ALL hole size computations for SAP rounds.

Step 5: Tphe (noADF) = 1.68 + 2.18 = 3.86 inches maximum thickness of STS for a caliber-wide hole

To find the minimum thickness of STS that ensures that no crack will be made in the plate (just a dent), we multiply 3.86 x 1.2 = 4.64 inches.

Intermediate thicknesses between 3.86 and 4.64 inches of STS have progressively smaller holes and shorter cracks in plate.

Continuing now for Hit 2, if the plate struck was made from STS, then as the plate thickness of 0.75 inches is less than T we use Equation 2 which gives us:

Hole diameter = 14 x [3.86 / 0.75] = 72.05 inches

Calculating for the damage that the typical World War II HE projectile would make in HTS plating, we get:

Tmod = 3.86 / 0.85 = 4.54 inches

Using Equation 2:

Hole diameter = 14 x [4.54 / 0.75] = 84.75 inches

As the 14-inch Type 0 HE projectile has a lower amount of explosive filler than the average World War II HE projectile, the size of the holes needs to be reduced by the SAP adjustment factor of 0.864 calculated above. This means that the hole created in 0.75-inch thick STS plate would be:

72.05 x 0.864 = 62.05 inches or just over 5 feet

And the hole created in 0.75-inches thick HTS plate would be:

84.75 x 0.864 = 73.22 inches or about 6 feet

These figures are far closer to the 4 x 5 foot exterior hole and the 8 x 6 foot interior hole in bulkhead 31 as documented by BuShips. This means that the 14-inch Type 0 HE projectile is far more consistent with the damage described by BuShips and is the best conclusion as to the projectile that caused this damage.

The timing of this hit is also important. When *Kirishima* re-opened fire at 0100, Lieutenant(jg) Michio Kobayashi, who was on her bridge at the time, thought that he saw *Kirishima* hit *South Dakota* in the area of Turret I.[23] This damage confirms that Lieutenant(jg) Michio Kobayashi did indeed witness one of *Kirishima*'s projectiles impacting very close to turret one.

The next question then is what made the holes below Hit 2? First of all, BuShips' report and *South Dakota*'s action report have significant disagreements as to what was the kind and extent of the damage to the hull below Hit 2. *South Dakota*'s Enclosure D lists three holes of 16 x 24 inches, 14 x 14 inches and 10 x 12 inches in the hull at compartment A-206L.[24] In contrast, BuShips reported finding six holes in this area of the ship's hull and that all of these were much smaller than the ones reported by *South*

[23] Michio Kobayashi in "*Senkan 'Kirishima' no Saigo* [The Last of Battleship *Kirishima*]
[24] USS *South Dakota* Action Report, Enclosure D, page 8

Dakota.[25] Plate 1 (shown as Figure 118 in this essay) from BuShips' report shows the six holes below Hit 2, and these are listed on Plate 1 as being five holes of 6 x 6 inches plus an additional hole that is not dimensioned but appears to be somewhat larger than the other five holes. Finally, looking at Figure 8 above, one can see four patches on the ship's hull (apparently applied shortly after the battle) that are covering up the damage in this area. Also in the BuShips' report, there is an assertion that although the ship's crew had concluded that these holes were made by 6-inch shell fire, the BuShips investigators had determined that there was no area within the ship where the extent of the damage would indicate that a shell had detonated inside the ship's hull and that there were no exit holes through the ship's structure. For these reasons, the BuShips investigators came to a different conclusion that no additional shells were involved and that these holes were the result of the cap head and windscreen from the AP projectile that they had concluded had made Hit 2.

One thing that is almost certain about these holes is that BuShips' assertion that they were made by the cap head and windscreen from an 8-inch AP shell cannot be correct. Our estimate is that Hit 2 was made by a HE projectile, so there would be no cap head or windscreen from this projectile to make these holes. Even if Hit 2 was made by an 8-inch Type 91 AP projectile, the 5-inch diameter cap head and light-weight windscreen of that projectile could not have made more than a single hole each of the size found by BuShips.

The authors and editor of this essay had a long discussion on the causes of these small holes, but in the end we have concluded that the BuShips investigators were probably on the right track and that these holes were most likely the result of fragments that were thrown out by the 14-inch Type 0 HE projectile that made Hit 2.

Finally, note that Hit 2 made a larger hole in the interior bulkhead #31 than it did in the outside hull plate. This bulkhead is listed as being 2.5 feet inboard of the hull and parallel to it. Assuming that this inboard bulkhead is made of thin steel of about 0.25-0.5 inch thick HTS or regular construction steel (Q = 0.7 or so), then it is still within the contact blast distance with the blast wave accelerating the fragments of the HE shell (not a lot of projectile fragments in the forward direction, of course) and, to a lesser extent, the fragments of the 0.75-inch HTS 5 x 4 foot hole from the hull plate (which would have made lots of plate fragments). These all hit bulkhead 31 in a widening cone of blast and fragments, making a larger pattern of fragment impacts than in the hull plate. Since this inboard bulkhead is thin enough for all of the rather few forward-directed fragments of the projectile and of the many 0.75-inch HTS hull plate fragments to punch through (this is only for this first spaced plate, though, since this uses up almost all of their penetrating power, with very few fragments capable of penetrating a second spaced plate), it gets plastered and riddled over a wide area and then the blast (reduced somewhat by the energy lost in puncturing and accelerating the pieces of the outer 0.75 inch thick hull plate but still with a lot of "overkill" energy to punch through such a thin second spaced plate) hits it, tearing it open even wider as the fragment holes unzip like stamp perforations and form narrow tears radiating outward for several feet to all sides. Also, as in Hit 4, the narrow air gap concentrates the forward-directed and even some of the side-directed (that passes through the wide outer hole) concussion and blast pressure, further enlarging the hole. This is why that second inner hole is wider than the outer impact hole. Trying to do a detailed calculation on this inner hole is not really possible, as the variables are many and indeterminate. The above discussion is meant as an explanation of the chain of events that created this hole.

[25] BuShips War Damage Report # 57, page 4