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BATTLESHIPS: Issues Arising from the Explosion Aboard the U.S.S. Iowa

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Before the
Committee on Armed Services
U.S. Senate

Mr. Chairman and members of the Committee:

I appear before the Committee today to discuss the results of our work concerning several issues pertaining to the April 19, 1989, explosion of the center gun in Turret II aboard the USS Iowa. The explosion killed 47 sailors. Since the Navy's September 1989 report on its investigation of the explosion, concern has been expressed on the adequacy of the investigation and the continued safety of battleships.

Our work was based on requests received from you; The Honorable Mary Rose Oakar, Chairwoman, Subcommittee on Economic Stabilization, House Committee on Banking, Finance and Urban Affairs; and the Honorable Howard M. Metzenbaum, United States Senate. We were asked to (1) conduct an independent investigation of the Navy's technical analysis of likely causes of the explosion, (2) review the safety aboard battleships, (3) examine manning and training issues raised by the Iowa's Commanding Officer after the explosion, and (4) review the battleships' employment plans and mission. We engaged the Department of Energy's Sandia National Laboratories to conduct a technical analysis and review the adequacy of the Navy's technical investigation. We addressed the other issues.

RESULTS IN BRIEF

Before discussing in detail our findings in each of the areas reviewed, let me briefly summarize.

Technical Analysis

Sandia's analysis could not corroborate the Navy's technical finding that an improvised chemical device initiated the explosion. Furthermore, Sandia has identified a potential hazard -- the impact sensitivity of the gunpowder in combination with an overram at higher than normal speeds which could have caused the explosion. Sandia believes that further testing on this is needed to confirm its finding.

Safety and Serviceability

As discussed in the Navy's report on the explosion and the subsequent Navy Inspector General's report on the gunpowder experimentation that was taking place at the time, safety policies and procedures were not being followed at the time of the explosion. Both Navy reports concluded, however, these violations did not cause the explosion. We examined various equipment, ammunition, and personnel safety records for the four battleships and did not find anything to lead us to believe that the battleships had experienced safety or material problems different than those experienced by other naval ships.

Manning and Training

We found that, as a result of the Navy's assignment process, the Iowa and the battleships were assigned a disproportionably low percentage of enlisted supervisory personnel, including gunners mates and fire controlmen, when compared to a selected sample of other ships. Also, we corroborated the Iowa's former Commanding Officer's perception that the quality of manning on the battleships was lower than that for naval ships on average.

We also identified some specific training issues. However, because training records were destroyed in the explosion, we could not reconcile the conflicting statements from the former Commanding Officer that his personnel were adequately trained on the day of the explosion and the Navy's accident investigation report that said they were not.

Battleship Missions

The battleships, with their combination of weapons, provide an imposing array of firepower. They perform a strike mission with their cruise missiles and their 16-inch guns are the best source of naval surface fire support for an amphibious assault. Also, according to Navy officials, the battleships can be a strong deterrent in a third-world scenario. However, other ships with cruise missiles provide excellent strike warfare capability and the changing world security environment brings into question the Navy's need to maintain the battleships to support a large scale amphibious assault.

Moreover, the planned retirement of two battleships, including the Iowa, raises questions about the usefulness and supportability of the other two ships in the active fleet. A deployed battleship's presence in overseas theaters will be limited because of the effect of peacetime operating and personnel tempo restrictions on the two remaining battleships. Manning and training problems will also be compounded by a smaller pool of experienced 16-inch gun-related personnel.

It is inevitable that the defense budget will be reduced over the next several years. Given the unanswered safety-related questions, the manning situation, the mission-related questions, and the usefulness and supportability concerns, the two remaining battleships seem to be top candidates for decommissioning as we look for ways to scale back U.S. forces.

SANDIA'S REVIEW OF NAVY TECHNICAL FINDINGS

When we were asked to obtain technical assistance to review (1) the issue of evidence of foreign material in the rotating band of the projectile lodged in the gun barrel in which the explosion occurred, which the Navy interpreted as being from a detonating device, and (2) the stability of the gunpowder, we counseled with the National Science Foundation and the Office of Technology

Assessment. Both stated that the Department of Energy's laboratories, especially Sandia National Laboratories, were capable sources of conducting an independent analysis.

At our request, Sandia performed an analysis concentrating on two areas. First, Sandia explored whether the Navy's finding of foreign material in the rotating band of the projectile lodged in the Iowa's gun and the Navy's analysis of such material indicated that an improvised chemical detonator ignited the powder and caused the explosion. A major constraint to Sandia's analysis was that, after the Navy's and the FBI's analyses, there was no longer any part of the Iowa's rotating band that had not been subjected to an analysis or examination. Furthermore, the Navy could no longer locate a significant piece of evidence-- the iron fibers with encrusted material that the Navy said came from a detonating device. However, Sandia was able to build upon the Navy's analysis and to obtain parts of the band to examine. It is confident in its findings, which conclude that the foreign materials that the Navy found were not inconsistent with the nominal levels found throughout gun turrets and were consistent with the maritime environment. For example, calcium and chlorine--two elements in the Navy's postulated detonator--were readily detectable in both Turrets I and II (the turret in which the explosion occurred) on the Iowa and in turrets on the battleships New Jersey and Wisconsin. Therefore, Sandia could not corroborate the Navy's finding that such foreign material was evidence of a detonator.

Second, Sandia explored whether the explosion could have been caused by an accidental ignition of the powder. Sandia agreed with the Navy accident investigation report that the powder was stable and confirmed that a significant overram of the powder charge occurred. However, Sandia has raised a question regarding the Navy's statement that impact and compression of the bag charge were not contributing factors to the Iowa incident.

Sandia believes that a possible alternate scenario to the Navy's finding of a deliberate act is that an unintentional high speed overram of the powder bags combined with the impact sensitivity of the powder led to the explosion. Suggestion of an unintentional high speed overram comes from (1) the Navy's accident investigation report which noted that the rammerman was conducting his first live firing and there were reports of an unidentified problem with the center gun immediately before the explosion and (2) Sandia's postulation that the car which brings the powder to the gun room had not returned, which it normally could have during the time of a normal speed ram. Sandia does not consider its study complete, in the sense that a clear and definite cause of the explosion has been identified, and it recommends areas of further investigation by the Navy.

The Executive Summary of Sandia's report is included as an appendix to this statement and its printed report will be available on June 4, 1990. Mr. Schwoebel, who directed Sandia's work, is with me today to discuss Sandia's analysis.

SAFETY AND SERVICEABILITY

According to the Navy's investigation report, approved procedures to ensure the safe firing of the 16-inch guns were not followed aboard the Iowa on April 19, 1989. Subsequently, the Navy Inspector General also concluded that the experimentation with gunpowder conducted aboard the Iowa was "at worst not safe and at best undetermined in its safety." To further investigate the safety and serviceability of battleships we reviewed reports of equipment problems, ammunition mishaps and malfunctions, and personnel-related injury data for all four battleships and compared them to Navy ships in general. This data disclosed no systemic problems with the material condition of the guns or the ammunition components involved in the explosion, or on the battleships, in general, that warrant any corrective action.

Safety Violations

The Navy's investigation of the explosion found that safety policies and procedures were not being followed. For example, although no spark producing items are allowed in the turrets, items such as cigarette lighters, rings and keys were found on the remains of the deceased sailors.

The Navy's investigation at the time of the explosion also believed that Iowa personnel had improperly approved and were conducting gunnery experiments. Ship personnel were loading an inappropriate projectile/powder combination when the explosion occurred. This involved 5 bags of an authorized type of powder with a 2,700-pound projectile rather than 6 bags of the authorized type of powder. Improperly authorized combinations were fired on at least two other occasions. The Navy believed that neither the presence of spark producing devices nor the experimental firing caused the explosion.

The Navy Inspector General subsequently investigated the reported experiments with 16-inch projectiles and propellant and concluded that the firings in question on the Iowa were, in fact, improperly authorized and contrary to Navy procedures. His report concluded that the safety hazard posed to the Iowa's crew by the experiments was, at best, undetermined.

No Prior Indications of Safety or Serviceability Problems

We reviewed reports of equipment problems, ammunition mishaps and malfunctions, and personnel-related injury data for all four battleships since their reactivation. For example, we examined the equipment failure reports that ships submit for all equipment failures that affect their ability to perform their mission and that cannot be corrected within 48 hours. All of the equipment failure reports the battleships submitted for equipment failures affecting the 16-inch turrets since their reactivation were categorized as having only a minor impact on the ships' primary missions. We also noted no trend or pattern in the reported equipment failures that indicated systemic problems with the guns and other turret equipment.

We also compared the battleships' equipment failure experience to that of other surface ships to determine if the battleships present any undue material or supply support problems. They do not appear to do so. Between 1984 and 1989, for example, the battleships operated without any major equipment failures for a substantially greater percentage of time than did surface combatants as a whole. There were no distinct differences in the percentages of the equipment failure reports submitted because the necessary repair parts were not available on the ships.

Previous Ammunition Mishaps/Malfunctions

We also examined several data sources, including ammunition mishap and malfunction reports and investigations. We found no indications of preexisting problems with the type of propellant involved in the explosion. However, ammunition problems have been encountered with other 16-inch ammunition components in the past. For example, there were problems with split powder bags. A program is underway to correct that problem. Other problems, which have been addressed, were encountered with earlier versions of the primers used to ignite the powder charges because the primers deteriorated in storage.

Susceptibility to Inadvertent Detonation

Concerns were raised after the explosion over the ammunition's sensitivity to the effects of electromagnetic radiation, frequently referred to as HERO. Communications and radar transmitters can transmit radiation that can cause ammunition components containing electrical circuits to detonate. The primer was the only ammunition component involved on April 19 that contains an electrical circuit and it requires only moderate protection from electromagnetic energy; it cannot be within 56 feet of a transmitting AN/WSC-3 antenna for example. Turret II is about 100 feet from that type of antenna, so HERO should not have been a concern. In their investigations, Sandia and the Navy ruled out the primer as the cause of the explosion.

While 16-inch ammunition components do not fully meet the Navy's criteria for insensitivity to unplanned heat, shock, or impact stimuli, the current inventory ranks 19th among the 25 munitions of greatest concern to the Navy. The ammunition does not meet the Navy's standards because it demonstrates some susceptibility to sympathetic detonation--detonating in response to a near-by detonation of another explosive item. The requirement to meet the standards has been waived for the current inventory, however, because the Navy considers that the 16-inch inventory poses a relatively low danger compared to other ship board munitions and because modifying other munitions has a higher funding priority.

Personnel Injury Experience

We also reviewed the reports of personal injuries and deaths occurring on board the battleships and compared the results to injury rates on all surface ships to determine if this would reveal any systemic gun or ammunition problems. They did not.

Any accident resulting in a fatality, a lost workday, an electrical shock, a person overboard, or a chemical or toxic exposure must be reported to the Navy Safety Center. We found that the injury rates for the battleships were lower than the rates of other ship types in 1987 and 1988. The battleships' 1989 rate was higher than that for surface ships overall, but it would have been lower if the Iowa explosion was excluded from the statistics. While the Iowa had the highest injury rate of the four battleships in 1989 (again, due to the turret explosion), its injury rate was not the highest among the four battleships in 1987 and 1988.

Other than the Iowa's turret explosion, none of the reported accidents aboard the battleships involved firing the 16-inch guns. One sailor, however, was injured in a turret during a training drill, and another was injured in a 16-inch magazine while conducting an operational test. Most of the accidents involved injuries such as toxic inhalation, contusions, and fractures incurred during routine operations. For example, sailors slipped and fell on decks and ladders, had hatches closed on their hands, or were injured handling heavy equipment or supplies.

Additionally, none of the reported accidents involved electrical shocks in the 16-inch turrets.

MANNING

We found that battleships, in comparison to other surface ships were not assigned an equal share of authorized enlisted supervisory personnel or personnel in ratings associated with gun turret operations. Additionally, the personnel assigned on battleships rated lower by several measures than those assigned to other ships.

Low Manning Level of Supervisory Personnel

We compared peacetime authorizations to on-board manning for the battleships with the average of 17 surface ships at various times in the deployment cycle. We did not include the battleship Wisconsin because it had not deployed since its reactivation. The 17 surface ships included destroyers, cruisers, and amphibious assault type ships. We found that the overall percentage of authorized enlisted personnel assigned to the battleships was comparable to that of the sample ships. However, manning levels of all battleship enlisted supervisors, including gunners mates and fire controlmen associated with the 16-inch turrets were generally lower than those of the other ships in our sample.

The battleships and the Iowa deployed with significantly lower percentages of their authorized enlisted supervisors and turretrelated journeymen. The ships in the sample deployed with an average of 101 percent of their authorization for supervisory enlisted personnel (pay grades E-7 through E-9), while the Iowa and battleships deployed with 92 and 93 percent, respectively. These differences were more pronounced for gunners mates and fire controlmen, as table 1 shows. The situation was similar with regard to journeymen (pay grades E-5 and E-6) in the gunners mate and fire controlman ratings.

Conversely, as the table shows, the battleships were assigned a higher percentage of their authorized apprentices in pay grades E-1 through E-4.

Table 1: On-board Percentages of Gunners Mates and Fire Controlmen Compared to Billets Authorized Levels at Deployment

	Iowa	Battleships	Ship Sample
	(percent)		
All Supervisors	92	93	101
Gunners Mates:			
Supervisors	73	77	100
Journeymen	88	82	135
Apprentices	94	92	73
Fire Controlmen:			
Supervisors	92	88	120
Journeymen	89	92	128
Apprentices	106	109	85

The impact of manning for gunners mates aboard the Iowa was highlighted at the time of the explosion. In Turret II, two of the three journeymen level gun captain positions, normally E-5s, were filled by E-4 apprentices. The center gun captain was the only journeyman gun captain. All three of the gun captain positions in Turret I were filled by E-4 apprentices and a journeyman was filling the supervisory turret captain's position, which is normally filled by an E-6.

Chief of Naval Personnel officials recently told us that they had difficulties in filling billets on battleships. The officials also said that the ship sample had excess gunners mates and fire controlmen at the journeymen and supervisory levels because their personnel were promoted at higher rates. Also, personnel promoted during a deployment are not reassigned, even though on-board excesses develop. Since the school terms for those ratings on the sample ships are longer than those for the 16-inch-related schools, the personnel tend to be a higher grade when reporting to ships of the types in our sample.

The officials also noted that personnel who are assigned to the battleships and who reenlist frequently request duty elsewhere to enhance their promotion opportunities by gaining practical experience in the more common gun weapon systems. Similarly, they prefer to attend schools for other gun weapons systems to enhance their promotion opportunities and, because the other guns have newer electronic technology to enhance their prospects for future civilian employment. Sailors aboard the Iowa expressed similar views to us.

Battleship Personnel Fare Worse In Advancement Opportunities

As of December 1989, battleship officers had been selected at a lower rate, compared to officers in the sample of other surface warfare ships for leadership positions such as executive officer and commanding officer. Only 23 percent of the commanders serving on battleships were considered qualified for commanding officer compared to 88 percent of the commanders on the sample ships. For lieutenant commanders be considered to serve as executive officers, the figures were more comparable -- 53 percent of battleship lieutenant commanders were considered qualified compared to 56 percent on the sample ships. However, the Iowa had only 25 percent considered qualified.

Battleship enlisted personnel also fared worse during the March 1989 promotion cycle than did personnel aboard other ships in our sample. Battleship personnel overall scored lower on the promotion tests, a key element in the promotion eligibility process. Gunners mates and fire controlmen failure rates for battleship and Navy-wide personnel were similar. However, the battleship gunners mates and fire controlmen failure rates of 11 and 6 percent, respectively, were significantly higher than the ship sample's failure rates of 0 and 1 percent, respectively.

Among those who passed the test, fewer battleship personnel in the gunners mate and fire controlmen ratings were selected for promotion. For example, 53 percent of the gunners mates on board the battleships was promoted compared to 65 percent for the ship sample and 58 percent Navy-wide. For fire controlmen, the results were 8 percent for the battleships, 15 percent for the ship sample, and 13 percent Navy-wide.

Higher Rate of Disciplinary Actions

During fiscal year 1989, battleship personnel experienced a higher rate of disciplinary actions, including non-judicial punishments (NJPs), courts-marital, and punitive discharges. For example, the battleships' NJP rate per thousand (195) was approximately 25 percent higher than the ship sample rate (158 per thousand) and 185 percent higher than the Navy-wide rate (69 per thousand). While the Iowa had the lowest rate (173 per thousand) among battleships, its NJP rate was still 150 percent higher than the Navy-wide rate. Similar results were noted for the battleships' and the Iowa's courts-martial and punitive discharge rates.

About 70 percent of the battleships' manning consists of personnel in grades E-1 through E-4. Battleships also have a lower level of supervisory personnel than the ships in our sample. Navy officials agreed these factors may have contributed to the higher disciplinary rates aboard the battleships.

PROBLEMS IN 16-INCH TRAINING

The adequacy of training on the Iowa became an issue because the Navy's accident investigation report on the explosion said that unqualified personnel were manning the turret. However, the former Commanding Officer of the Iowa said the crew was trained, just that the records were not up to date. Since the training records for the deceased crew were destroyed in the explosion, never existed, or have not been located, we are unable to reconcile this conflict. We found, however, that oversight inspections, which should have assessed the Iowa's 16-inch Personnel Qualification Standard (PQS) program, failed to do so during the 18 months preceding the explosion. Priorities were placed on other areas during the review or the review teams lacked the expertise to evaluate the 16-inch PQS program. Additionally, the Navy had not approved a training plan for the battleship class and the advanced training school had limited hands-on training aids for operation and maintenance instruction.

While the Iowa had a PQS program for the personnel assigned to its turrets, insufficient records were available after the explosion to provide an overview of the individuals' qualifications. The Navy's accident investigation report criticized the Iowa for a lack of documentation, especially service record entries, for determining the qualifications of assigned personnel. We found, however, that service record entries, while preferable, were not required until personnel were transferred to another command. The Iowa and its type commander's regulations now require such entries upon completion of assigned PQS tasks. Our review of service records for selected turret positions in November 1989 found the new requirements had been implemented.

Using reconstructed data, Iowa officials attempted to evaluate the qualifications status of the personnel assigned turret positions on April 19. Personnel were considered to be "operationally qualified" based on the number of gun fire exercises and training drills in which they had participated. While the information they developed indicated that the personnel assigned in the turret were experienced, we found weaknesses in the analysis. In our opinion, the crew's proficiency cannot be verified because the information merely shows that the crew members were assigned to a position within the turret during the exercises and drills but does not document that they actually performed the responsibilities. For example, one person was classified as operationally qualified, even though he was serving in his assigned role for the first time on April 19. In another case, the status of one individual serving in Turret II was not included in the analysis.

The Iowa's Turret II was authorized five personnel who are required to have completed training at the Navy's formal school for 16-inch gunners. However, on the day of the explosion, only two of the positions were filled with individuals who had attended the school.

Weaknesses exist with the Navy's formal training program for 16-inch gun operations and maintenance. Gunners mates aboard both the Iowa and the New Jersey were very disappointed with the Navy's formal school for 16-inch gunners because it lacked actual turret equipment and they believed it offered little practical instruction. The crews believed that they learned their jobs through on-the-job training. Likewise, both the school's internal evaluations and the Navy's draft training plan for the battleships noted the problems caused by the lack of training aids. Our visits to the school confirmed that limited hands-on training was being provided due to the lack of training aids. Training films being used at the school were basically 1940's vintage. No improvements were noted in the structure or available training aids since the explosion. While the Navy developed a draft training plan to improve the 16-inch training courses in September 1989, the plan still awaits final approval and implementation.

BATTLESHIP MISSIONS

In response to your request, we reviewed the Navy's concept of battleship employment-- what are the ships' wartime missions and how they are scheduled for peacetime deployment. My remarks will be brief since much of the detailed information is classified.

While the battleships are very capable weapons platforms and have been included in deployment schedules and operational plans, emerging circumstances limit their utility. The battleships were reactivated to alleviate existing force structure shortfalls and to help meet the 600-ship goal using existing platforms. The battleships, with their combination of 9 16-inch guns in 3 turrets, 8 5-inch twin gun mounts, 16 Harpoon antiship cruise missiles, and 32 Tomahawk cruise missiles, provide an imposing array of firepower. The Tomahawk missiles give them a significant capability for attacking land targets and other surface ships. The Harpoon missiles also contribute to the battleships' capability to operate against hostile surface ships. The battleships' 16-inch guns are the best source of naval surface fire support for an amphibious assault and are, in fact, the only guns larger than 5 inches remaining on Navy ships. When compared to air support in an amphibious operation, Navy officials said the 16-inch guns, within their range limitations, can deliver more firepower under a wider variety of weather conditions. Because of its imposing size and configuration, the Navy believes a battleship's presence can be a strong deterrent in a third-world scenario.

While the battleships' Tomahawk and Harpoon missile capability is imposing, it is not unique within the Navy. Many other Navy vessels, submarines as well as surface ships, carry those same weapons. Also, the battleships' contribution to future amphibious warfare also may be limited. The current maximum range of just over 23 miles of the battleships' 16-inch guns (their only unique weapon system) impairs the ships' ability to provide effective naval surface fire support within the context of an "over the horizon" amphibious assault--one launched from 25 to 50 miles offshore and extending far inland.

Furthermore, with only two battleships, operating and personnel tempo restrictions will limit future deployments. Current policies, for example, preclude a ship from deploying for an additional 12 months after it returns from a 6-month deployment. Thus, with only two ships in the active force, it is unlikely one would be available on short notice should a crisis erupt. The battleships are also labor intensive, requiring a crew of about 1,500 compared, for example, to a crew of about 360 on an Aegis cruiser. Finally, reducing the number of battleships to two, especially with one homeported on each coast, will compound the manning and training problems discussed earlier and further limit availability.

There is current pressure to greatly reduce the defense budget, which led to the decision to retire two battleships. Because the battleships are costly to maintain (about $58 million to operate annually according to the Navy), and difficult to man, and because of the unanswered safety and mission-related questions, they should be actively considered in budget trade-off decisions currently being explored by the Department of Defense.

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Mr. Chairman, that concludes my prepared remarks and I would be happy to answer any questions.

Executive Summary

This report describes work by Sandia National Laboratories (SNL) relevant to three aspects of the explosion that occurred in the center gun room of Turret 2 of the USS IOWA on April 19, 1989, killing 47 crewmen. Our studies began in December 1989 with initial contacts and information exchange with the United States Navy (USN). Technical work began in January 1990 and continued to May 15, 1990.

The essential results of our study are as follows:

(1) We could neither prove nor disprove the presence of a chemical ignitor proposed by the USN. The interpretation of evidence for a chemical ignitor is complicated by the fact that some chemical constituents of such an ignitor are found throughout 16 in. gun turrets, not only on the USS IOWA, but also the USS WISCONSIN and the USS NEW JERSEY. Forms of these constituents are either commonly used in the turrets or are a part of the maritime environment. Steel wool was another component of the proposed ignitor. We found iron fibers in the rotating band that could be steel wool, but we were unable to clearly identify a source of fibers of their diameter. We believe evidence for the presence of a chemical ignitor is inconclusive.

(2) Our analyses indicate that the propellant stabilizer was within acceptable limits. We also found only a very remote possibility that this propellant could be initiated in the breech by friction, electrostatic discharge, or electromagnetic radiation. Similarly, we conclude there is only a very remote possibility the black powder could have been initiated in the breech by any of these mechanisms. Ether/air combustion cannot be achieved because minimum necessary concentrations are precluded. Even if the minimum concentrations are achieved and combustion occurs, our analyses show that the propellant cannot be ignited. These findings are in general agreement with those of the USN.

(3) We confirmed that the powder bags were overrammed against the projectile and determined that the extent of the overram was approximately 3 in. greater than that established by the USN. Our analyses indicate that the bag charges were under a compressive load of at least 2800 pounds at the time of the explosion. There may have been even higher transient forces due to dynamic loading resulting from a greater than normal ram speed. While the rammer is capable of a speed of 13.9 ft/s, we could only establish that the rammer speed was at least 2 ft/s.

(4) The cause of the explosion was not conclusively determined. However, an important factor may have been the increase in impact sensitivity of a

> powder bag with a reduced number of pellets in its trim layer. (The trim layer is an incomplete layer of pellets lying on their sides in the front of the bag and just behind the black powder pouch on the next bag.) Our half-scale experiments indicate that reducing the number of these pellets lying next to the powder pouch increases impact sensitivity enough that an explosion could have been caused by an overram at a higher than normal speed. Our studies indicate that impact initiation depends on two key factors: the number of pellets in the trim layer, and the speed of the overram. However, these experiments must be extended to actual 16 in. gun conditions to establish the validity of this ignition mechanism.

Navy personnel were most helpful in providing information and materials germane to this study. In particular, we are grateful to Captain Joseph D. Miceli, USN, Director of the Technical Support Team, Naval Sea Systems Command, who responded without fail to a host of requests that grew out of our study. This included arranging for information gathering visits aboard the USS IOWA and two other battleships; extensive interactions with personnel at the Naval Surface Warfare Center (NSWC-Dahlgren), Dahlgren, VA; Naval Weapons Support Center (NWSC-Crane), Crane, IN; Naval Ordnance Station (NAVORDSTA), Indian Head, VA; Norfolk Naval Shipyard (NNSY), Norfolk, VA; Naval Ordnance Station (NAVORDSTA), Louisville, KY; and access to numerous reports and the testimony of several crewmen at the Judge Advocate General manual investigation. We are also indebted to the USN for arranging for us to speak with Gunner's Mate (Guns) First Class Dale E. Mortensen, who drew on his extensive experience to provide us with firsthand information regarding 16 in. gun operations.

The USN investigation of the accident was extensive and included a variety of studies that were conducted in considerable depth. Our studies drew heavily on that work. It served as a valuable basis on which to extend certain elements of this investigation, and made our studies more productive than they would otherwise have been.

Our studies focused on: 1) debris and any foreign materials in the rotating band of the projectile in the center gun; 2) their possible relation to or consistency with the hypothetical ignitor described by the USN; and 3) stability and sensitivity of the propellant and black powder contained in the individual bag charges used on the USS IOWA. The rotating band is located toward the rear of the projectile and, by engaging the rifling of the barrel, spins the projectile to ensure stability in flight.

Studies of debris from the rotating band had been performed by the USN and, to a much more limited extent, by the FBI. Evidence from the rotating band is considered potentially important because the cannelure of the band was exposed to the initial part of the explosion, and then closed as the projectile was propelled partway up the barrel of the gun. (The cannelure is a groove in the rotating band of the projectile.) That is, any foreign material found in the sealed cannelure region of the rotating band might contain important evidence regarding the initiation process. The stability and sensitivity of propellant is of interest because of its age at the time of the explosion (approximately 44 yrs) and the possibility of unforeseen effects of storage at elevated temperatures that occurred during part of the life of this material.

SNL personnel had access to an approximately 10 in. length of the USS IOWA rotating band. (The remaining approximately 40 in. of band had been consumed in experiments by the USN in its studies.) The 10 in. length of the band forwarded to us had originally been sectioned into several pieces and the cannelure opened and examined by the FBI. Accordingly, our studies are based on regions of the cannelure that had been opened, examined, and stored some months before.

The USN reported the presence of calcium (Ca), chlorine (Cl), polyethylene terephthalate (PET) film fragments, certain glycols and iron fibers in the rotating band of the projectile. The USN reported that these were foreign materials and evidence for the presence of an ignitor device composed of steel wool, brake fluid, and an oxidizing chemical (calcium hypochlorite), placed in a plastic bag.

We find that Ca and Cl are readily detectable throughout the entire region of both Turret 1 and Turret 2 of the USS IOWA, Turret 2 of the USS NEW JERSEY, and Turret 2 of the USS WISCONSIN. The presence of these elements is consistent with the maritime environment and the cleaning operations carried out in the turrets. We found these elements on two iron fibers that we extracted from the rotating band from the USS IOWA. We also observed an additional four small iron-fiber fragments that could not be removed from the rotating band for analysis without destroying them. The surfaces of three of these iron-fiber fragments had concentrations of Ca and Cl that were similar to the two that were extracted. (The fourth fiber was retained for another analytical procedure.) The occurrence of these elements on the various fibers does not clearly establish the presence of an ignitor device because the concentrations of these elements are within the statistical variation of Ca and Cl levels on metal fibers found elsewhere in the turret.

The USN had previously removed and analyzed several iron fibers from the USS IOWA rotating band. One of these fibers was described in the NWSC-Crane report to have crusted regions containing high concentrations of Ca and Cl. It was the analysis of this fiber that was the basis of the USN's assertion that iron fibers with abnormally high concentrations of Ca and Cl were found in the rotating band of the projectile of the USS IOWA. When we visited NWSC-Crane to examine this fiber, we found that it, along with some others, could not be located. SNL personnel worked jointly with NWSC-Crane to examine and analyze several other fibers that were retained by NWSC-Crane. All of those fibers were free of crusted regions, as were the six fibers we had previously either extracted or observed in the rotating band at SNL.

The surface concentrations of Ca and Cl on all the fiber samples that we have analyzed, both at SNL and jointly with USN personnel at NWSC-Crane, were of nominal levels, not greatly different from levels of these elements on fibers found in other turret locations. In fact, the concentrations of Ca and Cl observed by both ourselves and the USN were very similar, i.e., only small quantities of Ca and Cl were measured. We could not clearly identify any of the fibers that we extracted as remnants of steel wool. However, these fibers were found to have low (<0.6 at. %) bulk carbon concentrations consistent with steel wool, which is commonly made of iron fibers.

The USN also reported steel wool in the rotating bands of other projectiles stored aboard the USS IOWA. Those fibers could not be located so we were unable to analyze their surface composition. We identified some steel fragments in a brush used to clean the guns in Turret 2, but our analyses indicate that those high-carbon steel fragments came from bore liners inside the barrels. (A bore liner is the inner surface of the gun barrel and in direct contact with the projectile.)

The diameters of fibers found in the USS IOWA rotating band by both the USN and SNL were very similar. The USN states that the fibers found on other projectiles stored aboard the USS IOWA were of smaller diameter. We have not corroborated that observation because those fibers could not be located.

Two glycols in the rotating band of the projectile were identified by the USN as "significant foreign materials," possibly constituents of brake fluid used in the hypothetical ignitor device. Our studies show that the first of these glycols is a constituent of a cleaning and lubricating fluid (Break-Free™) routinely used in the turrets. Our analyses indicate that the USN identification of the second material as a glycol is incorrect. The material is actually phenol, which is also a constituent of Break-Free™. A third glycol, not considered to be a "significant foreign material," was identified by the USN as a constituent of a marker pen. We agree with that identification, but we find that it is also a constituent of Break-Free™.

The USN found a single fragment of a polymer film in the cannelure and identified it as a possible residue of PET. The USN proposed that a plastic bag of this material was used to contain the hypothetical ignitor device. We also identified fragments of this material in the brush used to clean the guns in Turret 2. PET is known to be chemically equivalent to Dacron™ and Mylar™. Accordingly, such fragments could have come from several sources, including the bore socks used for gun cleaning and ordinary clothing. We observed the presence of many polymeric species in the cannelure of the rotating band, but not PET. Because polymeric fragments can be found in various regions of the turret, their occurrence is not a unique indication of the presence of the hypothetical ignitor device.

SNL personnel also examined cannelure debris from a test at NSWC-Dahlgren in which the bag charges were ignited by a chemical ignitor similar to the one proposed by the USN. This ignitor used steel wool, but we found no iron fibers or fragments of iron fibers in the limited length (~8 in.) of the rotating band that we examined. The USN found five fibers in the entire band (~50 in.) from another test of this same kind. Apparently there can be considerable variation in the quantity and distribution of fibers from such experiments.

The USN provided us with twelve bags of propellant with black powder pads from the same lot as that aboard the USS IOWA at the time of the explosion. In addition, the USN provided access to its extensive studies and background information on this propellant and black powder.

The propellant used in the bag charges for the 16 in. guns contains a stabilizer (DPA) that scavenges decomposition products that are oxides of nitrogen. The stabilizer helps maintain uniform performance of the propellant over time. The USN stated that the level of stabilizer in the propellant aboard the USS IOWA was within specification. We also find that the average level of stabilizer is near the level reported by the USN. There is a small change in propellant sensitivity over the range of stabilizer concentration that we measured in pellets from the USS IOWA bag charges. We have not yet completed our investigation of the significance, if any, of this change.

The manufacture of propellant involves the dissolution of nitrocellulose in a mixture of ether and alcohol. Some ether remains in the propellant and evaporates over an extended period of time, suggesting a potential fire hazard. Our analysis shows that the probability of initiating an explosion by ether/air burning in the breech is so remote as to be practically impossible. Calculations show that the maximum temperature increase of the propellant that could occur in the burning of an optimum mixture of ether/air is only 30°C to 40°C. Initiation of the propellant requires a temperature increase of at least 170°C. However, the thermal ignition of finely crushed black powder by ether/air combustion remains an unresolved issue requiring additional study. Our studies also indicate that it is virtually impossible to initiate the propellant or black powder in the breech by electrostatic discharge, friction, or electromagnetic radiation at levels found within the turret.

An interior ballistics model was developed for the open-breech explosion. The model involves the high-speed flow of both hot propellant gases and pellets from the open breech. The model was used to calculate the time variation of pressure at the base of the projectile depending on the point of initiation along the five powder bags. It predicts with some accuracy the movement of the projectile up the barrel following the explosion. Our results indicate that the initiation site was most likely between the first and second bag charge, which agrees with conclusions reached by the USN in its field tests.

The USN reports that the propellant bags were overrammed into the breech of the center gun of Turret 2 by a distance of approximately 21 in. The USN interpretation was based in part on an analysis which assumed that parts of the rammerhead gouged the spanning tray. In our analysis we show that the gouges were caused by the rammer chain. Using this analysis, we found that the overram was more nearly 24 in. That is, the rammer moved approximately 24 in. beyond the point it would normally reach in placing the bag charges in the breech of the gun. Therefore, a significant overram and compression of the powder bags occurred.

The USN reports that "impact and compression (of the bag charges) were not contributing factors in the IOWA incident." Our results regarding the impact sensitivity of the propellant raise the possibility that initiation occurred by impact. Our one-half-scale (8 in.) experiments indicate that the fracture of propellant pellets lying transverse in the trim layer at the forward end of the bag can lead to initiation of the powder train. Initiation apparently occurs when the fractured pellets in the trim layer release burning particles from the fractured surfaces, igniting the black powder pouch of the adjacent bag. Ignition of the black powder then rapidly propagates the ignition throughout the rest of the powder train. Therefore, the ignition process involves the trim-layer pellets of one bag and the adjacent black powder pouch of the next (forward) bag.

We believe the probability of this initiation process depends on two key factors: 1) the number of trim pellets in the forward-most layer and 2) rammer speed. If there are a reduced number of trim pellets and the rammer is operated at higher speeds, the initiation process during an overram becomes more probable. For example, if there are twenty pellets in the trim layer, we estimate there is a probability ranging from approximately one in two to one in three that the propellant can be initiated at energy levels attainable when the rammer is operated at 13.9 ft/s, its maximum speed. However, propellant initiation by impact is a complex phenomena and much more work needs to be done to verify this estimate, particularly in actual 16 in. guns or systems that closely duplicate the 16 in. gun.

During a number of inspections in conjunction with USN personnel, we found that the powder hoist, powder door, rammer, and other mechanisms in the gun room appeared to be in proper operating condition at the time of the explosion. We concur with the USN that mechanical operations appear to have been normal and not associated with the explosion.

As established by the USN investigation, the door to the powder hoist was closed and locked, but the powder car had not been lowered at the time of the explosion. Immediate lowering of the car on closure of the powder door is the standard procedure. This suggests to us that the ramming occurred soon after the closing of the powder door and took place at high speed. That is, if a slow ram of 1 to 2 ft/s had occurred followed by 15 or 20 s of sustained overram as proposed by the USN, the upper powder hoist operator would have had approximately 20 to 25 s to begin lowering the powder car. However, if a high-speed ram occurred, there would have been little opportunity for the upper powder hoist operator to begin lowering the powder car. A high-speed overram seems consistent with these considerations.

A factor that may have contributed to the overram was an undefined problem in the loading operation. This undefined problem, reported through the ship's phone system by a member of the gun crew, led to a delay in loading the center gun relative to both the left and right guns in Turret 2. This undefined problem and delay could have created confusion during the powder-loading phase.

We conclude that a plausible cause of the explosion aboard the USS IOWA was a higher-than-normal speed overram of the bag charges into the rear of the projectile, initiating one of the forward bag charges that contained a reduced number of pellets in the trim layer. The fact that the bags were moved to a position substantially beyond the normal location is evidence supporting a higher-than-normal speed overram.

Our experiments of initiation by impact are incomplete and more work needs to be done on larger assemblies of pellets than we were able to accomplish in the short time available. Nevertheless, it appears from our present models that the probability of initiation of an explosion by impact is such that measures should be taken to insure that overrams do not occur at any speed.

These studies of the explosion aboard the USS IOWA represent a brief but concerted effort by SNL personnel to supplement the USN's investigation. Our starting point was the extensive work by the USN, and those studies were helpful in several phases of our study.

We do not consider this study to be complete in the sense that a clear and definitive cause of this explosion has been identified. There are several open issues that should be further explored, and the Recommendations section of this report lists areas we believe warrant further investigation.