Insensitive Munitions Modeling and Test Effort for The New Harpoon Replacement Container

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20 May 2015

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1.0 EXECUTIVE SUMMARY

The Precision Strike Weapons Program Office (PMA-201) sponsored the development effort for a new Harpoon shipping container. The Naval Weapons Station, Earle, New Jersey, was the design agent and performed container qualification testing. The Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, California, provided Insensitive Munitions (IM) design input and conducted IM tests. The main objective of the replacement container effort was to design a new shipping and storage container that would prevent water intrusion and weapon corrosion. Another objective was to provide an incremental improvement to the containerized weapon Sympathetic Reaction (SR) IM response. This report documents the SR IM analyses and tests conducted, including the final results of the testing.

2.0 INTRODUCTION

The Harpoon replacement container was constructed with proven technology, including aluminum extrusions, appropriate seals, shock isolators, and IM panels. This container is constructed with the weapons in a flipped orientation (nose-to-tail, see Figure 1), as opposed to the Mk 607 fiberglass container, in which the weapons are stored facing in the same direction (see Figure 2). This configuration precludes an adjacent alignment of the warheads and reduces the risk of a single-container SR. This warhead orientation also ensures that the warheads will never be horizontally aligned in the logistical configuration. This configuration does ensure that the warheads will always be aligned in the vertical direction. As such, the vertical shot line is expected to be the worst case because of the warhead alignment and the shorter distance between warheads. To mitigate this risk, the new container has a 0.75-inch-thick aluminum shield incorporated into the weapon cradle under the warheads to prevent high-velocity fragments from detonating the warhead directly above or below it.

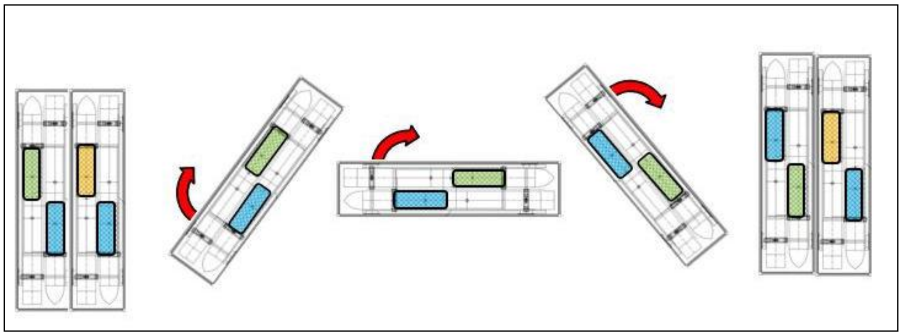


FIGURE 1. Horizontal Warhead Placement in New Container.

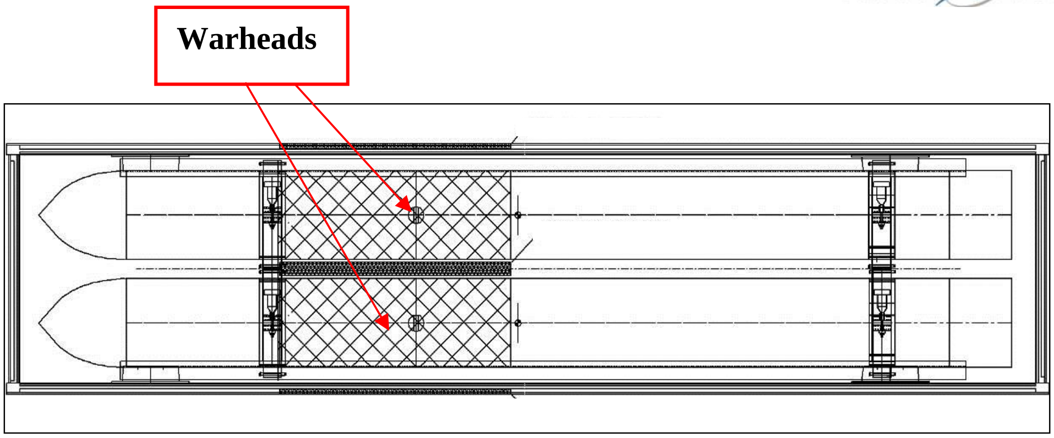


FIGURE 2. Harpoon Warhead Configuration in Legacy Mk 607 Shipping Container.

The Harpoon weapon itself has not been altered for the new container effort and has remained unchanged since the historical IM tests performed under requirements dating back thirty or more years. The historical bare-weapon Harpoon SR performance was a Type I detonation reaction. However, the Mk 607 container and the Harpoon weapon were never tested together as a system to demonstrate logistical IM compliance. Predicted IM result of this configuration would still indicate a Type I reaction (See Reference 1).

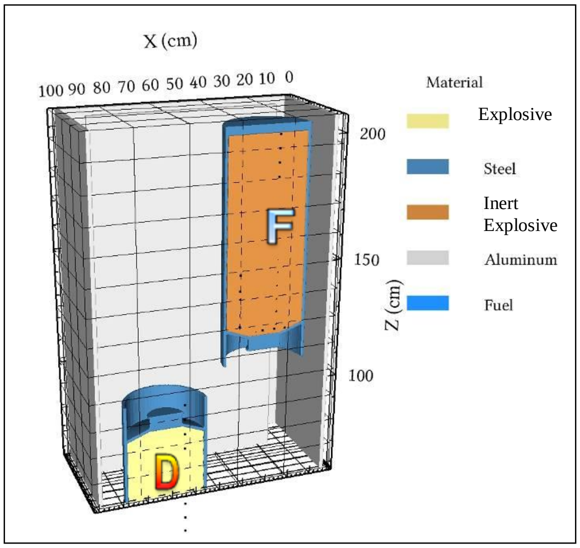
3.0 MODELING

Modeling was conducted to determine, the most realistic worst-case IM scenario, as well as the location and quantity of warheads that would be required for SR tests. The modeling was performed using CTH, a hydrocode developed by Sandia National Laboratories that uses an Eulerian mesh to track materials that deform greatly during events such as a detonation. Multiple CTH models were created and run to determine the likely results of a test involving the new replacement container. The aluminum IM plate was modeled with variations to its thickness and location within the container in order to determine the optimum protection against SR. In the models, tracers (i.e., gages) were placed inside the warheads' explosive fills to determine the pressures to which the explosive in the acceptor warheads was being subjected. The pressures recorded aided the analysis to determine the optimum aluminum plate thickness.

Models were created and run in both three-dimensional (3D) and two-dimensional (2D) configurations in order to simulate all required orientations, but be able to run on the available computing resources. The Eulerian mesh covered a large volume and was therefore, very time-consuming to run. To evaluate container designs, pressures were measured in the acceptor warheads. The lower the pressures measured, the better chance that container design would be able to mitigate SR. Therefore measured pressures became the success criteria for each design. Should the pressures measured inside of the acceptor warheads remain below 50% of the Large Scale Gap Test (LSGT) pressure for the warhead explosive fill, then that container design/IM plate thickness was considered successful. For this series of models we chose 27 Kbar to be the upper limit pressure for success.

3.1 SINGLE-CONTAINER, WARHEAD-ONLY 3D MODEL

Two 3D model types were generated and run in CTH. A single container was simulated in these models. They were generated to show that the detonation of a donor (D) warhead would not set off the adjacent warhead inside the same container but in the flipped (F) position (see Figure 3). The first model evaluates an extreme worst-case scenario because the missile skins and other structures were omitted, therefore fragments would not encounter other objects that would slow it down. The second model included other structures from the missile to allow shock to reflect off of and transmit through the structures to see the effect on the acceptor. Both models were simulated with the donor warhead being detonated from the forward end toward the aft end in order to throw the maximum number of fragments toward the flipped acceptor warhead. Although this situation would not occur without external initiation, such as a shaped charge jet initiating the forward end of the warhead, the purpose of the model is to evaluate the worst-case scenario. Tracers were placed inside the donor and acceptor warheads to verify that the donor detonated appropriately and to measure pressures within the acceptor warhead. The first model predicted a peak pressure of 2.6 kbar in the flipped-position acceptor, well below the allowable maximum of 27 kbar. noting that 1 kbar = 10^9 dyn/cm^2. The second 3D simulation was run, and it showed a 1.5-kbar pressure within the acceptor—well below the explosive's initiation pressure. The relatively low acceptor pressures predicted by the models built confidence that SR between two weapons in the same container was extremely unlikely.



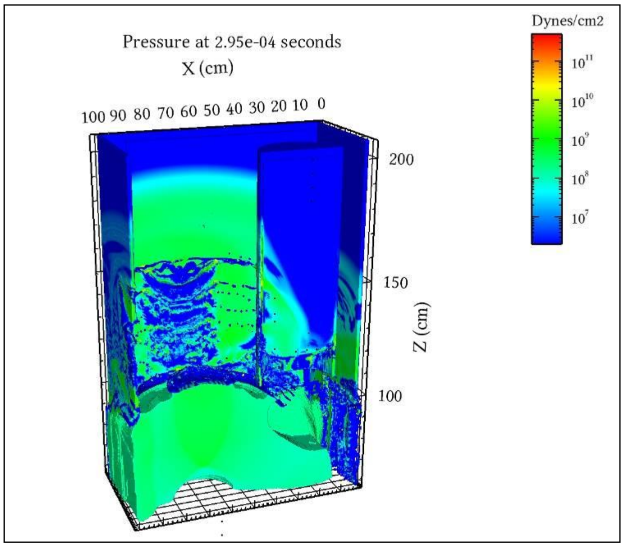


FIGURE 3. Single Container Flipped Acceptor Warhead Pressures.

3.2 LOGISTICAL STACK 2D MODELS

A two-by-two logistical stack of new containers were modeled in 2D to determine which acceptor warhead (vertical, horizontal, or diagonal) in a neighboring container would be subjected to the greatest pressure from blast and fragments. This model was also used to determine optimal aluminum plate thickness to place under the weapons cradle in order to prevent SR.

These two simulations examined a 2D slice across the containers, warheads, and missile structure (see Figure 4) near the forward end, and aft end, of the donor warhead. The CTH model was run many times to determine the optimal thickness and location of the aluminum IM plate in the container cradle. The model showed the vertical (V) direction acceptor was the worst case, as it was the closest to the donor warhead. Accordingly, it showed the highest internal pressure of all the acceptors. A 0.75-inch-thick aluminum plate was shown to be optimal to prevent SR. A 0.50-inch-thick plate did not reduce pressures enough, and a 1.0-inch-thick plate became a flyer that caused excessive pressures on impact. The pressures in the acceptor warheads were recorded with the use of tracers placed inside the explosive fills. The maximum pressure received by the vertical acceptor was 18 kbar. The horizontal (H) acceptor received a maximum input pressure of 13 kbar and received the second-greatest pressure of all the acceptors. The acceptor diagonal (K) to the donor measured a maximum pressure of 8.6 kbar. All of the pressures recorded in the acceptors were below 27 kbar (see Figure 4), thus building confidence that the warheads would not react when tested.

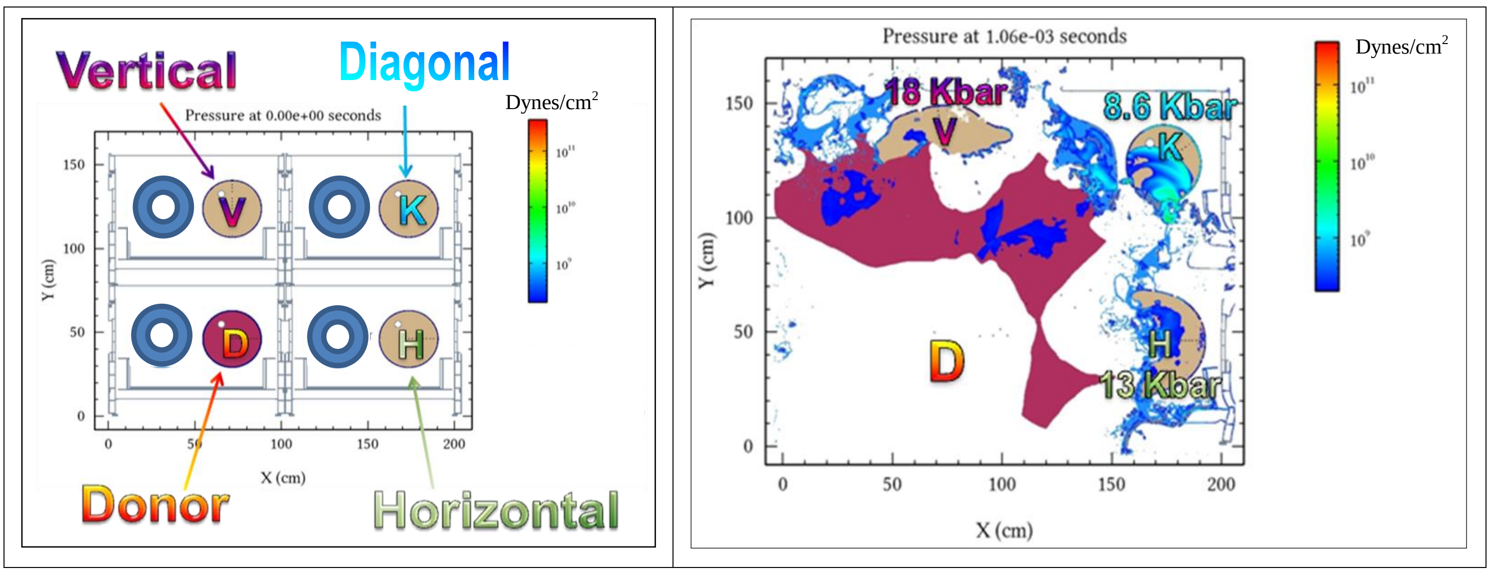


FIGURE 4. Forward-End 2D Slice Logistical Stack Model and Results 1.06 milliseconds after Simulated Initiation.

The results of both of the 2D cross-sectional CTH models agreed, thus showing that the 0.75-inch-thick aluminum plate was sufficient to prevent SR along the length of the warhead. The model also showed that, within each slice, the vertical acceptor had the greatest input pressure and the horizontal acceptor had the second-highest input pressure. These modeling observations helped build confidence that the testing results would be favorable. The 2D model predicted no SR among warheads in different containers, and the 3D model showed that SR would not occur between two weapons within a single container.

3.3 MODEL VALIDATION

A simple IM test was conducted to verify the model results for the worst-case scenario. The test used two vertically spaced Harpoon warheads, as well as a 0.75-inch-thick aluminum plate placed below each warhead. The distances between the warheads and the plates represented those in the logistical configuration. A detonator holder with dimensions similar to those of the fuze was used, and 0.5 pound of C-4 was used in place of the booster. The test was conducted at the Burro Canyon Test Facility at NAWCWD, China Lake, California. After the test was completed, there was a small crater left where the test stand had been sitting, and the dirt around the test site was discolored with fine pieces of black colored material. The black material was found to be un-reacted explosive. Based on the un-reacted explosive found at the test site, it can be deduced that the acceptor did not detonate. The vertical witness plate (there was no horizontal witness plate present) also confirmed that deduction. Large and deep fragment marks were visible near the base of the witness plate where the donor warhead was located, but fewer fragment impacts were seen near the top of the witness plate (see Figure 5). Blast predictions also correlated with measured values of a single detonation event.

FIGURE 5. Validation Test Hardware Setup and Posttest Witness Plate Photographs.

4.0 INSENSITIVE MUNITION TESTS

4.1 SYMPATHETIC REACTION TEST #1—CONFINED

The first SR test conducted was the confined SR test, conducted at the Burro Canyon site. Warheads were placed in each container section after the end plates were attached. A simulated missile structure filled with JP-10 was also in each container section (see Figure 6). The acceptor warheads retained the live fuze and booster in the fuzewell, but the donor warhead had the fuze removed and a simulated fuze/detonator holder used in its place as described in the model validation test. The booster was attached to the bottom of the detonator holder and placed inside the donor warhead. Three container sections were used for this test. Dirt was piled on top of the containers to a depth of 1 meter in all directions to represent the appropriate confinement. The depth was verified by a probe.

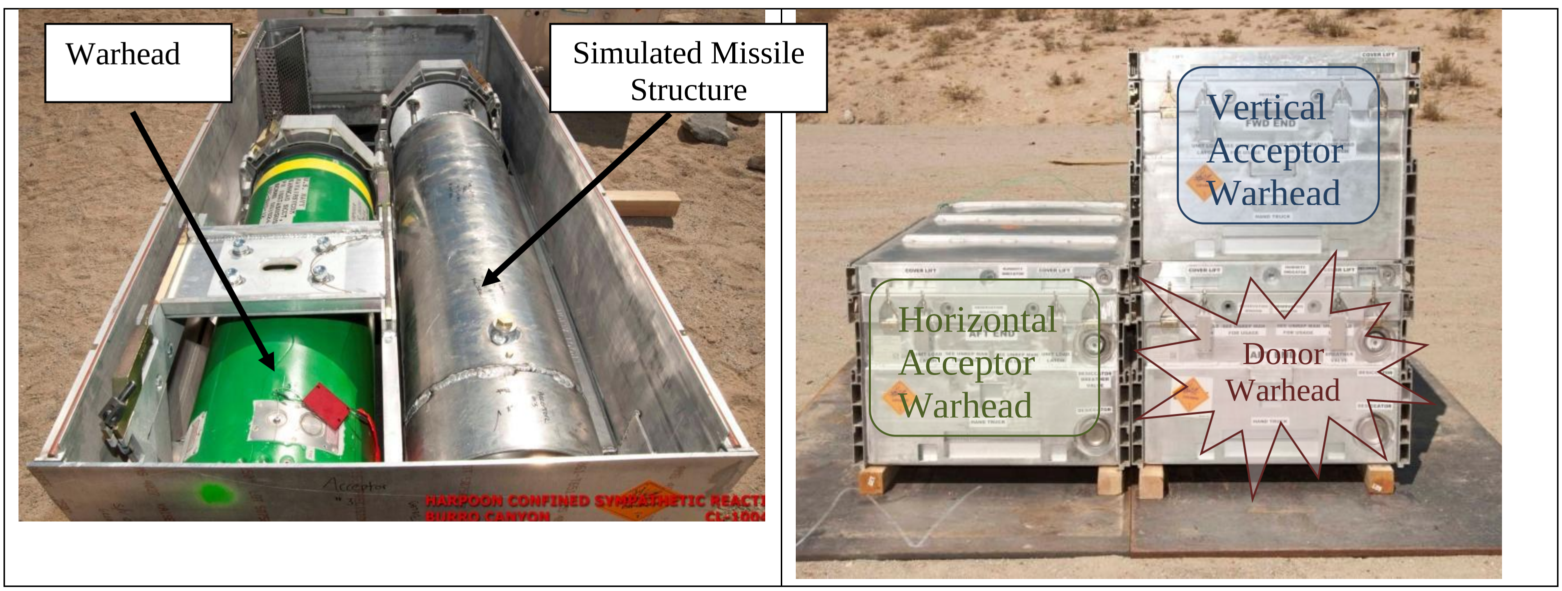


FIGURE 6. Confined SR Test configuration (Before Dirt Confinement Added) – Container Sections Loaded with Warhead and Simulated Missile Structure.

The instrumentation for the confined SR test included a horizontal witness plate placed under the stack of container sections, as well as video cameras (two recording at normal speed and two recording at 8,000 frames per second). A firing line light was also included in the test that would light up the instant the detonator saw the firing pulse; this configuration allows easy recognition of time zero in the video footage.

When the donor was fired, the entire dirt berm used for confinement was thrown away from the test site. All of the test items were also thrown from the test site (see Figure 7). The horizontal acceptor warhead was thrown from the test site and was found mostly intact up against a rock-covered hillside next to the access road on the southeast side of the test site. This acceptor warhead case had ruptured; however, the majority of the explosive fill appeared to still be inside. Some pieces of raw explosive were found around the test site that appeared to be too large to have come out of the crack in the ruptured horizontal acceptor warhead; these pieces likely came from the vertical acceptor. No other large pieces of the vertical acceptor were found and video coverage didn't help locate anything else from the vertical acceptor. The witness plate was dented where the donor warhead had been placed directly above it; and, as expected, there were very few dents elsewhere on the plate. The ground was covered with small black un-reacted explosive. After review of all the test data, the Navy's Munition Reaction Evaluation Board (MREB) rated this SR test as a pass, and assigned a Type III explosion score.

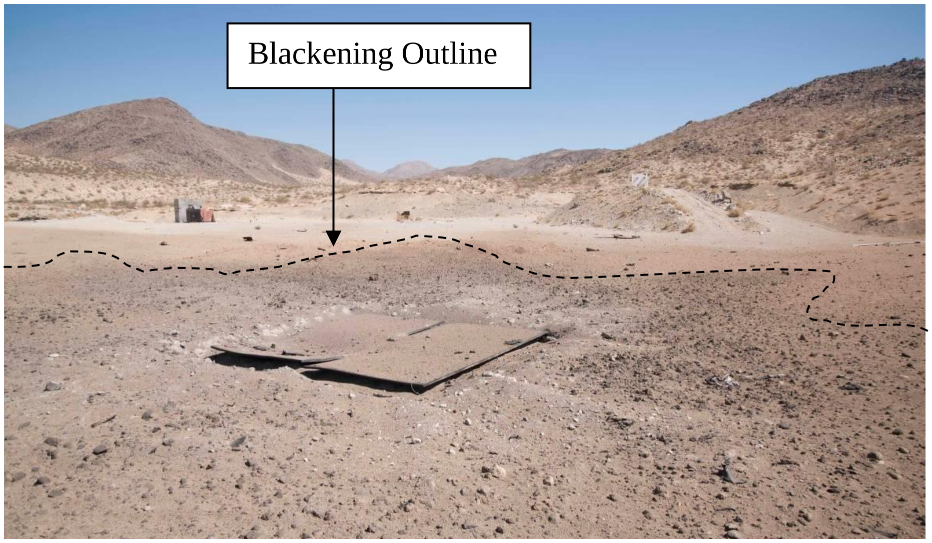


FIGURE 7. Visual Blackening of Test Pad.

4.2 SYMPATHETIC REACTION TEST #2—UNCONFINED

Due to the nature of this test and the requirement for extensive fragment recovery and mapping, this test had to be performed at NAWCWD China Lake's Cactus Flats Test Facility. The weapon configurations inside the containers for this test were the same as those for the confined test. The location of the container sections in the stack were different from those of the confined SR test as the Insensitive Munitions Office (IMO) thought the worst-case scenario would involve the donor warhead placed directly on top of the vertical acceptor. The placement of the donor on top of the vertical acceptor would allow shock to reflect back up from the ground (see Figure 8). The horizontal acceptor was placed next to the donor atop a wood stand to keep it properly aligned, and minimize metallic fragment debris. This change would also allow the fragments to disperse around the area much more freely, as desired by Hazard Classification and the IMO.

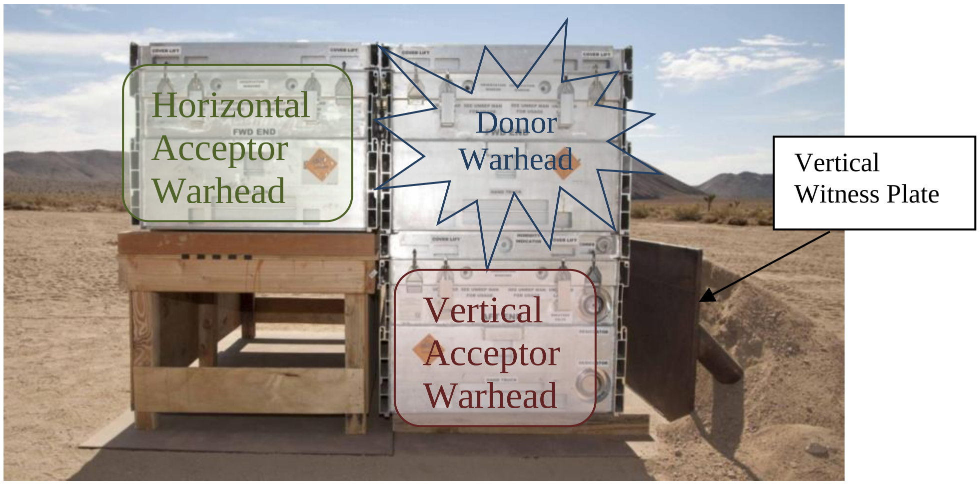


FIGURE 8. Unconfined SR Test Configuration.

This test used more instrumentation than the confined test. Blast pressure gages were used along two radii. Video and high-speed video cameras were used to capture the event. A witness plate was placed under the container stack, and a half-height vertical witness plate was used to catch additional fragments from the vertical acceptor but not disrupt the post-test dispersion of the donor warhead fragments. Warheads were also painted prior to the test, with the horizontal acceptor painted green, the vertical acceptor painted red, and the donor painted white. When the firing signal was given, the test items were scattered around the test site in a large fireball and fragments were thrown everywhere. The horizontal acceptor was found intact (the direction it was thrown and the green paint still visible on the outside of the warhead were used to identify the specific acceptor). The ground around the test pad was once again blackened with pieces of explosive (See Figure 9), as seen previously.

FIGURE 9. Test Pad Blackened From Small Pieces of Explosive.

The fragment recovery effort took into consideration both IMO and Hazard Classification requirements which required that "significant" fragments be recovered in a 360-degree arc around the test items. One of the most important fragments found was the aft end of the vertical warhead (painted red) with the fuze still attached in a relatively undamaged state. Large pieces of energetic were found around the test pad. The condition of the witness plates also helped determine the extent of reaction for this test. The vertical witness plate only had fragment marks near the top where the donor fragments impacted it, and nothing next to the vertical acceptor. Recorded blast pressures were well below predicted values for a multiple warhead detonation event. After the MREB reviewed the data, the test was given a passing score of a Type III explosion reaction.

5.0 SUMMARY

The replacement container project was conducted in an effort to provide the Fleet with a container for Harpoon that would prevent loss of weapons due to corrosion from water intrusion and to provide an incremental improvement in IM with respect to its SR response. These objectives were achieved with no change to the weapon system. By implementing an improved container design that incorporated appropriate seals, shock isolators and an IM aluminum plate this new container has achieved its objectives.

6.0 REFERENCES

1. Naval Air Warfare Center Weapons Division. *Harpoon Insensitive Munition (IM) Study Preliminary Assessment on the Harpoon Weapon System for the United Kingdom*, by Aubrey Farmer. China Lake, California, NAWCWD. 16 March 2010. (NAWCWD TM 8606, publication UNCLASSIFIED.)

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