FAST COOK-OFF REACTION IMPROVEMENT OF THE 2.75-INCH ROCKET MOTOR

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ABSTRACT

This paper is intended to summarize the development of a modified 2.75-Inch Rocket Motor with improved Fast Cook-Off (FCO) reaction performance. The current rocket motor exhibits a deflagration or propulsive reaction. The FCO improvement was achieved with the incorporation of a venting system in the aluminum motor tube. The improved rocket motor will be designated the MK 66 MOD 5 Rocket Motor.

INTRODUCTION

The Indian Head Division, Naval Surface Warfare Center (IHDIVNAVSURFWARCEN) is responsible for product improvements to the 2.75-Inch Rocket Motor designated as the MK 66 Rocket Motor. The 2.75-Inch Rocket System is an unguided tri-service weapon designed to be operated from rotary and fixed wing aircraft. The 2.75-inch Rocket System is used in large numbers for prosecuting soft and lightly armored targets and additionally provides unique battlefield illumination, target marking, and smoke screening capabilities.

BACKGROUND

The goal of the development program is to improve the FCO performance of the MK 66 Rocket Motor. Currently, the MK 66 Rocket Motor can deflagrate or be propulsive when subjected to a FCO environment. The FCO requirement is outlined in MIL-STD-2105. In order to improve the FCO reaction, IHDIVNAVSURFWARCEN has modified the MK 66 Rocket Motor with a venting mechanism in the forward end of the motor tube. The venting system is designed to lower the reaction pressure by lowering the propellant burn rate and prevent a propulsive reaction. The vented rocket motor operation is illustrated in Figure 1.

The program has completed its Design Verification Testing (DVT) and currently is in the qualification phase. The DVT involved environmental, static fire, ground launch and Insensitive Munitions (IM) testing. This paper will present only the IM test results.

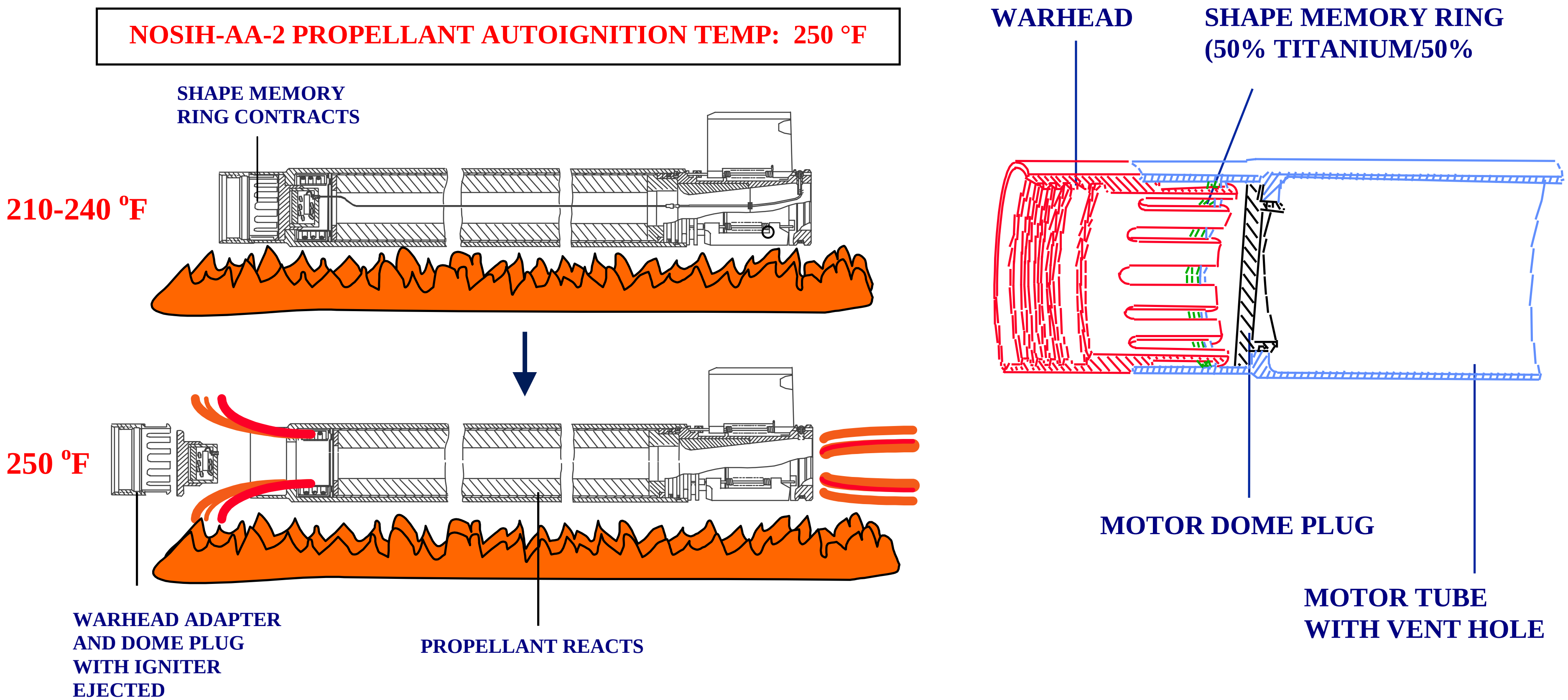


Figure 1. Vented Motor Tube Operation

TEST ITEM DESCRIPTION

The MK 66 MOD 5 Rocket Motor is MK 66 MOD 4 Rocket Motor modified primarily with a fast cook-off venting system. The current and proposed rocket motor configurations are shown in Figure 2. The venting system consists of the following components.

Nitinol Rings
Vented Motor Tube
Ejectable Warhead Adapter
Integral Igniter/Vent Plug

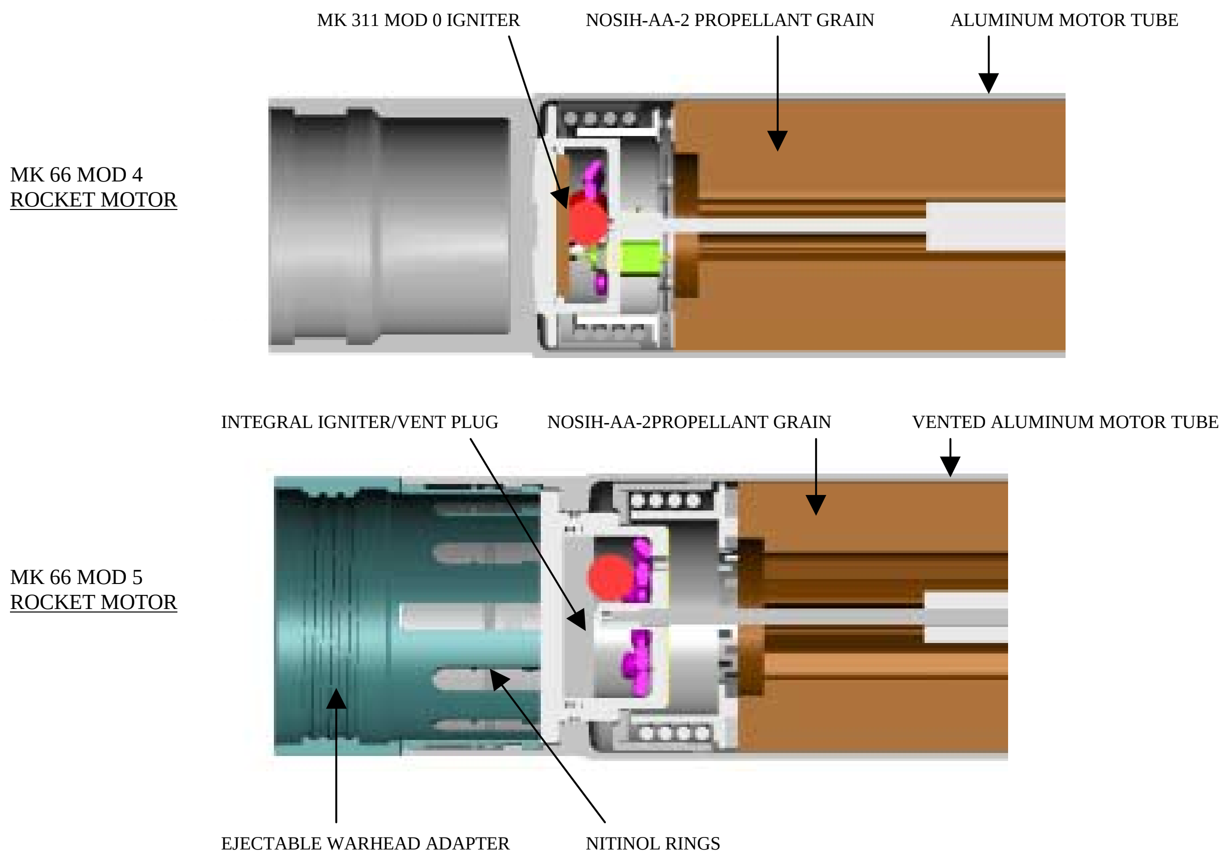


Figure 2. MK 66 MOD 4 and 5 Rocket Motor (Detail of Forward End)

a. Nitinol Ring Description:

The Nitinol Ring is the key component that provides motor tube venting. There are actually 3 rings used. Each ring is a 0.028-inch diameter Nitinol wire with flattened and resistance welded ends. They are installed around the 12 tang “fingers” of the ejectable warhead adapter, which is snapped into a groove inside the motor tube. The Nitinol Rings are designed to contract 4 percent and pull the warhead adapter tang “fingers” away from a motor tube groove thus detaching the warhead adapter. The Nitinol Ring transformation temperature range is 210 to 240 F. This is above the maximum temperature transferred to the ring from the motor operation (200°F) and below the NOSIH-AA-2 propellant autoignition temperature (250 °F).

This shape memory phenomenon is associated with a material phase transformation from martensite to austenite. All shape memory alloys exhibits these two crystal phases. The martensite phase exists at lower temperatures and the austenite phase exists at higher temperatures. The presence of each phase is dependent upon temperature and amount of stress applied to the alloy. The shape memory properties are dependent upon the amount of each crystal phase present.

b. Vented Motor Tube:

The vented motor tube is a modified version of the current 7075-T6 aluminum tube. The current motor tube has a solid bulkhead and is threaded to accept warheads. Only the forward end of the tube was modified. The vented motor tube contains a 2-inch diameter vent hole in the bulkhead and modified forward end to accept a separate warhead adapter. The warhead adapter tangs “fingers” snap into a groove around the tube wall and secures an integral igniter/vent plug. Environmental sealing is provided by an o-ring and flat gasket on the vent plug.

c. Ejectable Warhead Adapter:

The ejectable warhead adapter is threaded to allow a warhead to be mated to the rocket motor and secures the integral igniter/vent hole plug for normal motor operation. The Nitinol Rings are installed around the 12 tang “fingers”. The 12 warhead adapter tang “fingers” snap into a groove in the forward end of the motor tube. The warhead adapter material is 7075-T6 aluminum. The warhead adapter is only released from the motor tube by the Nitinol Ring contraction during a thermal cook-off.

d. Integral Igniter/Vent Plug:

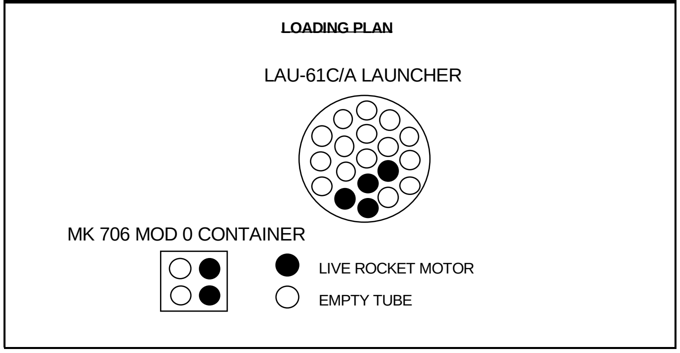
The igniter configuration in the MK 66 MOD 4 Rocket Motor is the MK 311 MOD 0 Igniter. Only the aluminum case and lid were modified for the venting system. This was necessary to prevent the igniter from blocking the vent hole and provide a vent hole plug. All other components such as the MK 26 MOD 0 Initiator and $BKNO_3$ ignition charge are the same. The igniter lid serves an important purpose by acting as the vent plug for the 2-inch diameter hole in the tube bulkhead. An o-ring and flat gasket provides a seal for normal motor operation. After the Nitinol Rings release the ejectable warhead adapter, the integral igniter/vent plug will be ejected by the low-pressure reaction of the propellant grain.

IM TEST RESULTS

The venting system was successfully demonstrated during 2 FCO and 1 Slow Cook-Off (SCO) test. The tests were conducted by IHDIVNAVSURFWARCEN at a test site located at Fort A.P. Hill, Virginia. Although the venting system was predicted to have only minimal SCO benefit, 1 SCO test was conducted for information. The lower expectation in a SCO environment is due to the propellant's rapid SCO reaction regardless of containment. The test matrix is shown in Table 1.

Table 1. FCO and SCO Test Configurations

TEST & INSPECTIONS	CONFIGURATION	IMPROVED IM SAFE MK 66 ROCKET MOTOR						
		22	23	24	25	26	27	28
MOTOR LOAD		X	X	X	X	X	X	X
X-RAY & CONT/RESISTANCE		X	X	X	X	X	X	X
FAST COOK-OFF #1	4 MOTORS WITH INERT WARHEADS IN A LAUNCHER	X	X	X	X			
FAST COOK-OFF #2	2 MOTORS IN A MK 706 MOD 0 CONTAINER					X	X	
SLOW COOK-OFF #1	1 MOTOR IN A MK 706 MOD 0 CONTAINER							X



The test results are summarized below.

a. FCO #1: The first FCO test involved 4 live motors mated with inert 9 pound warheads loaded into a 19-tube LAU-61C/A Launcher. Two 8 x 20 burn pans were filled with a total of 200 gallons of JP-8 fuel. The test set-up is shown in Figure 3. The first reaction (rapid burning) occurred 11 minutes into the test. The last reaction (igniter "pop") occurred 18 minutes into the test. Venting from both ends of the rocket motors was recorded on video. The average flame temperature of 1310 ºF was lower than the MIL-STD-2105 recommended 1600 ºF. The average winds recorded were below 5 knots but occasional gust up to 10 knots were seen. The wind gust contributed to the lower average flame temperature.

The warhead adapters were found fully contracted around the inert warheads. Inspection of the warhead adapters indicated no evidence of the adapter tang "fingers" engaging with the motor tube at the time of motor reaction. If a warhead adapter failed to fully contract at time of reaction, the tang "fingers" and motor tube groove would show evidence of shearing. Only 1 inert warhead was ejected from the fuel pans at a distance of 28 feet as measured from the center of the launcher. The longest fragment thrown was a motor tube with attached nozzle thrown 46 feet. The fact that the nozzles were still attached to the motor tube indicates lower reaction pressures. The post-test photographs are provided in Figure 3. The fragment debris map is also provided in Figure 3.

b. FCO #2: The second FCO test involved two live motors in an aluminum MK 706 MOD 0 Shipping Container suspended 36 inches above the fuel level. The motors were loaded into shipping tubes so that one motor was loaded directly above the other. The test set-up is shown in Table 1 and Figure 4. The average flame temperature was again in the 1300-1400 ºF range. The first motor to react blew off the container caps and ejected 2 fragments beyond 50-feet. The second motor exhibited only active burning and venting. All rocket motor parts from the second motor were within a 35.5-foot radius around the fuel pan. All container parts were found within a 35-foot radius. The post-test photographs are provided in Figure 4. The debris map is also presented in Figure 4.

The reaction severity of the first rocket motor was increased due to the pressure buildup caused by the sealed aluminum container. The aluminum container is permanently sealed on the aft end and closed on the other end with a removable aluminum cap. This containment will prevent release of the motor vent plug and cause higher motor reaction pressures. Once the container cap was released, the second motor vented its reactants to open air, thus resulted in a less severe reaction. Inspection of the warhead adapter indicated that the warhead adapters on both motors fully contracted at the time of motor reaction. The reaction of the first motor can be improved if the container incorporates a venting system. One concept would involve low-melt plastic vent plugs at each end of the container, which will allow the release of the motor vent plug and prevent additional pressure build-up by the container. At the time of motor reaction, the vent plugs would melt or weaken. Despite the apparent deflagration of the first motor, the test results were a significant improvement over the current motor.

c. SCO Test: The SCO test involved 1 live motor in an aluminum MK 706 MOD 0 Shipping Container. Although the rocket motor was not expected to pass SCO, the effect of the venting system on fragment throw distance was sought for information only. The current rocket motor deflagrates or explodes depending upon the heating rate and containment. The partially loaded container was placed in a SCO oven at a height of 8-inches above a steel witness panel. The test set-up is shown in Table 1 and Figure 5. The oven was constructed of 1/16-inch thick aluminum panels. The loaded container was heated at a rate of 40 ºF per hour. The reaction temperature was 280 °F. Although the propellant appeared to react all at once, the motor tube did not rupture indicating a lower reaction pressure. The nozzle separated from the motor tube and could not be recovered. The nozzle was likely thrown beyond 50 feet. No other rocket motor parts were ejected past 50 feet. Container fragments were found as far as 63 feet away. The oven was destroyed by the reaction. The warhead adapter was recovered and performed successfully. Inspection of the warhead adapter indicated no evidence of engaging with the motor tube at the time of motor reaction. The post-test photographs are shown in Figure 5. The SCO test debris map is also presented in Figure 5. The test demonstrated that the venting system could improve the motor's SCO reaction; however, a complete SCO solution will require propellant modifications.

LAU-61C/A LAUNCHER
WITH ROCKETS
(4 LIVE MOTORS WITH
INERT WARHEADS)

3 INERT
WARHEADS

LEGEND	DESCRIPTION	DISTANCE (FT)	WEIGHT (LBS)
A	Warhead with adapter	3	8.970
B	Warhead with adapter	3.5	9.145
C	Warhead with adapter in slag (not collected)	1.5	9.100 *
D	Stabilizing rod	3	0.165
E	Stabilizing rod	9	0.160
F	Stabilizing rod	1.6	0.160
G	Igniter body	12	0.375
H	Immobilizer spring	2	0.120
I	Stabilizing rod with igniter	17.5	0.650
J	warhead with adapter	28	9.110
K	Inner heat shield	37.75	0.020
L	Sealing ring	18	0.015
M	Detent arm	20.5	0.100
N	Sealing ring	35.5	0.015
O	Nozzle fin	41.5	0.090
P	Motor tube with nozzle (2 fins)	46	5.270
Q	1/2 motor tube with nozzle	1	4.890
	Molten Slag (collected)	0	1.010
	Three nozzles in slag (not collected)	3	8.630 *
		TOTAL WEIGHT	57.995

Figure 3. Fast Cook-Off Test #1 Setup and Results

MK 70 MOD 0 ALUMINUM
CONTAINER WITH 2 LIVE
MOTORS

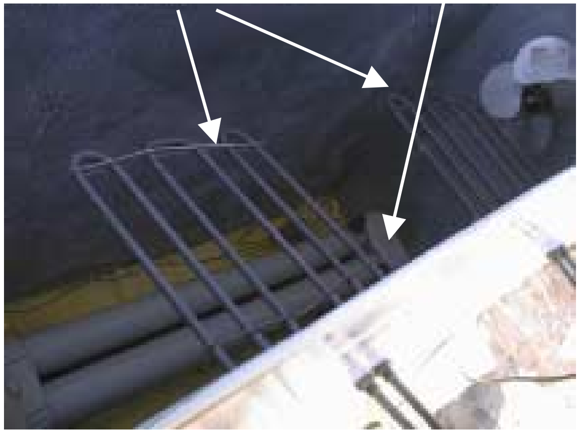
MELTED CONTAINER
AND MOTOR PARTS

LEGEND	DESCRIPTION	DISTANCE (FT)	WEIGHT (LBS)
A	Stabilizing rod with igniter	90	0.580
B	Warhead with adapter	75	0.185
C	Steel ring	46	0.040
D	Shipping container forward cap	40	7.800
E	Forward end of motor tube	35	0.265
F	Immobilizer spring	35	0.130
G	Shipping spacer (plastic)	35	0.040
H	Shipping spacer (plastic)	18	0.040
I	Shipping tube (frag)	16	0.035
J	Shipping tube (frag)	11	0.015
K	Stabilizing rod with igniter	8	0.530
L	Steel ring	14	0.040
M	Immobilizer spring	0	0.120
N	Warhead adapter	35.35	0.175
O	Nozzle	1	2.650
P	Nozzle	1	2.740
	Slag (in pan)		15.720
		TOTAL WEIGHT	31.105

Figure 4. Fast Cook-Off Test #2 Setup and Results

MK 706 MOD 0 CONTAINER
WITH 1 LIVE MOTOR

HEATING COILS



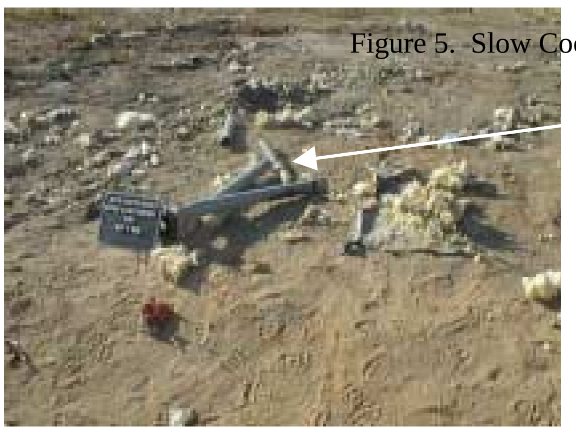


Figure 5. Slow Cook-Off Test Setup and Results

INTACT MOTOR TUBE

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LEGEND	DESCRIPTION	DISTANCE (FT)	WEIGHT (LBS)
A	Vented motor tube	5	2.460
B	Shipping Container (2 tubes)	5	11.160
C	1/2 motor tube (live)	6	1.460
D	Inert motor in shipping container	5	14.700
E	Shipping container frag	10	0.570
F	Small cylinder	13	0.205
G	Shipping container frag	21	0.125
H	Rear and left side of oven + fan	29	
I	Top of oven	26	
J	Top witness panel (no frag impact)	26	
K	Shipping container tube	26	2.200
L	Oven front and right side	55	
M	Shipping container frag	63	0.085
N	Front witness panel (no frag impact)	50	
O	Shipping spacer (plastic)	58	0.040
P	Warhead adapter	1	0.150
Q	Immobilizer spring	43.5	0.130
R	Stabilizing rod	48	0.165
		TOTAL WEIGHT	33.450

Figure 5. SCO Test Setup and Results

CONCLUSIONS

The venting system for the MK 66 Rocket Motor operated as designed and provided significant improvement in the rocket motor's FCO reaction. The current MK 66 Rocket Motor can deflagrate or be propulsive during an FCO test. Fragment throws over 100 feet are common. The venting system limited the MK 66 Rocket Motor reaction in a launcher to Type V burning as defined by MIL-STD-2105. All fragments including the inert warheads were found within a 50-foot radius of the fuel pans.

The FCO test involving 2 rocket motors in a MK 706 MOD 0 Container was also an improvement over previous tests. The vented system functioned as designed but the test revealed that in order to have a complete FCO solution, the container must also incorporate a venting system. The container acts as a pressure vessel and prevents release of the motor vent plug, which increased the severity of the rocket motor reaction. The first vented motor to react blew off the container caps and deflagrated 2 fragments beyond 50-feet. The second vented motor reacted into open air and appeared to be a Type V burning reaction. A relatively simple modification such as adding vent plugs to the container caps that melt or weaken in a fuel fire would allow the first vented motor to react with a Type V burning reaction.

The single SCO test demonstrated that the venting system partially mitigate the SCO reaction. A new propellant grain with better SCO performance would be required to provide a complete SCO solution.

The Nitinol Ring is key to the success of the venting system. Inspection of recovered parts clearly showed that the Nitinol Rings fully contracted and released the warhead adapter from the rocket motor prior to motor reaction. No shear damage on the warhead adapter tang "fingers" or motor tube groove was found.

The results were presented to Navy's IM Office, Weapons Explosive System Safety Review Board (WSESRB) and U.S. Army's IM Board. They concluded that the vented motor appeared to provide a significant FCO reaction mitigation. A qualification program has been fully funded by the U.S. Army. The qualification program is scheduled for completion in fiscal year 2002.