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V27 Test Report

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Abstract

The V27 containment vessel was procured by the US Army Recovered Chemical Material Directorate (RCMD) as a replacement vessel for use on the P2 Explosive Destruction Systems. It is the third EDS vessel to be fabricated under Code Case 2564 of the ASME Boiler and Pressure Vessel Code, which provides rules for the design of impulsively loaded vessels. The explosive rating for the vessel, based on the Code Case, is nine (9) pounds TNT-equivalent for up to 637 detonations. This report documents the results of explosive tests that were done on the vessel at Sandia National Laboratories in Albuquerque New Mexico to qualify the vessel for explosive use. The primary qualification test consisted of six 1.5 pound charges of Composition C-4 (equivalent to 11.25 pounds TNT) distributed around the vessel in accordance with the User Design Specification. Four subsequent tests using less explosive evaluated the effects of slight variations in orientation of the charges. *All vessel acceptance criteria were met.*

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NOMENCLATURE

ASME	American Society of Mechanical Engineers
EBW	Exploding Bridgewire
EDS	Explosive Destruction System
RCMD	US Army Recovered Chemical Materiel Directorate

1. INTRODUCTION

The Explosive Destruction System (EDS), which was developed at Sandia National Laboratories, is designed to destroy recovered chemical munitions. The apparatus treats chemical munitions through explosive access using shaped charges followed by chemical neutralization of the agents. The process is conducted inside a stainless steel vessel which both contains the detonation and serves as a chemical reactor. As part of the acceptance process, each vessel is subjected to a 1.25X over-test.

The vessel was designed and fabricated per Section VIII Division 3 and revision 4 of Code Case 2564 of the 2013 ASME Boiler and Pressure Vessel Code. The static pressure rating is 2800 psi. The explosive rating, based on the Code Case, is 9 pounds TNT equivalent with distributed-charges for up to 637 detonations. This is the third EDS vessel to be designed per the Code Case. Prior to publication of the Code Case vessels were designed based on Sandia defined criteria that limited the pressure rating to 4.8 pounds TNT equivalent.

The vessel consists of a cylindrical cup, a flat cover or door, and clamps to secure the door. The vessel is sealed with a metal compression ring. A fragment suppression system is used to protect the vessel from high-velocity fragments during the detonation, as well as dissipate the blast. Basic dimensions are shown in Table 1.

The body is a deep cylindrical cup machined from a 316 stainless steel forging. The door is also machined from a 316 stainless steel forging. Fluid penetrations in the door have either 3/8 or 3/4-inch female coned-and-threaded fittings that adapt to tubing and valves. These fittings have a static pressure rating of 20,000 psi.

A flange with four high-voltage electrical feed-throughs is bolted to the door and sealed with a small compression ring. These feed-throughs conduct the firing signals for the high-voltage Exploding Bridgewire Detonators. Small blast plates on the inside of the door protect fluidic components and electrical feed-throughs. A large blast plate provides additional protection.

The closure clamps are SA 372, grade J, Class 70 (4140 steel). They are secured with four threaded rods with threaded-nuts on one end and hydraulic nuts on the other. The rods and nuts are SA 564 Grade 630 (17-4 PH) and SA 372, grade J, Class 70 (4140).

Table 1: EDS Vessel Dimensions

Overall length	71.89 inches
Inside length	56.58 inches
Outside diameter	36.53 inches
Inside diameter	29.22 inches
Door thickness	9.00 inches
Cylinder wall thickness	3.65 inches
Aft end thickness	6.30 inches

2. TEST OBJECTIVES

Code Case 2564 states that the User's Design Specification shall provide the impulsive loading design basis and the impulse source location within the vessel (i.e., vessel center, off-center, etc.). Because EDS is used to destroy various munitions, it is necessary to define a design basis that blankets all munition configurations. The design basis for the previous two vessels fabricated under Code Case 2564 was specified as a single bare charge in the center of the vessel. In the specification for this vessel we opted to distribute six smaller charges, with the same total explosive weight, located as described below. The distributed configuration mimics the destruction of six munitions and provides more realistic strain data relative to actual operations. The distributed configuration has the effect of distributing the strain more evenly through the vessel so the strain at most locations is increased, but the peak localized strain directly adjacent to the charge is less.

The objective of the first test described here was to qualify the vessel for its intended use by subjecting it to a 25 percent over-test. Specifically, the test was to validate the Vessel Impulse Rating specified in the User Design Specification for the V27 vessel. [1]:

Design Impulse: *11.25 pounds of TNT, consisting of six 1.875 pound (TNT equivalent) cylindrical charges distributed in two clusters of three located forward and aft with the centerline of each charge 4 inches from the vessel centerline and 20.7 inches from the nearest end. Detonation will occur at room temperature. The design impulse applies to the explosive qualification test only. Vessel explosive rating for normal operation is 9 pounds of TNT or equivalent.*

Vessel Impulse Rating: *Nine pounds TNT equivalent (80 percent of the qualification test) in various configurations. In an actual EDS operation, there can be multiple explosive charges dispersed around the vessel. There are also obstacles such as munition housings and the fragment suppression system that can dissipate or redirect the pressure shocks. Specific munition configurations are evaluated and approved by the Army and operational procedures are implemented to ensure that the actual impulse loads will not exceed the design basis load.*

In the next four explosive tests, various orientations were used to hold 6 charges of a reduced explosive loading (6-0.8 lbs C-4 (6 lbs TNT equivalent)) [3], [4] in order to provide insight into the effects of minor variations in placement and orientation of the charges. These tests are also important in providing input for hydrocode calculations for further predictions of various, alternative orientations of munitions.

3. INSTRUMENTATION

Dynamic strain gauges (Vishay EP-08-250BG-120, 120 ohm) were installed on the EDS vessel in the configuration shown in Table2. In addition, plastic strain, or permanent vessel deformation, was measured after each test at four locations along the length of the vessel by measuring the outer diameter using a stainless steel π-tape around the circumference, as well as by processing the dynamic strain data from the records by comparing before and after static strain offsets. In the table below, 0 degrees is considered top-dead-center of the vessel body, 30 degree and 60 degree radial orientations are offset clockwise while facing the door of the vessel. All longitudinal offsets are measured from the interior aft end of the vessel. An offset of 1/3 is approximately 18.75 inches from the interior aft end, "mid-point" is approximately 28.125 inches from the interior aft end, and 2/3 is approximately 37.50 inches from the interior aft end.

Table 2: Strain Gage Location

Gauge #	Hoop/Axial	Channel	Longitudinal offset (% from interior aft end)	Radial offset (degrees)
1	H	1	Vessel body 1/3	0
2	H	2	Vessel body 1/3	30
3	H	3	Vessel body 1/3	60
4	H	4	Vessel body mid-point	0
4	A	5	Vessel body mid-point	0
5	H	6	Vessel body mid-point	30
5	A	7	Vessel body mid-point	30
6	H	8	Vessel body mid-point	60
6	A	9	Vessel body mid-point	60
7	H	10	Vessel body 2/3	0
8	H	11	Vessel body 2/3	30
9	H	12	Vessel body 2/3	60

A helium leak test was performed on the main seal and the smaller feed-through flange seal before and after each test using approximately 15 psi of helium. Balloons were placed over leak check ports and other fittings in an effort to detect any transient leaks that might occur. The static pressure in the vessel was measured after each test. The vessel was inspected and photographed after each test. The vessel seal ring was inspected and measured for deformation at various locations to help assess the feasibility of re-using seal rings in an operational environment [2]. A new seal ring was used after the initial over-test shot, and re-used through-out the four subsequent shots.

4. TEST DESCRIPTIONS

The test series consisted of a 9 lbs Composition C-4 (11.25 lbs TNT equivalent) qualification test, and four reduced-weight (4.8 lbs Composition C-4 (6 lbs TNT equivalent)) tests varying the orientation of the six distributed charges. These are listed in Table3.

Table 3: Test Summary

Test	Orientation	Description
9 lb. Composition C-4	1/1	Qualification test
4.8 lb. Composition C-4	1/1	Reduced loading test, close spacing, clocked out of line
4.8 lb. Composition C-4	1/2	Reduced loading test, increased separation, clocked out of line
4.8 lb. Composition C-4	2/1	Reduced loading test, close spacing, clocked in line
4.8 lb. Composition C-4	2/2	Reduced loading test, increased separation, clocked in line

Orientation for each test is shown below.

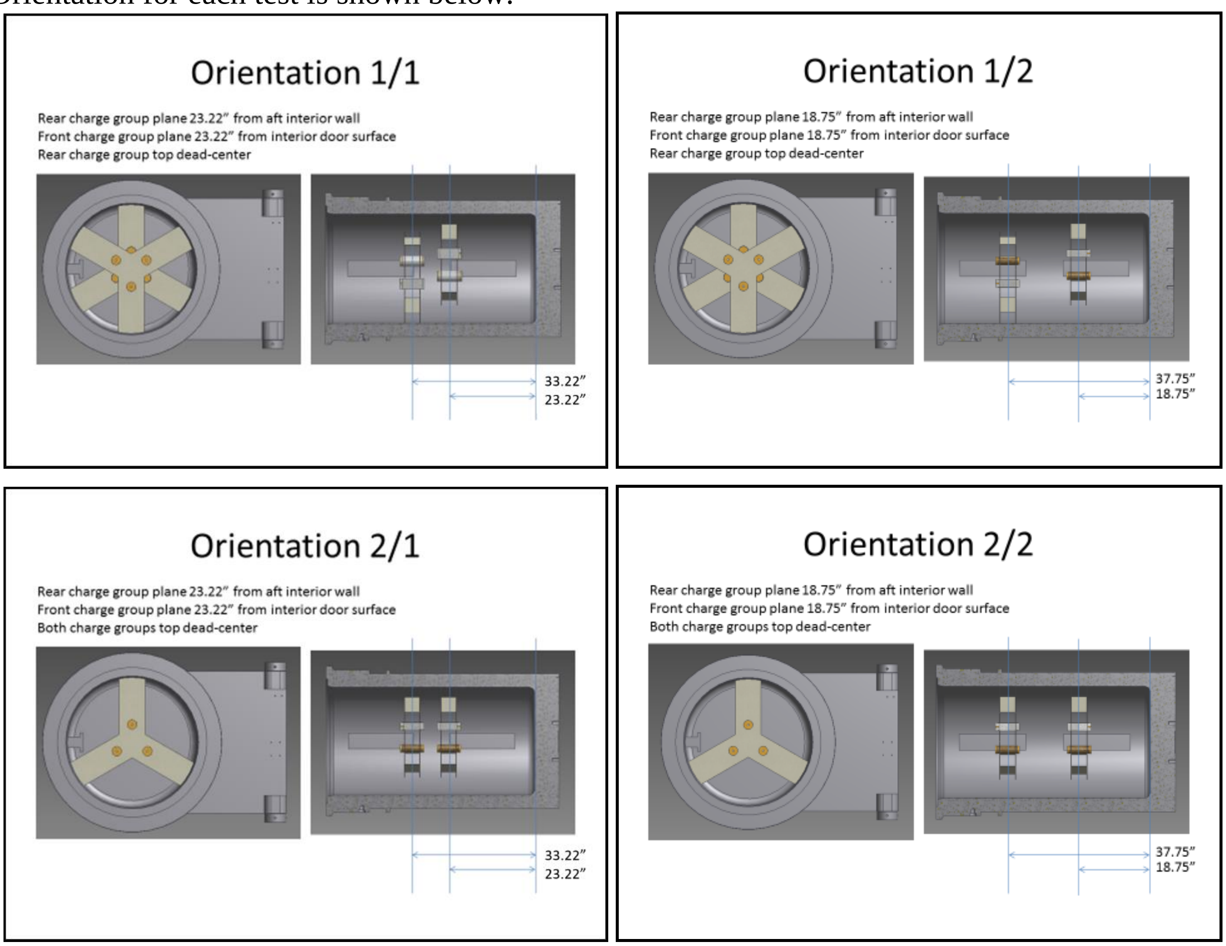

Figure 1: Various charge orientations

The first explosive test consisted of 6 each 1.5 lbs, cylindrical charges of Composition C-4 (11.25 lbs total TNT equivalent) configured in orientation 1/1 above. The explosive was packed into a 2.5-inch inside diameter, 5.3 inch long, thin plastic tubes to a density of 1.6 g/cc. An Exploding Bridge-wire (EBW) detonator and 1/2-inch by 1/2-inch Tetryl booster was placed on each charge, oriented towards the ends of the vessel. All detonators were initiated simultaneously (within tens of nanoseconds). The charges were held with 1/4-inch thick sheets of Styrofoam insulation board. The axis of each charge was oriented parallel to the axis of the vessel, centered about the vessel axis on an 8-inch diameter circle. Two sets of 3 charges were positioned flush on an 8-inch circle so that one set was forward, and one set was rearward. The two sets of charges were separated by approximately 10 inches center to center. The forward set of charges was clocked radially so that one charge was bottom dead-center, with other two at 120 degrees in either direction. The rear set of charges was oriented so that one charge was top dead-center, with the other two charges at 120 degree locations.

Figure 2: Charges prior to detonation

Left: Individual charges packed into plastic bottles – Tetryl booster and detonator holder shown in foreground.
Right: Six 1.5 lb. C-4 Charges (11.25 lb. TNT eq.) arranged in the V27 vessel.

The next four explosive tests consisted of 6 each 0.8 lbs C-4 cylindrical charges (6 lbs total TNT equivalent). The explosive was packed into a 2 inch inside diameter, 4.4 inch long cardboard shipping tube to a density of 1.6 g/cc with an EBW detonator and Tetryl booster place toward the vessel ends. The charges were held with 1/4-inch Styrofoam board.

In each of the four reduced-weight tests, the charge axes were again oriented on 8-inch circles in two groups of three charges so that the center lines of each group was centered about the central axis of the vessel. In each test, either the rotational clocking of the two groups was offset by 60 degrees or the longitudinal separation of each group was changed (see orientations 1/1, 1/2, 2/1, 2/2) above.

In the first of these tests, the orientation was kept exactly the same as in the qualification test with the longitudinal center-to-center separation at approximately 10 inches. The forward set of three charges was rotated so that one charge was oriented at bottom dead-center, and the rear set of three charges was rotated by 60 degrees, so that one charge was oriented at top dead-center.

In the second of these four tests, the radial orientation was kept the same, but the separation was increased to about 19 inches, positioning the charges at the one-third and two-thirds locations of the interior dimension of the vessel.

In the third of these four tests, the longitudinal spacing was returned to 10 inches center-to-center, and the rotation of each group was brought in line, so that both groups had one charge at top dead-center.

In the final test, the rotational orientation was kept so that each group had a top dead-center charge, but the separation was increased to 19 inches.

Figure 3: One of six 0.8 lb. C-4 Charges (6 lb. TNT eq.)

5. RESULTS AND COMPARISONS

Dynamic Testing

Certification of the vessel is based primarily on the results of the first explosive test. The key parameter is the amount of plastic or permanent strain sustained by the vessel. The criteria for success are that the measured strains do not exceed the calculated strains from the vessel analysis and/or are consistent with past acceptable results, there is no significant additional plastic strain on subsequent tests at the rated design load (shakedown), and there is no significant damage to the vessel and attached hardware that affect form, fit, or function.

For the V27, 9 lbs. C-4 distributed-charge qualification test, the highest vessel body peak strain was recorded for gage #4 (Table 2: mid-point hoop, top dead-center). Transient strain data from that gage are plotted in Figure 4. The peak strain value was approximately 1381 microstrain.

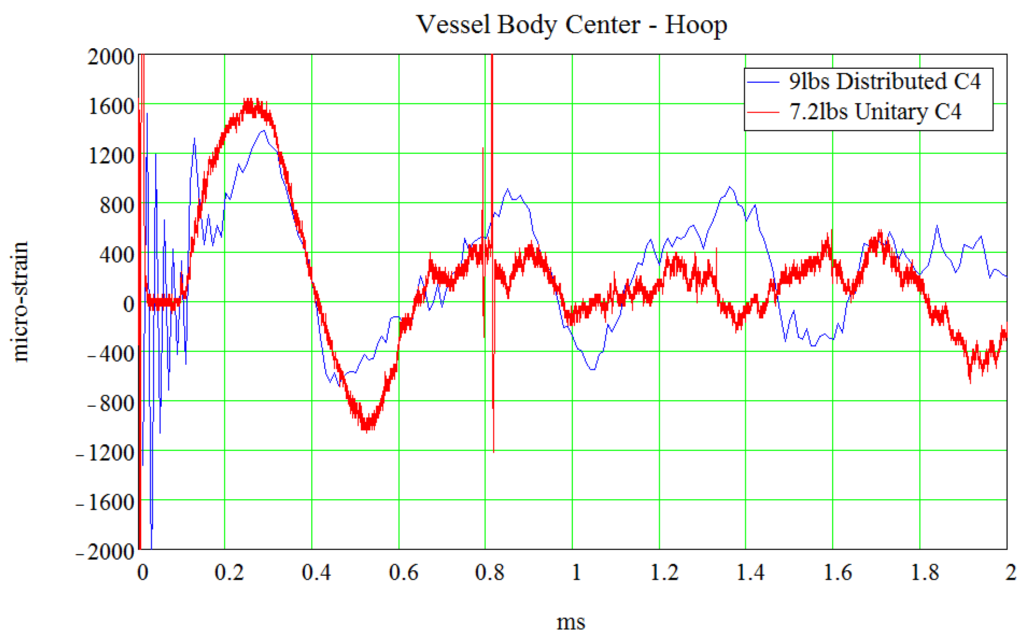

Figure 4: Comparison of Dynamic Strain for 9 lbs C-4 (11.25 TNT) Distributed Charge to 7.2 lbs (9 lbs TNT) Unitary Charge.

Plastic strain, or permanent vessel deformation, was calculated from changes in the outer diameter of the vessel measured with a stainless steel π-tape around the circumference, and independently, from the baseline offset on the dynamic strain gauge data before and after detonation. Pre-detonation offset was derived from the average of 1000 data points before trigger. The post-detonation signals were averaged from approximately 5 ms to approximately 10 ms. These values were chosen to remove the initial strain dynamic but still provide a reasonable signal extent to calculate average strain change. The actual start and stop points were hand chosen to mark points at the bottom of a trough in the cyclic signal, ensuring that there is little offset due to a partial cycle. The values for permanent strain then were taken as the differences in these averages.

Agreement between the two measurement methods is very good. The π-tape measurements made before and after the V27 distributed charge test showed an increase of between 0.015 and 0.020 inches around the mid-point of the vessel body, indicating an average permanent strain of about 508 microstrain. Using the data analysis technique described above, a value of about 400 microstrain was determined for the V27 test. From these data, we conclude that the strain resulting from the qualification test was well within the limits of the code and the vessel meets the design requirements and is fit for use.

<u>Comparison of Distributed 5 lbs C-4 (6 lbs TNT) charge orientations</u>

The purpose of the final four tests, where the six discrete charges were positioned in four different orientations, was to evaluate the effects of slight variations in orientation of the charges. The charge weight was chosen so that the load on the vessel through these tests: 1) somewhat reduced the repeated maximum load on the vessel over the test series; 2) mimicked the likely load from the greatest, typical operational load on the vessel from 6 each 155mm Artillery Shells; 3) yet provided enough load on the vessel to provide adequate strain dynamic range for analysis. There is no comparison between the qualification-loading of 11.25 lbs TNT equivalent to these reduced load tests, as this was not the purpose for conducting these experiments.

Since, in all configurations, the six charges are distributed symmetrically about the vessel axis and the longitudinally bisecting plane of the vessel, the mid-point, hoop, top dead-center gage will be reviewed, as it is expected that this location experiences the greatest strain loading in every test. Below is a comparison of the “orientation” tests plotted together. Note that the overall appearance over the first 2ms is very much the same in every configuration. With the exception of the timing of some of the peak strain values, the general response is essentially the same. This indicates that the strain is not sensitive to these variations in orientation so normal variations in EDS operation are not significant.

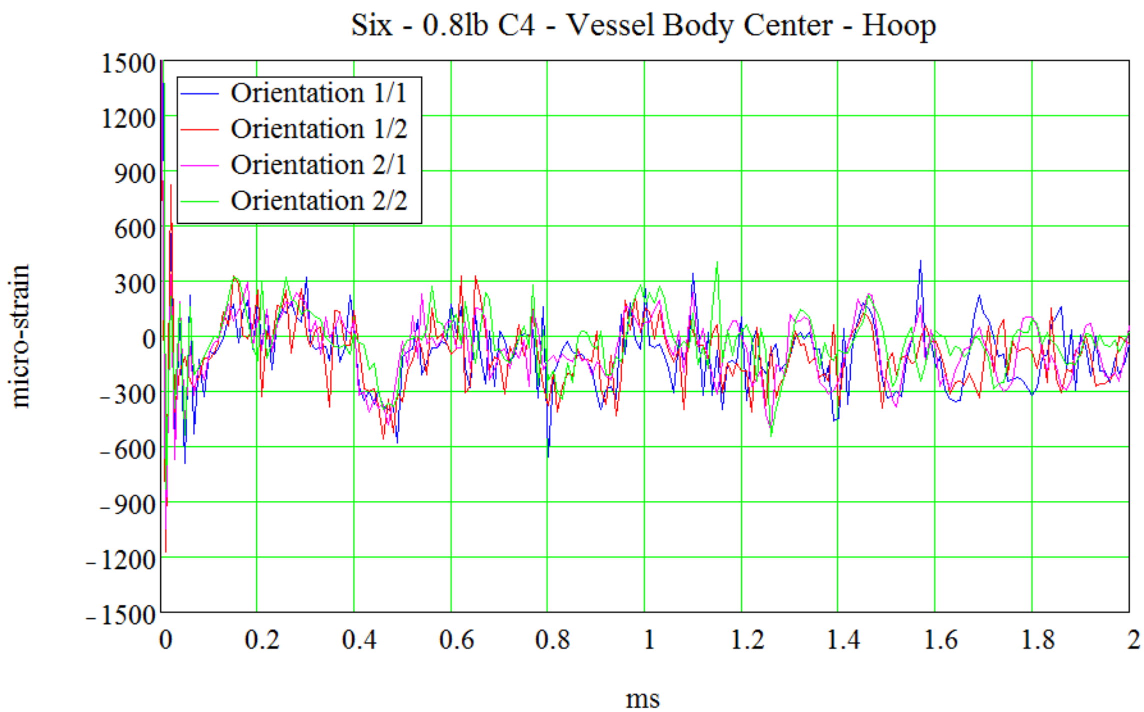

Figure 5: Comparison of Reduced Load 4.8 lbs C-4 (6 lbs TNT) Distributed Charges

Other Considerations:
Static pressure inside the vessel was measured for each of the five tests. As expected, the static pressure from the qualification test was greater than from the four subsequent tests by about 50 percent. The static pressure from the four orientation tests was reasonably consistent as shown in the table below.

Table 4: Static Residual Pressure

Test	Details	Static Pressure (psi)
1	9 lbs C4, orientation 1/1	160
2	4.8 lbs C4, orientation 1/1	102
3	4.8 lbs C4, orientation 1/2	101
4	4.8 lbs C4, orientation 2/1	110
5	4.8 lbs C4, orientation 2/2	108

The helium leak rates at the vessel body seal and at the detonator feed-through seal were measured before and after each test. All measurements were within accepted values. In each test, a balloon was placed over the drain port; and in each case, the balloon was inflated with approximately 5 ccs of air. A helium sniffer was used to determine that no helium from the vessel interior was present in the balloon volume. Seal ring deformation was measured after each experiment. Analysis of this information was reported in a separate report [2]. Pi-tape measurements were made before and after each test. All measurements of plastic deformation (permanent strain) through this process resulted in values that are within the noise of these measurements (between 0.002 and 0.004 inches on average).

6. CONCLUSIONS

The EDS V27 explosive containment vessel has been qualified for use at its design working load rating of 9 lbs TNT-equivalent through a 125 percent explosive over-test. The test results meet ASME code criteria and the vessel is fit for use. Additional tests were completed using a distributed, reduced-load charge configuration where the rotational and longitudinal orientations of the six charges were varied. These tests were used for informational purposes to ensure that the design basis is robust against reasonably small variations in placement and orientation of the distributed charges.

7. REFERENCES

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2. Grayloc Seal Reuse Test Report, US Army Chemical Materials Activity, Recovered Chemical Materiel Directorate, January 2017.

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