SAND2013-5040C

Experience with Using Code Case 2564 to Design and Certify an Impulsively Loaded Vessel

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ASME 2013 Pressure Vessel and Piping Division Conference

July 14-18, 2013

Paris, France

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000. This work was sponsored by the US Army Project Manager for Non-Stockpile Chemical Materiel.

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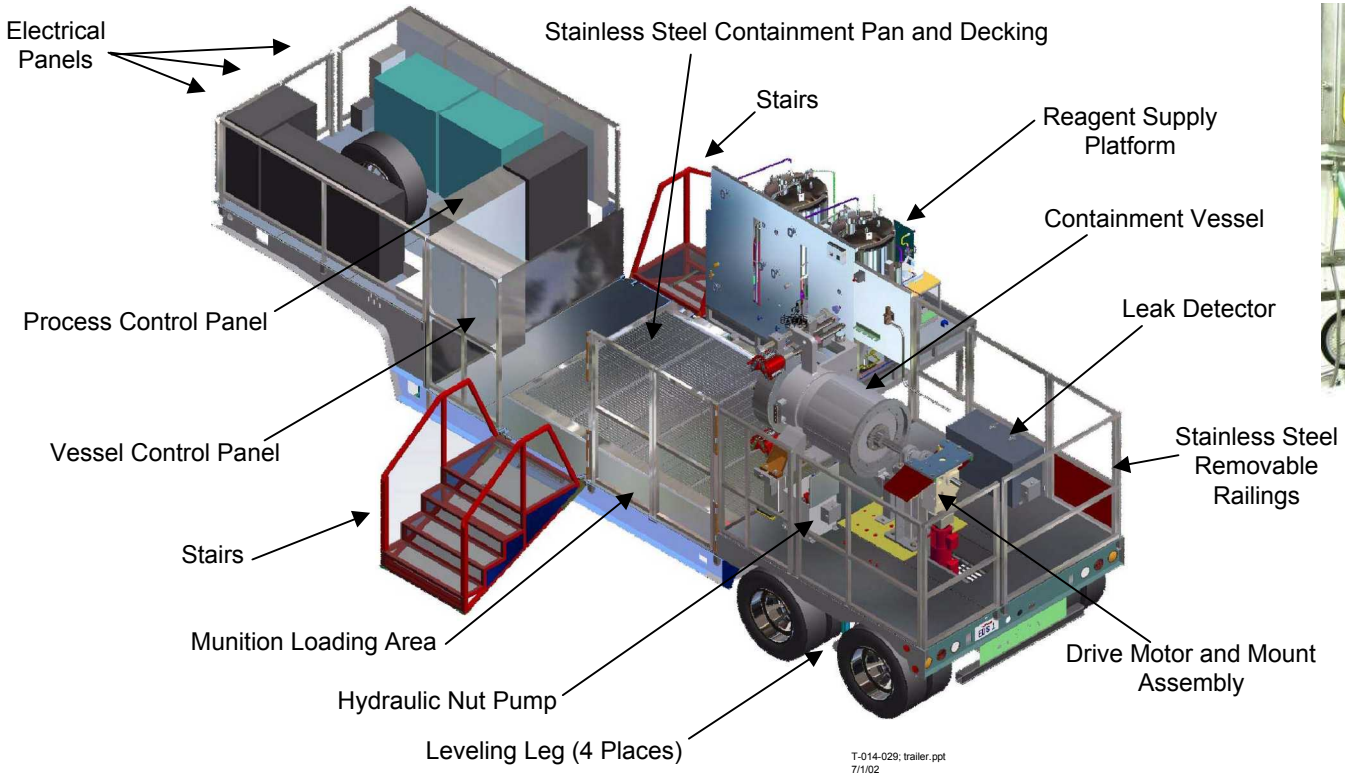
EDS System Overview

EDS is a mobile chemical munition treatment system with a thick-walled, 316-SS, explosive containment vessel.



Designed for the US Army Project Manager for Non-Stockpile Chemical Materiel

Five Systems in operation

Destroyed over 1600 items

First vessel fabricated in 1997

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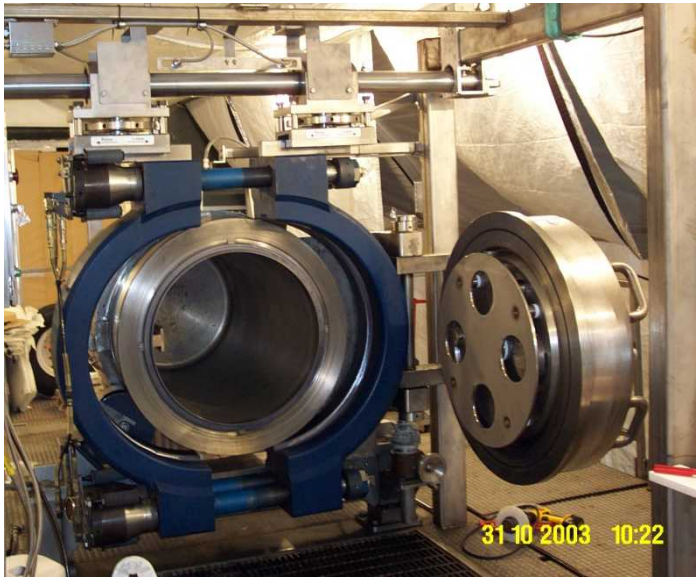
Original Design Basis

- There were no codes or standards
- Vessel dimensions were based on modeling of the detonation and vessel response
  - Centrally loaded bare charge
- A static pressure rating was back-calculated from the dimensions
- The vessel was fabricated per Section VIII, Division 1
  - The calculated pressure was used as the design basis
  - Rating had no relevance to the intended use
  - The ASME stamp primarily provided quality control and documentation



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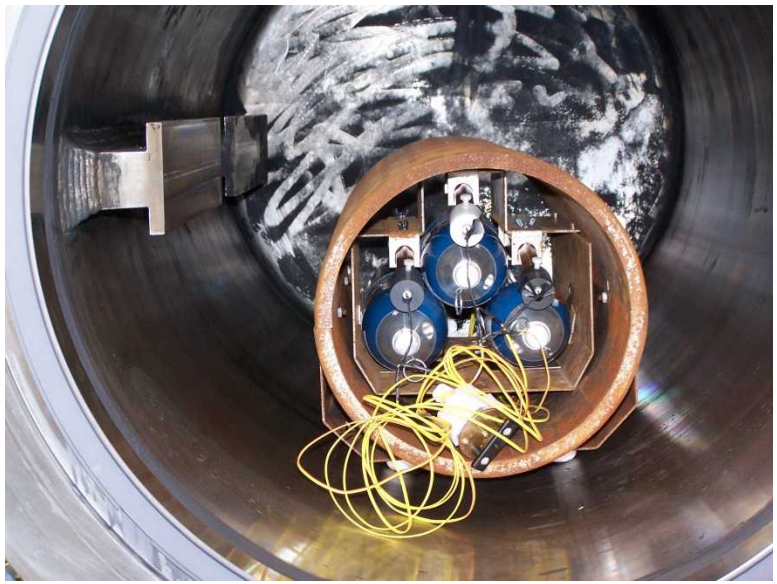
Original Design Basis - Continued

- Calculations were verified with extensive explosive testing
- There was no regulatory requirement for a code vessel
  - Regulatory approval to use the vessel came from the DoD Explosive Safety Board (ESB) and individual states
  - DoD ESB required a 1.25X overtest



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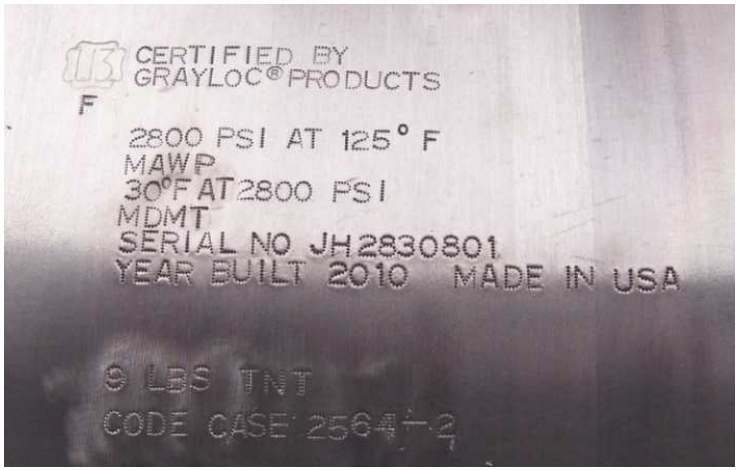
US Army PMNSCM Supported Development of the Code Case

- Provides increased confidence in the vessel design
  - Provides consensus design criteria
  - Provides validation of the basic design approach
- Makes the regulatory approval process easier
  - Third party standards are important to regulators
  - Minimizes the amount of additional documentation that is needed
- Provides basis for higher explosive rating
  - Initial EDS designs were very conservative
- Reduces the amount of testing that is required

Two New Vessels Were Built Per Code Case 2564



- First vessel was fabricated in 2010
  - Believed to be the first impulsively-loaded vessel with a U3 stamp
  - Approved for use by DoD ESB in 2012
- Same design as earlier vessels
  - Different material specification for 316
  - Different material for clamps and fasteners
- Explosive rating increased from 2.2 to 4.1 kg TNT (4.8 to 9 pounds)
  - New limit was based on the Code Case
  - DoD ESB again required a 1.25X overtest

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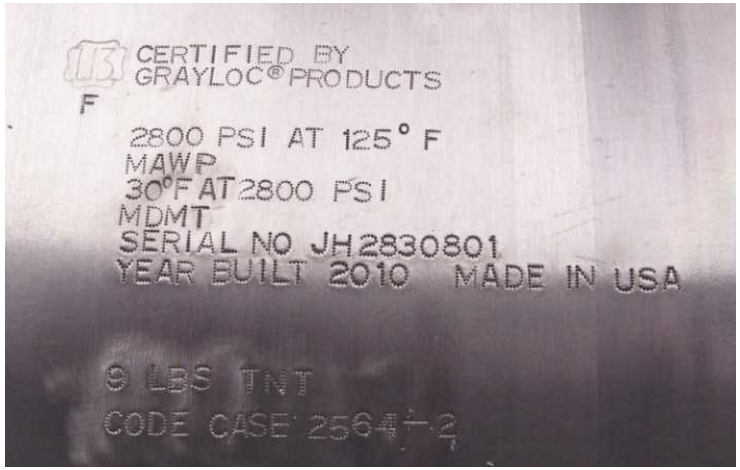
General Observations

- Code Case 2564 fills an important need
- A limited number of manufacturers have U3 certification
- Many manufacturers aren't able to perform the required analysis
- The material list in Division 3 is limited
- The design basis can be hard to specify
- The Code Case is silent as to how the vessel is to be stamped
- Requirements for acceptance testing are not defined
  - Hydrostatic proof test
  - Explosive qualification test



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Vessel Design Basis

- The User's Design Specification shall provide:
  - The impulsive loading design basis
  - Impulse source location with the vessel (i.e., vessel center, off center, etc)
  - The basis for administrative controls limiting impulse source
  - Any protective lining requirements, such as fragment shielding
- Historically the design basis has been a quantity of TNT
  - Analogous to a pressure rating
  - Assumes a single, centrally-loaded, bare charge
  - TNT equivalency calculations account for different explosives
- This approach might be insufficient and over-restrictive

Impulsive Loads Are More Complicated than Static Pressure

- Hydrostatic loads depend only on the pressure
- The response of an impulsively loaded vessel depends on:
  - Quantity of explosives,
  - Location of the explosives within the vessel,
  - Type of explosives,
  - Shape of the charge,
  - Number and location of detonators,
  - Relative timing if there are multiple charges or multiple points of detonation,
  - Location of obstructions such as munitions or fragment barriers that can mitigate the blast

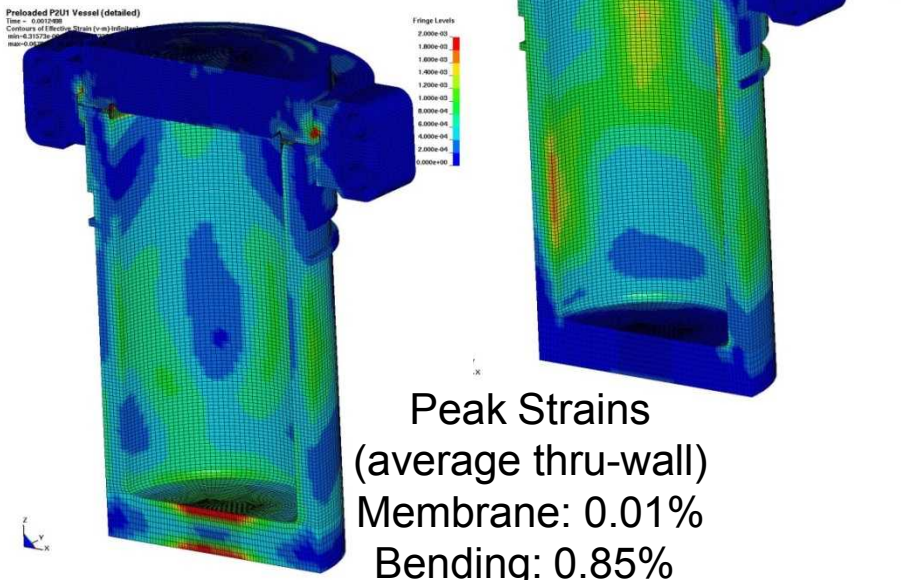
A Simple Explosive Rating Doesn't Consider How the Vessel Is Used

- Doesn't restrict improper configuration of explosives
  - The Code Case requires the source location be specified
  - Also requires administrative controls to limit the source
- Might not envelope the peak loads at all locations
- Doesn't take credit for mitigating factors
  - Spatial and temporal distribution
  - Energy expended in fragmentation of metal parts
  - Shock mitigation effects of obstructions

One Charge Versus Six Smaller Charges

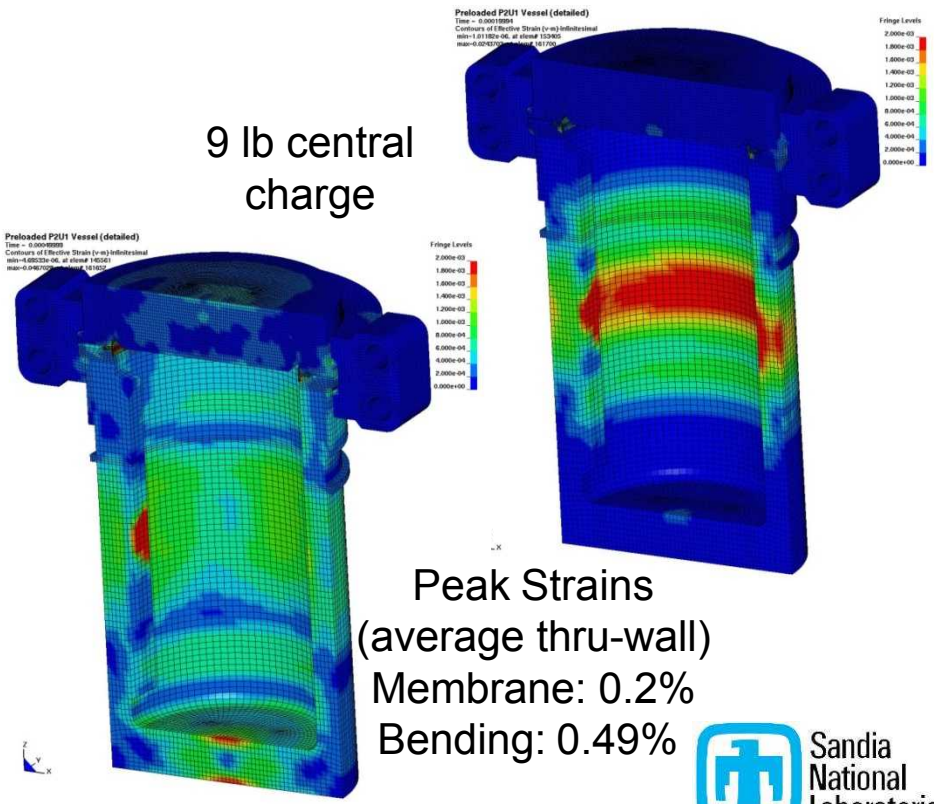
- Peak strain is less with multiple charges
  - Explosive rating could be increased for that configuration
- Multiple charges produce greater strain at the ends
  - Single charge design basis could lead to under design

Six 1.5 lb charges distributed



Peak Strains
(average thru-wall)
Membrane: 0.01%
Bending: 0.85%

9 lb central charge



Peak Strains
(average thru-wall)
Membrane: 0.2%
Bending: 0.49%

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Recommendations

- Stop rating impulsively loaded vessels using a simple explosive weight
- Instead, rate them for actual explosive configurations
  - i.e. six mortars or munitions in a defined arrangement, each with a combined burster and shaped charge weight up to 0.8 kg
- Might require multiple ratings
- Questions and concerns
  - What should be stamped on the vessel?
  - How do we maintain flexibility?

Pressure Rating and Hydrostatic Proof Testing

- Division 3 requires a hydrostatic proof test
  - At least 1.25 times the design pressure
  - Provides a final test of material and manufacturing
  - Eliminates residual tensile stresses
  - Ideally inner wall stress should be close to yield
- What is the design pressure of an impulsively loaded vessel?
  - Residual gas pressure is trivially small for EDS (~400 kPa)
- EDS used a hypothetical design pressure
  - Proof tested to 29 MPa (4200 psi)
  - Unrelated to any operating condition
  - Intended to provide a meaningful test

Explosive Qualification Testing

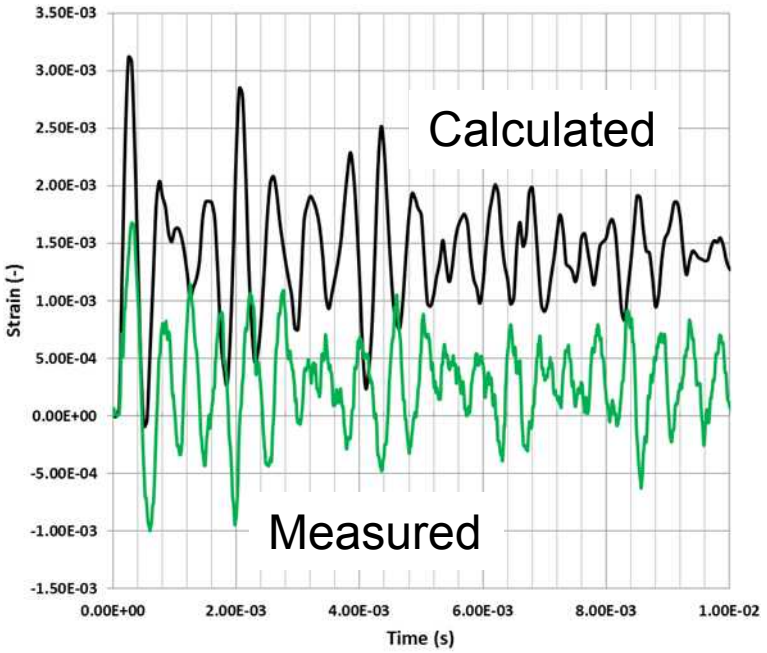
- US DoD and DOE require a 1.25 times explosive test
  - Analogous to a hydrostratic test for a pressure vessel
  - Objectives and methods are not well defined
  - The Code Case allows for experimental qualification of diagnostic covers and instrumentation penetrations
- Two tests were done on EDS
  - 1.25 X bare charge detonation – meet overtest requirement
  - 1 X bare charge detonation – evaluate shakedown
- It would be beneficial if the Code Case defined an explosive qualification requirement

Questions Related to Explosive Qualification Testing

- What is the appropriate level for a qualification test
  - EDS used 125% of the single bare charge explosive rating
  - What if we don't use a bare charge explosive rating?
  - What about single use vessels?
- Is it acceptable to exceed the limits of the Code Case during a qualification test
  - Hydro-test analogy suggests yes
  - Impact on vessel life should be considered
- What is the intent?
  - Over-test all parts of the vessel for all loading conditions?
  - Over-test the points of maximum strain?
- When is the test performed and by whom?
- Is TNT equivalency valid in impulsively loaded vessels?

TNT Equivalency

- The EDS qualification test used C-4 explosive
  - TNT equivalency = 1.25
- Four methods were used to calculate TNT equivalency
  - Peak pressure = 1.3
  - Positive impulse = 1.3
  - Total energy = 1.25
  - Comparison of theoretical isentropic expansion curves = 1.25
- Measured strain was less than predicted



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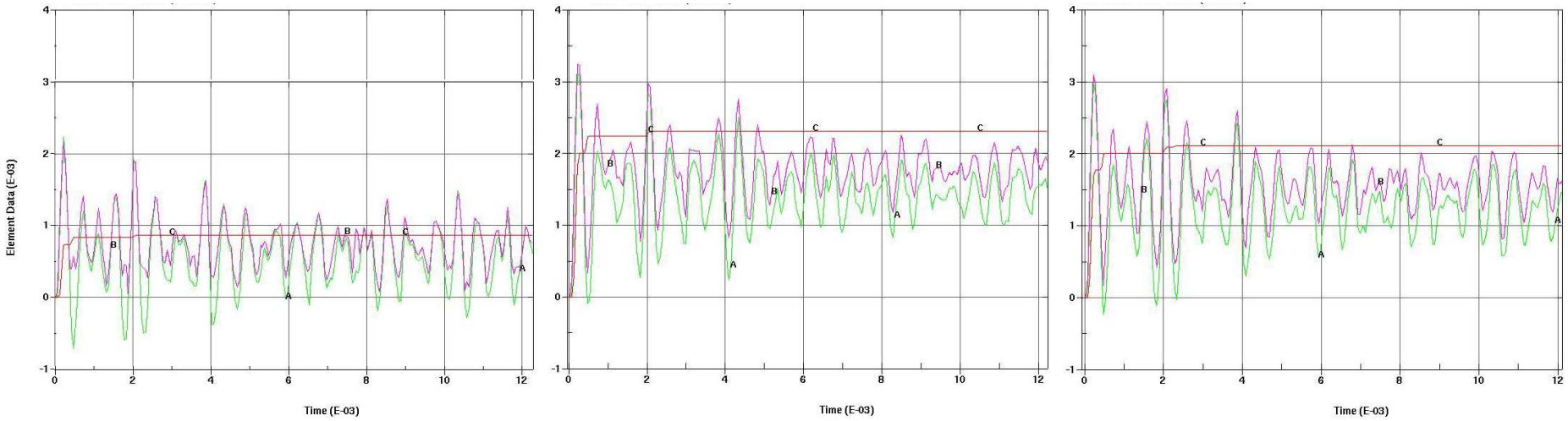
Subsequent Analysis

- Calculated impulse with TNT was ~25% greater than with “equivalent” quantity of C-4
  - Peak pressure and pulse width were both greater
- Apparent equivalence based on calculated strain is ~1



4.1 kg C-4 | 5.1 kg TNT | 5.1 kg C-4

A – Hoop strain, B – Effective strain, C – Cumulative plastic strain

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Conclusions

- Code Case 2564 is useful and needed
  - The task group should continue to refine the requirements
- Careful consideration must be given to the User Design Specification for an impulsively loaded vessel
  - A simple explosive weight rating might not be appropriate
- Hydrostatic proof test requirements for impulsively loaded vessels need to be defined
- Requirements for explosive qualification tests should be included in Code Case 2564
- Further study is needed concerning the relevancy of TNT equivalence in impulsively loaded vessels

Acknowledgements

This work was funded and directed by the US Army Project Manager for Non-Stockpile Chemical Materiel.

Sandia California
John Didlake
Brent Haroldsen
Robert Crocker

Sandia New Mexico
David Cole
Jerome Stofleth

US Army Non-Stockpile Chemical Materiel
Allan Caplan
William Adams

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