# WATER MITIGATION SYSTEMS

## for Explosives Safety of Ordnance Facilities

**L. Javier Malvar, Jim E. Tancreto**

**28th DDESB Seminar**

**Orlando, FL, 18-20 August 1998**

# *GENERAL CONCEPT AND APPLICATIONS*

# Problem

Numerous Navy activities with insufficient Explosives Safety Quantity Distances (ESQD's) now require either:

– Explosives Safety Waivers/Exemptions

– Severe Operational Limitations

## Solutions

## *EXISTING SOLUTIONS*

- New/Retrofit Facilities for:
  - Hardening Acceptor Facilities
  - Containment/Mitigation of Effects at Donor
    - NPW / HPM / MTC
- Purchase Land
- Relocate Activity

*Disadvantages:*
*- Expensive*
*- May not be applicable*

## *ADDITIONAL SOLUTION*

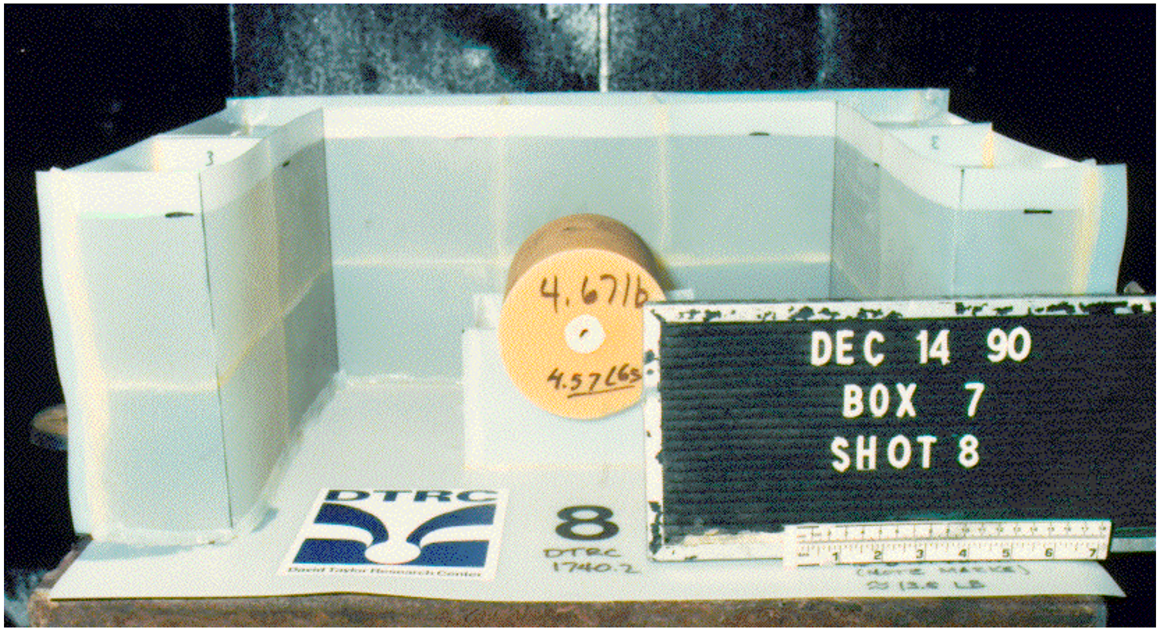
- Use Water Mitigation to reduce explosive effects and meet ESQD requirements

*Advantages: - Easy retrofit*
*- Relatively inexpensive*
*- May be only alternative*

# Water Mitigation Concept

- Shock wave aerosolizes water
- Water absorbs energy in phase change, prevents combustion, and reduces temperature of gases
- Gas pressure and impulse from confined explosion are dramatically reduced

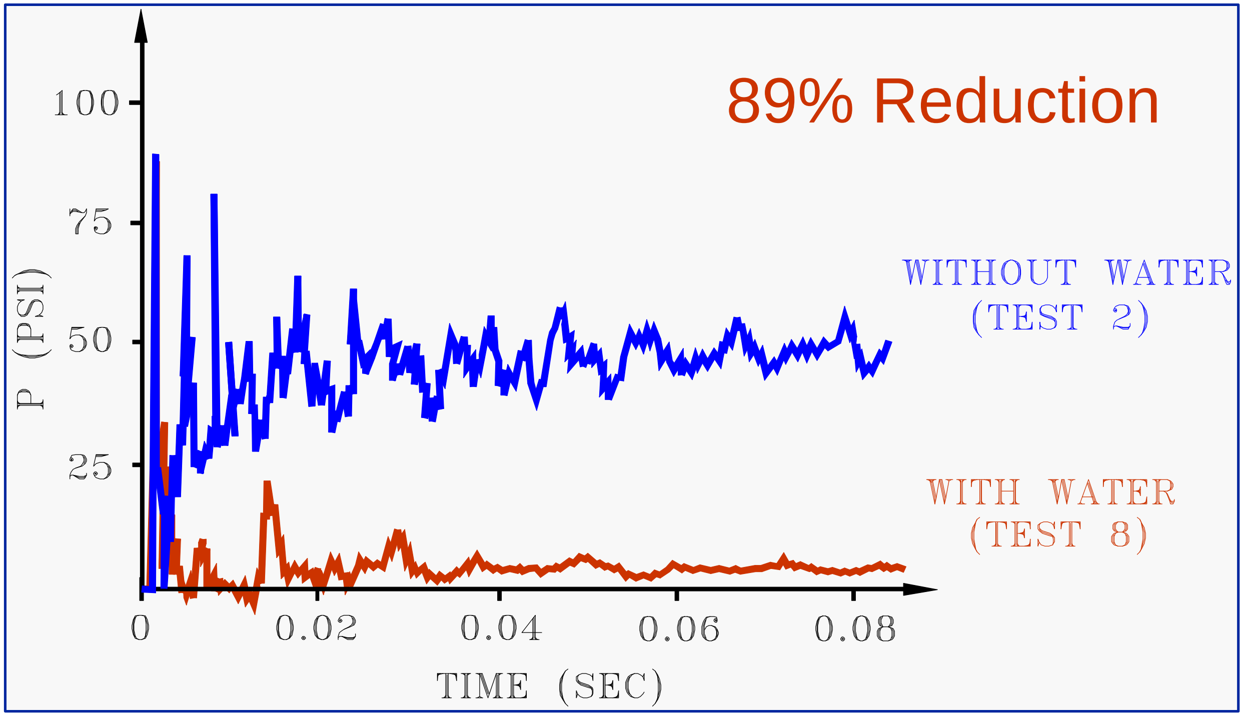
***NCEL Feasibility Test***



# Gas Pressure Mitigation

- 50% - 90% Reduction in Gas Pressure & Impulse
- Facility Retrofit < 25% Cost of Replacement

***NCEL Feasibility Test Results***



# Application

| | Water | Non-Prop. Walls |
|---|---|---|
| **Operating Facilities / Test Cells**[1] | *** | ** |
| **Ready/Missile Magazines**[1,2] | *** | ** |
| **Tunnel Magazines**[2] | *** | ** |
| Standard Magazines | * | *** |
| High Performance Magazines | - | *** |
| Open Storage | - | *** |

[1] **USN main application**
[2] **Singapore main application**

***** Optimum**
**** Good**
*** Possible**

# Sample Application - Ready Service Magazine

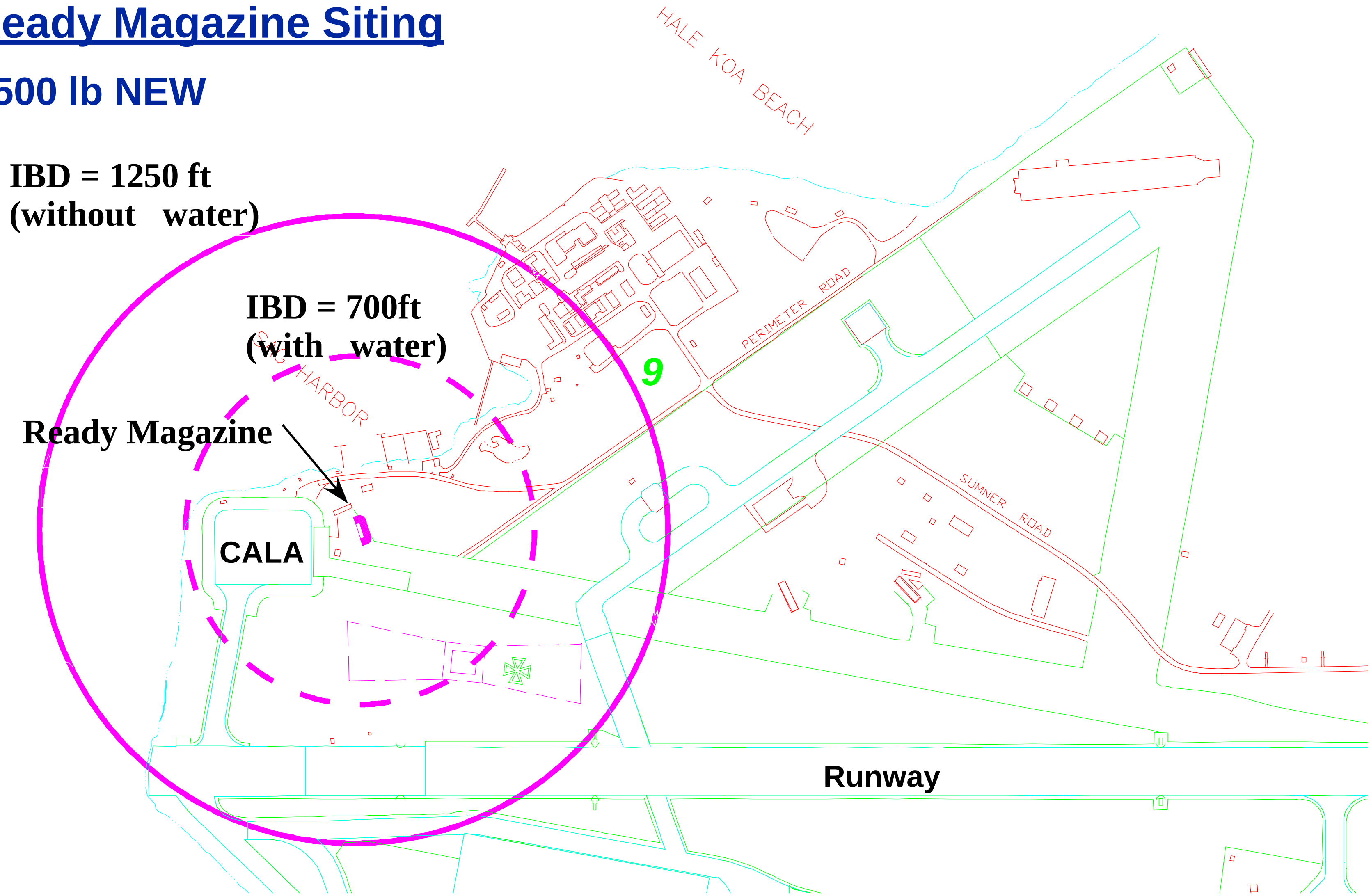
**Reduced Encumbered Land with Water Mitigation**

| NEW | Encumbered Land | | | | | |
|---|---|---|---|---|---|---|
| | Standard Magazine | | Std Magazine with Water Mitigation | | | |
| (lbs) | Range (ft) | Area (acres) | Range (Back) (ft) | Range (Fr/Side) (ft) | Area (acres) | **Reduced Area (%)** |
| 45000 | 1250 | 113 | 889 | 1250 | 99 | **12** |
| 30000 | 1250 | 113 | 777 | 1088 | 75 | **34** |
| 20000 | 1250 | 113 | 700 | 950 | 58 | **49** |
| 10000 | 1250 | 113 | 700 | 754 | 40 | **65** |
| ≤8000 | 1250 | 113 | 700 | 700 | 35 | **69** |

# Sample Application - Ready Service Magazine

## Ready Magazine Siting

### 2500 lb NEW



# Dual Use

## General Application

- Chemical Industry
- DOD Tri-service Explosives Safety (ESQD)
- FAA, Police & DOD (EOD, UXO)

## Leveraging

- Joint Project with Singapore
- NSWC Carderock IMPS (Integrated Magazine Protection Systems) (Test data and setup)
- Great Britain & Sweden (Test Data)

# U.S. Performers

## NFESC

**Engineering Development**
**Analytical Modeling**
**Test Design**

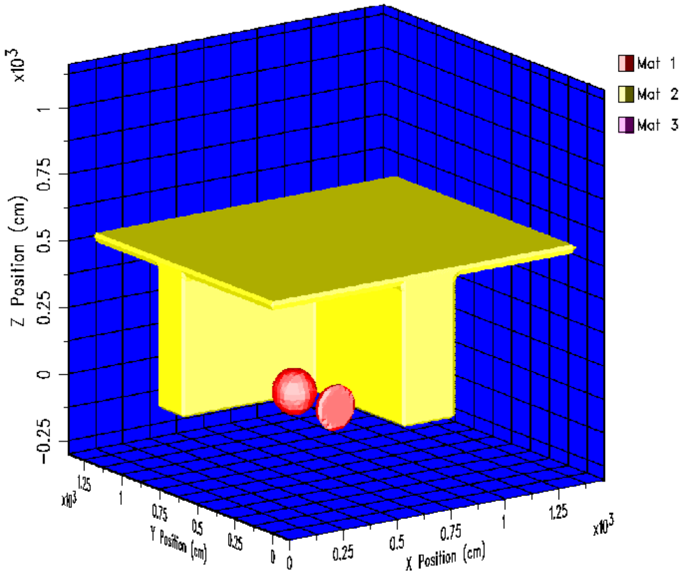
### TESTING

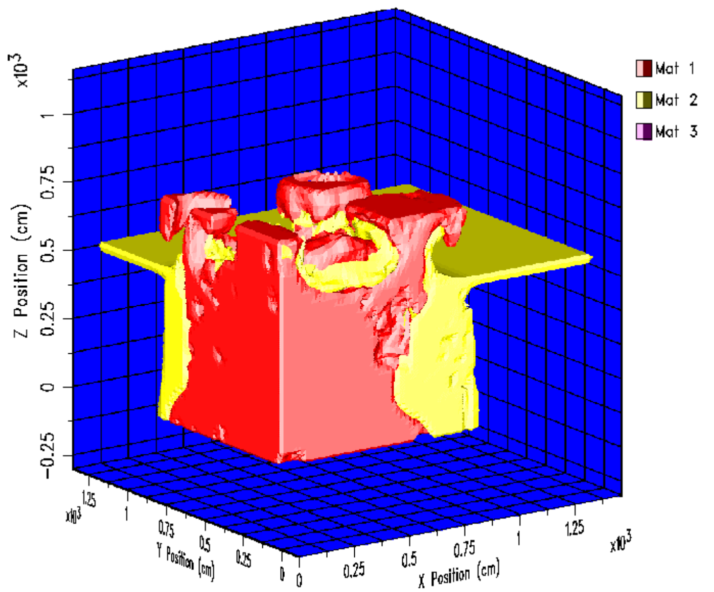
- ATC (Aberdeen)
- NSWC (Carderock)
- NAWC (China Lake)
- USACE (Huntsville)

### ANALYTICAL MODELING

- NFESC (AUTODYN, CTH, SHARC, PHOENICS)
- ARA (SHARC)
- JAYCOR (EITACC)
- Century Dynamics (AUTODYN)
- CRAFT Tech (CRAFT)
- MAXWELL $S^3$ (STREAK)

# *ANALYTICAL MODELING AND FEASIBILITY TESTS*




# Analytical Modeling

## NUMERICAL TOOLS

- HYDROCODES
  - CTH
  - SHARC
  - AUTODYN
  - STREAK
- CFD CODES
  - CRAFT
  - EITACC
  - PHOENICS

## FEASIBILITY TESTS

- NCEL Tests
- USACE Huntsville Tests
- Swedish Alvdalen Tests

## Technical Modeling Issues

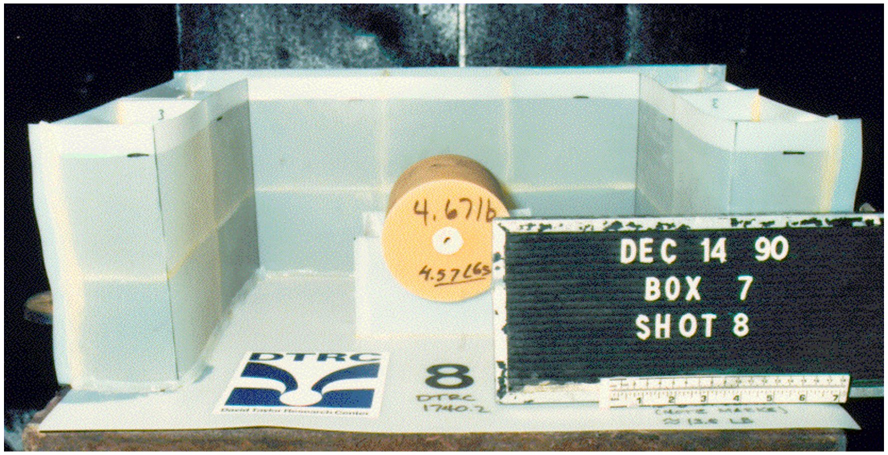
- Vaporization of water
- Combustion / after-burning of oxygen-deficient explosives, e.g. TNT
  - heat of detonation 1.97 E+06 ft-lb/lb
  - heat of combustion 5.05 E+06 ft-lb/lb
- Effect of turbulence on heat transfer
- Effect of dispersed-phase modeling (droplets/bubbles/particulates)
- Effect of boundary layers

# Modeling Issues Addressed by Codes

| TECHNICAL ISSUE | HYDROCODE | | | CFD | |
|---|---|---|---|---|---|
| | CTH | AUTODYN | SHARC | CRAFT | EITACC |
| heat of vaporization of water | X | X | X | X | X |
| combustion / after-burning of oxygen-deficient explosives | | X | X | X | X |
| effect of turbulence | X | X | X | X | X |
| dispersed-phase model (droplets/bubbles/particulates) | | | | X | X |

# Evaluation of Numerical Tools

- Compare code predictions against feasibility test results to assess capabilities
- 3 feasibility tests analyzed
  - USN NCEL
  - USACE Hunstville
  - Swedish tests (KLOTZ club Tunnel, Alvdalen)
- Use most promising numerical tools to analyze large-scale Alvdalen test and further evaluate codes
- Use most successful numerical tools and models to predict NFESC / Singapore tests and water mitigator concepts
- Conduct post-test analyses if necessary

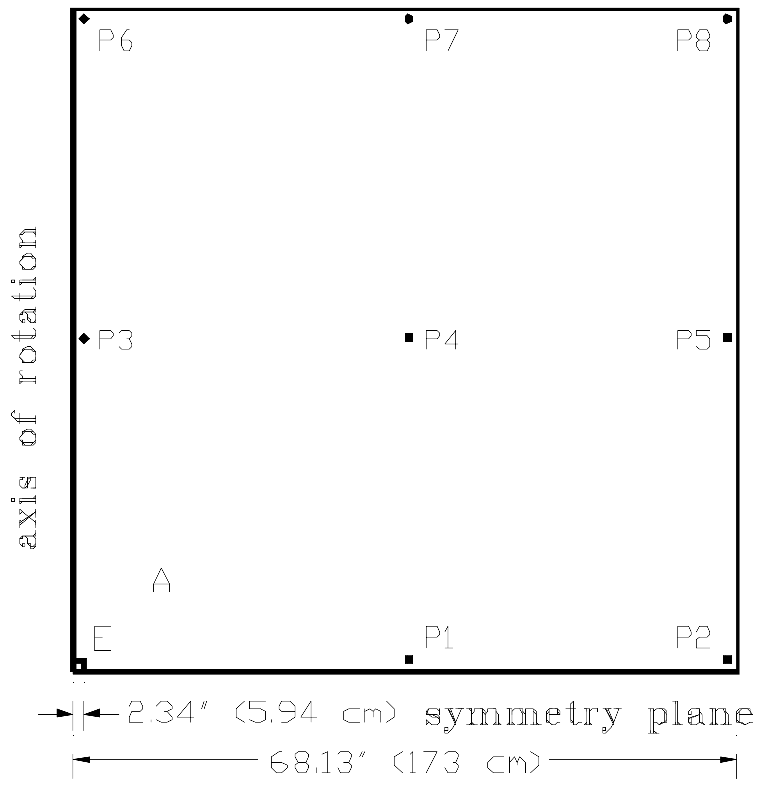



# NCEL Tests

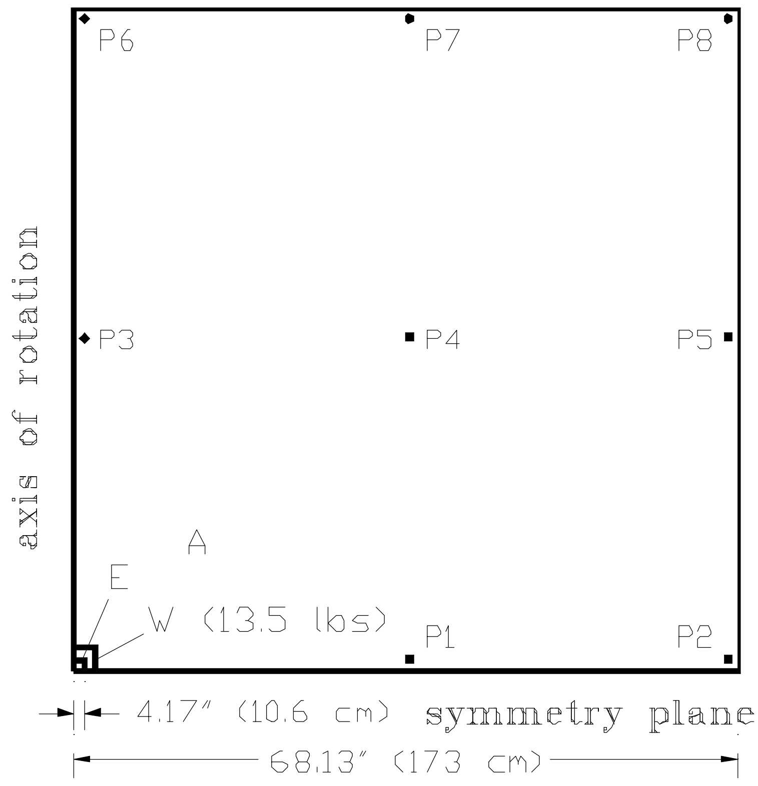
**TNT WEIGHT 4.67 lbs**

| TEST | CONFIGURATION | FLUID | PEAK GAS PRESSURE (PSI) |
|---|---|---|---|
| 1 | Hung Bare Charge | None | 55.4 |
| 3 | Cube | 9 lbs Water | 5.1 |
| 4 | Cube | 13.5 lbs Water | 4.4 |
| 5 | 2" Buffer Wall | 9 lbs Water | 8.3 |
| 6 | 2" Buffer Wall | 9 lbs Water | 7.5 |
| 7 | 3" Buffer Wall | 13.5 lbs Water | 5.9 |
| 8 | 3" Buffer Wall | 13.5 lbs Water | 5.8 |
| 9 | Cube | 9 lbs 50/50 Antifreeze | 6.0 |

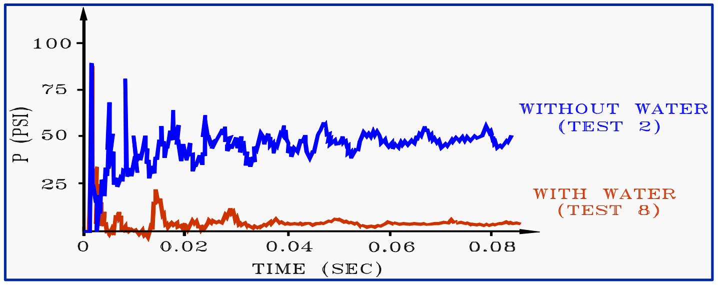
# Simplified Numerical Model




Explosive only



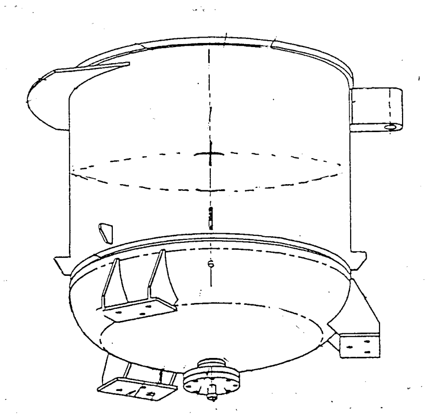

Explosive + water




# NCEL Tests : Modeling Summary

| WATER | CODE | GAS PRESSURE (PSI) | |
|---|---|---|---|
| | | PREDICTED | TEST |
| none | CTH | 13.1 | 55.4 |
| | AUTODYN | 48.3 | |
| | STREAK | 47.8 | |
| | SHARC | 54.0 | |
| | EITACC | 42.9 | |
| | CRAFT | - | |
| 13.5 lbs (immersed) | CTH | 6.0 | 4.4 |
| | AUTODYN | 5.8 | |
| | STREAK | 5.9 | |
| | SHARC | - | |
| | EITACC | 7.2 | |
| | CRAFT | - | |

# USACE Tests & Models

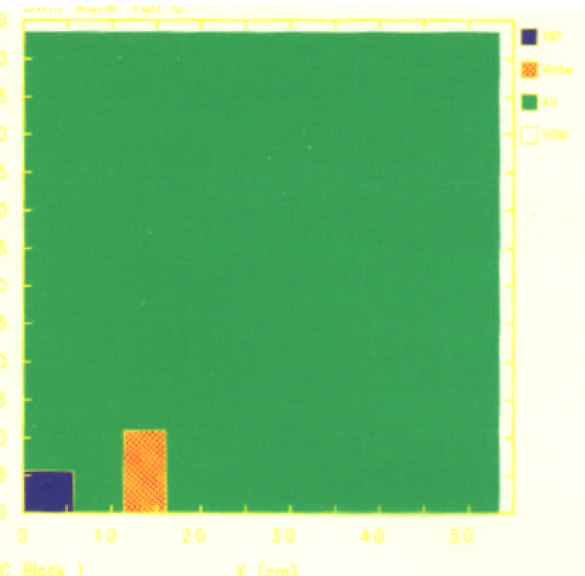


MUNITION
DEMOLITION
CONTAINER

TEST SETUP

TIME =

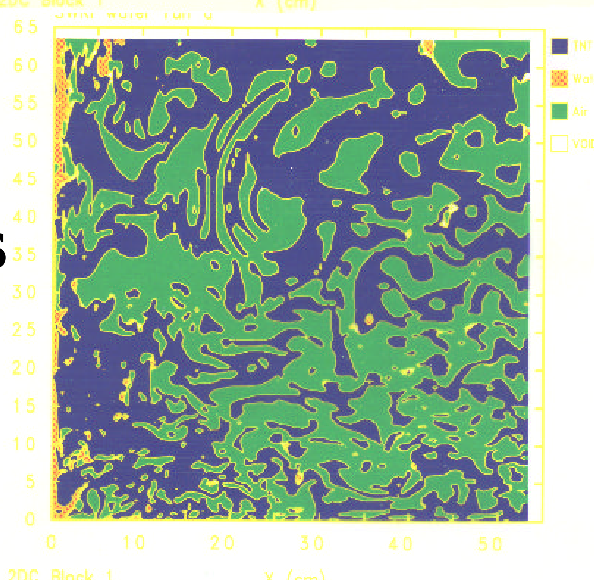
0 MS



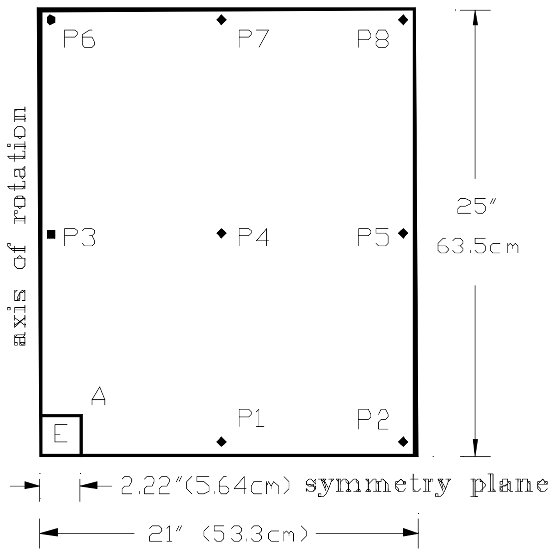

## USACE TEST SETUP

- 4 lbs TNT + 20 lbs water
- in steel cylinder, 1.325" thick
- cylinder 42" diameter, 50" long
- TNT surrounded by water bags

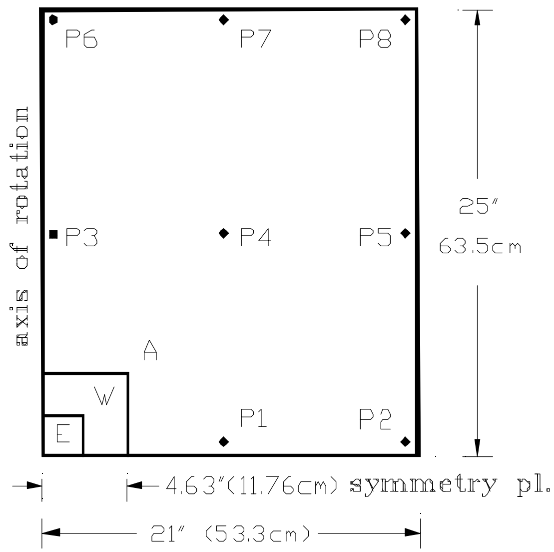
3 MS



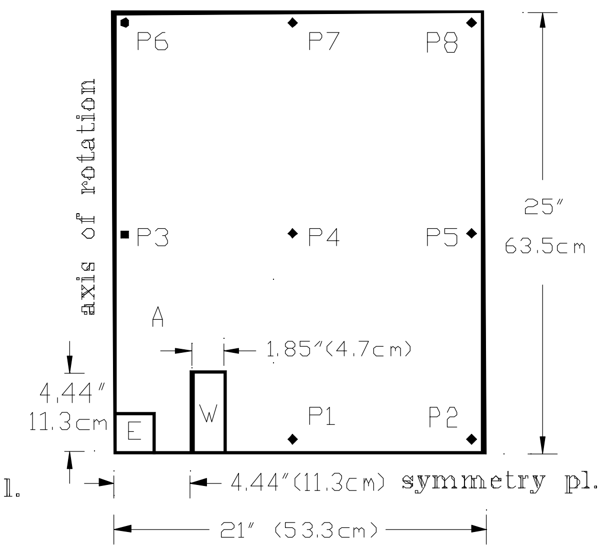
# Simplified Numerical Model




Explosive only




Explosive immersed in water



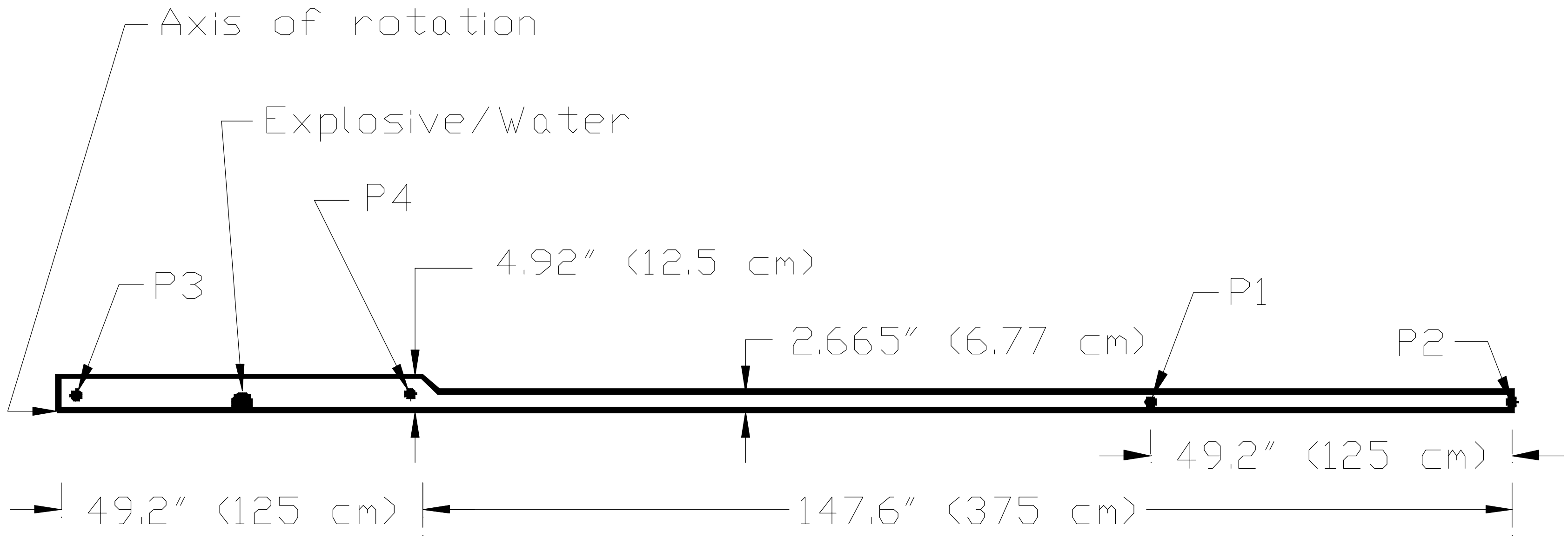

Explosive with water cylinder

- **model with water/TNT/air**
- **1/4 (axi)symmetry**

# Huntsville Tests : Modeling Summary

| WATER | CODE | GAS PRESSURE (PSI) | |
|---|---|---|---|
| | | PREDICTED | TEST |
| none | CTH | 257 | 350 |
| | AUTODYN | 450 | |
| | STREAK | 311 | |
| | SHARC | - | |
| | EITACC | 343 | |
| | CRAFT | 400 | |
| 13.5 lbs (immersed) | CTH | 99 | 100 |
| | AUTODYN | 95 | |
| | STREAK | 118 | |
| | SHARC | - | |
| | EITACC | 148 | |
| | CRAFT | 110 | |
| 13.5 lbs (cylinder) | CTH | 188 | N/A |
| | AUTODYN | 213 | |
| | STREAK | - | |
| | SHARC | - | |
| | EITACC | - | |
| | CRAFT | - | |

# **Swedish Alvdalen Tests Simplified Model**



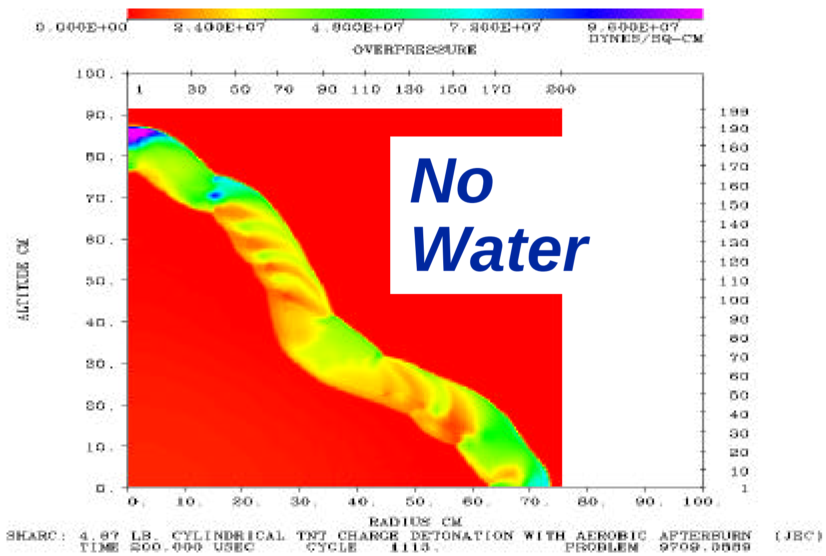

- 200 g of C4 in a cylindrical chamber
- 0, 400, 600 g of water (assumed C4 immersed)

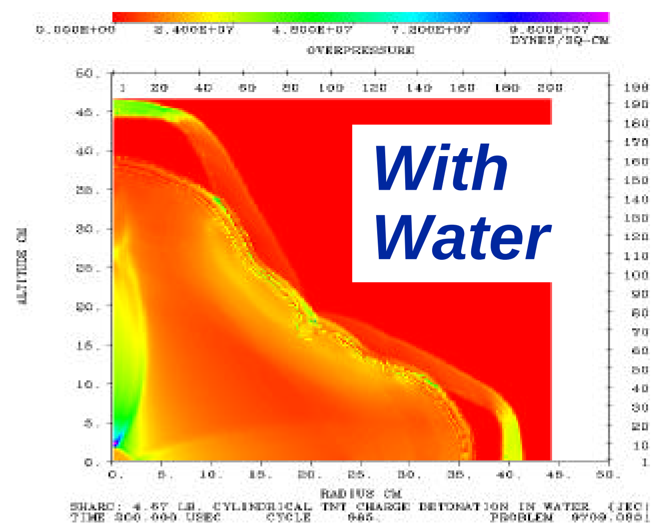
# Alvdalen Tests : Modeling Summary

| WATER | CODE | PEAK PRESSURE GAGE 2 (MPa) | |
|---|---|---|---|
| | | PREDICTED | TEST |
| none | CTH | - | 2.40 |
| | AUTODYN | 3.97 | |
| | STREAK | - | |
| | SHARC | - | |
| | EITACC | - | |
| | CRAFT | 2.50 | |
| 13.5 lbs (immersed) | CTH | - | 1.70 |
| | AUTODYN | > 2.27 | |
| | STREAK | - | |
| | SHARC | - | |
| | EITACC | - | |
| | CRAFT | > 1.50 | |

# Preliminary Conclusions: Physical Phenomena

- Modeling of vaporization and combustion is required
- Prediction of gas pressure in presence of water is accurate
- Water prevents combustion
- Location of water affects its efficiency
- Modeling of turbulence not necessary
- Effect of casing may be significant



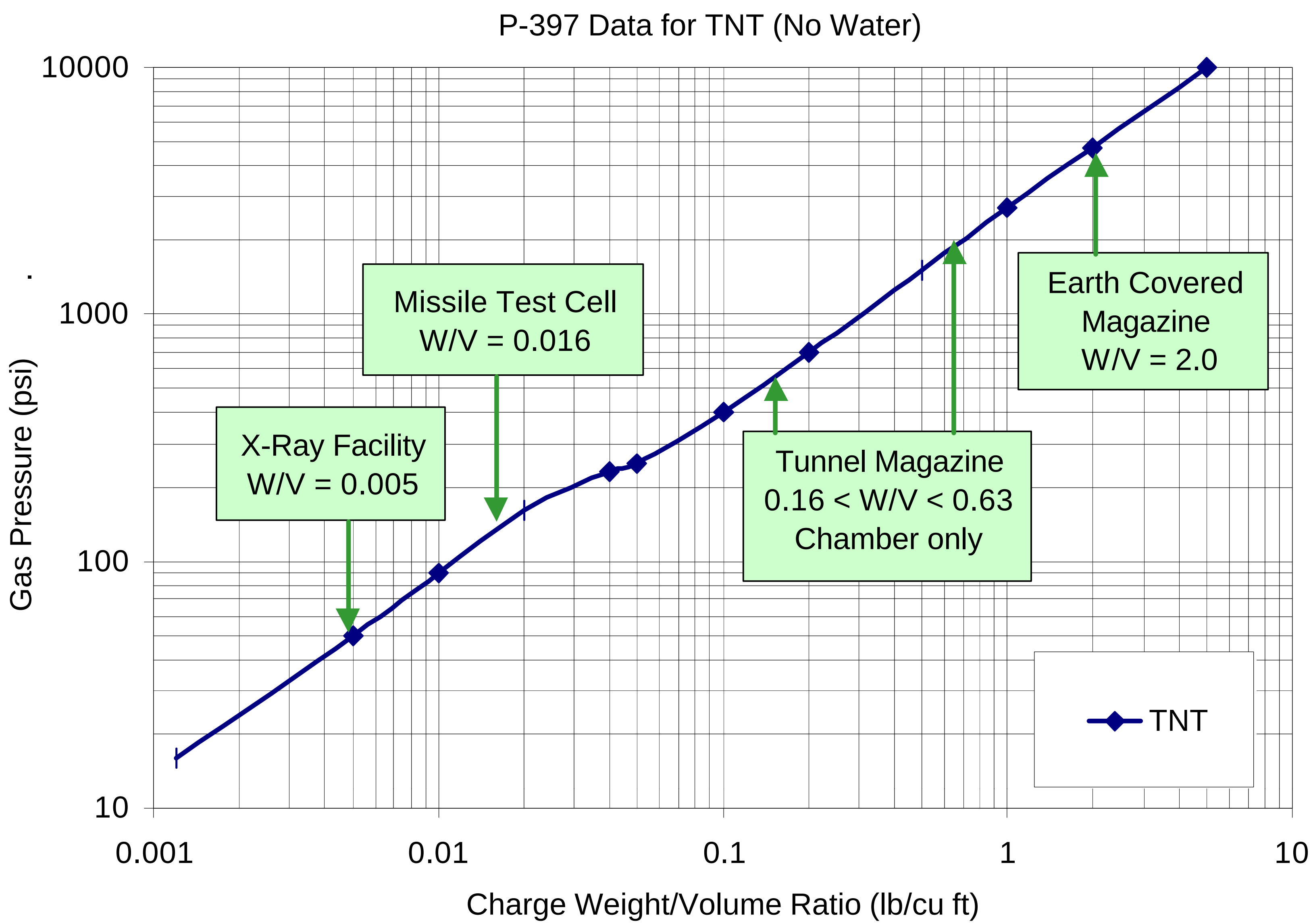



# Preliminary Conclusions: Code Assessment

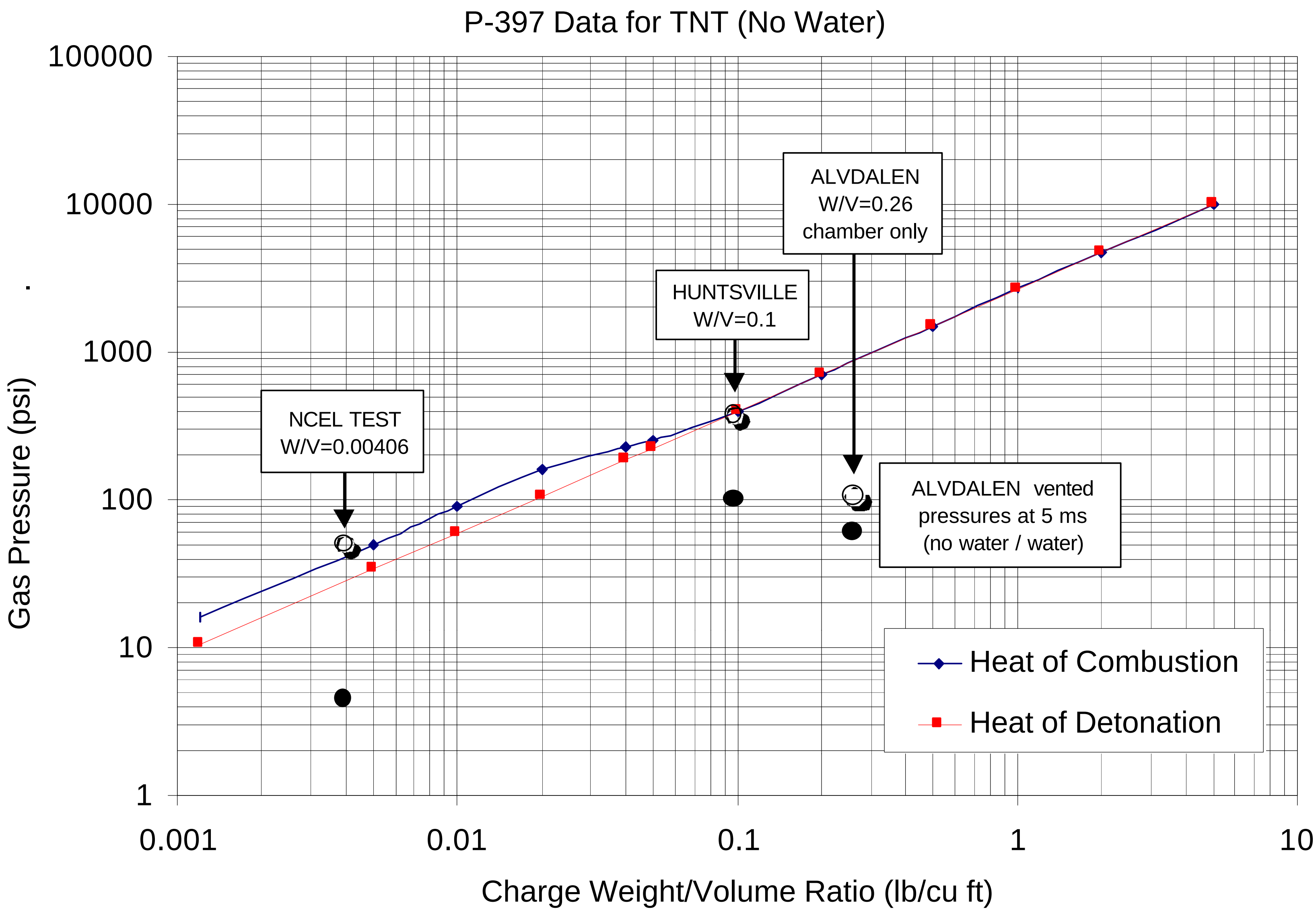
- All CFD and hydrocodes were able to model the aerosolization of water
- All CFD and hydrocodes were able to approximate the experimental gas pressures in the presence of water
- Some hydrocodes need to be enhanced to include combustion
- CFDs give adequate representation but are more complex / costly to run
- Pursue hydrocode analyses

# *PARAMETRIC TESTS*

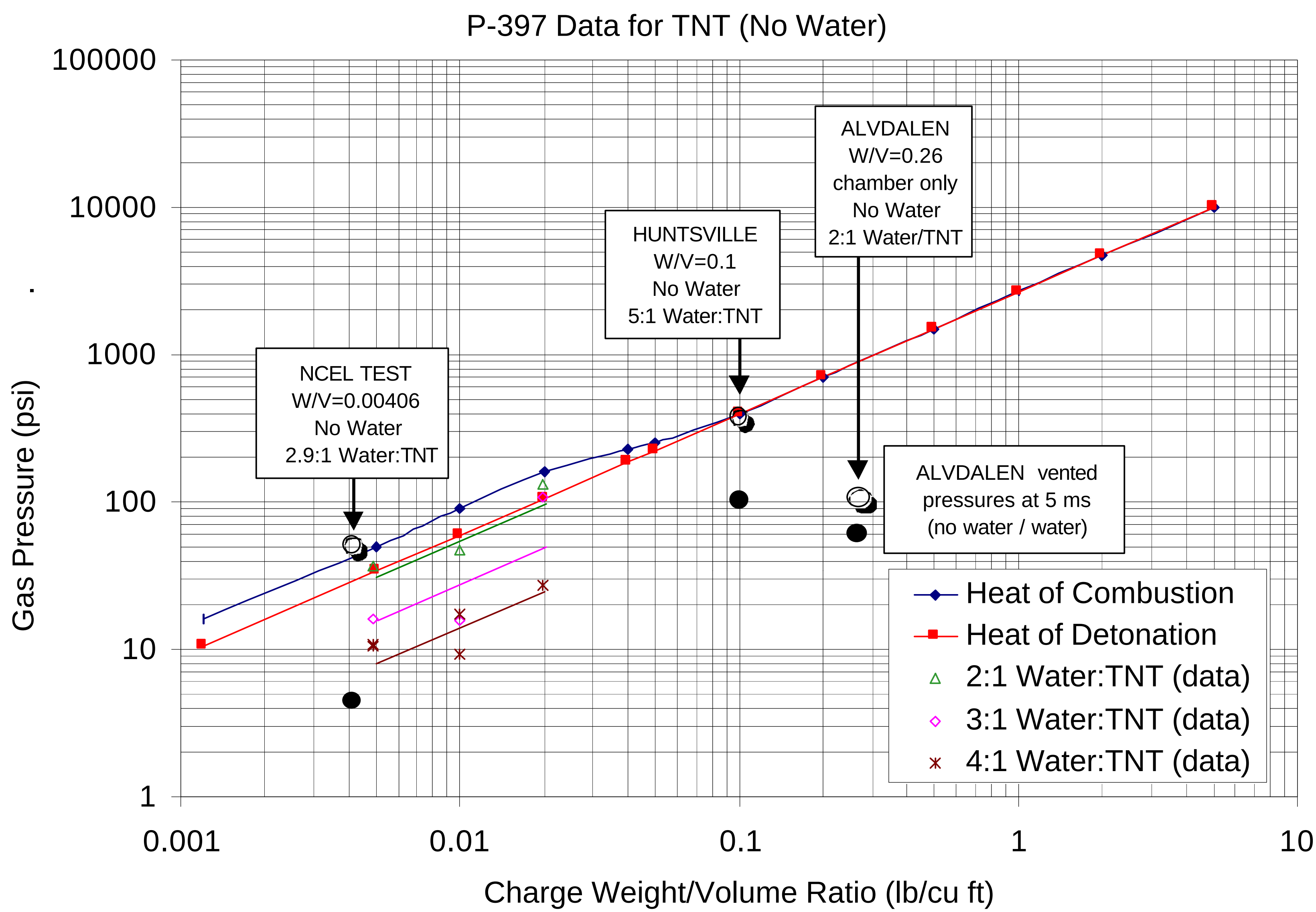
# Peak Gas Pressure in Contained Chamber : P-397



# Peak Gas Pressure : P-397 vs. Feasibility Tests



# Peak Gas Pressure : P-397 vs. Parametric Tests



## **Feasibility Tests: Conclusions**

For the NCEL and HUNTSVILLE tests:

- data without water agree with P-397 curve (heat of combustion curve)
- data with water (2.9:1 and 5:1) show reductions in gas pressure well below heat of detonation curve

For the Alvdalen tests

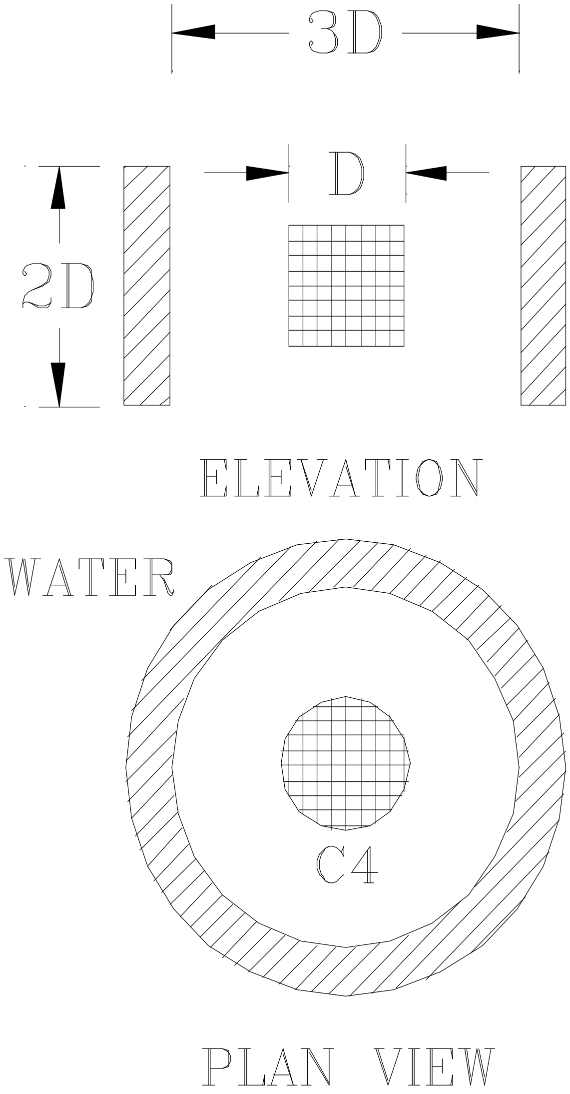
- data with venting still show reduction due to water

## TNT Parametric Tests: Conclusions

TNT parametric tests show that:

- the gas pressure decreases as the Water/TNT ratio increases from 2:1 to 4:1
- the level of gas pressure reduction is consistent with the NCEL (2.9:1) and Huntsville (5:1) tests

# Vented Tests




Additional tests have been carried out with various amounts of venting (on-going effort)

- Test chamber internal size
  78" long x 57.5" wide x 59" high
- Chamber is vented
- Water placed around explosive as shown in the figure

# Vented Tests Scope

| | |
|---|---|
| Charge weight to volume ratio | $0.005 < W/V < 0.1$ lb/ft$^3$ |
| Scaled vent area | $0 < A/V^{2/3} < 0.82$ |
| Water to charge weight ratio | $1 < W_W/W_E < 4$ |
| Maximum charge weight | 15 lbs TNT NEW |

# WATER MITIGATION SYSTEMS

## for Explosives Safety of Ordnance Facilities

## *SUMMARY*

# Summary

- Water near explosives will significantly reduce gas pressure and impulse in confined explosions
- Water location is critical - optimum reduction when water surrounds explosive
- Numerical models using hydrocodes and CFD codes can be used to predict gas pressure