NAVFAC
Naval Facilities Engineering Command
EXWC Engineering & Expeditionary Warfare Center

An Overview of AMO-CAT: DDESB's Explosives Safety Knowledge Improvement Program

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AMO-CAT Overview

- DDESB has established the program Advanced Munitions Operations – Consequence Assessment Trials (AMO-CAT)
- An integrated computational and testing program for development of new and/or enhancement of existing standards in support of explosives safety operations
- Attempt to integrate testing, advance computations, and engineering model development for explosives storage and demilitarization operations, protective construction, and risk assessment
- Intended to advance knowledge base as was done with ESKIMO and ESKIMORE
  - –Suggest reading paper for summary of Project ESKIMORE

AMO-CAT Gap Priority Matrix

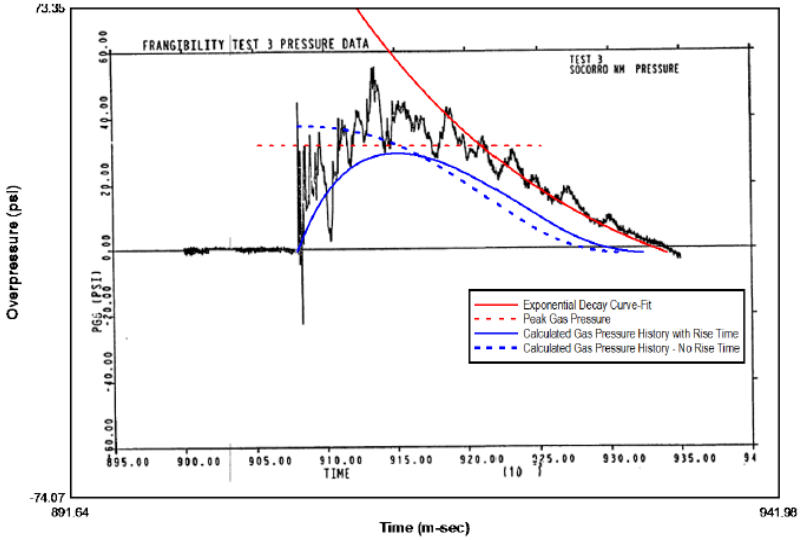
- Effort conducted in 2016 to analyze explosives safety technology gaps and compared with DDESB's mission priorities to develop gap priority matrix
- Categories were discretized into Blast and Primary Fragmentation, Structural Breakup, Mass Fire, and Underwater Explosions
- Example of Gap Priority for Blast and Primary Fragmentation shown below:

Blast and Primary Fragmentation	Gap Priority
Detonation and Fill Expansion	4
Quasi-Static Pressure (fully vented & frangible vents)	3
Shock Pressure	4
Dynamic Pressure	3
Detonation Product Combustion	3
Case Breakup	4
Fragment Environment	3
Human Injury/fatality	2

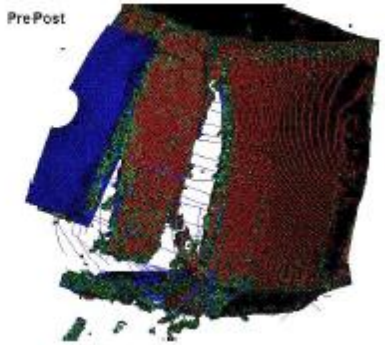
Gap Priority Key	
1	Critical Gap - Top Priority - Must do
2	Significant Gap - High Priority - Should do
3	Gap - Normal Priority - Should do with partners
4	Enhancement Needed -Average/Normal priority
5	No need for effort currently - Adequate knowledge exists

Ongoing R&D Programs

- Various efforts have been ongoing under AMO-CAT
- Two examples
  - –Development of an enhanced gas pressure model
  - –Modeling of mass fire in heavy confinement



Gas Pressure rise-time investigation
(Protection Engineering Consultants)

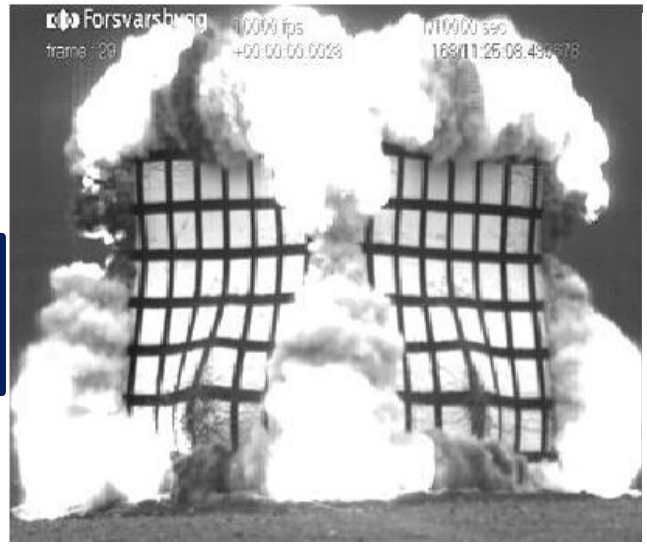


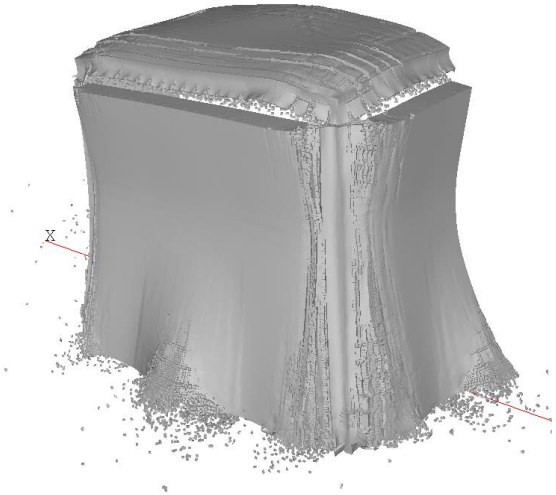
Mass fire effects of HD 1.3 in semi-confined conditions
(Testing: NAWC-WD China Lake
Modeling: NAVFAC EXWC)

Ongoing R&D Programs

- Recently began numerical simulations of structural break-up for the purposes of quantifying hazardous debris
- Structural Breakup topic has been separated into ECM and non-ECM technology gaps for investigation
- ECM specific issues have been elevated in priority

AGM structural break-up
Testing: Klotz Group
Modeling: Applied Simulations, Inc.





Development of ECM Technical Requirements

- Reached out to Services, end-users, approval authorities, and engineering community to identify issues, gaps, and deficiencies associated with QD criteria
- Maturity of blast/effects and QD technology gaps were assessed in addition to other pressing Service needs
  - –Significant overlap with AMO-CAT Gap Priority Matrix
- The technology focus area requirements established based on this feedback are:
  1. **Legacy Flat-Roof ECMs**
  2. **ECM IMD Design Loads**
  3. **ECM Debris Hazards**
  4. **ECM Earth Cover Requirements**

AMO-CAT: ECM Testing & Modeling Initiative

- A draft testing and modeling initiative has been established under AMO-CAT to address the Focus Areas identified from the ECM technology focus area requirements
- Each Focus Area has a series of sub-topics that either address separate, but related, issues or represent sequential steps from the overall goal
- Important note: Realization being addressed by multiple sources – not just AMO-CAT Program and/or DDESB
- Background and realization addressed in more detail in associated paper

Focus Area 1: Legacy Flat-Roof ECMs

- An Undefined arch-type ECM does not have an explicit blast design load required but flat-roof ECMs do
  - –Legacy flat-roof ECMs roof not designed against load
- Thousands of these legacy flat-roof ECMs in the DoD inventory
  - –Navy SP&P Type I, Type IIA, and Type IIB most common
  - –Multiple other ECM types currently in service
- Revised siting guidance has required Barricaded AGM IMD unless otherwise specified
- Goal of this research area is to generate data to make ECM IMD criteria less restrictive than Barricaded IMD (K6) where appropriate

ECM IMD Comparison

- Per NAVSEA OP-5, Change 14:
- Minor reduction for Type IIA/IIB up to 350K lb
- Type I has minimal benefit over Barricaded AGM < 250K lb

To Exposed Site (ES)		PES			
		Existing ECM			
		S	R	FB	FU
Type I Smokeless Powder/Projectile Magazine	S	4.5	4.5	6	6
		6	6		
	R	4.5	4.5	6	6
		6	6		
	FU	6	6	6	11
	FB	6	6	6	6
Type IIA or Type IIB Smokeless Powder/Projectile Magazine	S	1.25	1.25	6	6
		2	2		
		6	6		
	R	1.25	1.25	6	6
		6	6		
	FU	6	6	6	11
	FB	6	6	6	6

Use up to 250K lb
Use up to 350K lb

To Exposed Site (ES)		PES			
		Existing ECM			
		S	R	FB	FU
ECM (Undefined)	S	1.25	1.25	4.5	4.5
		2	2	6	6
	R	1.25	1.25	2	2
	FU	6	6	6	11
	FB	6	6	6	6

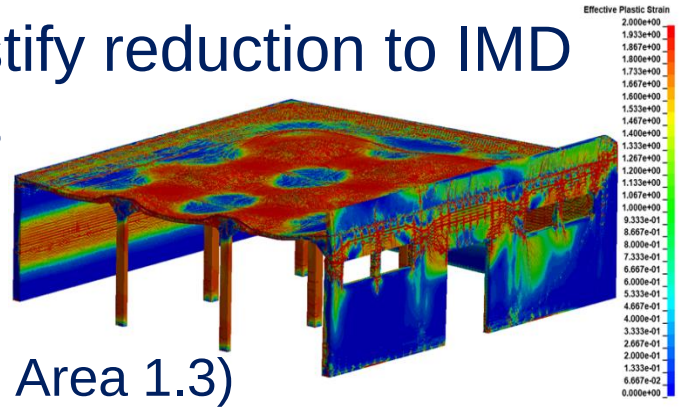
Use up to 250K lb

Focus Area 1.1: Modeling of the SP&P Type IIA/IIB ECM

- Goal: Through numerical analysis, justify reduction to IMD criteria in certain PES-ES orientations
- Product: Numerical model validated against available test data (ESKIMO VI & VII)
- Realization:
  - –SDOF analysis of the Type IIA/IIB roof does not satisfy UFC 3-340-02 criteria (but not significantly off)
  - –ERDC conducted numerical analyses of the half scale ESKIMO test – focus was on the response headwall
  - –Demonstrate acceptable roof response at lesser K-values
    - K2 Front-to-Rear likely not realistic
    - Partially dependent upon confidence of designs loads at distance other than the minimum ECM IMD (Focus Area 2)

Focus Area 1.2: Modeling of the SP&P Type I ECM

- Goal: Through numerical analysis, justify reduction to IMD criteria in certain PES-ES orientations
- Product:
  - –Numerical model justifying results
  - –Likely requires test data validation (Focus Area 1.3)
- Realization:
  - –Type I roof “not close” to being good by analysis
  - –K&C has generated numerical model responding to a variety of roof loads
  - –Full, 500K lb design load response no good, but model shows more resistance that UFC prescribed analysis
  - –Validation test(s) required for criteria change consideration



Karagozian & Case, Inc.

Focus Area 1.3: HEST Tests of SP&P ECMs

- Goal: Provide validation data points for numerical models of SP&P analyses of Focus Areas 1 and 2
- Product: If approval authorities are agreeable to reduce IMD for SP&P types based on modeling results (pending empirical validation), then a series of HEST tests on the roof are necessary
- Realization:
  - –Most economical path forward is to **identify existing ECMs where conduct of a HEST test is possible**
  - –Based on numerical results and expected blast loads, need to determine which orientations show promise
  - –Based on input from Services, need to determine which IMD reductions would be of most value

Focus Area 2: ECM IMD Design Loads

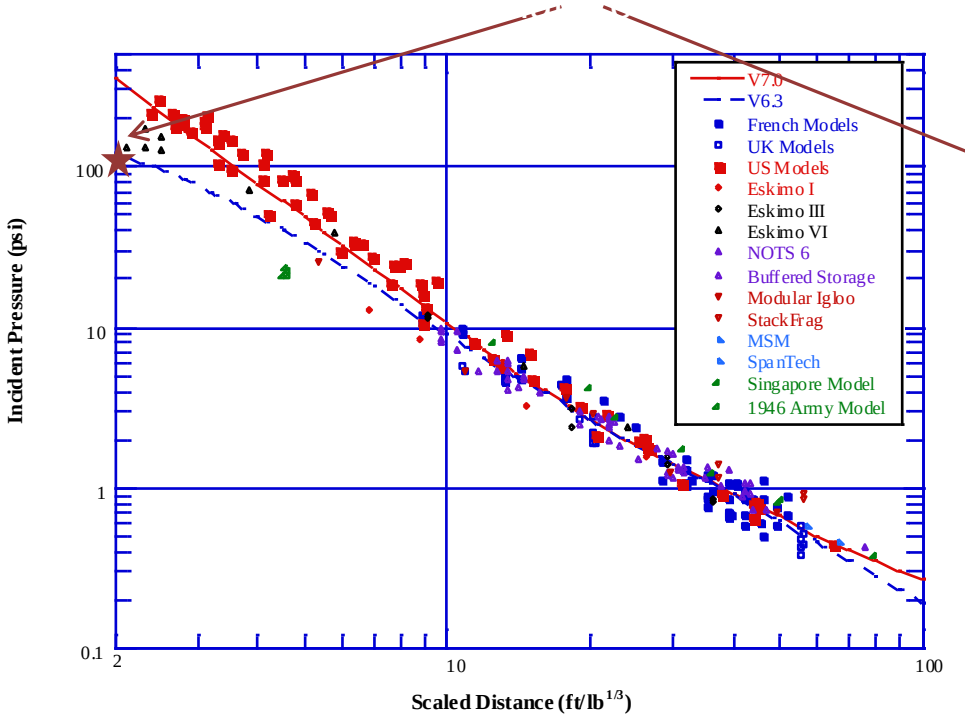
- ECM blast design loads prescribed in DoD 6055.09-M based on:
  - –Specific PES-ES orientations
  - –Test data (and many times singular data points)
- Current design load basis:
  - –7-bar headwall (101.5 psi & $13.9W^{1/3}$) – K2 Rear-to-Front orientation
  - –3-bar headwall (43.5 psi & $11.3W^{1/3}$) – K1.25 Side-to-Side orientation
  - –Flat-roof load (108 psi & $19W^{1/3}$) – K2 Front-to-Rear orientation
- If you have an existing layout that does not satisfy criteria, an existing legacy flat-roof ECM where Barricaded ECM siting won't work, or have a site specific requirement, there is not currently a path for analysis and/or design
- Note: All new DoD Standard ECM designs are primarily 7-bar ECMs based on 500K lb loads at minimum IMD

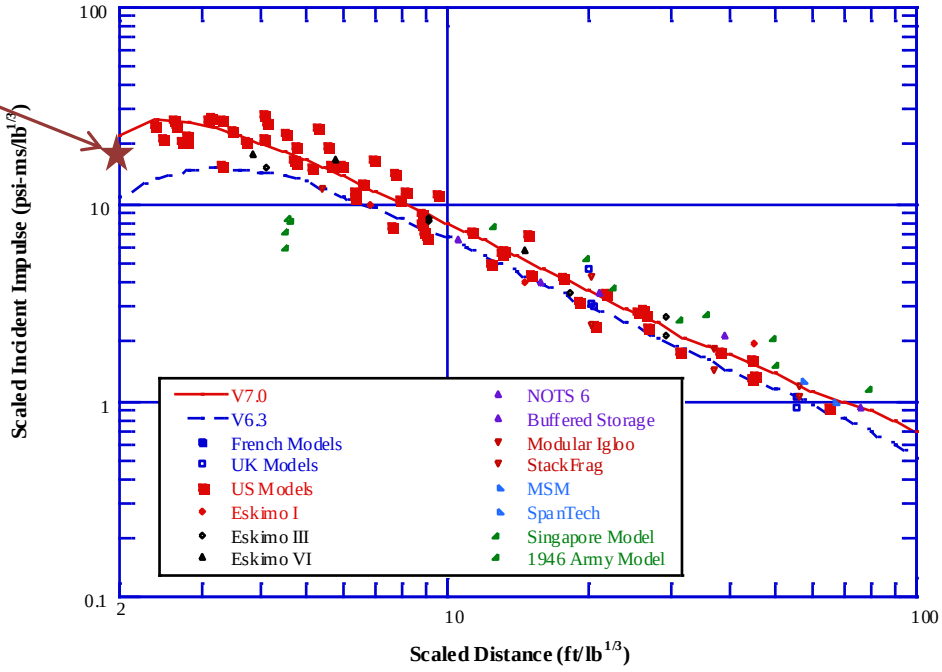
Example: ECM Roof Load Prediction

- Singular data points defining design loads are not consistent with other (**scaled**) data
- Questions about validity of scaled ECM blast data

DoD 6055.09-M Flat-Roof ECM Design Loads

Figures from DDESB TP-12, "Blast Effects Computer – Open Version 1"





Focus Area 2.1: Numerical Analysis of Existing Scaled Data

- Goal: Validate numerical modeling techniques by reproducing ECM tests pressure/impulse data
- Product: Documented set of coupled CFD/CSM models that reproduce results from past test data (mostly scaled)
- Realization:
  - –Large amount of past data (primarily scaled) that if can be reproduced provides high degree of confidence in prediction of ECM directional blast loads via numerical modeling
    - Various Kingery small scale tests
    - ESKIMO VI
    - Modular Igloo Test
  - –Numerical analysis coupling fluid-structure interaction is assumed to be necessary to accurately capture blast wave formation

Focus Area 2.2: Numerical Analysis of Equivalent Full Scale

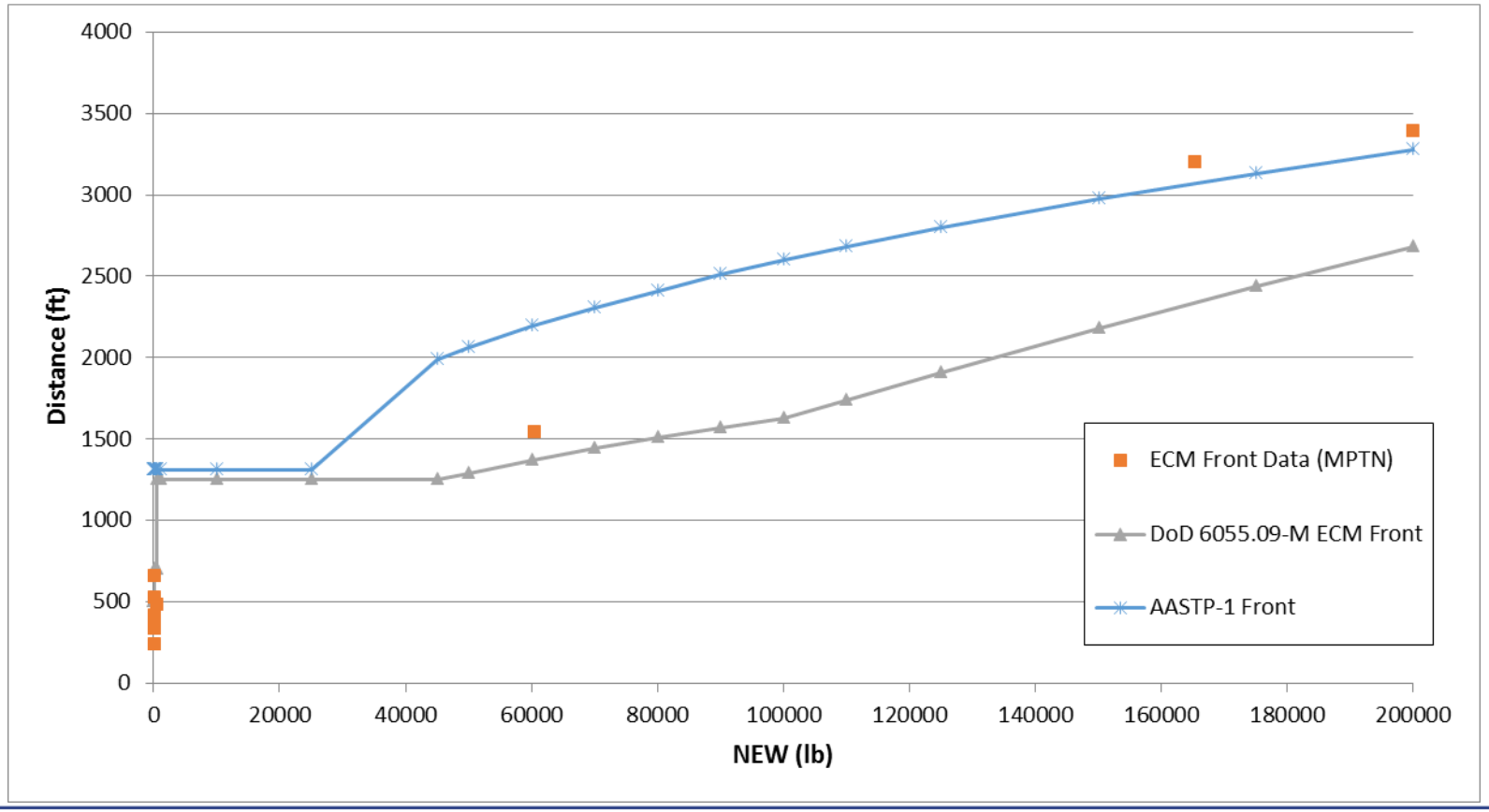
- Goal: Given that scaled test data can be adequately reproduced, rerun numerical simulation in full-size to account for inertial effects plus other scaling issues and compare/assess results
- Product: Documented set of coupled CFD/CSM models that predict ECM directional blast loads
- Realization:
  - –Given a successful comparison in Focus Area 2.1, rerun the analyses at full-scale for all scaled tests
    - If model can capture rationale for higher loads at scaled tests, then reasons shall be documented
    - If model doesn't capture any difference, design loads should be reassessed
  - –Result is a better definition of directional ECM blast loads at distance

Focus Area 3: ECM Debris Hazard

- Debris hazards from ECMs are poorly characterized above NEWs of 450 lb
- QD implies that debris controls IBD up to:
  - –45,000 lb for Front and Side
  - –100,000 lb Rear
- Debris IBD for large NEWs in ECMs is poorly understood, but limited data suggest:
  - –1250 ft for 45K lb out the front of an ECM is insufficient
  - –1250 ft for 45K lb out the side of an ECM is probably conservative
- Initial assessment of existing ECM test data has identified existing data gaps
- Test data necessary to fill in these knowledge gaps

ECM Debris IBD

- Available test data does not support QD out the ECM front



Focus Area 3.1: ECM Debris IBD Investigation

- Goal: Conduct a literature analysis of all available ECM test data and assess both PTN and MPTN debris IBD
- Product: Repository of ECM debris data, comparison of debris IBD data with current QD, and identification of knowledge gaps
- Realization:
  - –Study has been completed and database has been generated
  - –Plot for ECM Front MPTN Debris IBD presented on previous slide

Focus Area 3.2: Scaled ECM Test Series (Optional)

- Goal: 1) Conduct scaled ECM tests to fill in knowledge gaps for debris hazard, and 2) Use to optimize instrumentation for full-scale tests
- Product: 1) Scaled ECM test data for both debris and blast pressure, 2) validation on numerical prediction models, and 3) optimization of full-scale test layout
- Realization:
  - –TBD if even necessary
  - –Efficacy of results not entirely clear at this point due to questions with scaled ECM test results

Focus Area 3.3 & 3.4: Full-Scale ECM Tests

- Goal: Produce two full-scale ECM tests with comprehensive debris collection and measured IMD & IBD blast loads
- Product: Fully documented test report with reliable blast and debris test data at NEW of interest
- Realization:
  - –Pre-test numerical simulations of directional blast loading secondary debris generation
  - –Conduct of full-scale ECM Test #1 – NEW in the 45K to 60K range
  - –NEW of Test #2 will be determined by Test #1 results and numerical predictions
  - –Validation of “correct” ECM design loads for future ECM designs
  - –Will generate missing data for debris IBD at Front, Side, and Rear as well as feed into risk/consequence assessment models

Focus Area 4: ECM Earth Cover Requirements

- Per V2.E5.5.3.2 of DoD 6055.09-M, a fundamental requirement for an A/E storage facility to be designated an ECM is to maintain a minimum of 2 ft of earth cover
- V2.E5.5.3.1 provides additional guidance on fill
  - –Reasonably cohesive
  - –No stones heavier than 10 lb or 6-inch diameter
  - –No solid or wet clay
- Less than 2 ft of earth cover, e.g., 23 inches, results in large reduction of storage capacity if ECM is sited at minimum IMD
- Limited guidance on acceptable erosion control techniques

Focus Area 4.1: ECM Earth Cover Alternative Criteria

- Goal: Identify solution to siting ECMs where erosion has reduced earth cover to less than 2 feet
- Product: Proposed DoD 6055.09-M criteria change for existing ECMs with less than 2 feet of earth cover
- Realization:
  - –Testing and Modeling series to assess effects of less than 2 ft of earth cover on ECMs
  - –Assess effect of reduced earth cover on ECMs
    - Directional blast attenuation as a PES
    - Production of secondary debris as a PES
    - Structural response as an ES
    - Afforded protection from secondary debris impact as an ES
  - –ERDC is beginning to address this critical issue with Project MERCURY and associated modeling effort

Focus Area 4.2: ECM Erosion Control Solutions

- Goal: Identify erosion control solutions for ECM earth cover that do not adversely affect explosives safety aspects of ECM
- Product: Report with readily available/COTS approved erosion control solutions applicable to all DoD (CONUS & OCONUS) with concurrence by DoD explosives safety community
- Realization:
  - –First step is to identify solutions available that have minimal impact on explosives safety aspects
  - –Second step is to get concurrence from DoD ES community
  - –Document would also have agreed upon responses to FAQs

Summary

- Testing and Modeling initiative is intended to address ECM technology focus area requirements
- Intent is to fully utilize numerical modeling capabilities to supplement testing
  - –Testing is expensive
  - –Validated models produce “synthetic data”
- Program not intended to address standard ECM designs
  - –Separate effort underway to address optimizing standard designs
- Finally, if you have a Navy Type I SP&P ECM you’re looking to get rid of, I think I have a solution!