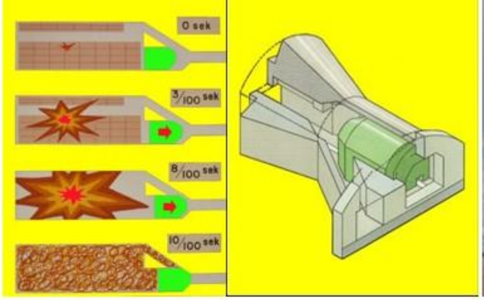
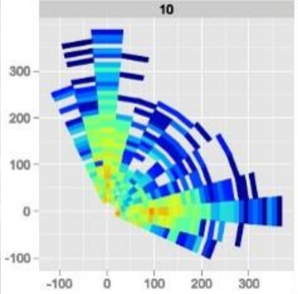
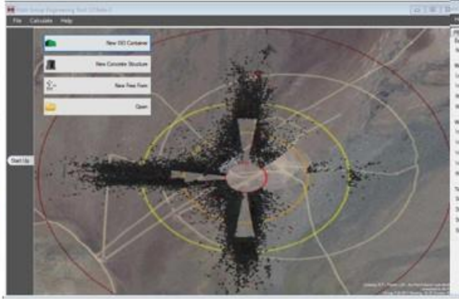
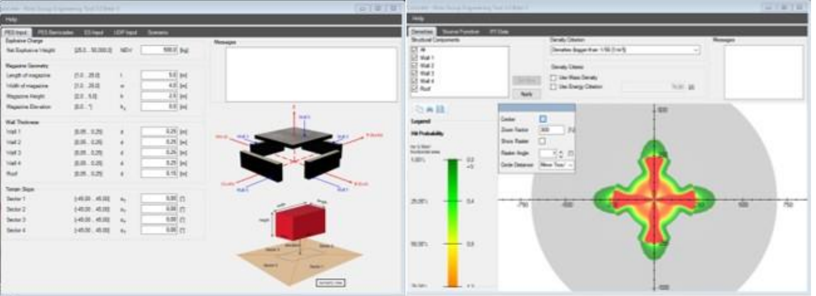



# The Klotz Group Contribution to Explosives Safety

Jaap Weerheijm; TNO Defence, Safety & Security; The Netherlands

Bob Conway; NAVFAC Engineering & Expeditionary Warfare Center; USA

# Overview

- Introduction
- Klotz Group Strategy – 2018
- Historical Overview of Klotz Group Research
- Highlights of Klotz Club & Klotz Group Research
  - Klotz Closing Valve
  - Water Mitigation
  - Debris Launch Velocity (DLV) Formula
  - Reinforced Concrete (RC) Magazines
  - Klotz Group-Engineering Tool (KG-ET)
- Conclusion

# Introduction

- The Klotz Group (KG) is an international group of experts on explosives safety that collaborate based on two objectives:
  - (i) to improve the knowledge base of explosion effects associated with the storage, processing and transport of ammunition and explosives, and
  - (ii) to develop engineering data bases to quantify the explosion effects that enable safety focused consequence assessments and risk analyses
- The KG is currently comprised of eight member nations: Germany, Norway, the Netherlands, Singapore, Sweden, Switzerland, the United Kingdom, and the United States
- This brief shall provide a brief overview of the group and work

# Klotz Group Strategy – 2018

- To achieve the objectives, explosion effects modeling experts from member nations meet twice a year to define and update the KG research program
- Primary focus is on explosion produced debris
- Subset of tasks are
  - Discuss, plan, and execute projects of common explosives safety interest
  - Develop tools to aid in explosives risk analyses
  - Identify gaps in the knowledge of explosion effects
  - Coordinate national R&D programs within areas of common interest
- Product of research effort is the Klotz Group-Engineering Tool (KG-ET)

# Historical Overview of Klotz Group Research

| Years | Era | Work Efforts |
| --- | --- | --- |
| 1966 – 1971 | Pre-Klotz | Definition of Klotz design |
| 1971 – 1975 | Klotz Testing | Test & development of Klotz design; testing in Älvdalen, Sweden |
| 1975 – 1998 | Klotz Club (KC) | Underground ammunition storage. Focus on experiments and gaining reliable data, numerical modeling in later years. |
| 1998 – Present | Klotz Group (KG) | General ammunition storage, aboveground magazine debris throw. Testing, modeling, and transition to predictive tool. |

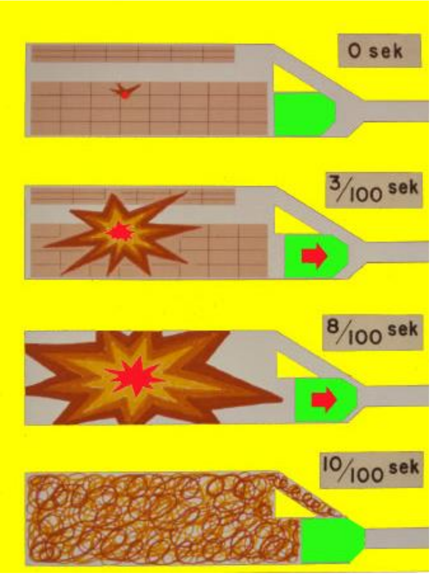
- A “Klotz”, German word for “Block”, is a massive closing device that acts as a gigantic blast valve in underground storage facilities
- Klotz Club avoided formal relationship with NATO in order to focus solely on technical issues
- Klotz Group reestablished formal ties with NATO, but still avoids any discussion of “acceptable risk/hazards” and discussion remains entirely technical

# Highlighted Research: Klotz Club & Klotz Group

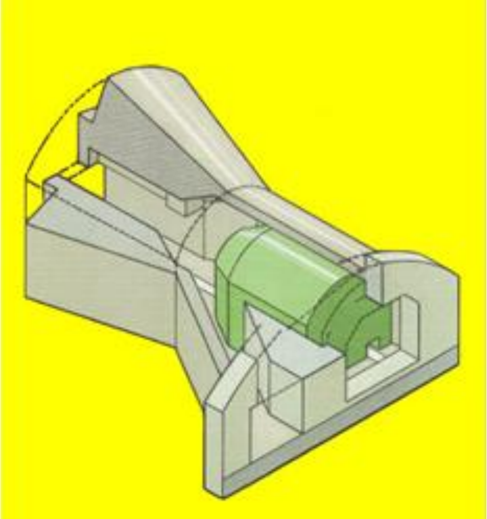
- Been multiple contributions over the years by this entity to the explosives safety community in the form of analysis, testing, and modeling
- The following slides provide a quick glimpse at just some of the work conducted in previous years

# Klotz Closing Valve

- The origins of the Klotz Club, and now Klotz Group, date back to 1966 when a group of Swiss and Norwegian engineers were searching for solutions to mitigate hazards from underground storage
- The Klotz concept was envisioned as a giant blast valve
- Theoretical an experimental studies were carried out in Switzerland and Norway from 1967 to 1970
- Full-scale proof test successfully performed in Älvdalen, Sweden in 1973
  - Full size Klotz has a mass of approximately 250 tonnes



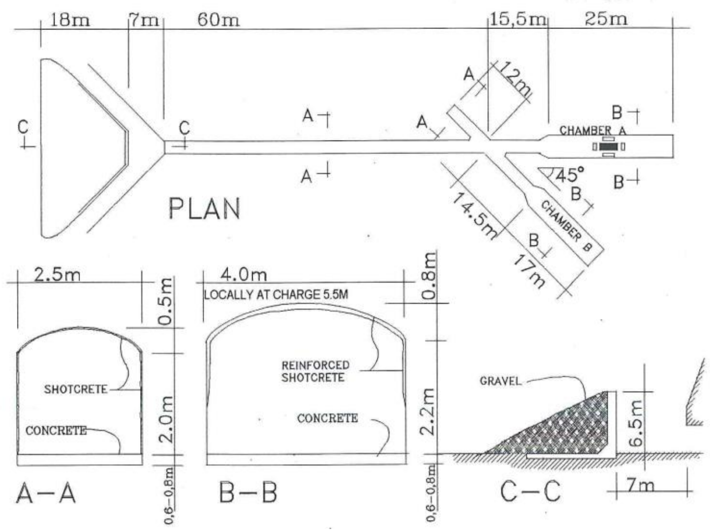

**Plan View**



**Klotz Device**

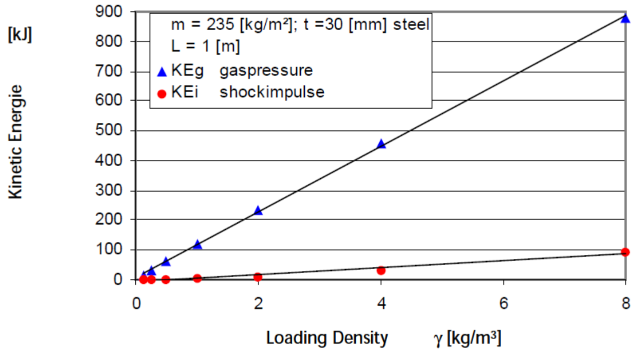
# Water Mitigation

- Klotz Club started to look at water mitigation in 1993
    - Previous small scale experiments had shown reduction in pressure & impulse
- In September 1996, the Klotz Club and Singapore conducted a full-scale test using 1000 kg of 152 mm artillery shells
    - Conducted in KC-tunnel at Älvdalen range
    - Identical to test without water mitigation conducted in 1989
- Results showed reduction in explosives output, but far less than that of scaled tests
- Klotz Club conducted additional analytical studies and Singapore funded additional testing in 2000 and 2001




# Debris Launch Velocity (DLV) Formula

- One of the critical parameters for determining debris throw distances from an aboveground magazine is the debris launch velocity
- The 1990s DLV test series aimed to investigate this in more detail
  - Planned by Klotz Group and Ernst Mach Institute (EMI)
  - Conducted at test sites in Germany
- Early tests had fully vented vs. enclosed conditions
  - The results of this series showed that the shock loading contributes 10% and the gas pressure 90% to the launch velocity
  - The above results are specific to loading regime and specifics of the test, but the general trend is true for confined structures

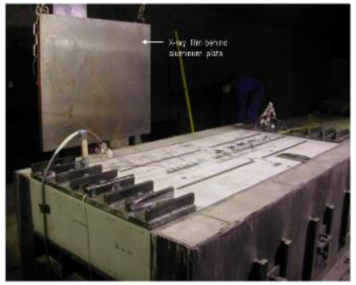


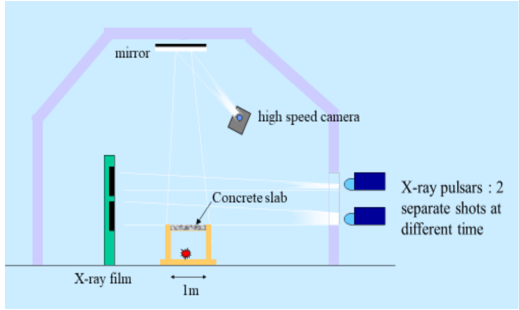
# DLV Formula

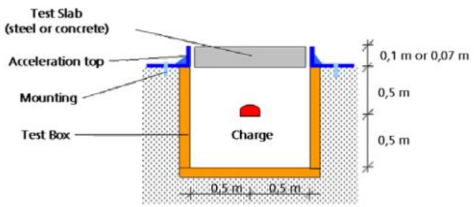
- Additional tests conducted with a wide variety of loading density, structure geometry, charge placement, & fixity of corner connections
- End product was the DLV equation
- Over the years, the DLV has been proven to be accurate for a wide range of structures and loading conditions
    - Modification factors have been developed
    - The basic DLV equation is used in the KG-ET

$$v_{launch} = 525\sqrt{\frac{\gamma \cdot L_{char}}{m}}$$

$V_{launch}$ = launch velocity (m/s)
$\gamma$ = loading density ($kg_{TNT}/m^3$)
$L_{char}$ = characteristic length; the cube root of the volume (m)
$M$ = aerial wall density ($kg/m^2$)

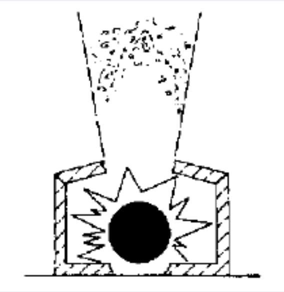
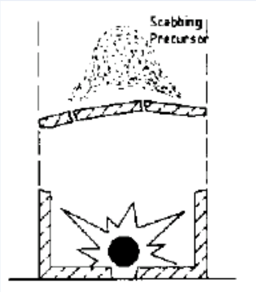
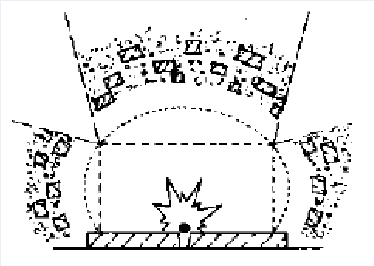




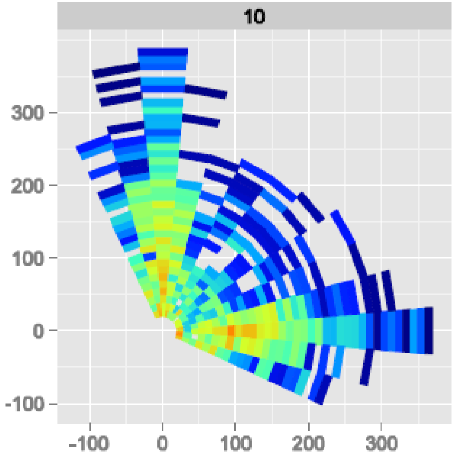

# Reinforced Concrete (RC) Magazines

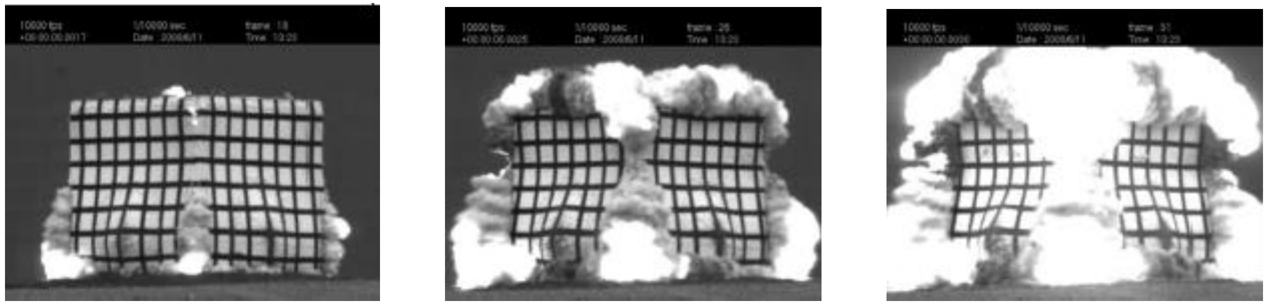
- After the extensive focus by the Klotz Club on underground magazines, in the 1990s the shift focused to aboveground heavy structures, such as RC, and their dominant debris throw hazard
- DLV work used to quantify RC debris launch velocities
- Klotz Group research range of interest for the prediction of debris hazards has been loading densities between 1 and 15 kg/m$^3$
- Information on mass distribution and launch angle distribution were still unknown

| Regime | Shock Overloading | Blast Pressure Overloading | Gas Pressure Overloading |
|---|---|---|---|
| Loading Density (kg/m$^3$)<br>or Scaled Distance (m/kg$^{1/3}$) | LD > 15<br>Z < 0.4 | 1 $\leq$ LD $\leq$ 15<br>0.4 $\leq$ Z $\leq$ 1 | LD < 1<br>Z > 1 |
| Illustration of Phenomena |  |   |  |

# RC Magazines: Kasun Tests

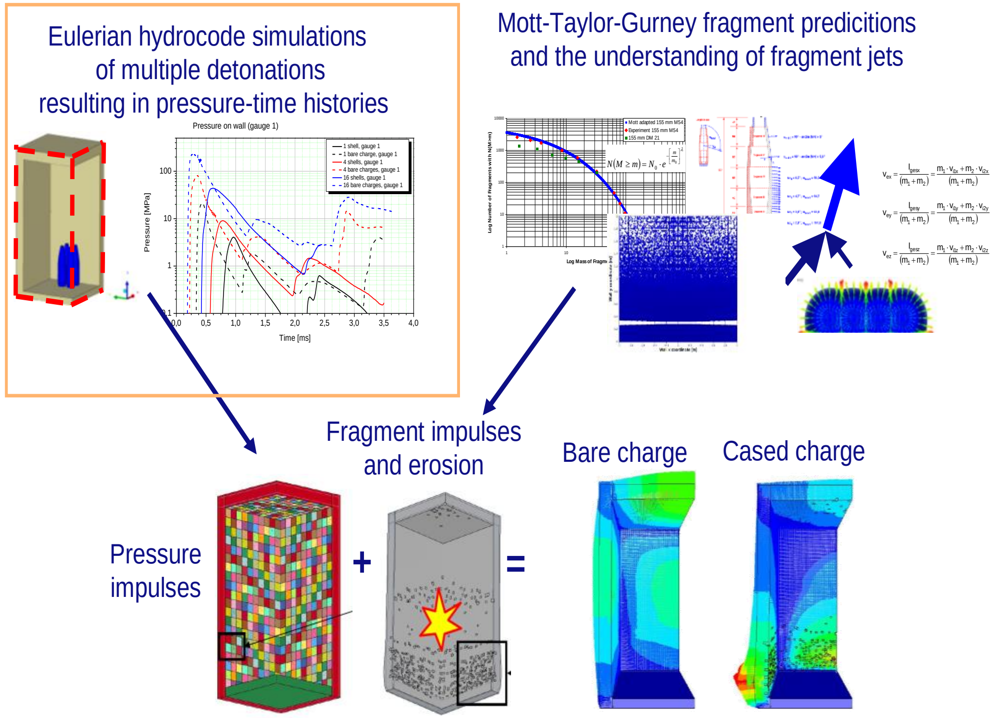
- The Klotz Group conducted multiple series of tests on small RC magazines
- Type of magazine tested was the Kasun, used for small NEW storage
  - 2x2x2 $m^3$ internal dimensions of heavily reinforced RC box
  - Wall & roof thickness of 15 cm; double layers of rebar in both directions
- Kasun test series generated extensive data on mass distribution, launch angle, and debris density as a function of distance, as well as debris launch velocity information

# RC Magazines: Numerical Modeling

- A three-step procedure was developed to model the sequence of events
  - Hydrocode for pressure-time histories
  - Fragmentation prediction and jetting
  - Input into coupled simulation of Kasun
- The developed procedure and applied numerical tools enabled study of the casing effects on loading and break-up
- Methodology will be applied to other geometries, munition types, and asymmetric storage conditions

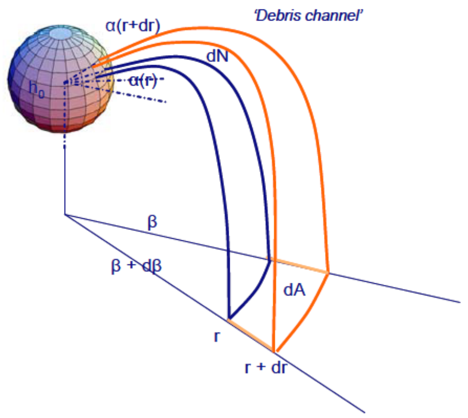


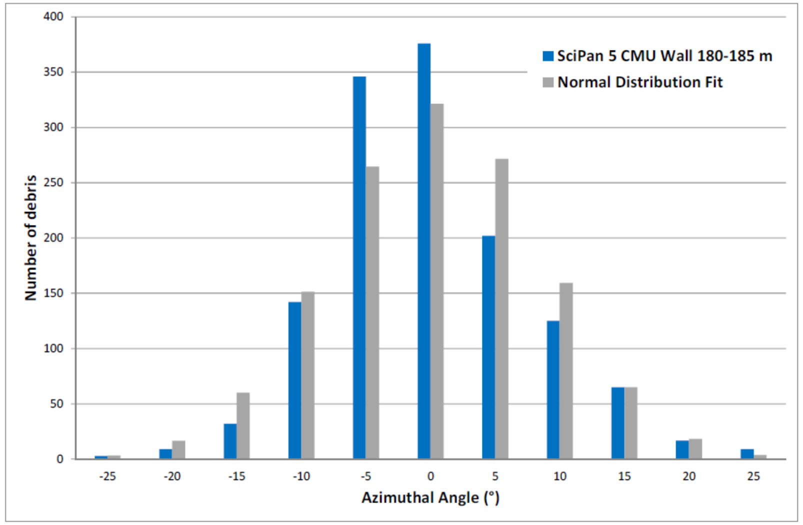
# Klotz Group – Engineering Tool (KG-ET)

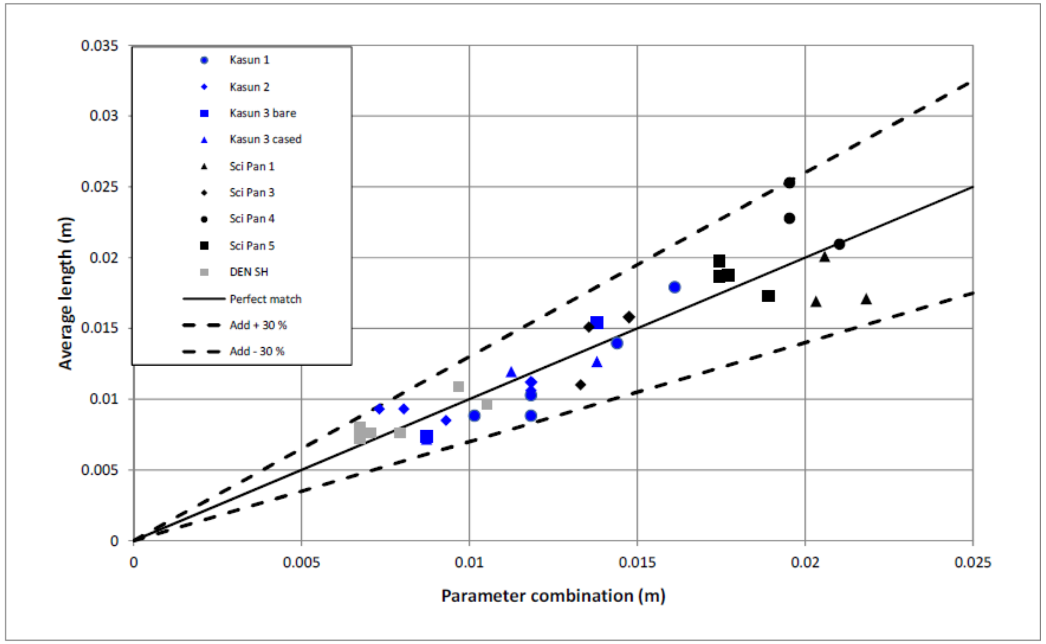
- Work on this debris prediction methodology and tool began about 15 years ago
- Methodology implemented in KG-ET represents state-of-the-art, physics-based engineering prediction model for debris throw hazards
- Tool implements “source function” methodology specific to each component of the donor being analyzed
  - Version 1.x is RC model, Version 2.x is ISO-container model, and Version 3 is RC model, ISO container model, and “free form” source function
- The addition of the “free form” source function is significant as it allows incredible flexibility to model any donor source if information describing debris throw phenomena are known.

# KG-ET: Methodology

- KG-ET source function is defined for each component of donor and is represented as a point source
- For example, in basic/default version, for the wall of RC magazine:
  - Mass distribution is a function of NEW & volume, launch velocity is based on DLV, and vertical/horizontal launch angles are predefined
- Parameters based on best available date

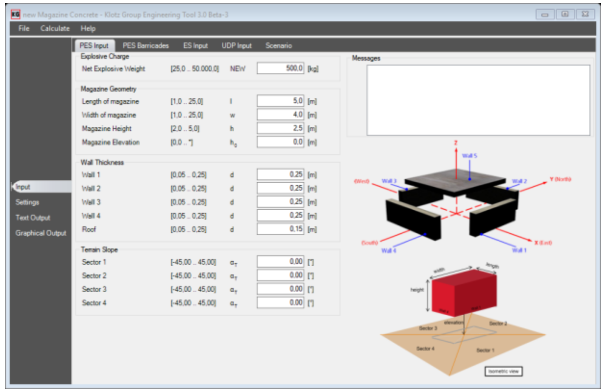


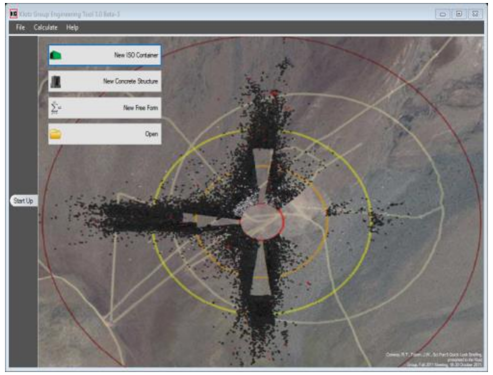



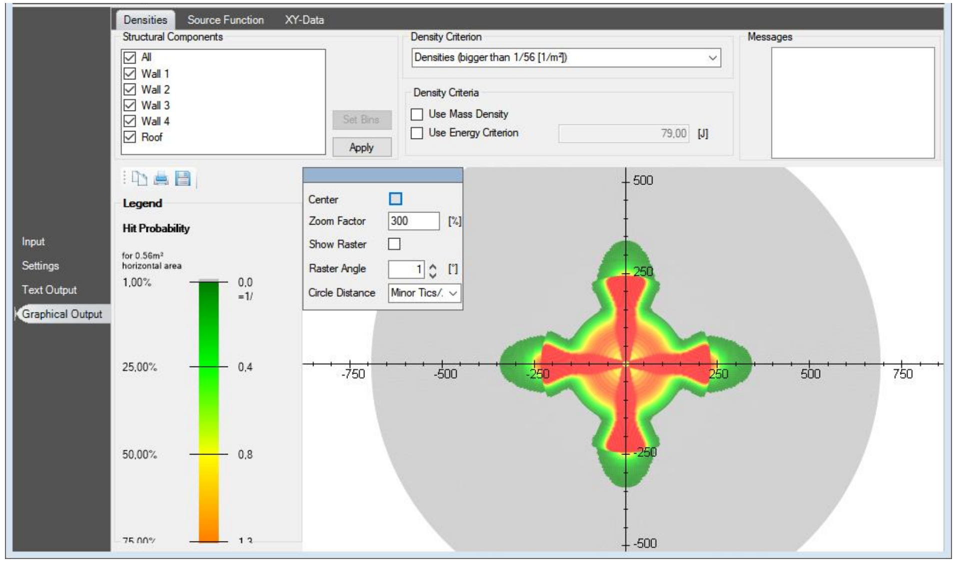



# KG-ET: Input & Output

- Simplistic user interface in basic mode; desired complexity in expert mode
- Output is debris density by mass bin, by all debris, or by defined kinetic energy criterion, e.g., 58 ft-lb (79 joules)
  - Targets/ESs can be defined to quantify debris hazard
- Successful validation efforts with test data

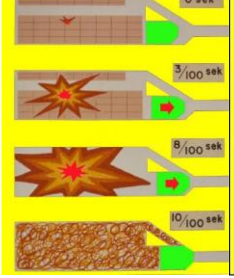


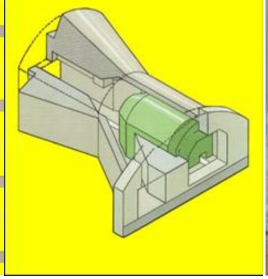


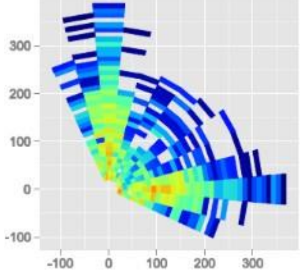


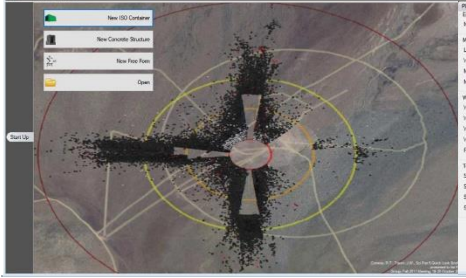
# Conclusion

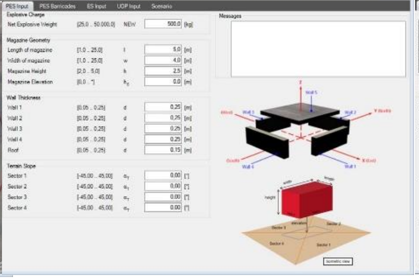
- The Klotz Group and its predecessors have provided extensive contributions to he explosives safety community for over five decades
- The pursuit of a fundamental understanding of explosion effects have resulted in state-of-the-art testing and research
- The KG-ET is an integrator of extensive expertise, test data, and analytical modeling to be used for enhancing explosives safety quantity distances and supporting quantitative risk assessments
- Future Plans
  - Develop KG-ET source functions for primary fragments & quantify stack effects
  - Develop the KG-ET ECM source function
  - Continue balance between testing, engineering models, and computational analysis to further develop the KG-ET to enhance explosives safety

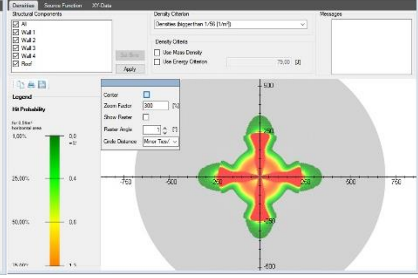










# Thank you for your attention.

# Questions?