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A Fast Running Model (FRM) for Lethality due to Wall Debris Throw from Above Ground Magazines

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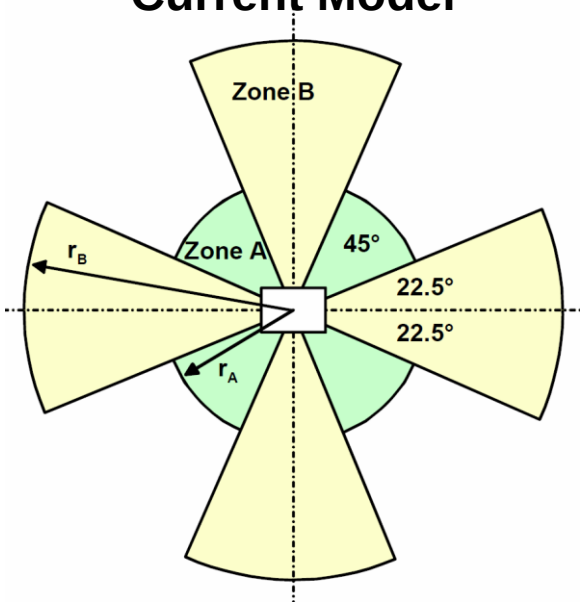
Peter O. Kummer - **Bienz, Kummer** & Partner Ltd.
on behalf of the Swiss Department of Defence

Background

- The current model for debris throw from explosions in above ground magazines in Switzerland is based on yesterday's knowledge and no longer state-of-the-art
- During the last decades many tests were performed, leading to a huge database on debris throw, now allowing to develop improved models

Current Model



Typical Magazine for Training Ammo

Background

- Based on new information from those tests, sophisticated computer tools were developed recently, such as:
  - **Klotz Group Engineering Tool (KG-ETool)**

    which allows to calculate debris dispersion in the surroundings of a magazine after an explosion
  - **LambdaT©**

    which allows to calculate lethality due to debris throw, based on the data provided e.g. by the KG-ETool
- However, to use these tools:
  - a lot of expert knowledge is needed
  - running the tools and data handling are time consuming
- In short: Procedure not really suitable for “standard every day risk analysis”

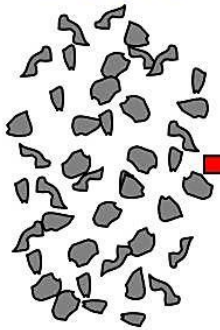
Aim

- Decision was made to develop a new Fast Running Model for wall debris throw (FRM) based on the KG-ETool, LambdaT© and all the test data on hand
- The following requirements for the FRM were defined:
  - Common Swiss above ground reinforced concrete magazines shall be covered
  - Model applicable for a larger range of charge sizes and loading densities
  - Model to serve as basis for standard risk analysis according to Swiss regulations for QRA
  - Input should be limited to a small number of parameters and variables that can be compiled easily
  - The model and its use is supposed to be straightforward

Methodology

General Procedure for Calculating Lethalities due to Debris Throw

Debris



Debris Properties

Mass Bin	Debris Pieces		Average Impact -		
	Average Mass	Number	Velocity	Angle	Energy
[No]	[kg]	[Pieces/m²]	[m/s]	[°]	[kJ]
1	0.05	6	80	15	0.16
2	0.10	1	87	12	0.38
3	0.25	0.2	92	9	1.06
4	0.50	0.04	110	7	3.03
5	1.00	0.01	120	5	7.20
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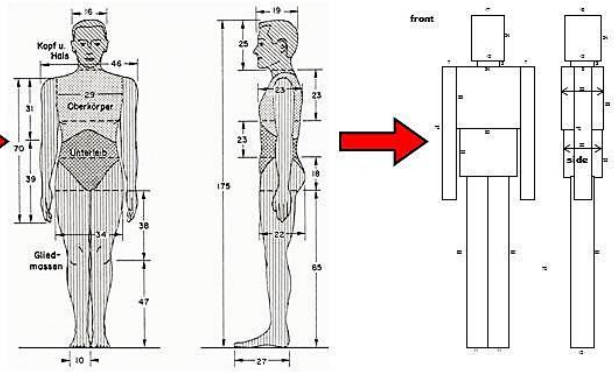
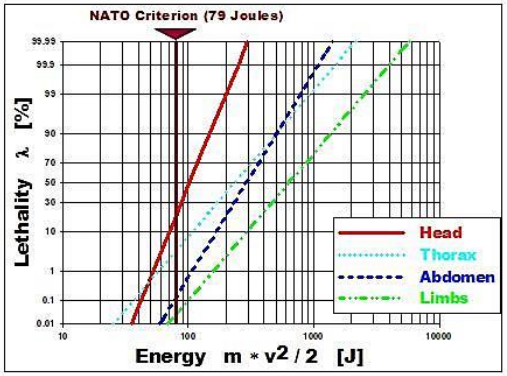
Body Areas



Basic Lethality

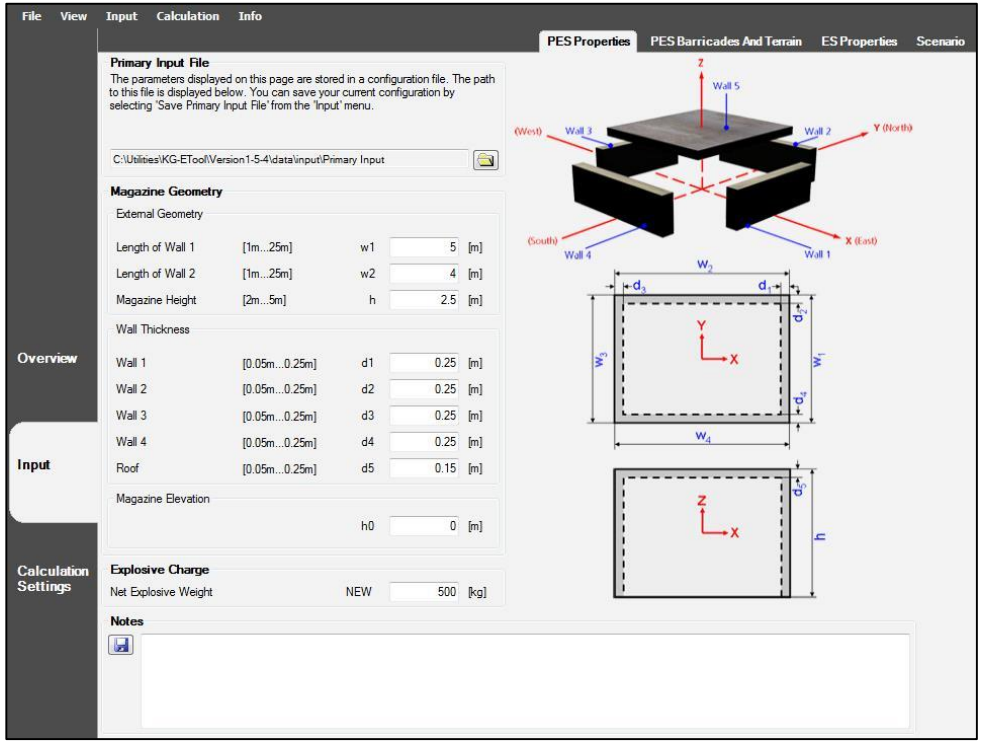


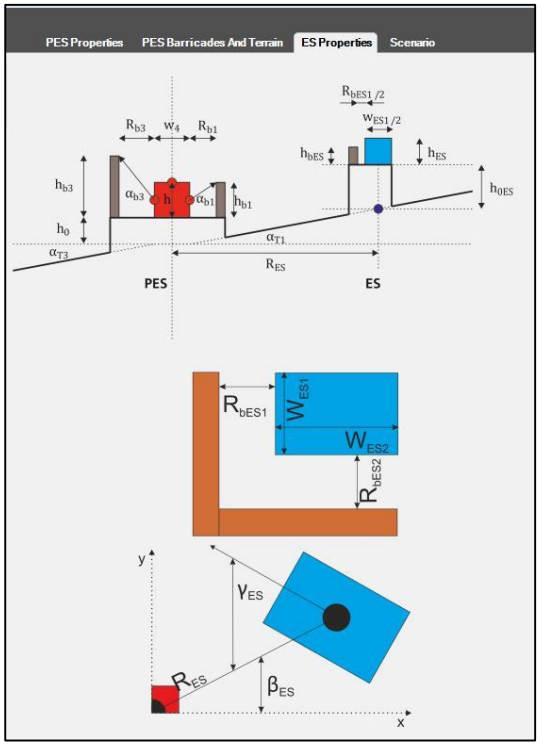
Body Model

[m²]	Head	Thorax	Ab-domen	Limbs	Total
front	0.044	0.112	0.075	0.296	0.527
side	0.049	0.058	0.039	0.171	0.317
top	0.032	0.043	0.000	0.013	0.088

Methodology

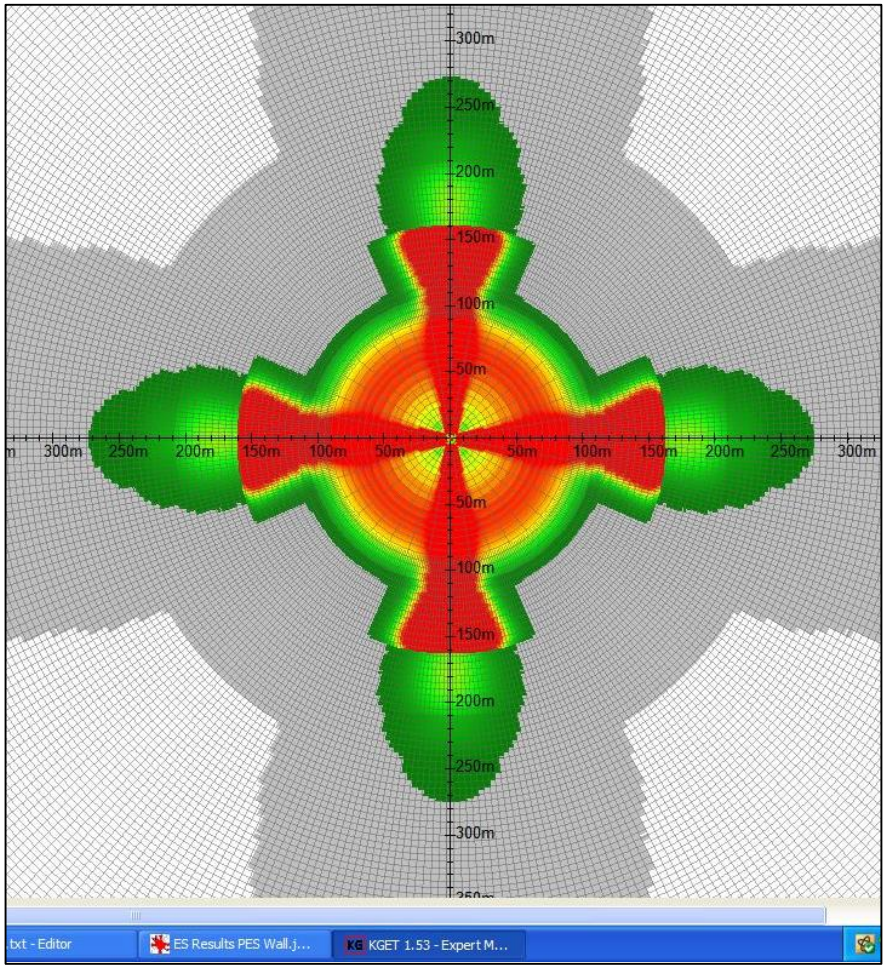
KG-ETool - Typical Input Screen





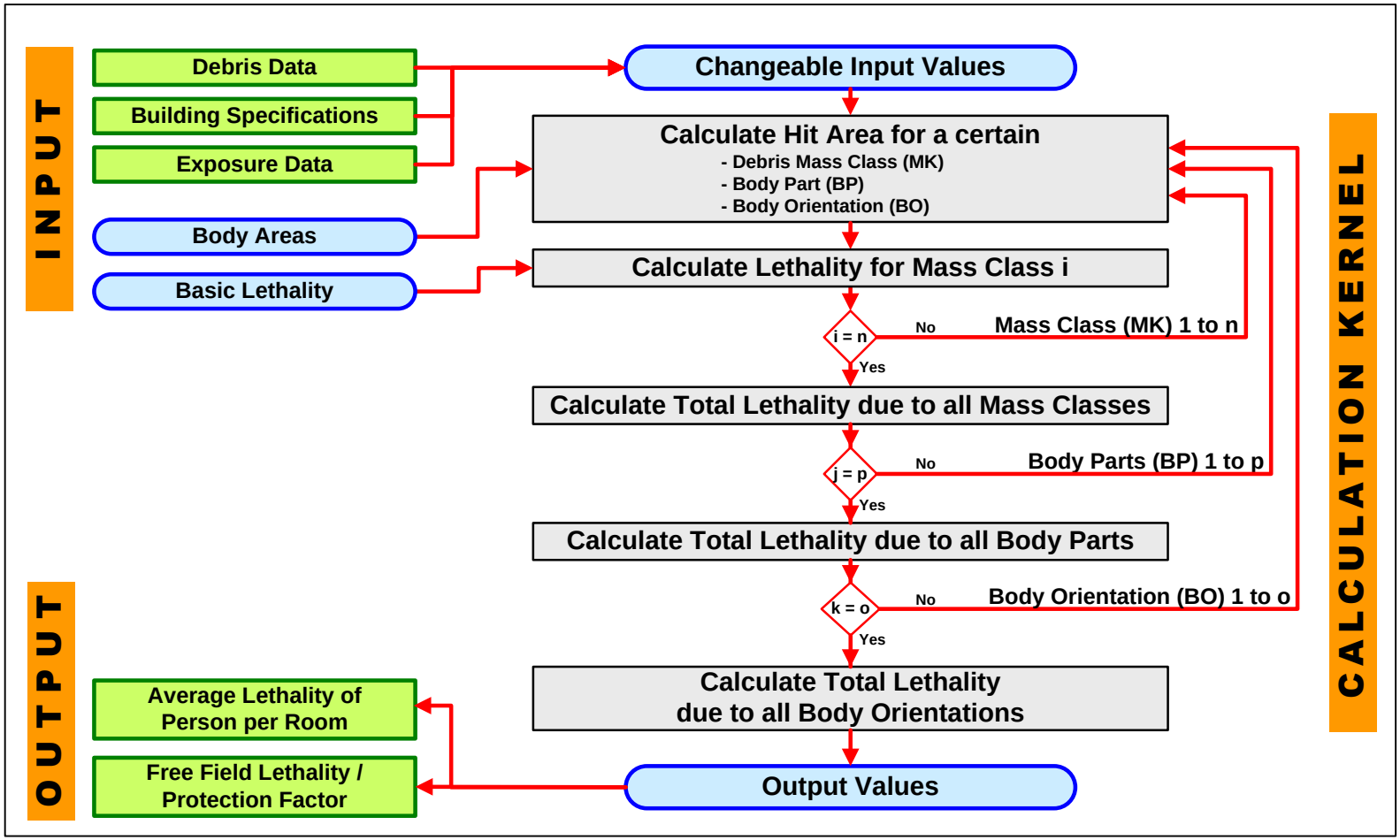
Methodology

KG-ETool - Typical Graphic Output, Showing Debris Densities



Methodology

LambdaT© - Flow-Chart, Showing Lethality Calculation Procedure



Methodology

Relevant parameters that drive debris throw from walls of above ground reinforced concrete magazines

- Launch Velocity dependent on loading density, specific wall mass, and length of structural element
- Total Wall Mass dependent on wall area, wall thickness and specific weight of construction material
- Average Mass of a Piece of Debris (per mass class) mainly dependent on loading density
- Lost Mass function of loading density
- Slope of Terrain

Methodology

Calculation of the Relevant Parameters can be done by Knowing the Following Quantities

- Outside size of the magazine (length, width, height)
- Thickness of the structural elements
- Mass of the explosives charge
- Visibility of a structural element
- Slope angle of the terrain

To calculate the lethality of a person at any point you like in the surroundings of a magazine, in addition:

- Distance from the magazine center on the axis of the wall
- Lateral deviation of this point from the wall axis

General Procedure

- The development of the FRM was an iterative process that took place in several sub-steps
- In each sub-step one of the variables was investigated in detail and a mathematical model was developed
- Finally, all sub-steps were combined into a relatively simple formula resp. model comprising all variables

- To get a relatively simple formula several assumptions had to be made, like:
  - The model should be accurate for lethalities smaller 50%
  - Lager charge sizes should always lead to larger distances for the same lethality
  - The model is required to show straight lines in a lethality-distance diagram (log-scale)
  - The straight lines for various charge sizes should be parallel

Example 1

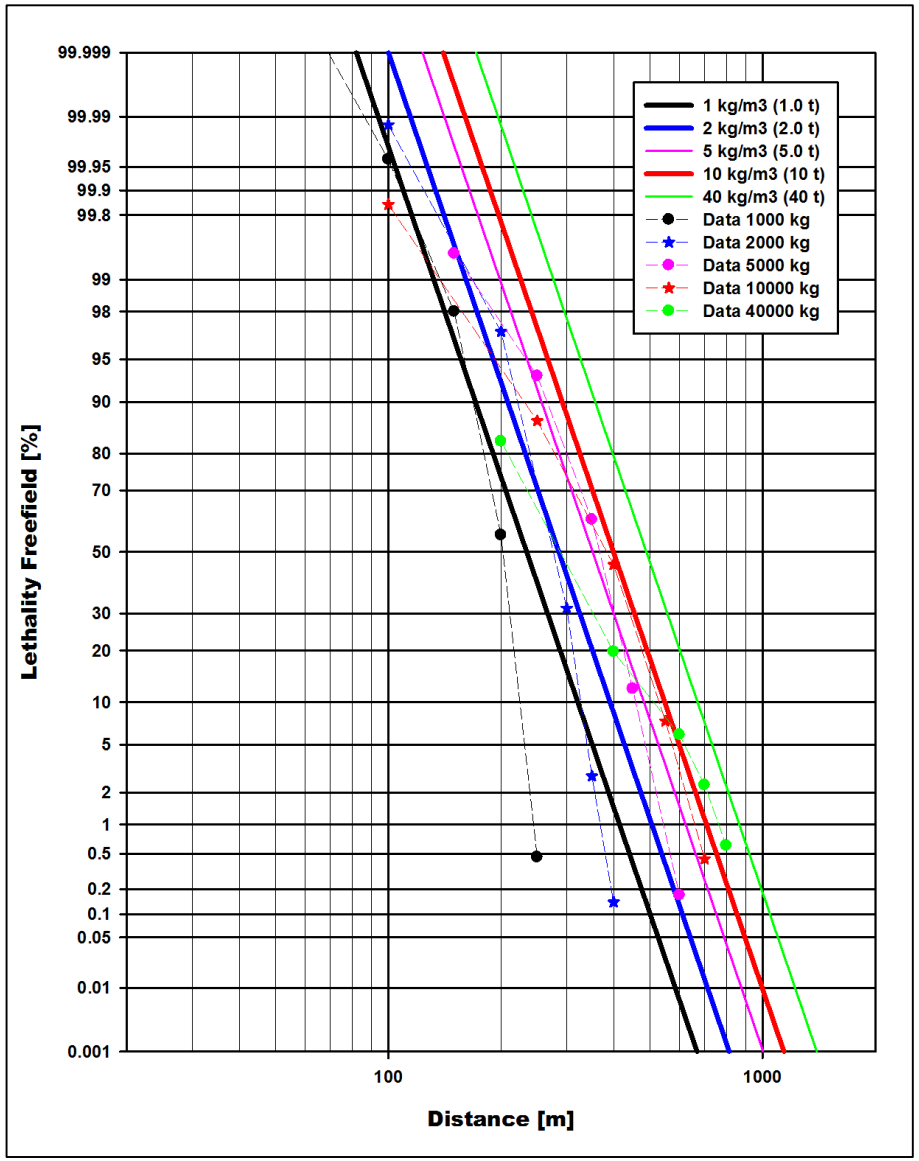
Influence of Charge Size

(Magazine V = 1'000m^3, lethality on wall axis for person in free-field)

Basic formula:

$$\mathbf{Pr_{(L)} = A + B * \ln(R)}$$

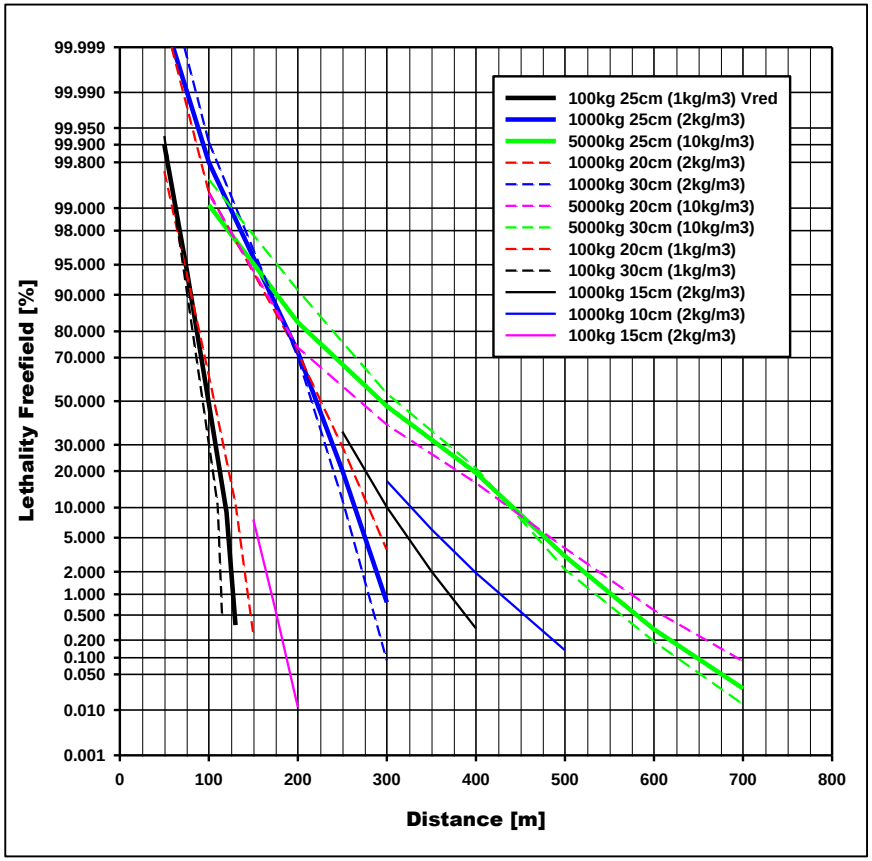
$Pr_{(L)}$ = Probit of the lethality
A = Factor dependent on loading density
B = Constant
R = Distance from magazine centre



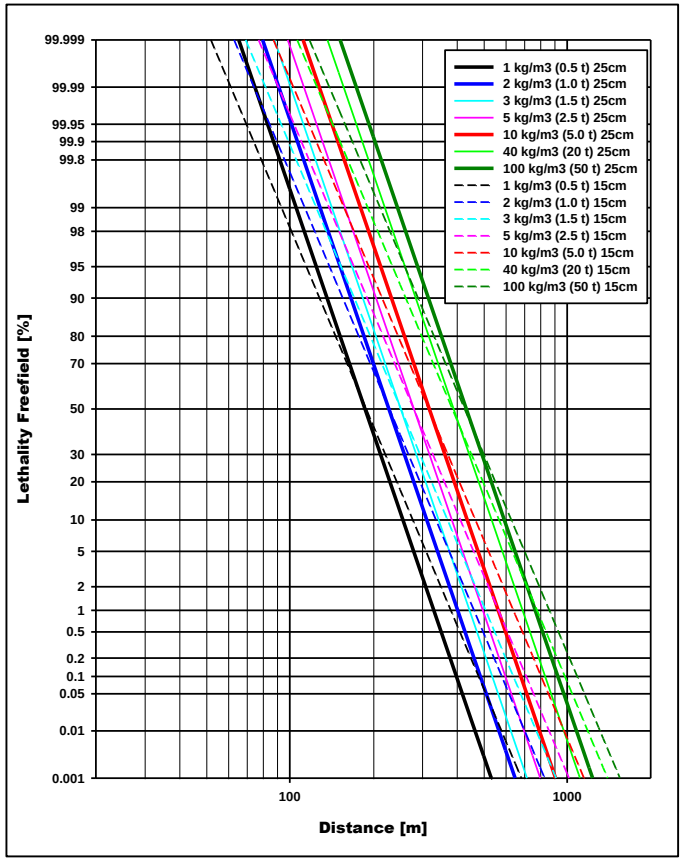
Example 2

Influence of Wall Thickness

With KG-ETool Calculated Distances



Model



Final Wall Debris Lethality Model

Final Formula for People Staying in the Open on Wall Axis on Flat Terrain

$$Pr_{(L)} = A + B * \ln(R / f_F)$$

$$A = ((26.25 + 5.53 * \ln(\gamma)) + (f_w * (2.95 + 0.68 * \ln(\gamma)))) / (1 + 0.161 * \ln(\gamma))$$

$$B = -4.07 + (f_w * -0.57)$$

$$f_w = (d_w - 25) / 7.5$$

$$f_F = (F_{eff} * f_a / 63) \wedge (1/3)$$

$$f_F = (F_{eff} * f_a * f_v / 63) \wedge (1/3), \text{ (in case of } \gamma < 1 \text{ kg/m}^3)$$

d_w =	wall thickness	[cm]	F_{eff} =	actual wall area	[m^2]
f_a =	visibility	[%]	V =	magazine volume	[m^3]
f_v =	$V_{red}/V_{eff,}$	[-]	R =	range from PES	[m]
γ =	loading density	[kg/m^3]	$Pr_{(L)}$ =	probit lethality free field	[-]

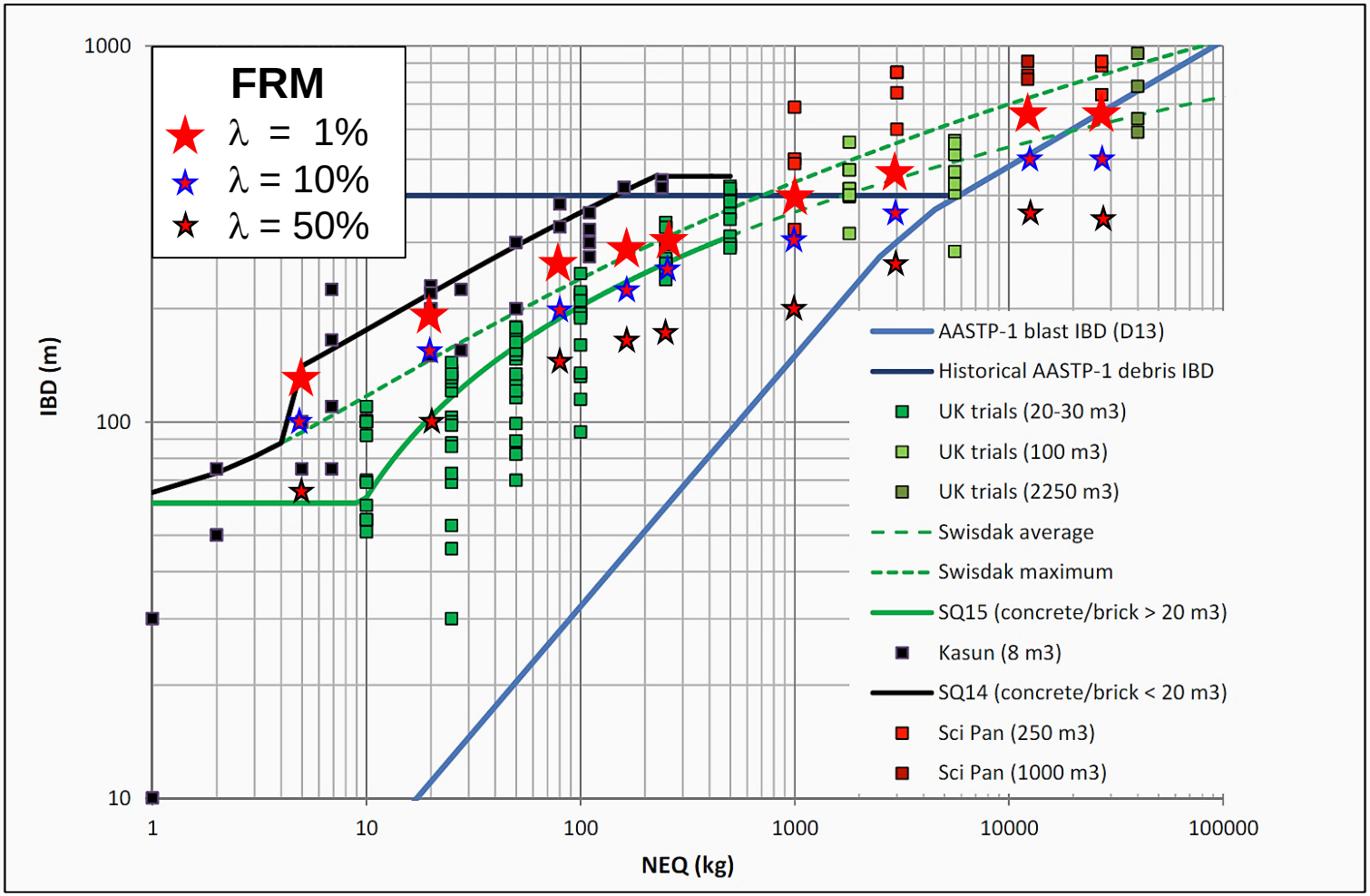
Range of Validity

- type of exposure: free field
- type of magazine: above ground, reinforced concrete, non-earth covered
- charge size: starting from a few kg up to 50 t, depending on size of the magazine
- loading density: approx. 0.1 kg/m^3 up to 40 kg/m^3
- volume of magazine: from approx. 5 m^3 up to over 1000 m^3 (on one or two storyes)
- wall thickness: from approx. 10 cm up to approx. 35 cm (depending on magazine size)
- lethality: from 99.99… % to 5 * 10^{-5} %

→ However, not all combinations make sense

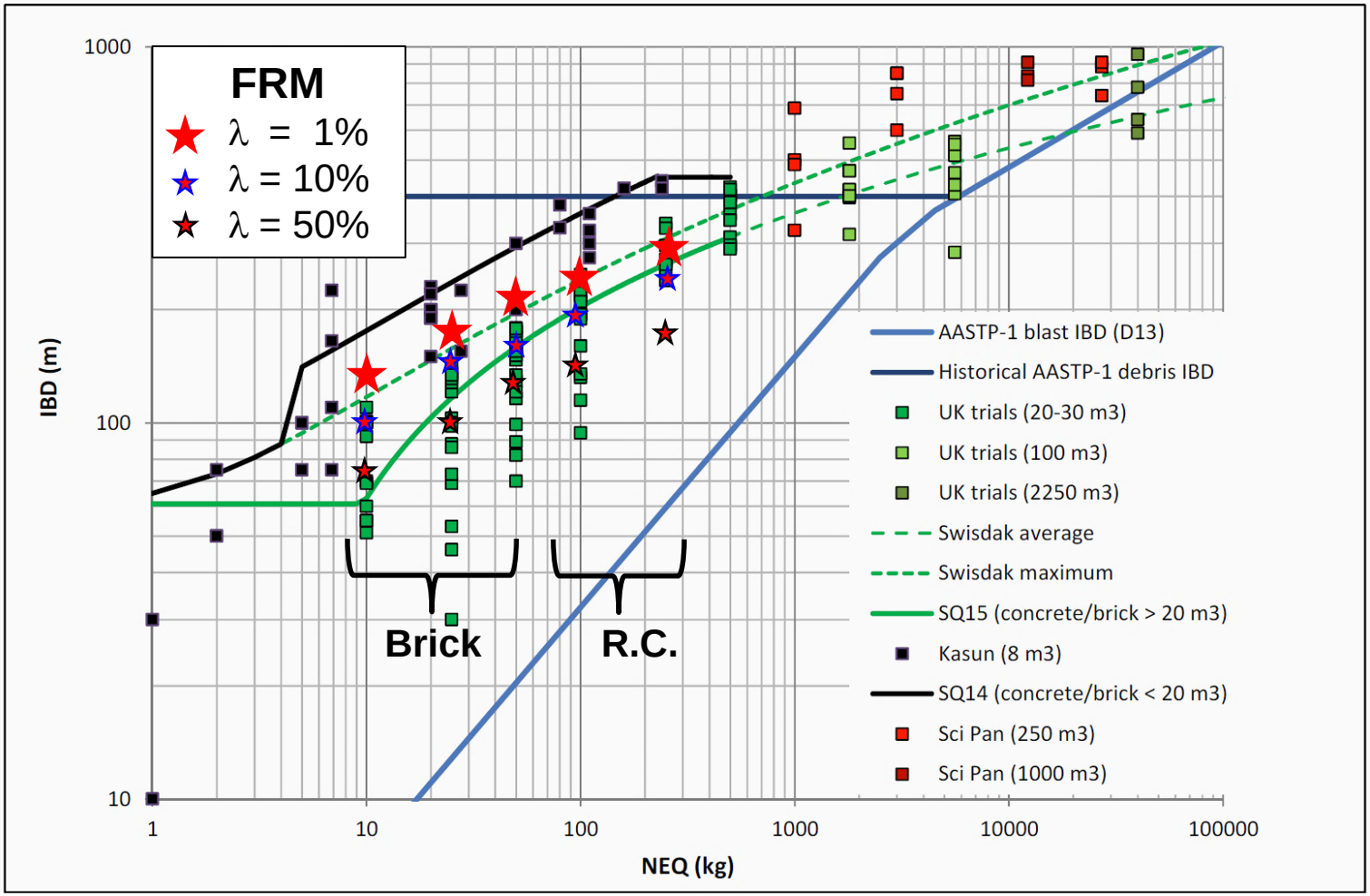
Comparison with Test Data

Comparison with KASUN and SciPan Data (black and red squares)



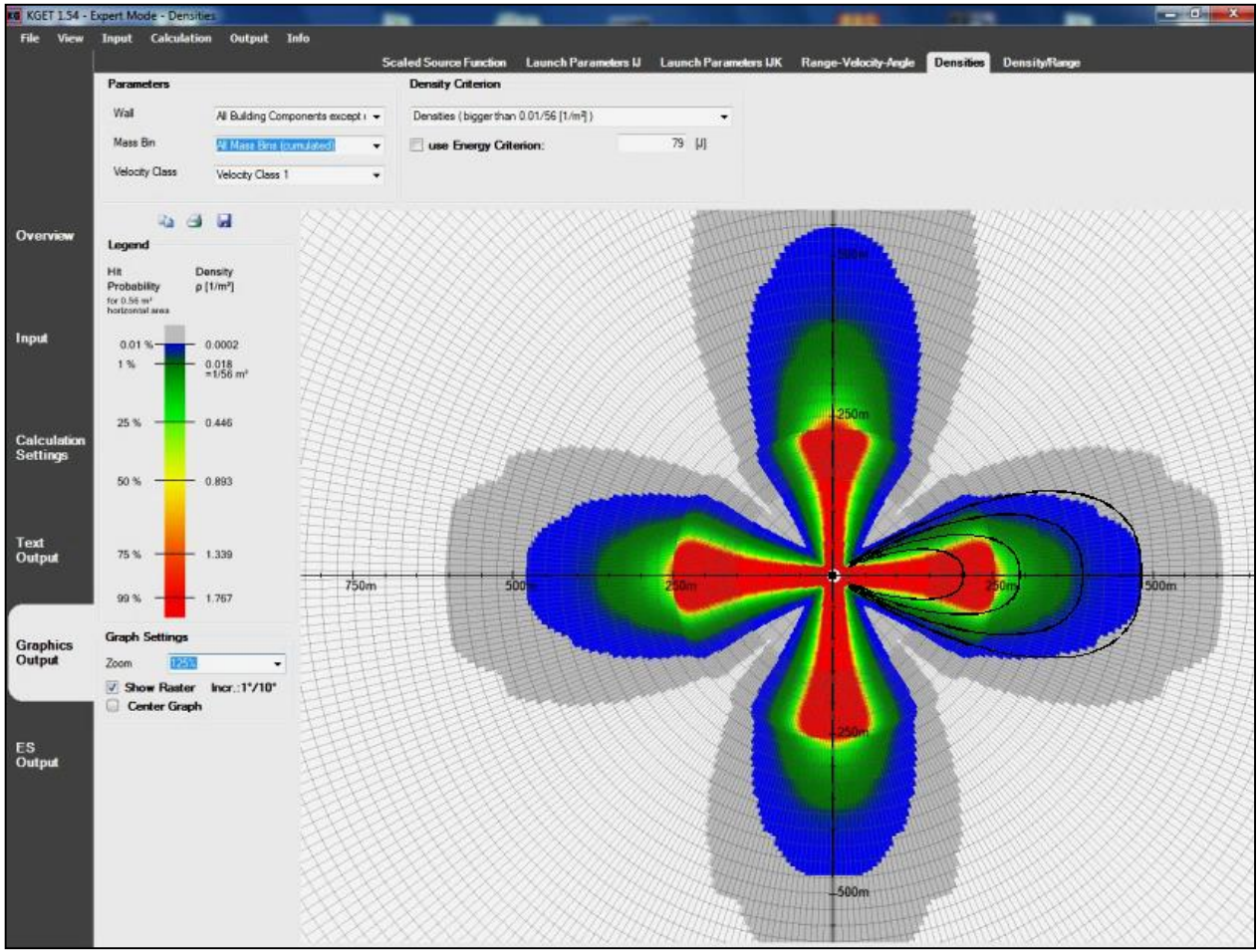
Comparison with Test Data

Comparison with UK Trials (green squares)



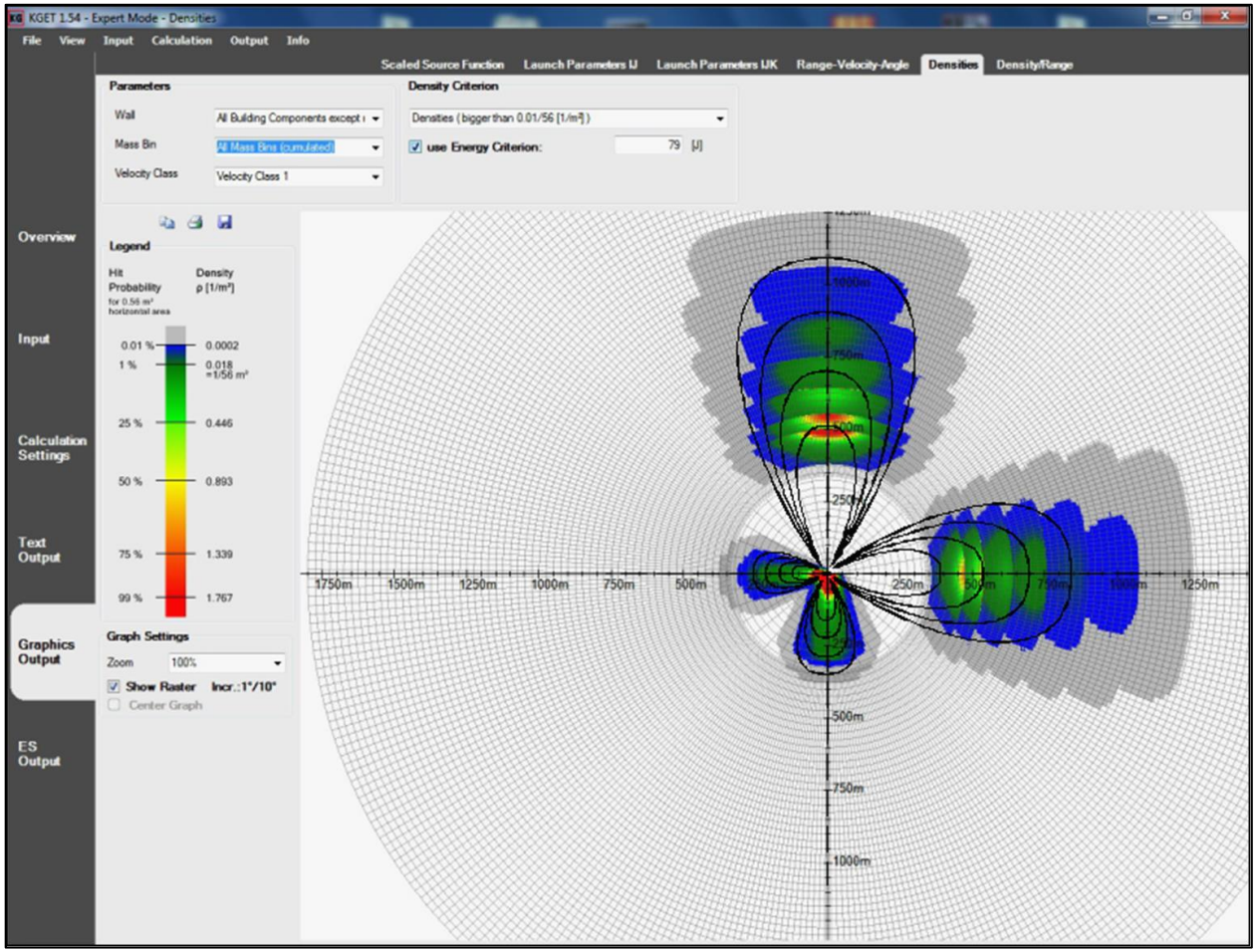
Comparison with KG-ETool

Comparison of KG-ETool Debris Densities with FRM Lethalities of 50%, 10%, 1%, 0.1% (solid black lines, right-hand side)



Comparison with KG-ETool

Comparison between KG-ETool and FRM for Sloped Terrain (+/- 20°)



Final Remarks

Summary

A new Fast Running Model (FRM) for the calculation of lethalities caused by debris throw from *walls of above ground free standing reinforced concrete ammunition and explosives storage magazines*, was successfully developed, using existing data and computer tools

Future Work

- to implement this model into existing regulations like the Swiss TLM 2010 and the NATO manual AASTP-4
- to develop similar improved fast running models, based on current data and computer models, also for roof debris throw of such magazines, crater debris throw and other effects

Acknowledgements

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