Comparison of the NATO 79J hazardous fragment with contemporary blunt impact and penetration injury models

Martijn van der Voort,

Dieter van der Pol, Hugo van Duijnhoven, Dennis Wullink

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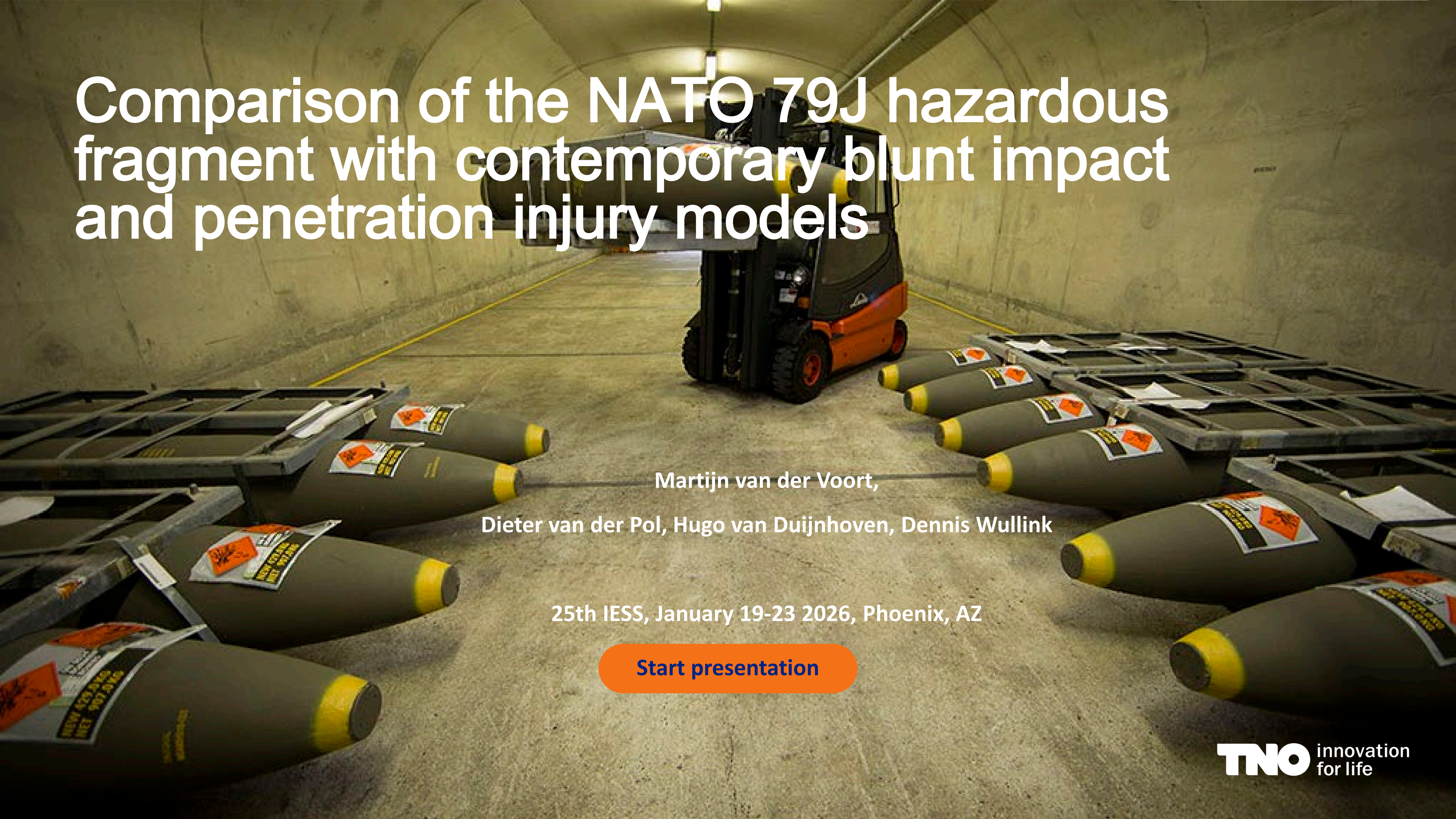
Start presentation



TNO innovation for life

Introduction

TNO develops the Quantitative Risk Analysis (QRA) software Risk-NL

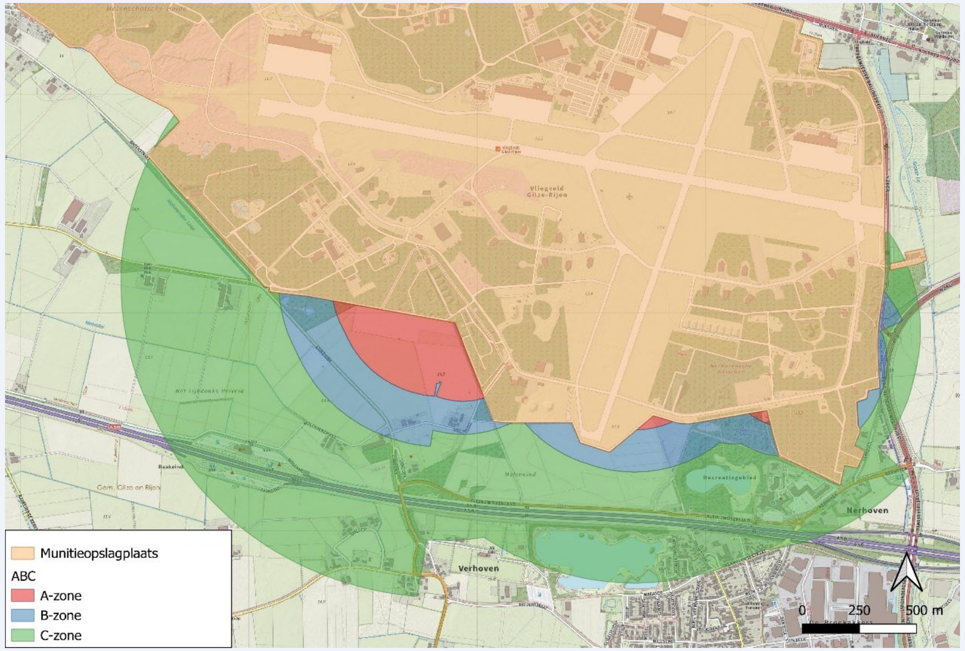
- Risk assessment and licensing of munition storage depots
- Over 40 munition depots, marine bases and air bases analyzed between 2023 and 2025

A Risk-NL analysis consists of:

- AASTP-1 Inter Magazine Distances (IMD) for a high level of protection against sympathetic reaction
- AASTP-1 exterior Quantity Distances (QD), such as the Inhabited Building Distance (IBD) to check for any infringements
- Location specific **individual risk** and **group risk**

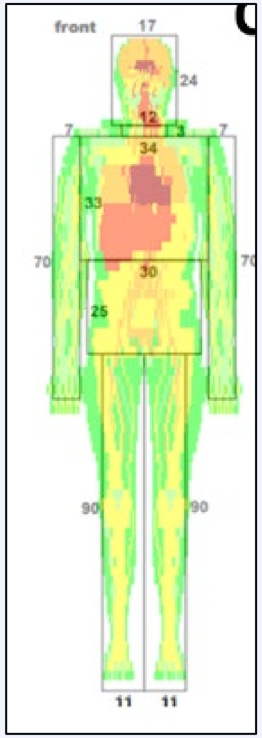
Risk-NL is periodically updated

- Latest versions of NATO and national standards
- Effect- and consequence models with latest insights from testing and modelling, e.g. blast, fragmentation, thermal



Explosives safety siting plan for a Dutch airbase

Aims

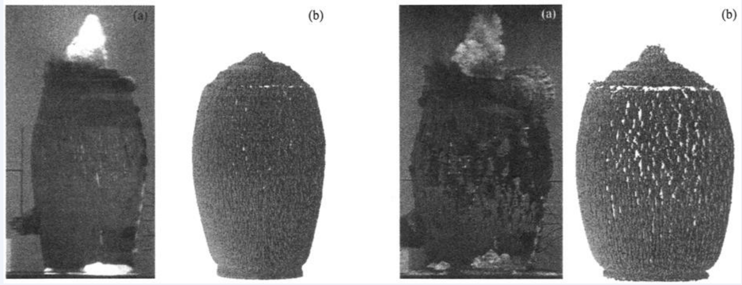


1. To develop a new **projectile injury model for Risk-NL**

- Overview and comparison of **blunt** impact and **penetration** injury models
- Focus on **lethality** (because of lethality risk)
- Approach for multiple hits at the body
- Impact study

2. To describe the implications of the findings for the

79J hazardous fragment, as used by NATO in its definition of the **Inhabited Building Distance (IBD)**



Fragments (steel)

Debris (concrete)

Overview of blunt and penetration injury models

Current assumption in Risk-NL:

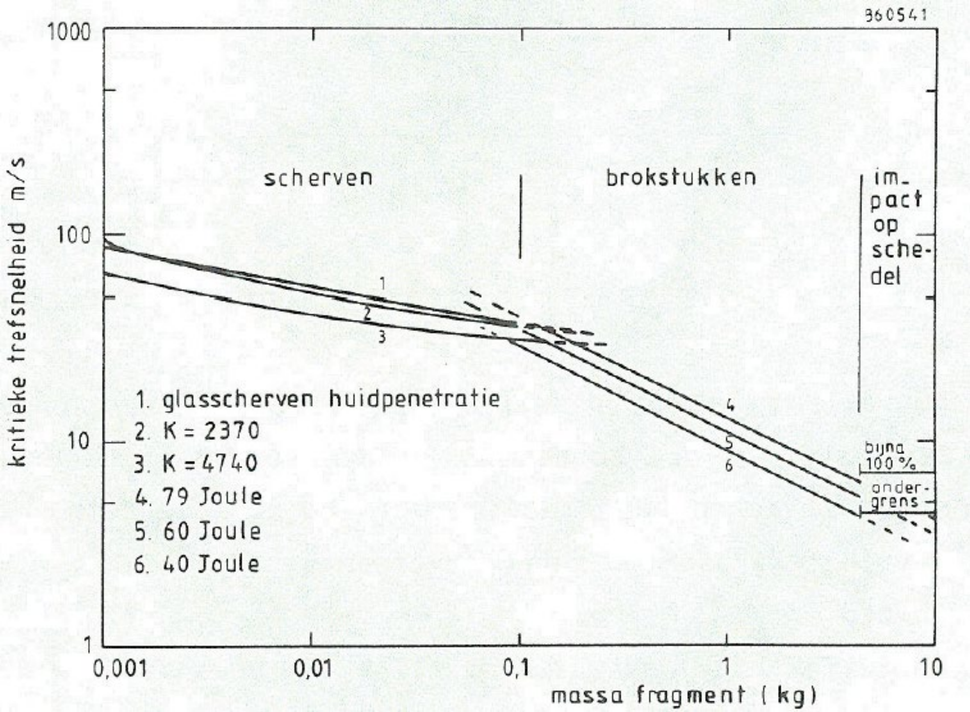
- Every projectile hit is lethal, irrespective of its mass or velocity (= conservative)
- Exposed persons are always facing the hazard

NATO AASTP-1 criterion for hazardous projectiles (79J)

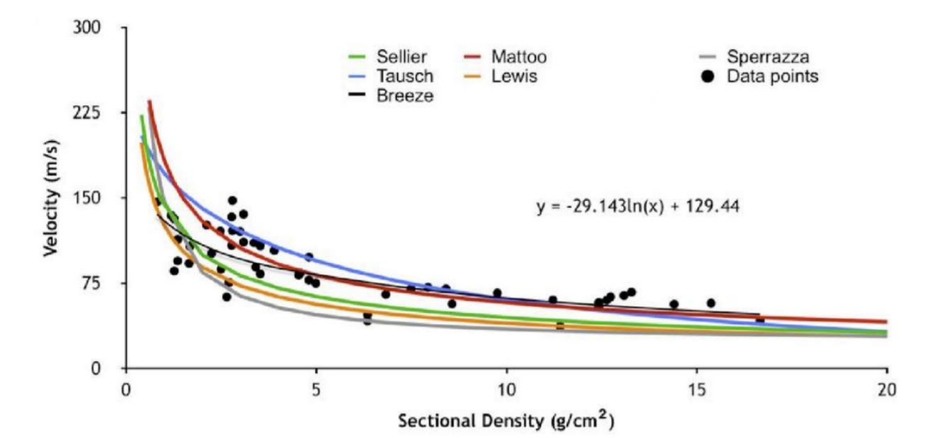
- Impact energy equal to or greater than **79J** is **hazardous**
- First notion of the **79J** kinetic energy level stems from Rohne (1906):
  - *"To remove a human from the battlefield, a kinetic energy of **8 m-kg** is sufficient according to the prevailing view in the German artillery community"*
- Definition of the **Debris and Fragment Distance (DFD):**
  - *"Beyond this distance, the number of **hazardous** projectiles per m^2 does not exceed **1 per 56 m^2**"*

Overview of blunt and penetration injury models

- **Model from "Publicatiereeks Gevaarlijke Stoffen" (2005)**
  - Probit functions for three regimes of projectile mass
  - Skin penetration, blunt impact (kinetic energy), skull fracture



- **More recent skin penetration data from Breeze (2015)**

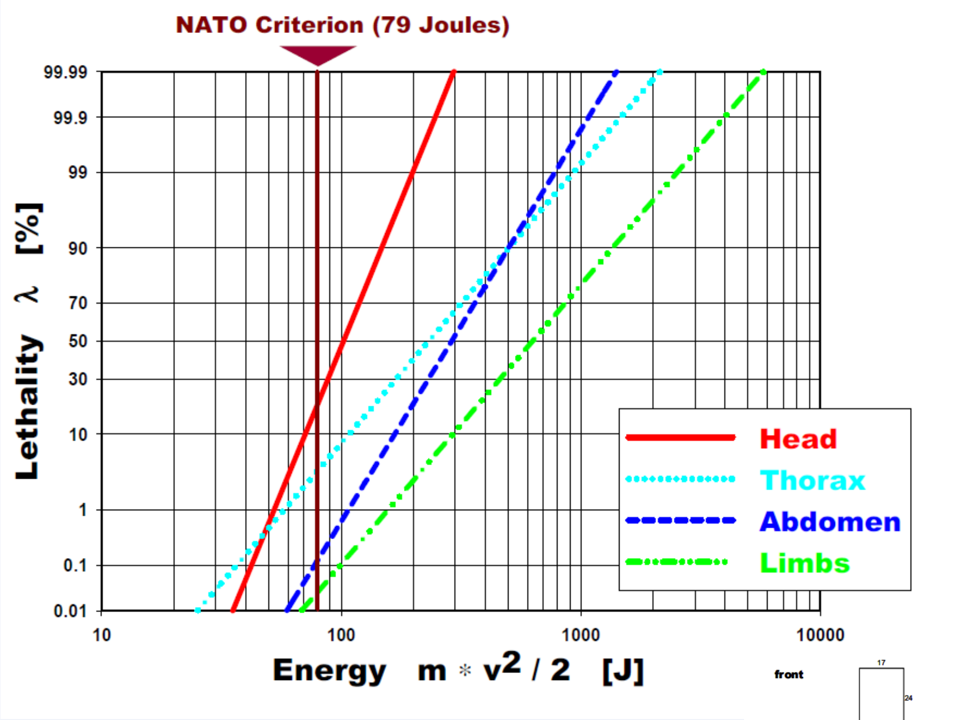


- Skin penetration is a prerequisite for lethality,
- But higher velocities are needed to impact vital organs/arteries and cause lethal injury

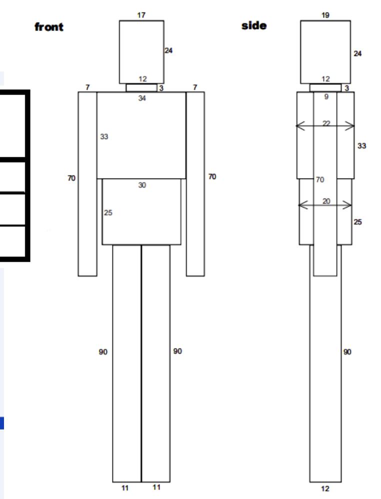
Overview of blunt and penetration injury models

- **Swiss model described in AASTP-4 (Explosives Safety Risk Analysis)**
  - Blunt injury model, developed and used by Switzerland in their national QRA software.
  - Based on research performed by Feinstein, Kokinakis, White, and others in the period 1960 - 1980.
  - Probability of lethality for **four body parts**, function of **kinetic energy**

- **US model described in TP-14 and AASTP-4 (Explosives Safety Risk Analysis)**
  - Same as Swiss model
  - ….but limbs are excluded (may be unconservative)
  - Also gives relations for major and minor injury

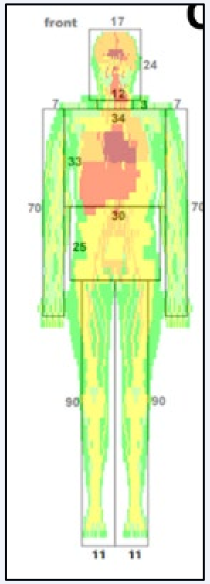


[m²]	head	thorax	abdomen	limbs	total
front	0.044	0.112	0.075	0.296	0.527
side	0.049	0.058	0.039	0.171	0.317
top	0.032	0.043	0.000	0.013	0.088



Overview of blunt and penetration injury models

- **Penetration injury model Computerman code in the TNO TARVAC software**
  - For injury due to ballistic penetrating threats
  - Contrary to previous models not simply a function of kinetic energy
  - Depends on more variables such as fragment mass, velocity, density and shape
  - Range of application generally below 10 to 30 g
  - Calculates retardation of projectile based on the penetration of various tissues
  - Penetration depth and corresponding damaged tissues are established
  - Abbreviated Injury Scale (AIS2005) Scores
  - AIS 5 and 6 are assumed to be lethal within context of QRA

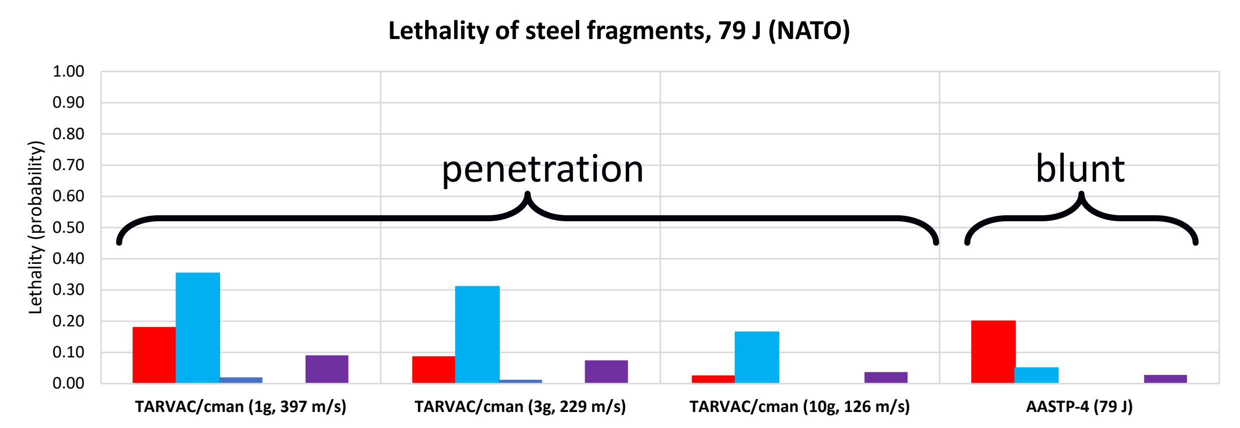


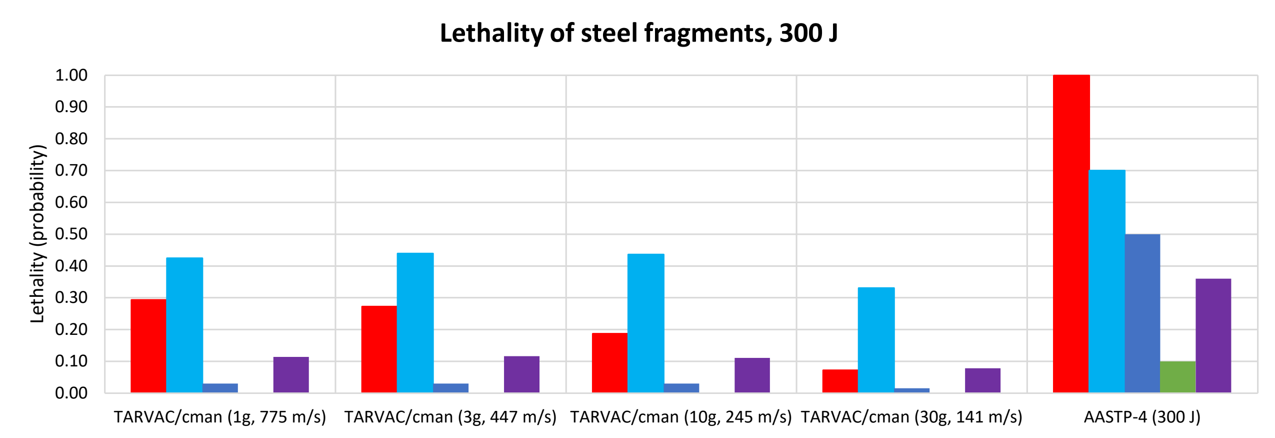
Vulnerability view TARVAC

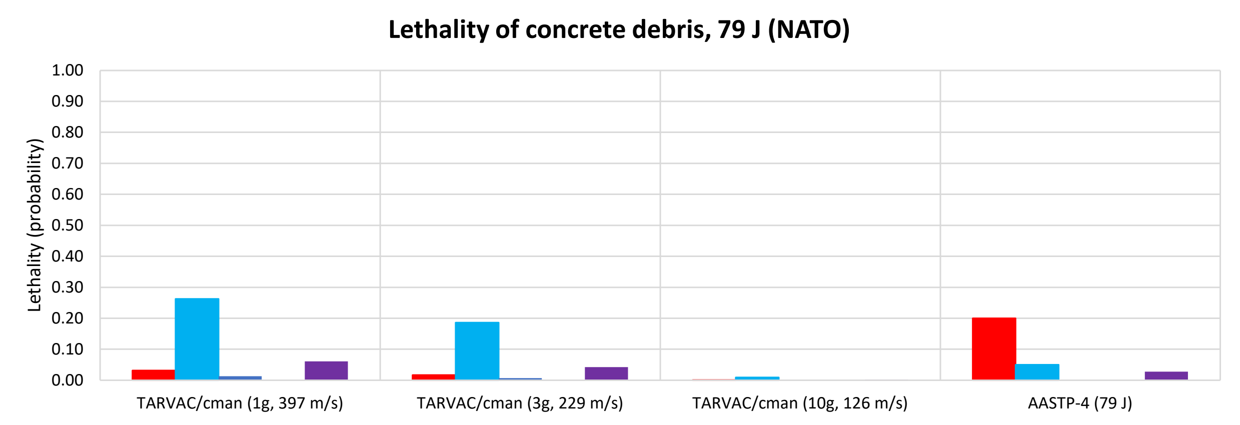
Colour	AIS	Label
(green)	1	Minor injury
(light green)	2	Moderate injury
(yellow)	3	Serious injury
(orange)	4	Severe injury
(red)	5	Critical injury
(dark red)	6	Fatal injury

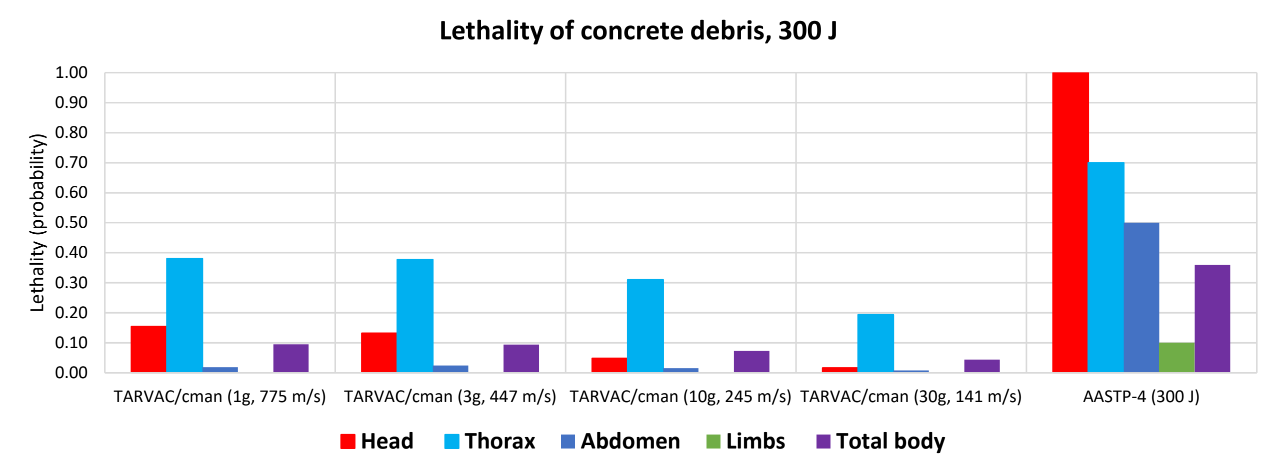
Comparison of injury models (Swiss versus TARVAC)

- Blunt impact: **head** is worst-case   Penetration: **thorax** is worst case   **Steel** is always worse than **concrete**
- Blunt impact usually has a higher probability of lethality than penetration, for a given kinetic energy
- For 79J penetration has a higher probability of lethality below about 3 grams



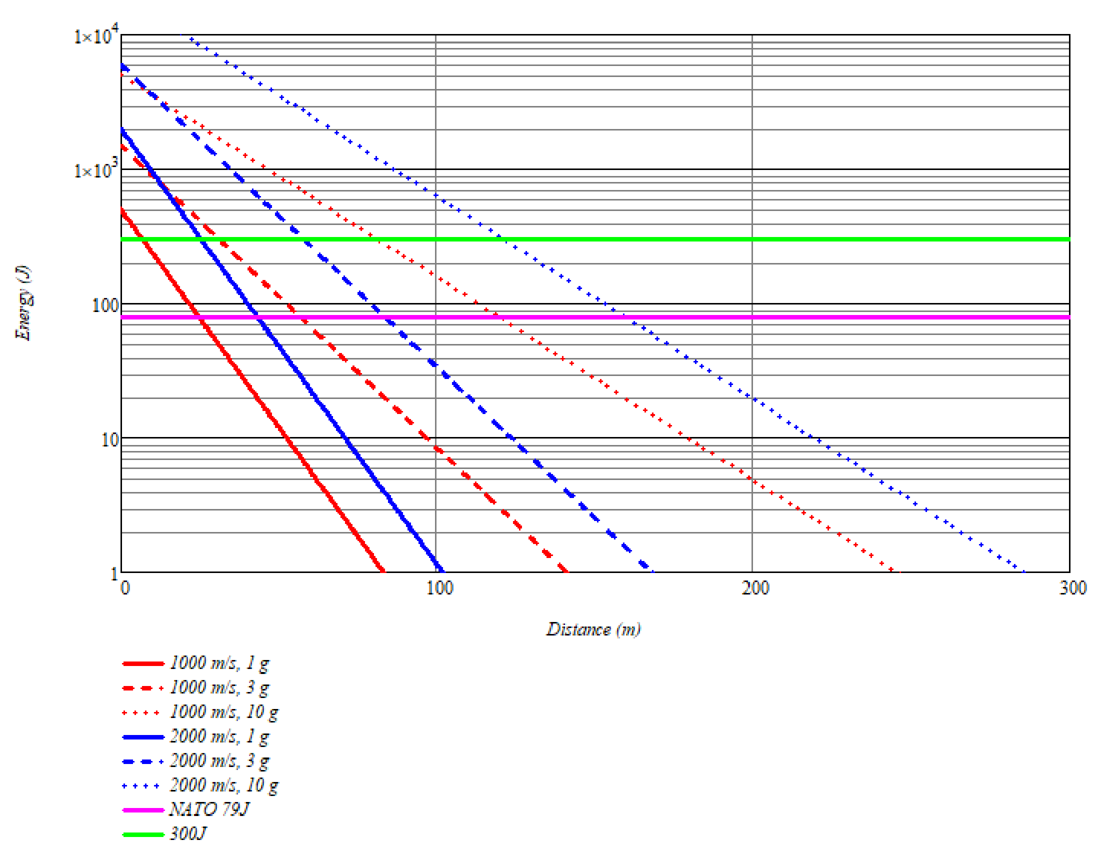






Comparison of injury models (Swiss versus TARVAC)

- **The Swiss blunt impact model was selected for implementation into Risk-NL for all types of projectiles and masses**
- Realistic and otherwise conservative for most cases
- Slight concern with penetration lethality of 1 and 3 g fragments was investigated
- Impact energy for 3 g steel fragments is only above 79J for distances below 50 to 80 m
- However, due to the many lethality mechanisms that play a role at such short distances (e.g. multiple hits, blast and thermal injuries) the overall probability of lethality is typically already close to 100%, and the proposed approach will not lead to underestimation of risk

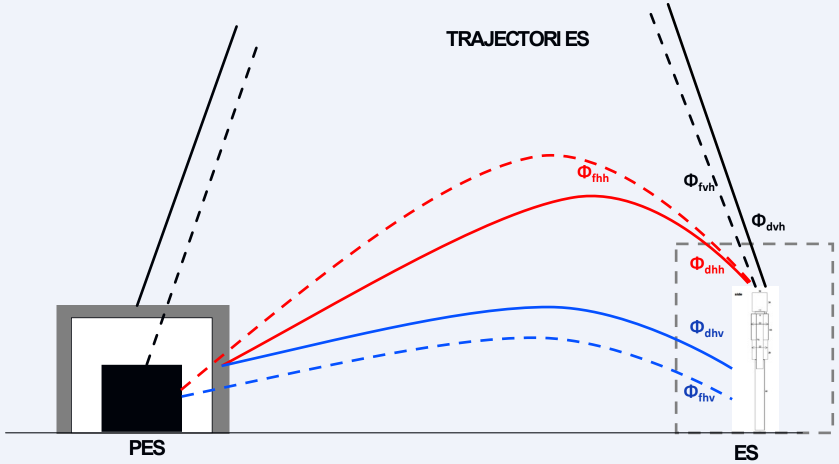


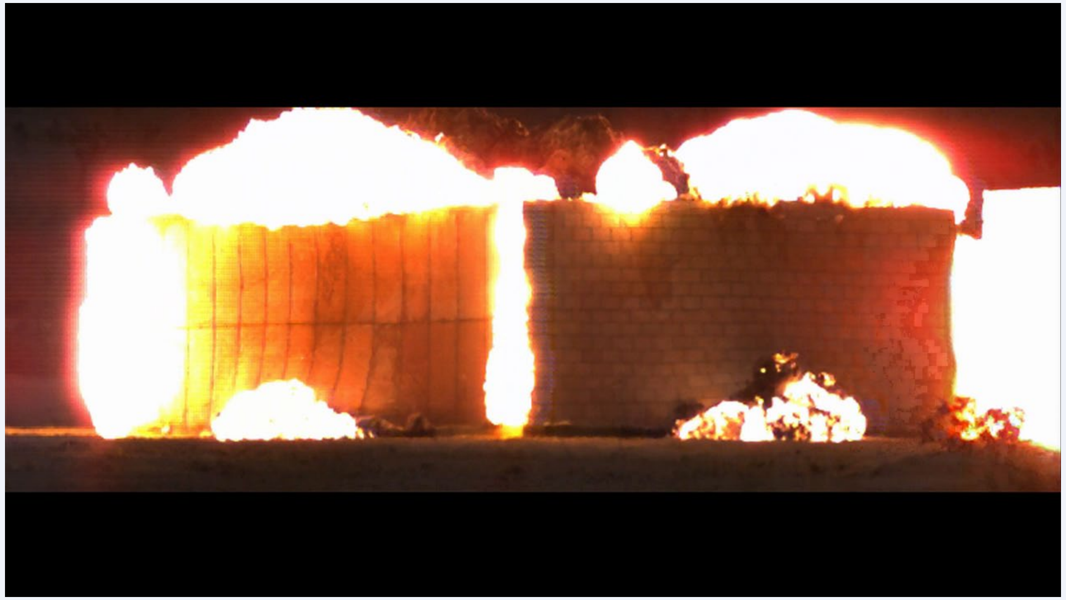
Number of hits and overall probability of lethality

- Previous slides are for a given **single hit**
- Number of hits (n) at body is a **Poisson process**

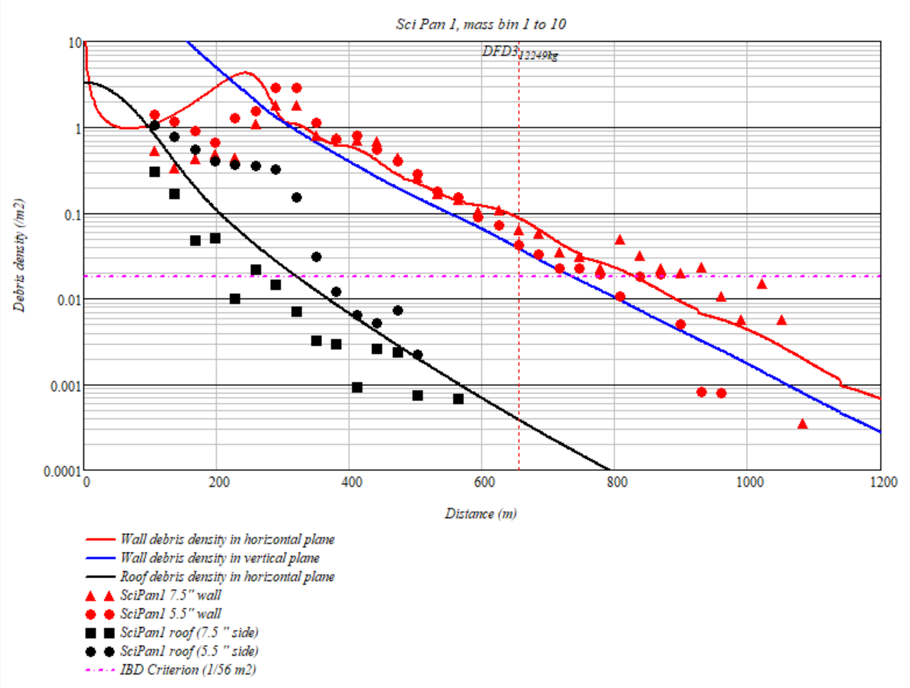
$$P_{hit}(n) = \frac{(\Phi \cdot A)^n \cdot e^{-\Phi \cdot A}}{n!}$$

- Poisson rate parameter $\Phi \cdot A$
- projectile density Φ, Area A





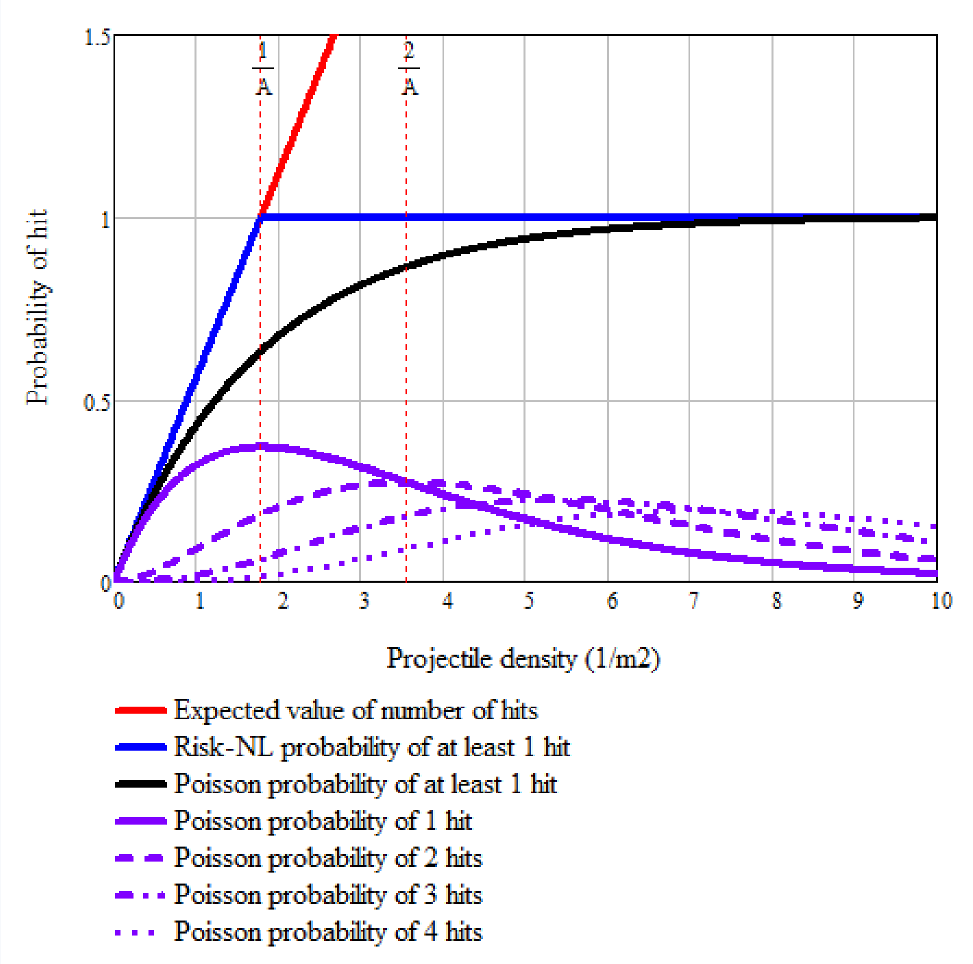
Sci pan 1 test



Number of hits and overall probability of lethality

- Poisson distribution enables calculation of
  - Probability of 0 hit, 1 hit, 2 hits, 3 hits, etc… at different body parts
  - This can be multiplied with subsequent probability of lethality after receiving those hits
  - Due to the enormous amount of possible outcomes, this approach is not considered feasible.
  - The limitation is not in the mathematics, but more so in the required effort and the knowledge gap in the medical field.
  - The paper discusses an approximation which works well

$$P_{let,tot} = 1 - e^{-\Phi \cdot A \cdot P_{let}}$$

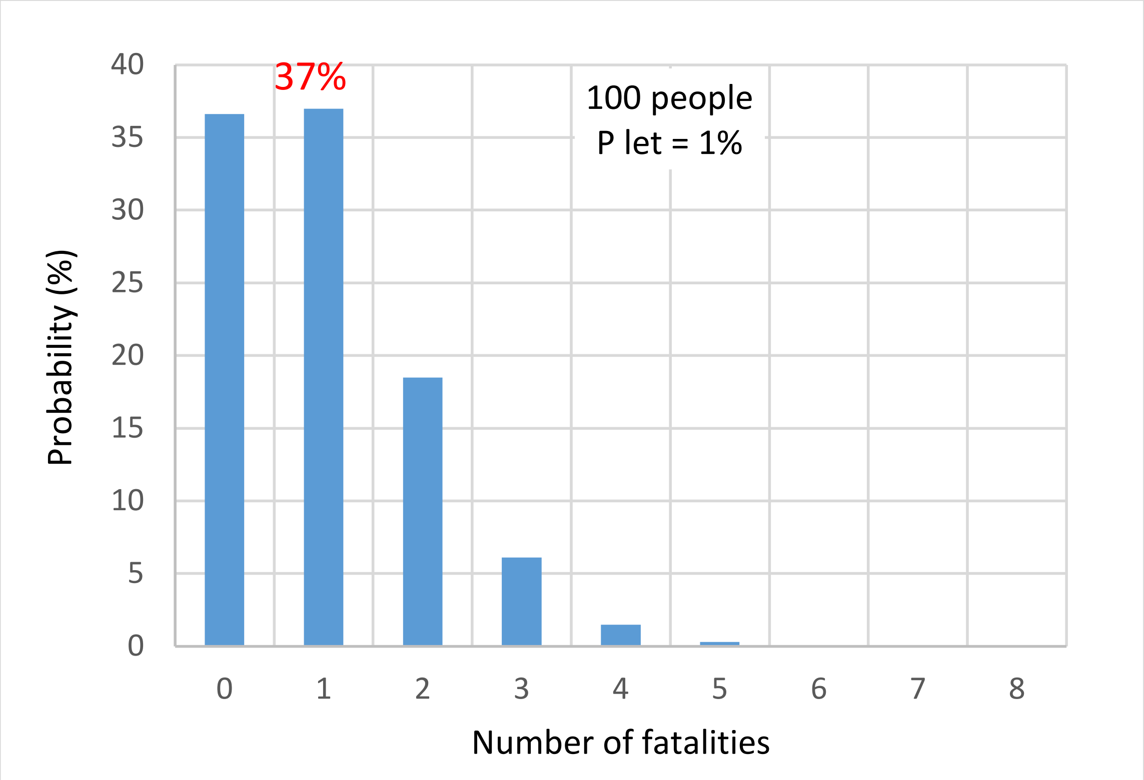


Number of fatalities in a group

Question:

- At a certain location the probability of lethality is 1%
- 100 people are present at this location
- What is the most likely number of kills?
- And what is the chance that this number occurs?
- The outcome may surprise you!

Binomial distribution

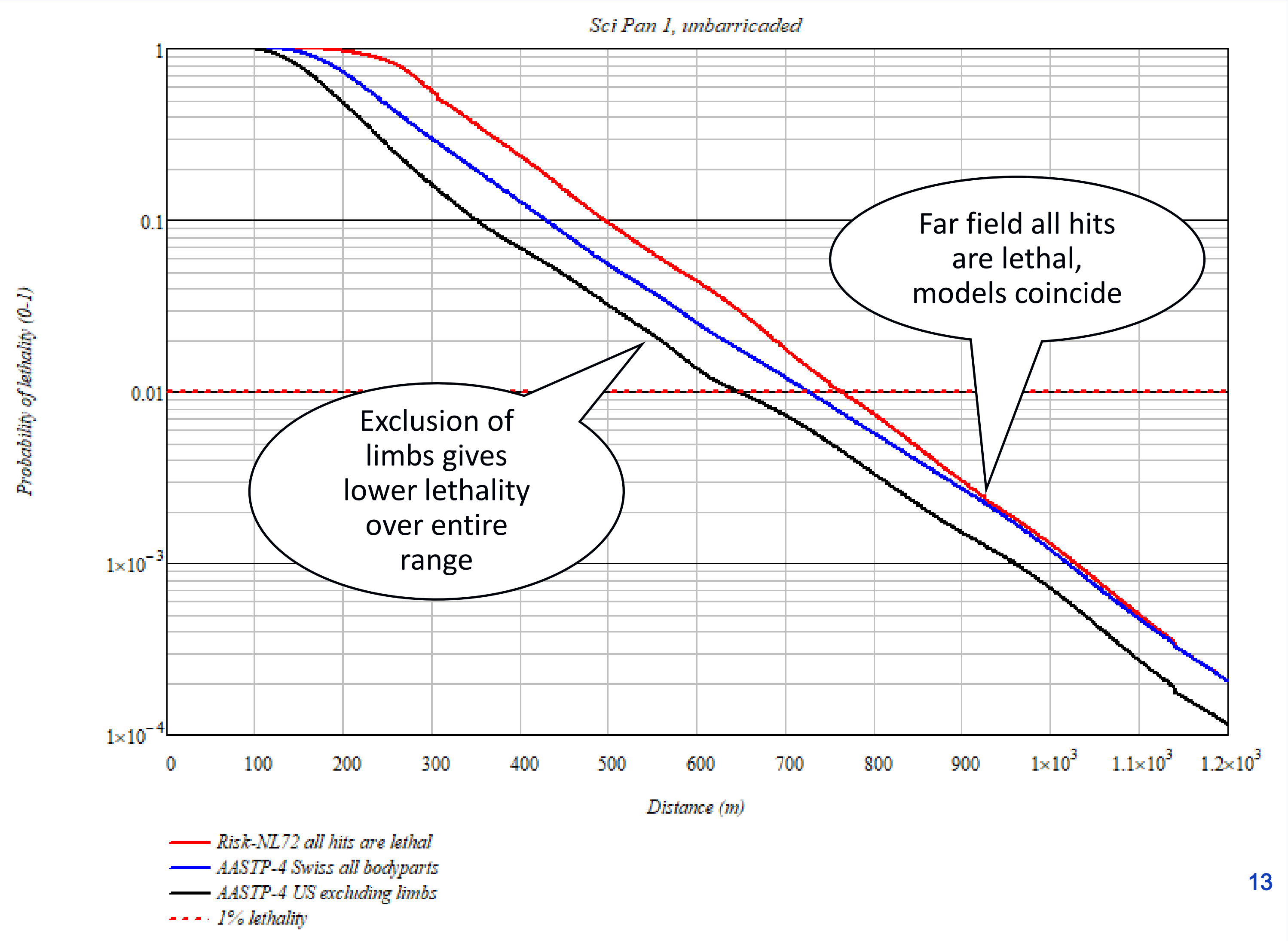


Impact studies

Comparison between:

- The current assumption in Risk-NL (all hits are lethal)
- Swiss model
- US model = Swiss model excluding limbs

For Sci pan 1 test, unbarricaded situation



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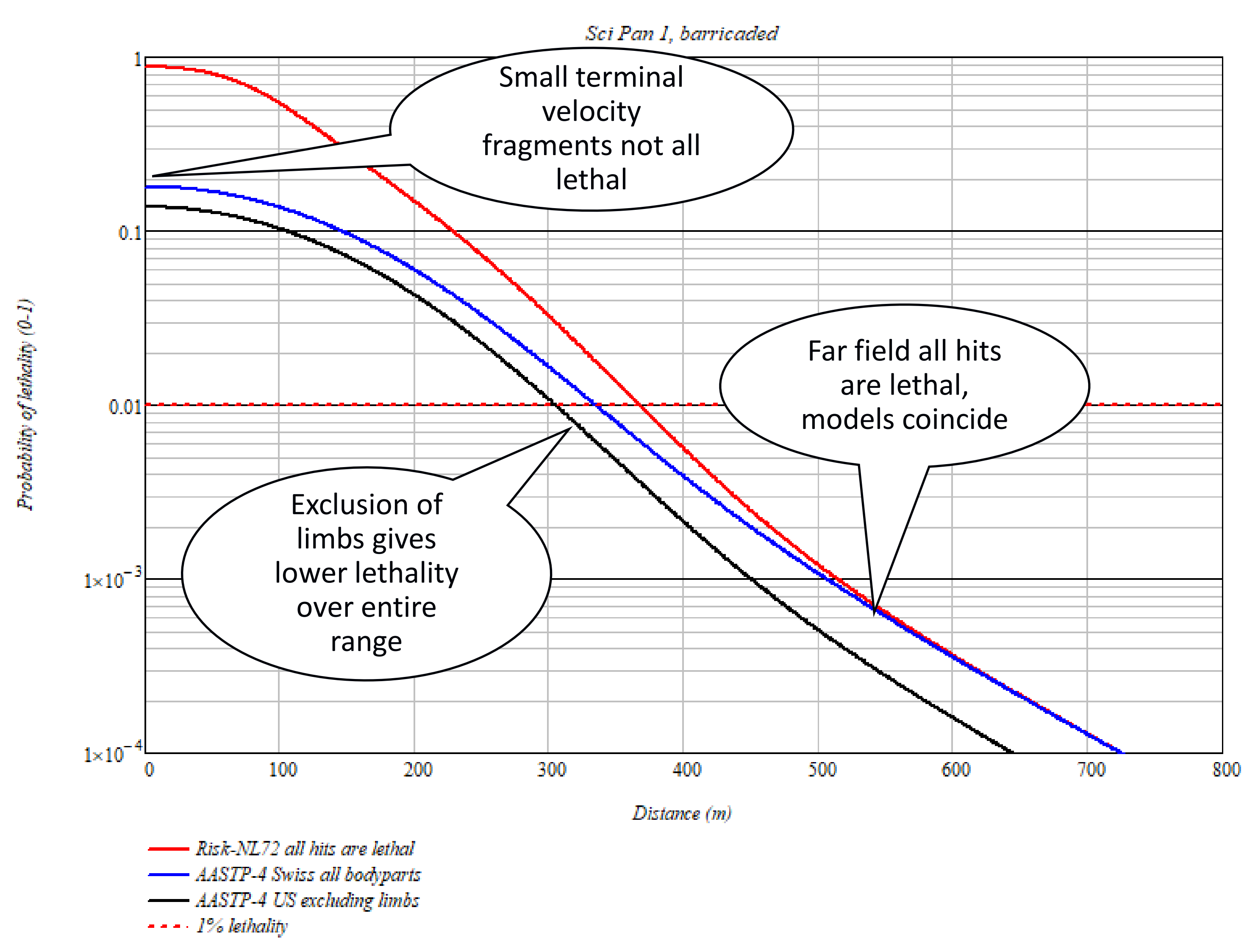
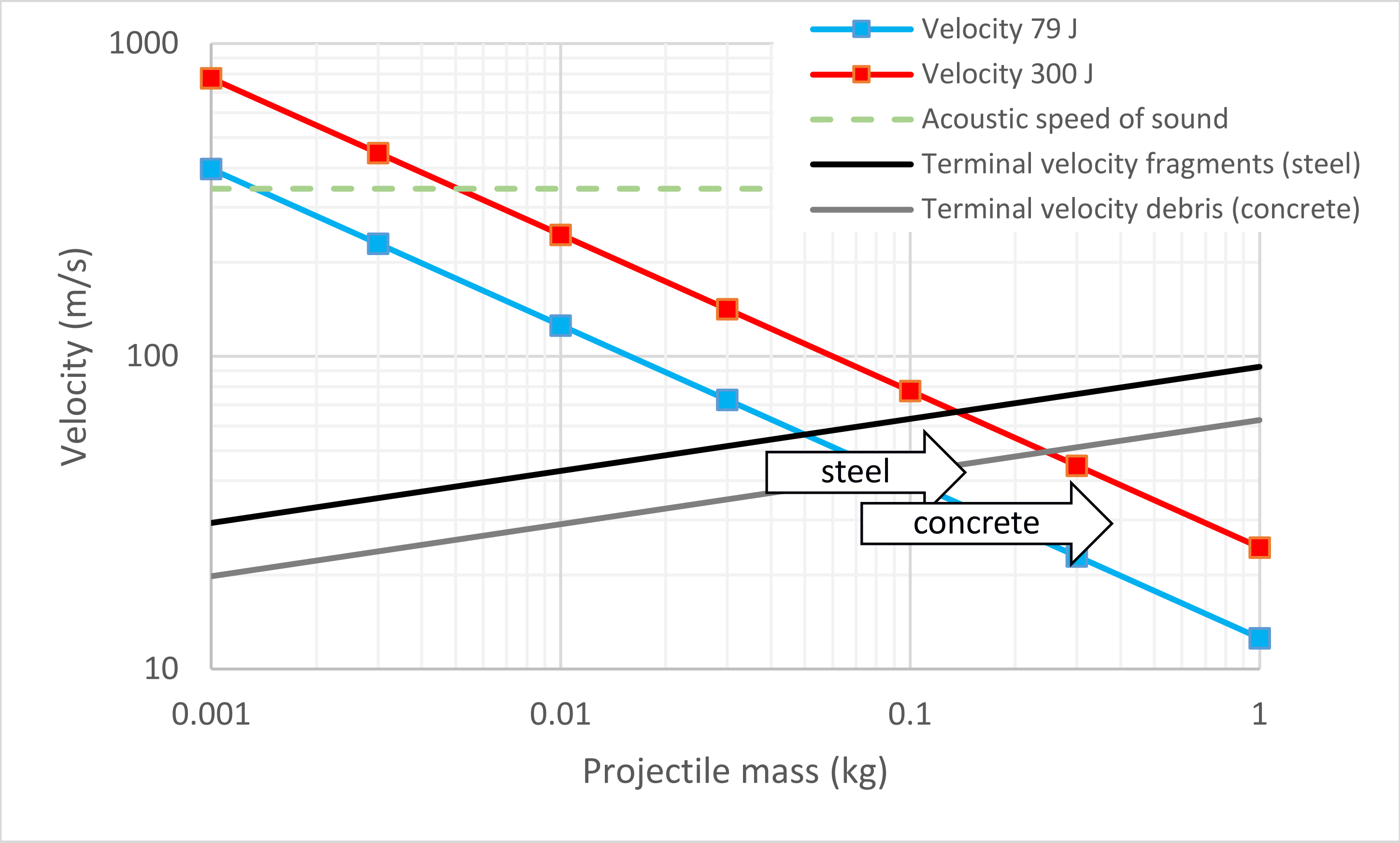


Implications for 79J hazardous projectile

- Possible injuries may span from the blunt impact regime to the penetration regime
- DFD is determined from pick-up data in explosives tests
- Minimum pick-up mass is determined with **terminal velocity** assumption
- >79J impact energy corresponds with
  - >50 g steel sphere
  - >90 g concrete sphere
- Terminal velocity assumption:
  - Valid in the far field
  - May not always be valid close-in
  - Small low angle projectiles can easily have higher velocities (and hence possibly also energies of 79J and larger)



Conclusions

- This paper has compared various blunt impact and penetration injury models.
- The Swiss blunt injury model was selected for implementation in Risk-NL for all types of projectiles and masses
  - Nearly always conservative when compared to penetration injury criteria
- A simplified approach was developed for multiple hits.
- An impact study shows that the new model(s):
  - Gives a smaller probability of lethality at short and mid-range.
  - Beyond the IBD, the differences disappear due to large projectiles which are always lethal

- This paper also sheds new light on the 79J hazardous fragment criterion
  - Possible injuries may span from the blunt impact regime to the penetration regime
  - With the IBD being based on minimum projectile masses that are derived from a terminal (free fall) velocity assumption, smaller but potentially lethal projectiles may be overlooked!

Questions?