A Comparison of the Quin Site Explosive Event Results to IMESAFR Consequence Predictions

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Introduction –
Quin Site: Authors' Connection

- UK Trials: explosion trials scheduled for Woomera, South Australia, in spring 2006
  - TNT charges for the events were stored at the Quin Site (Gladstone, South Australia) prior to shipment to Woomera
  - May 2006, an explosion occurred at the plant
    - One of the TNT charges burned
    - As a result, one US trial postponed until 2007
- Trial conducted in Woomera in April 2007; after event, two of the authors were invited to visit site
  - Site visit not as part of formal investigation
  - Visit to obtain data for comparison with QRA models

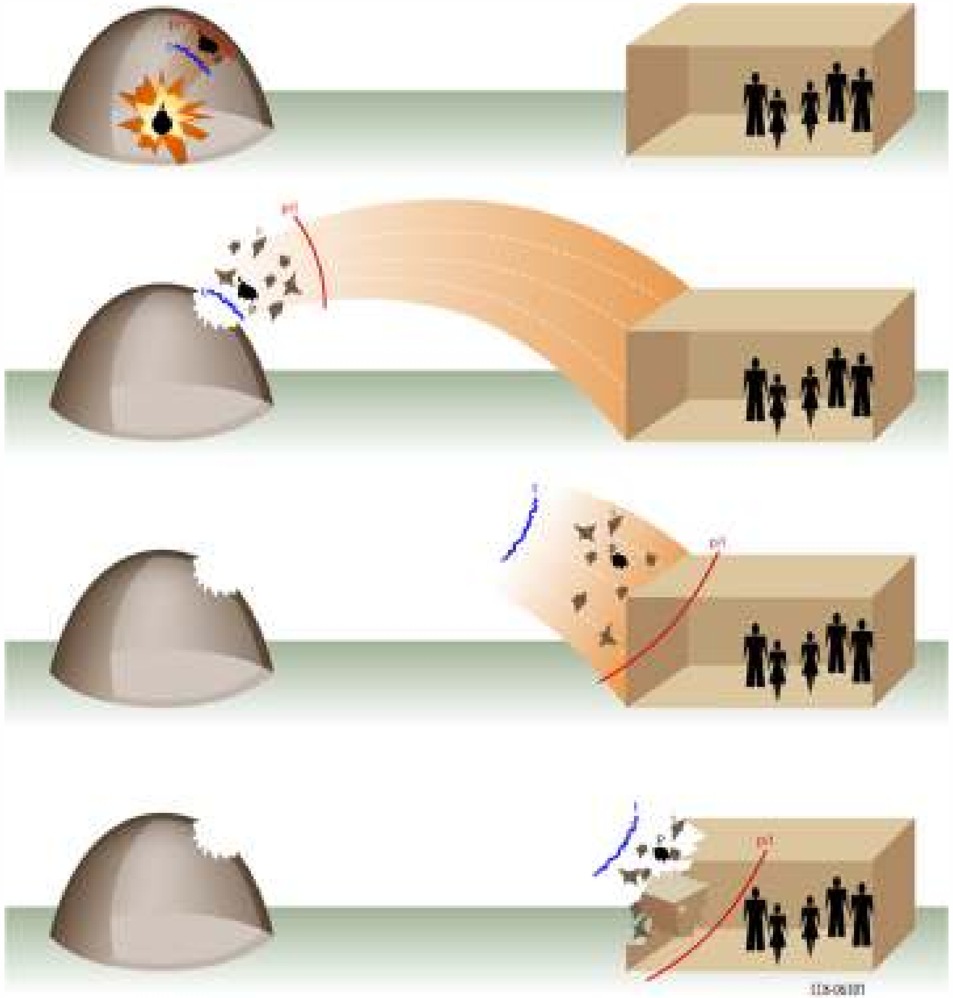
Introduction – Quantitative Risk Assessment Models

- What is a QRA model?
  - A Quantitative Risk Assessment (QRA) model generates numerical values for risk by considering all pertinent elements of the scenario.
  - Risk = Probability of the Event (P_e) x Consequence ($P_{f|e}$) x Exposure (E)
- Have explosives safety software QRA models been developed?
  - In the US, the Department of Defense has been developing **SAFER**. IME has now released a new software tool, **IMESAFR**, which has been tailored for the commercial explosives industry.
- What is the relationship between **SAFER** and **IMESAFR**?
  - The programs are independent of each other, but the sponsors maintain communication, cooperate on testing and algorithm development, and share lessons learned.
- What is the basis of the method used to calculate the risk?
  - **IMESAFR** is a semi-empirical model. The availability of applicable test data is a key component of such a tool. Without enough supporting data, the model must trend towards conservatism.

Introduction – IMESAFR: The Fundamental Math

- Risk =
  - Probability x Consequences
- Consequences =
  - Physical Effects x Exposure

- Physical Effects
  - Pressure and Impulse
    - Whole Body Displacement
    - Lung Rupture
    - Skull Fracture
  - Structural Response
    - Glass
    - Building Failure
  - Debris
    - Primary Fragments
    - Secondary Debris
    - Crater Ejecta
  - Thermal



Introduction – Consequence Modeling

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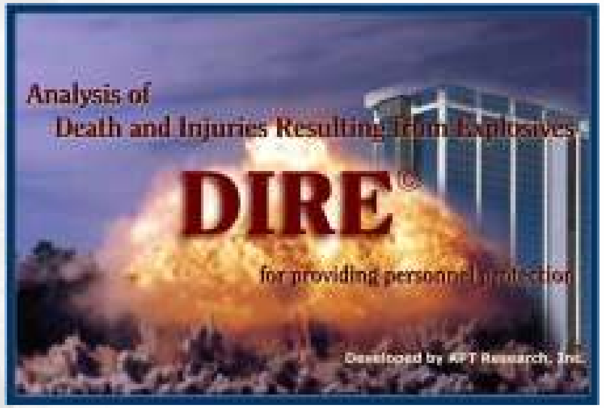
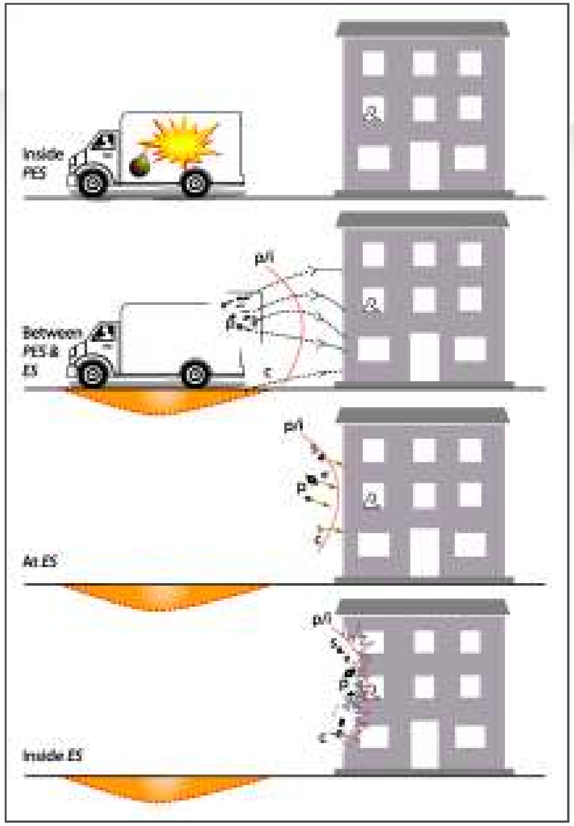
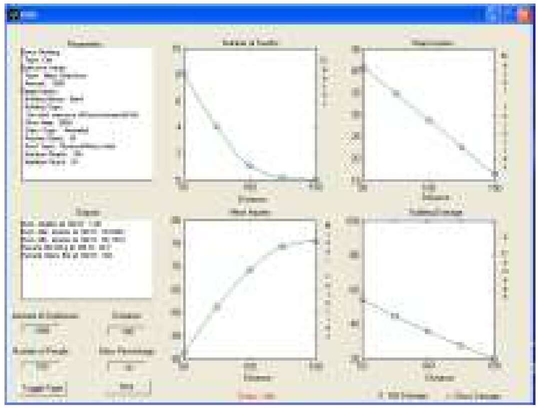


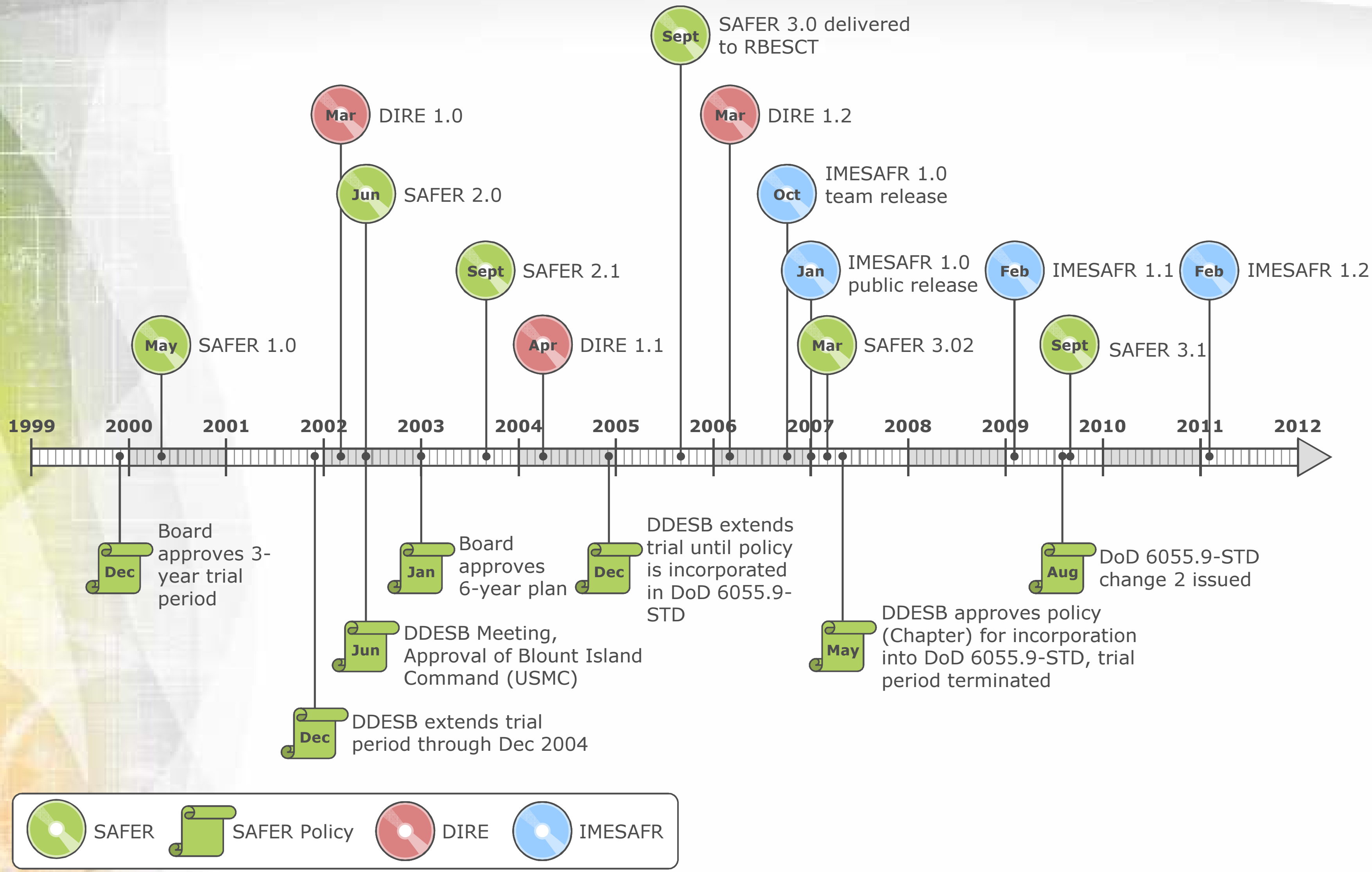
p/i	pressure/impulse
p	primary fragments
s	secondary fragments
e	ES fragments
c	crater ejecta



- Death and Injuries Resulting from Explosives (DIRE)
- Graphically depicts the predicted consequences as a function of range
- Consequences considered
  - Direct blast
    - Skull Fracture
    - Lung Rupture
    - Whole Body displacement
  - Debris
  - Structural Response (including glass hazards)
- Does not consider barricades



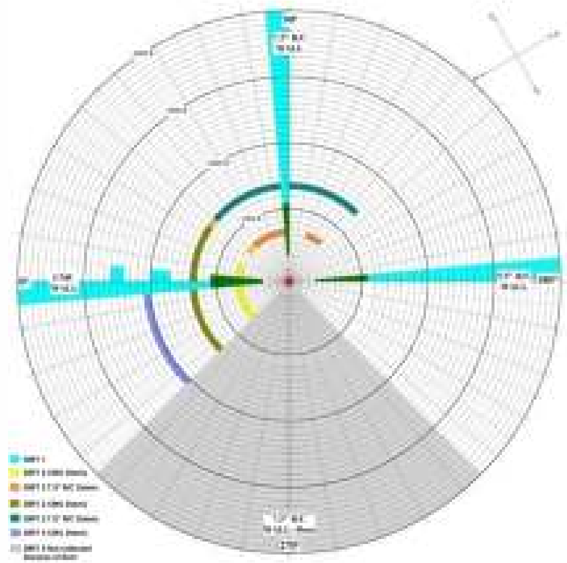
Introduction – Software Timeline



Comparison to Other Data – Summary

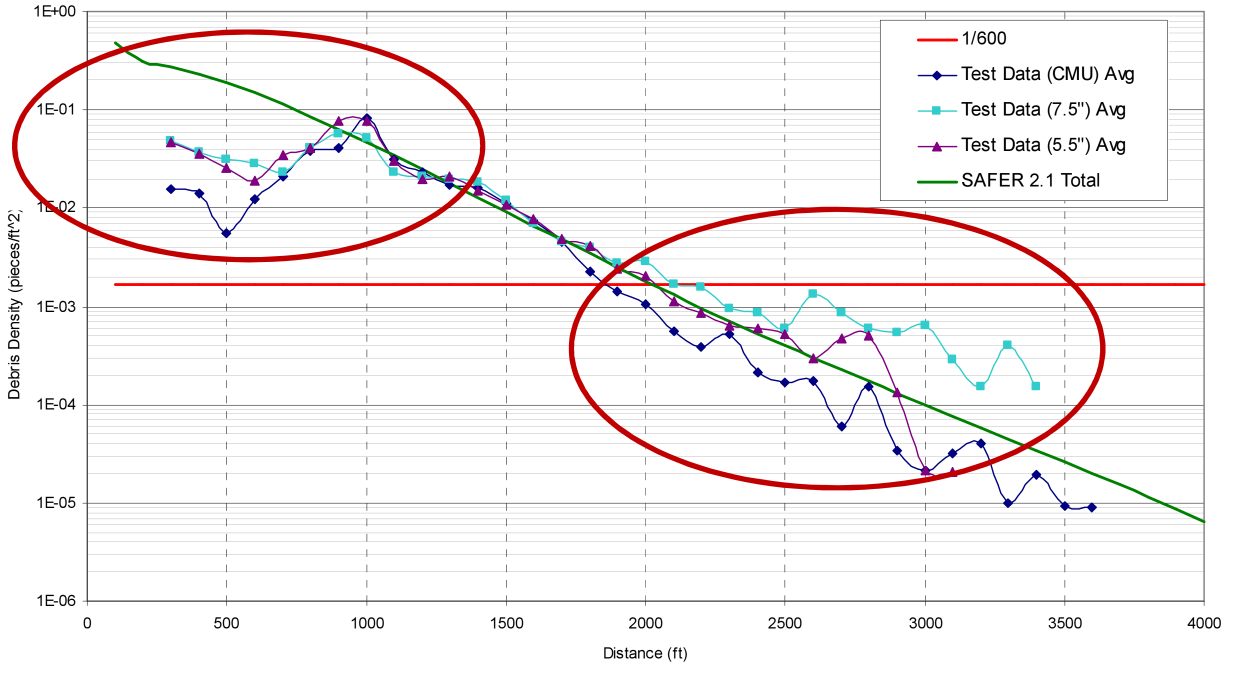
- The QRA models have been compared against test results
  - SAFER versus SciPan 1
  - IMESAFR versus ISO-1
- IMESAFR and DIRE have been compared against accident data (Assheton)
- DIRE has been compared against terrorist event data
  - DIRE versus Oklahoma City
  - DIRE versus Khobar Towers
- SAFER and other NATO models have been compared against test data (40 Tonne Trial)

Comparison to Other Data - SciPan 1



SAFER/SciPan 1
Debris Density Comparison

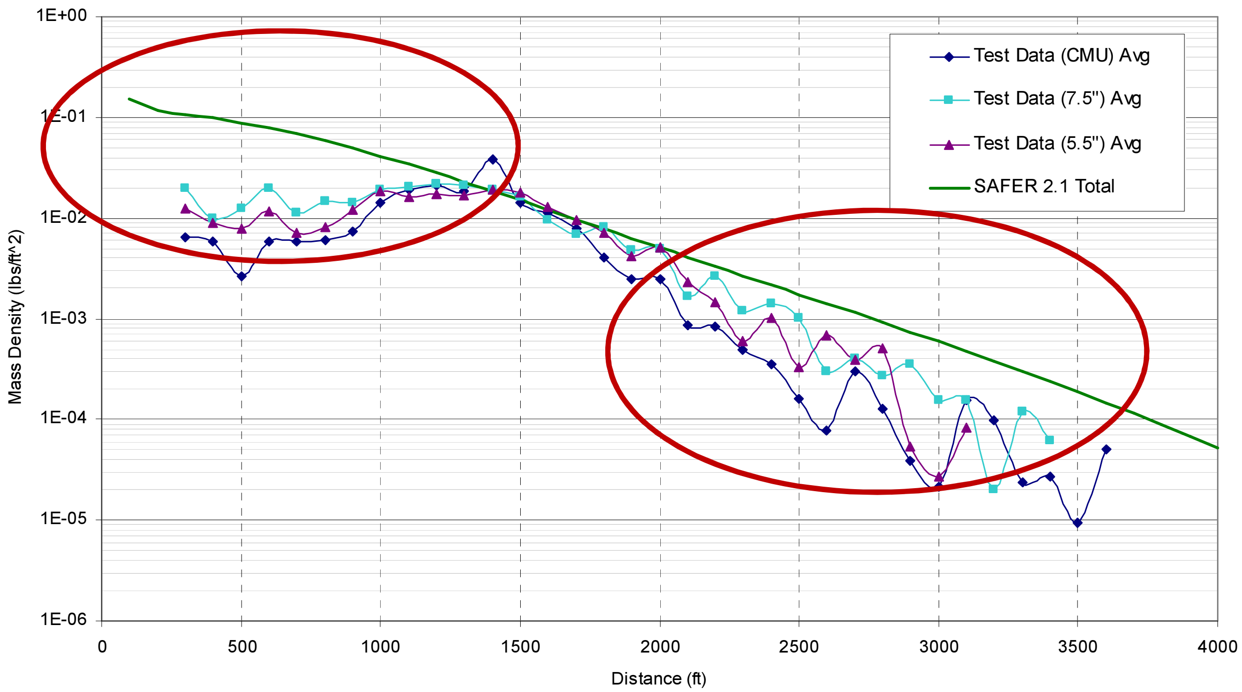
Plot shows average test results for lethal debris density compared against the SAFER prediction.



Comparison shows apparent over-prediction at close range and under-prediction farther out.

SAFER/SciPan 1
Mass Density Comparison

This plot shows the mass density compared against the SAFER prediction

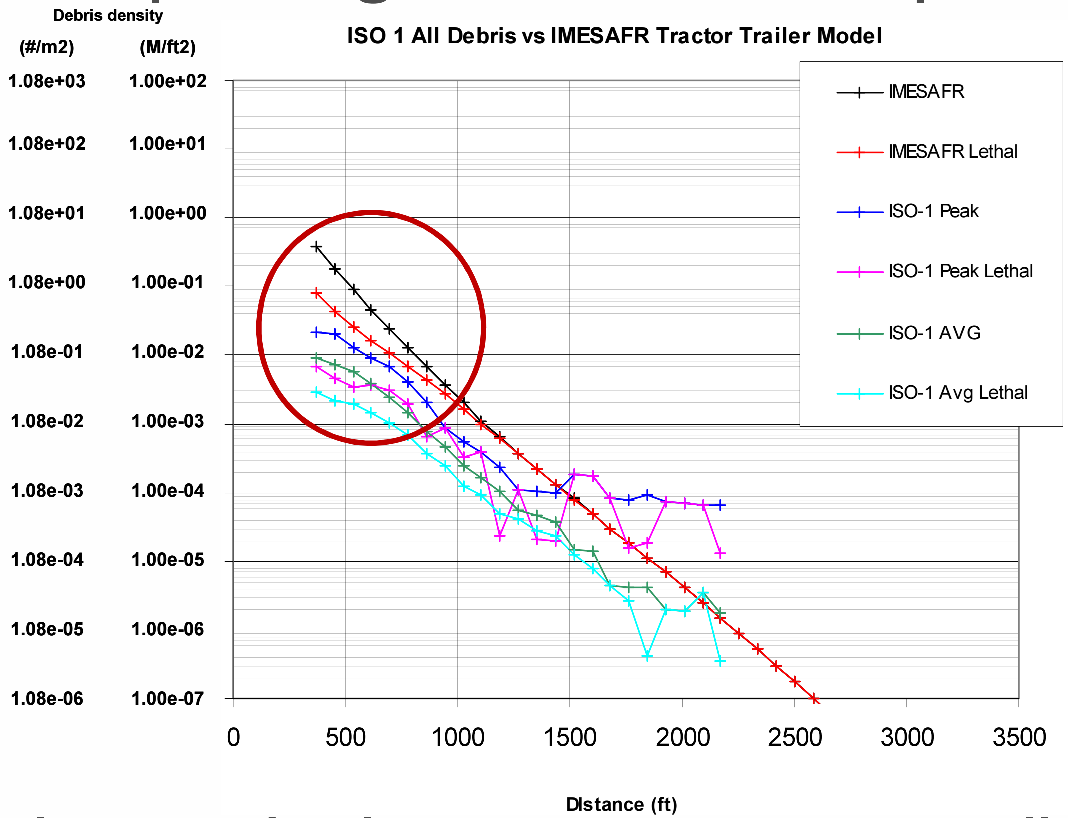


This comparison shows over-prediction at close range is an issue, but the under-prediction may not be (possibly due to shatter of debris at impact)

Comparison to Other Data - ISO-1

IMESAFR/ISO-1 Comparison

Plot shows average and peak test results for debris density compared against the IMESAFR prediction.



Comparison again shows apparent over-prediction at close range (this time for metal debris).

Comparison to Other Data - Assheton Data

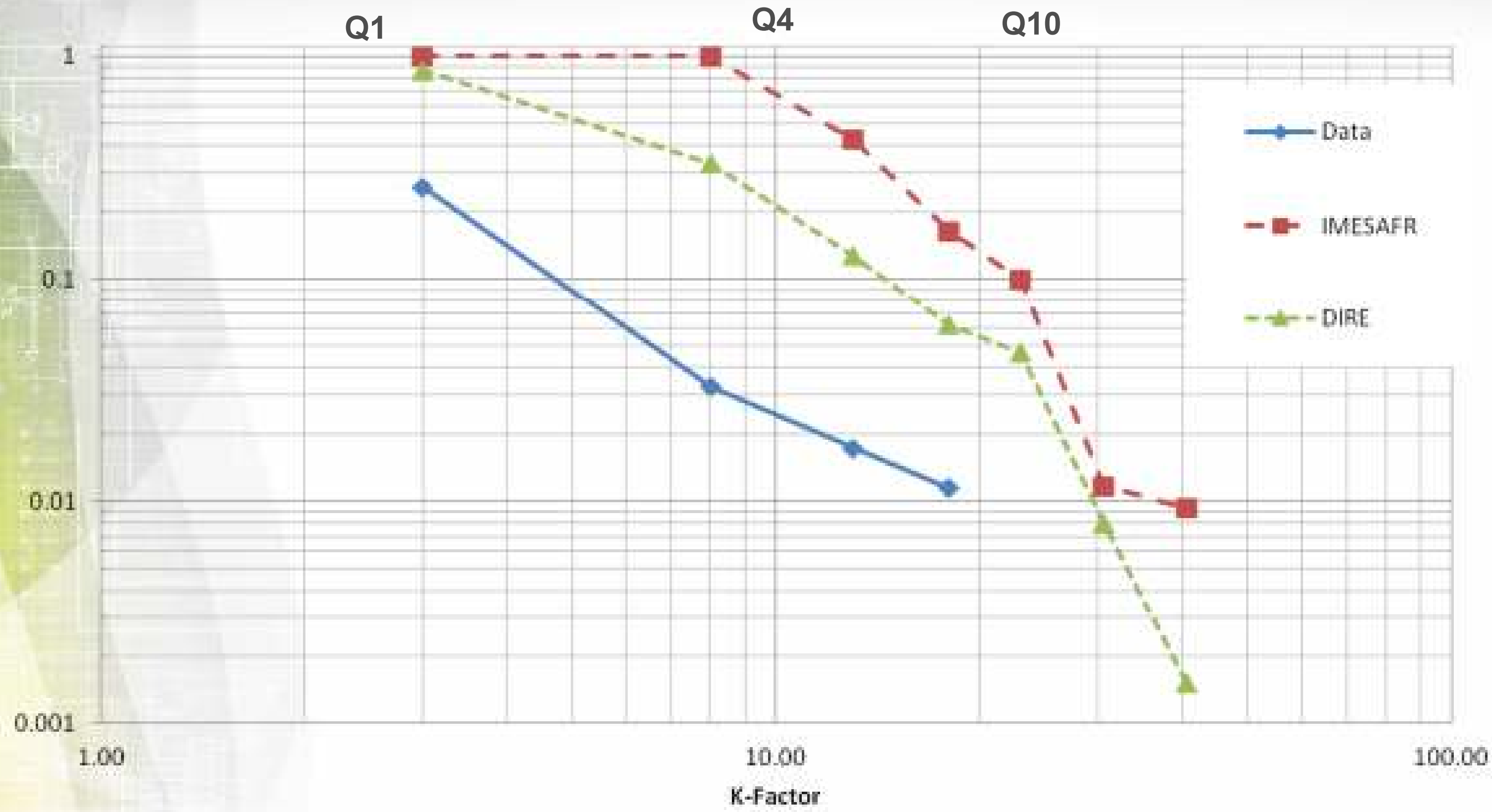
- Assheton study of nearly 100 accidents from early 1900s in the US commercial explosives industry
- Original study ignored number of people in ES
- New goal: correlate consequences to K-factor of each exposure

$$\text{Distance} = K \times NEW^{1/3}$$
$$K = \text{Distance} \div NEW^{1/3}$$

- Created bins for ranges of K-factors in English units (ft/lb$^{1/3}$)
- Calculated consequences for all 500+ exposures within bins

K-factor Bin	Q-factor Bin
1-5	0.4-2
6-10	2.4-4
10-15	4-6
16-20	6.3-8
21-25	8.3-10
26-35	10.3-14
36-45	14-18
46+	18+

Assheton Comparison:
Probability of Fatality (not open cases)



- IMESAFR predictions conservative, particularly at close ranges
- DIRE also conservative, but less so
- Conservatism less dramatic at K24-K40

Comparison to Other Data - DIRE/Oklahoma City

Murrah Building		
Item	**DIRE Output**	**Actual Observation**
Number of Deaths	185.6	163
Number of Major Injuries	117	50
Number of Minor Injuries	58.4	106

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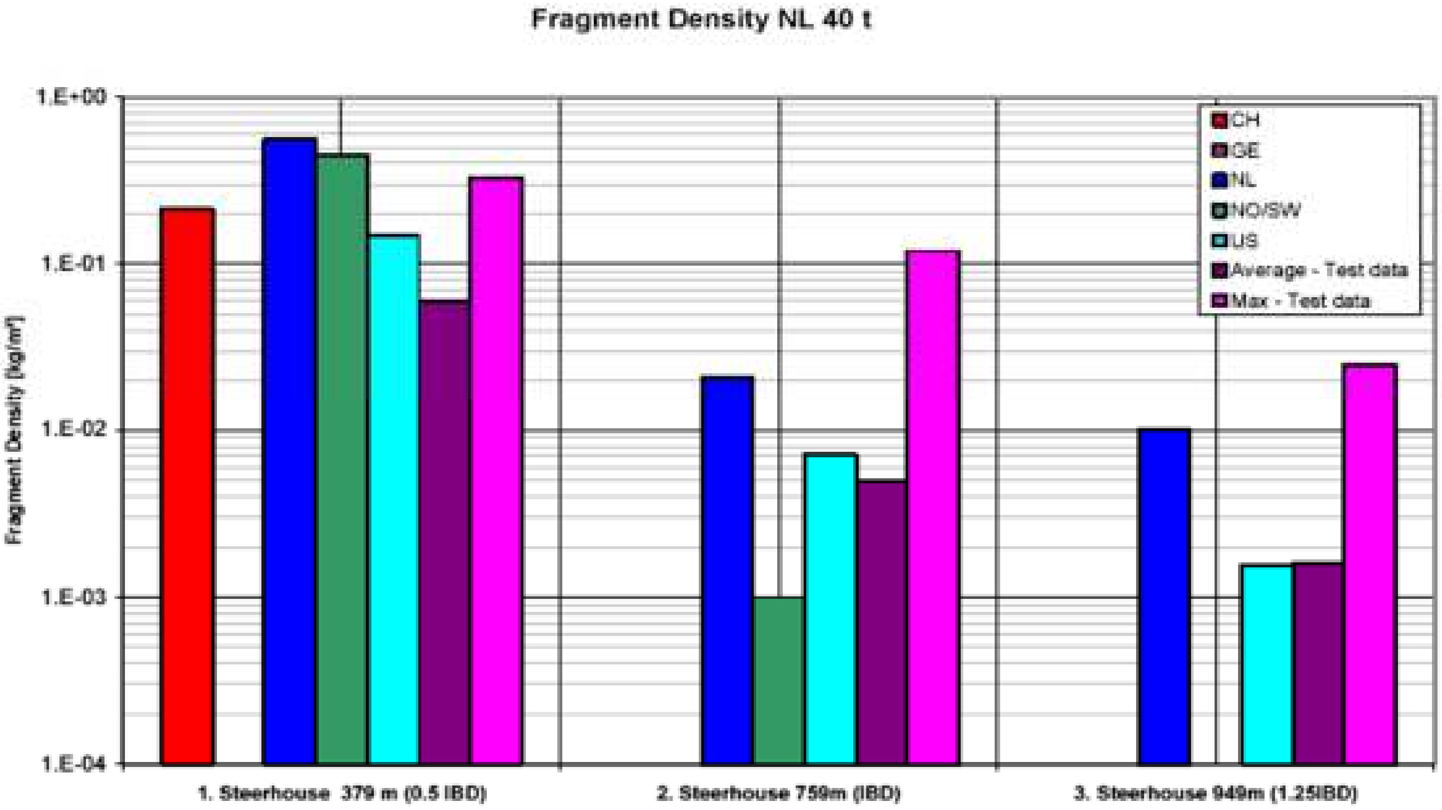
Comparison to Other Data - DIRE/Khobar Towers

Building #131		
Item	**DIRE Output**	**Actual Observation**
Number of Deaths	17.5	18
Number of Major Injuries	22.4	12-16
Number of Minor Injuries	3.1	Undetermined

Building #133		
Item	**DIRE Output**	**Actual Observation**
Number of Deaths	1.6	1
Number of Major Injuries	14.1	9-11
Number of Minor Injuries	35.3	Undetermined

Comparison to Other Data – NATO Models/40-Tonne Trial

Comparison to Other Data - SAFER/40-Tonne Trial



The Quin Accident Scenario

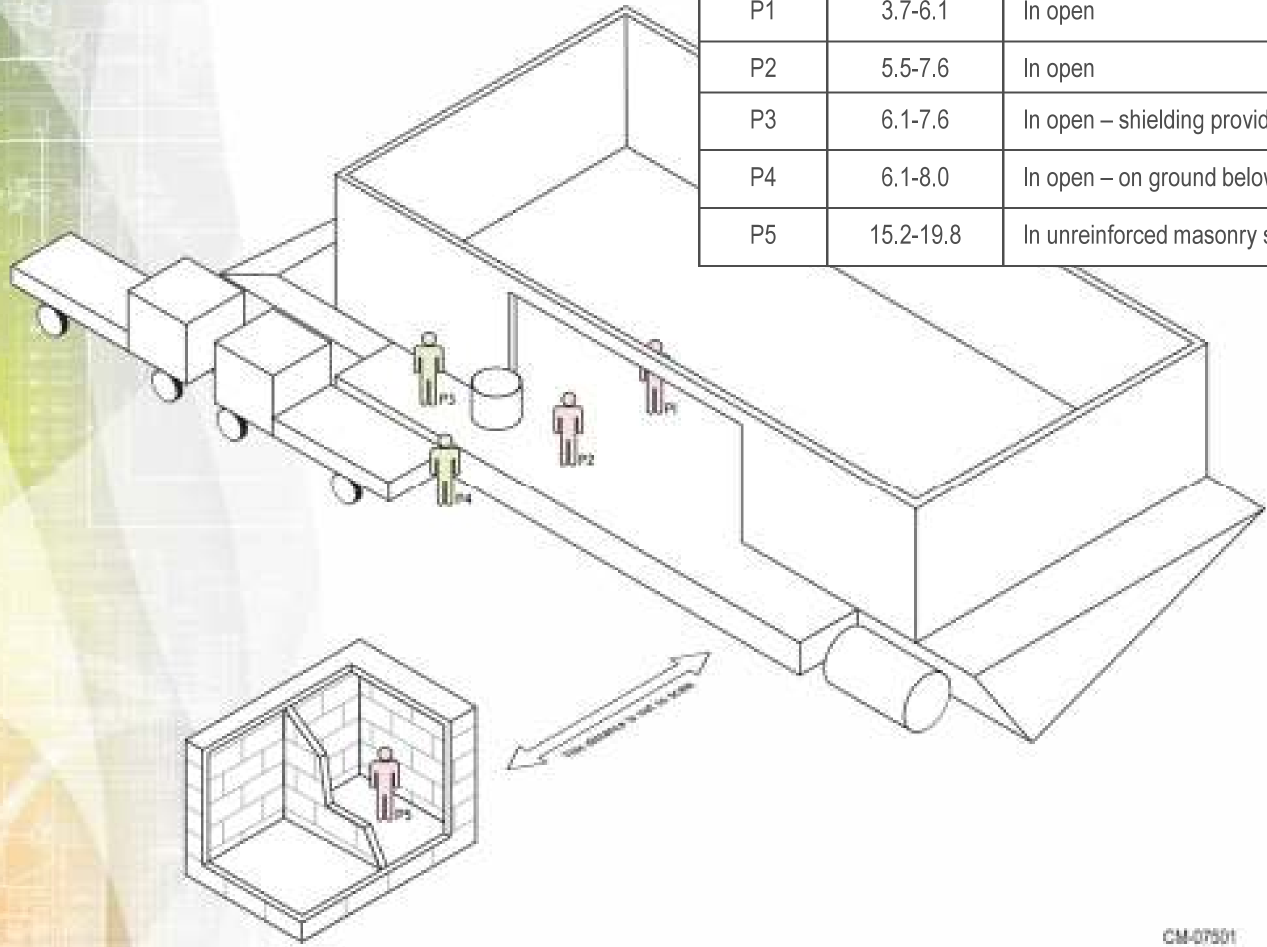
Quin Event Details

- Location: Watergel Plant, Quin Site, Gladstone, SA
- Exposure: 5 people present in immediate vicinity at the time of the explosion
  - Fatalities: 3
  - Survivors: 2
- Evidence suggests a detonation of the contents of the pre-mix hopper followed by fire
- Exact amount of material that detonated is unknown, but is estimated at about 1360 kg

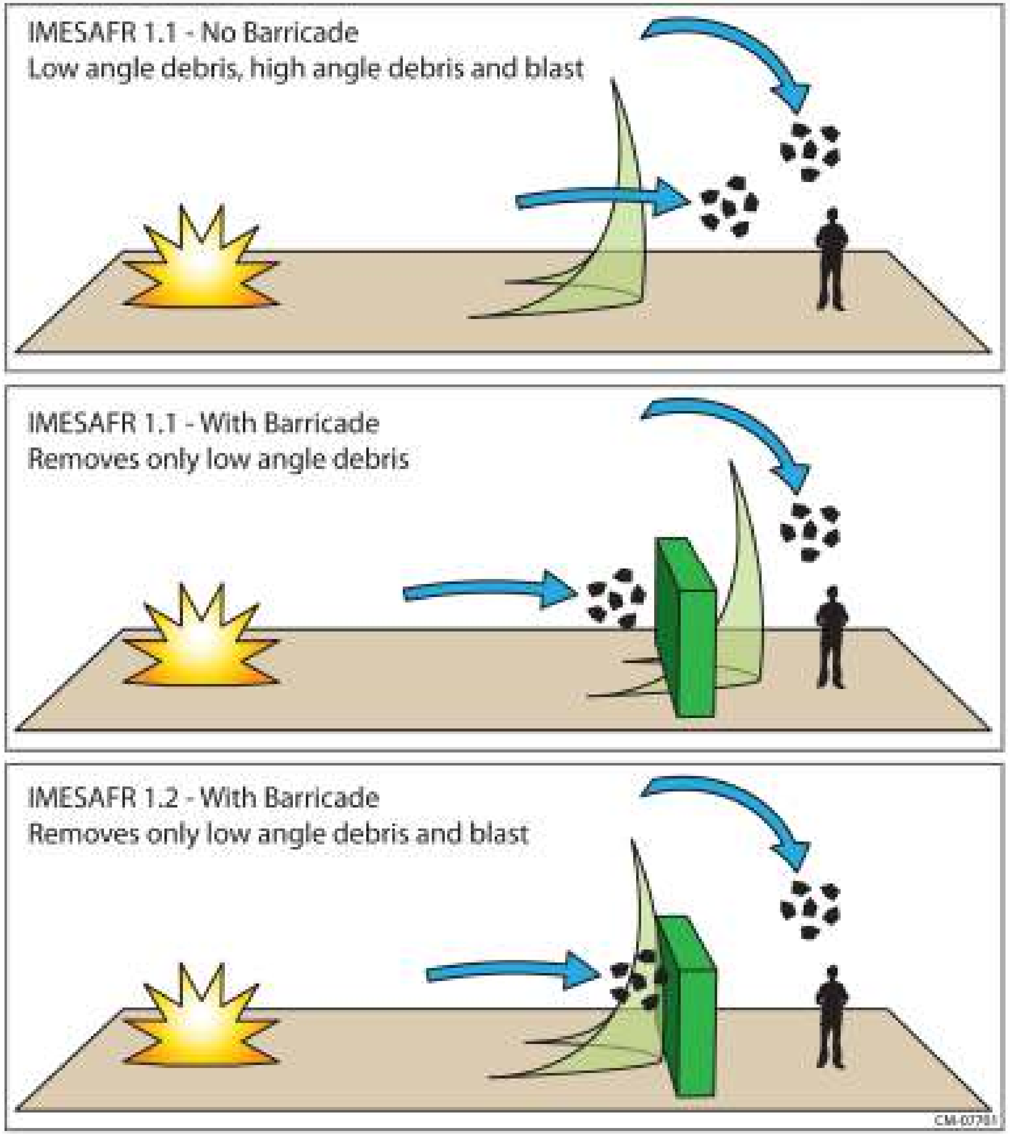
Post-Blast Aerial Photo

Estimated Personnel Locations (isometric view)

Person	Distance (m)	Description
P1	3.7-6.1	In open
P2	5.5-7.6	In open
P3	6.1-7.6	In open – shielding provided by material on loading dock
P4	6.1-8.0	In open – on ground below loading dock; shielding provided by dock
P5	15.2-19.8	In unreinforced masonry structure



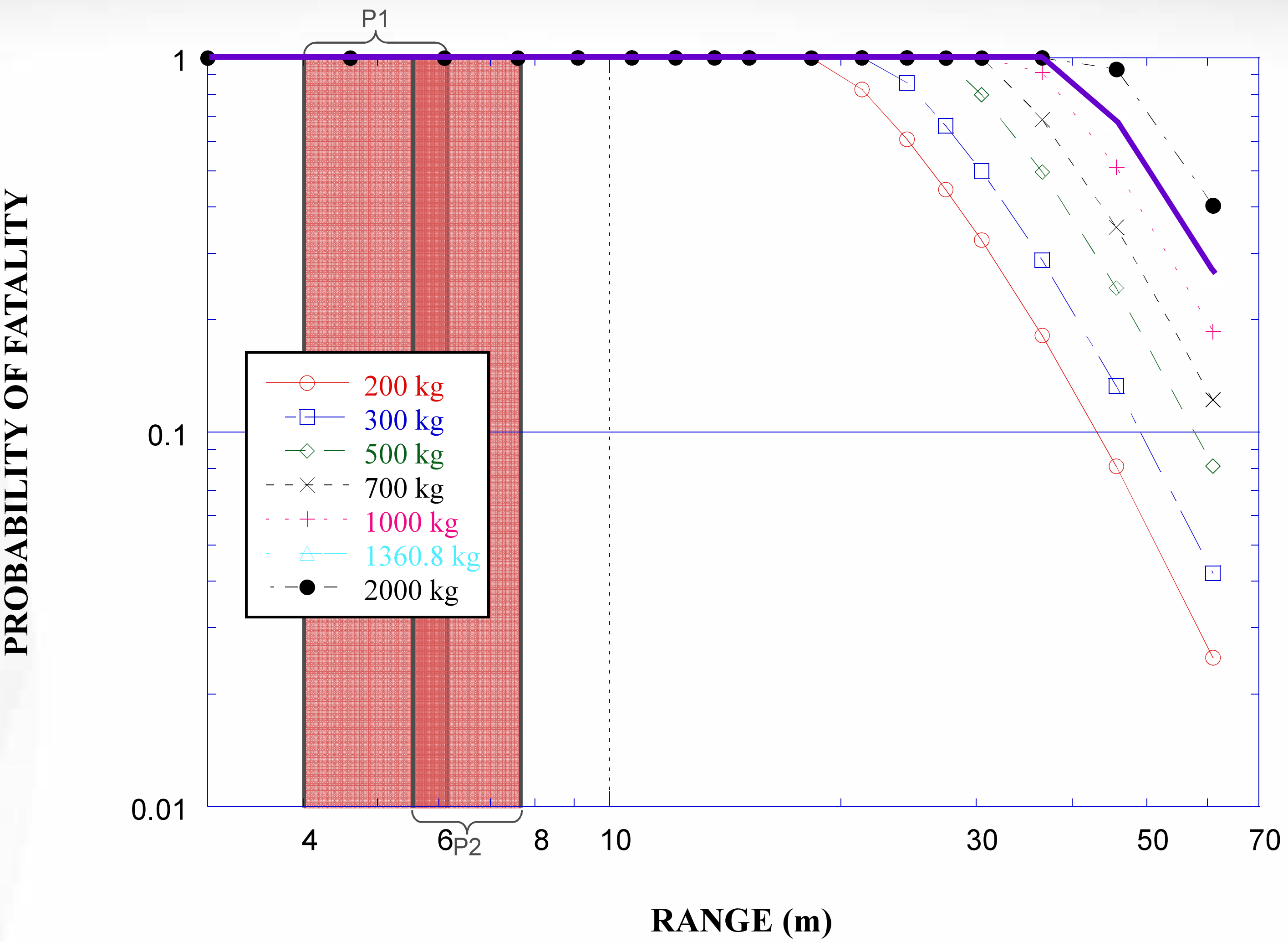
IMESAFR Modeling Options



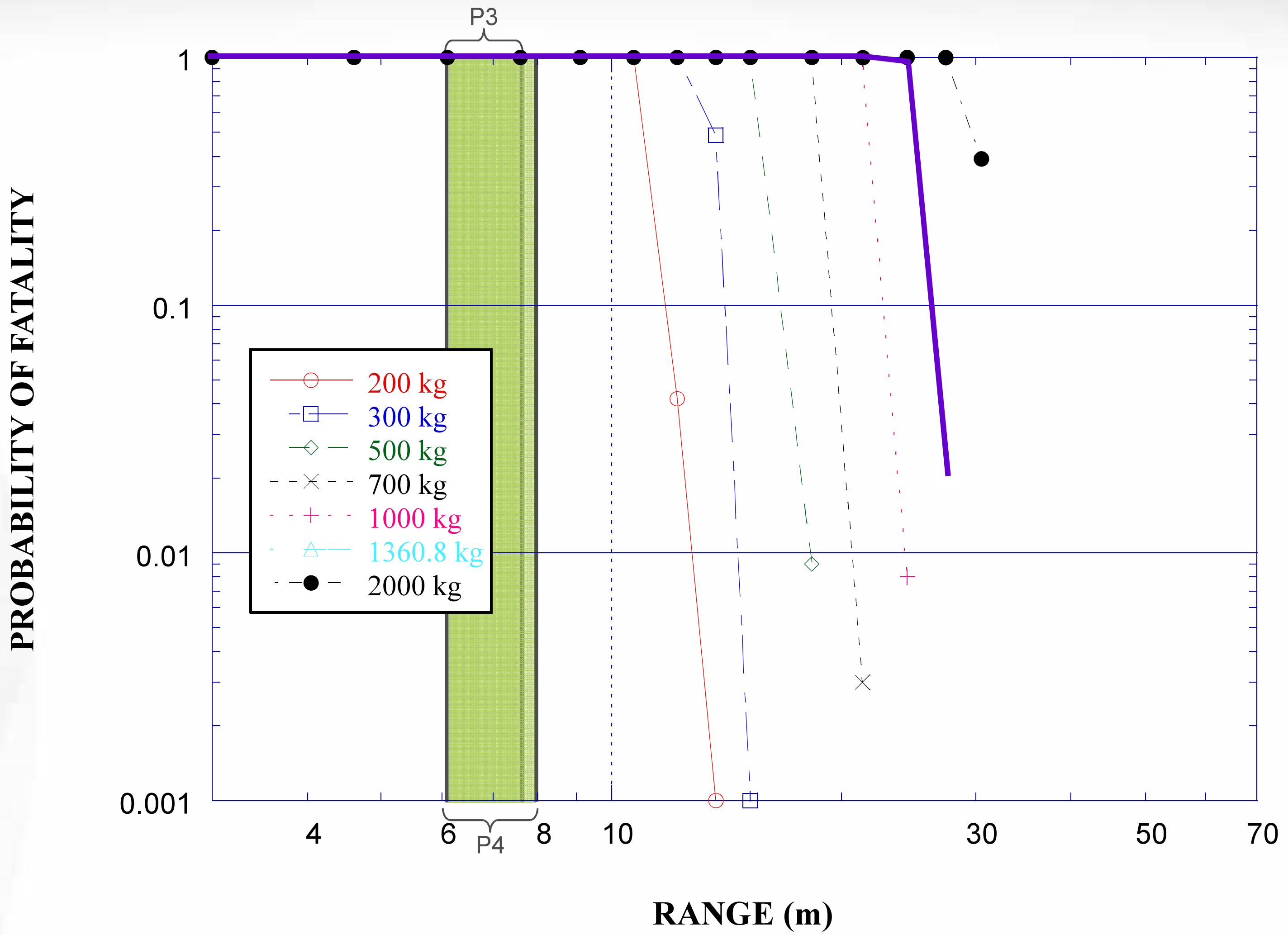
IMESAFR Modeling Selections

- Potential Explosion Site (PES): open
- Explosive Type: Hazard Division 1.1 material (boxes, bags, or bulk packaging)
- Soil type: concrete
- Exposed sites
  - P1, P2 (open ES)
  - P3, P4 (open ES with barricade)
  - P5 (unreinforced masonry)
    - 4.6 m^2 floor area
  - Distances varied between 1.5 and 61 meters for all sites
- Charge size varied

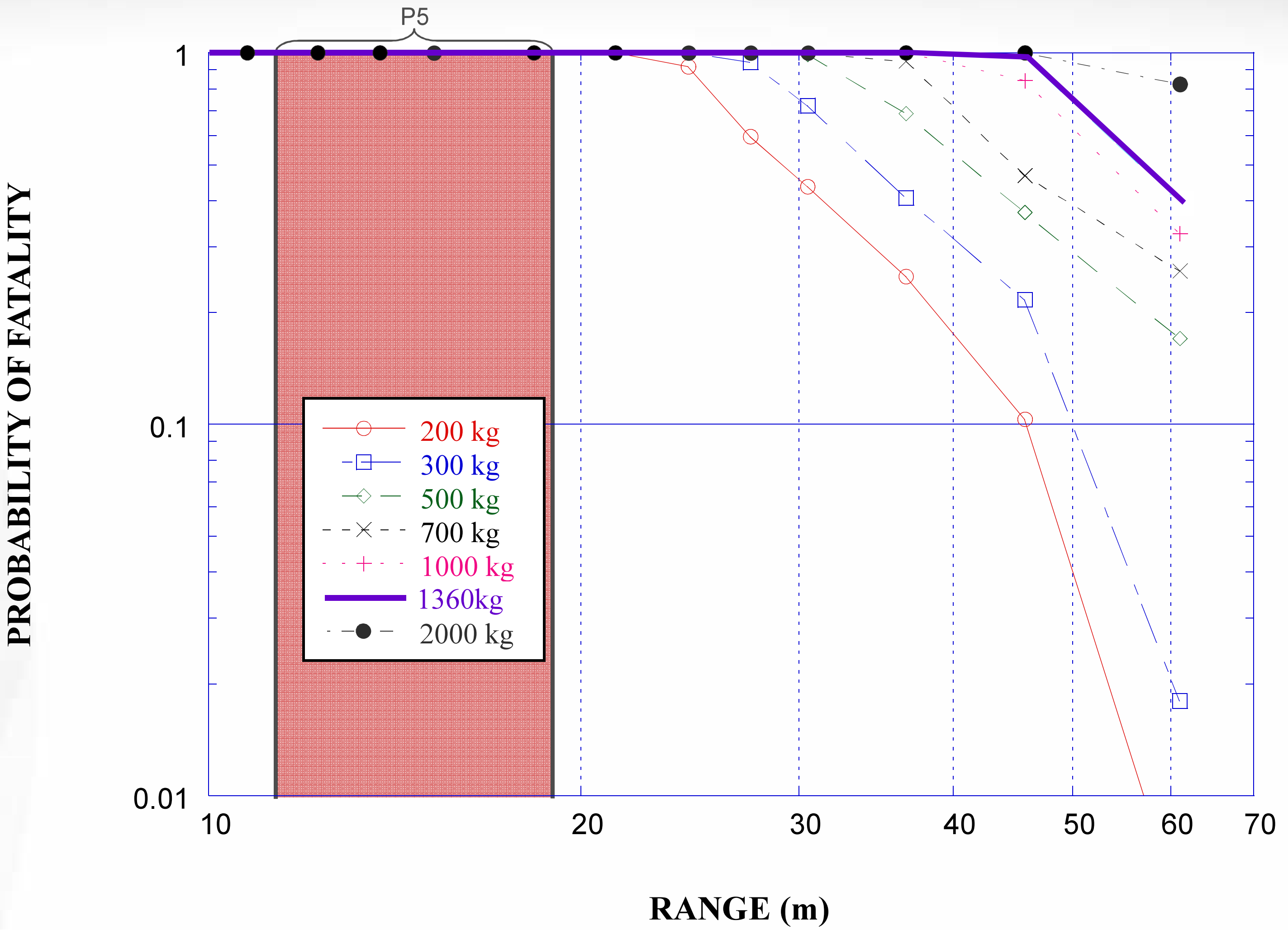
IMESAFR v1.1: Probability of Fatality Person in Open



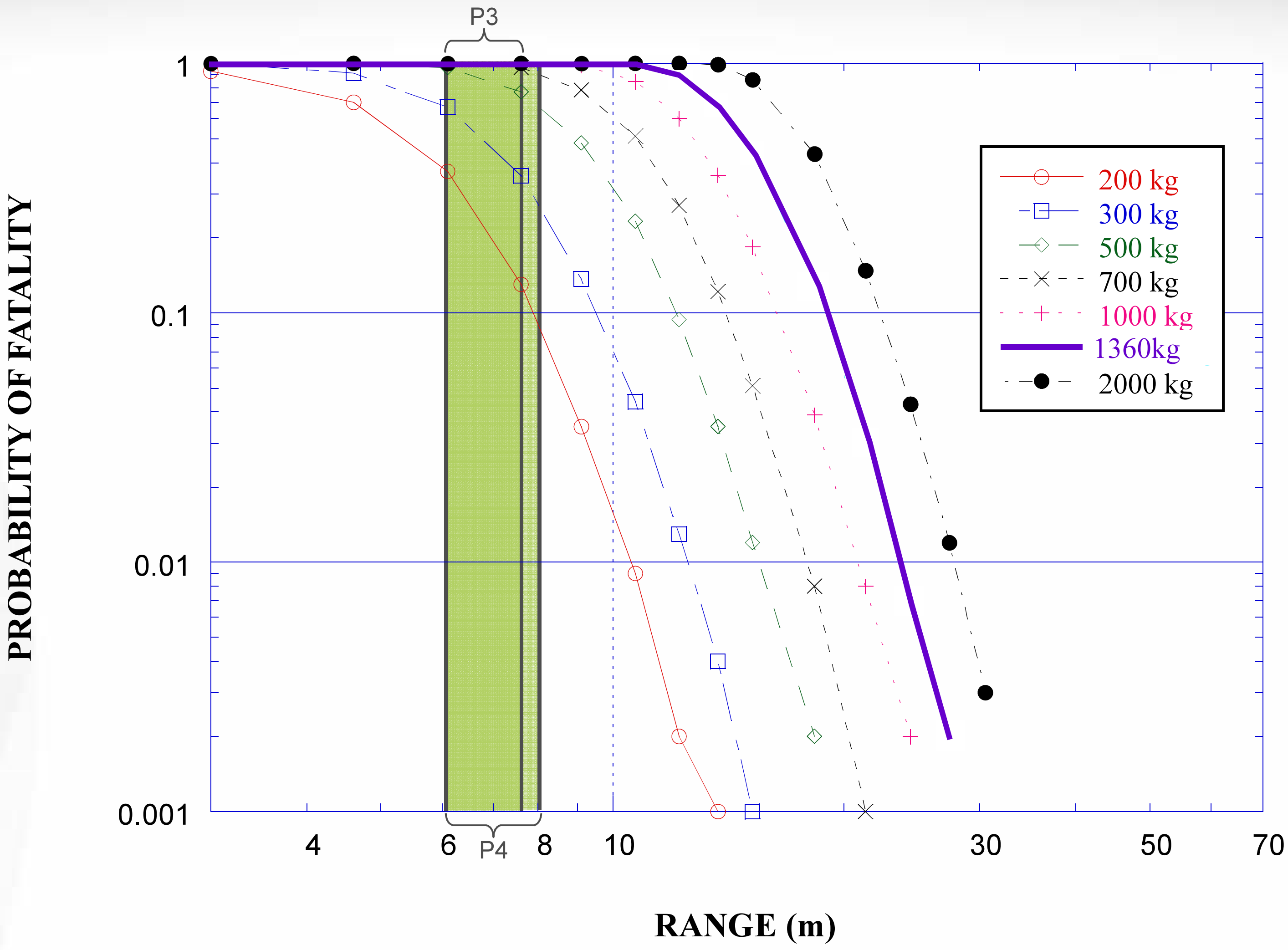
IMESAFR v1.1: Probability of Fatality Person in Open Behind Barricade



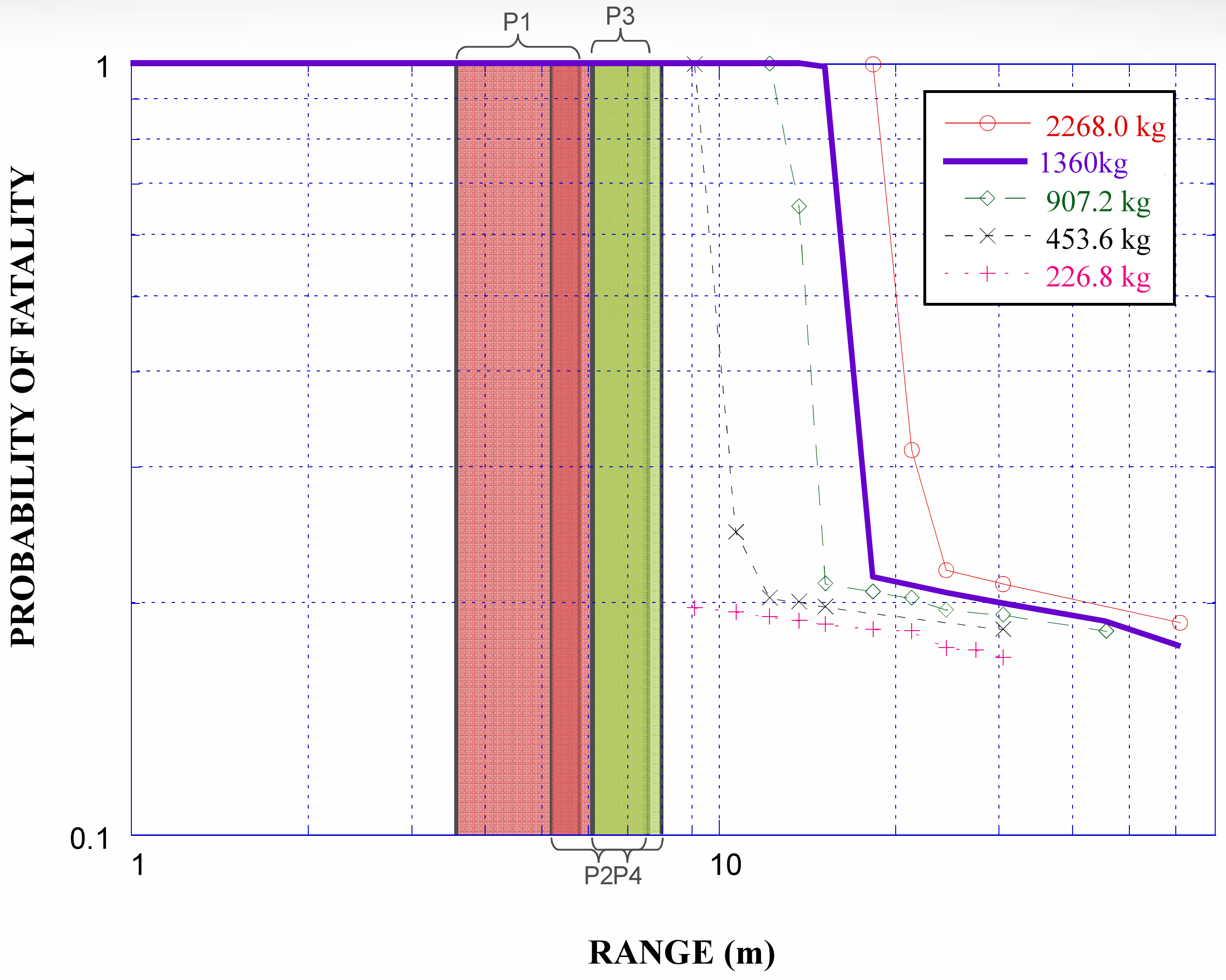
IMESAFR v1.1: Probability of Fatality Person in Unreinforced Masonry Structure



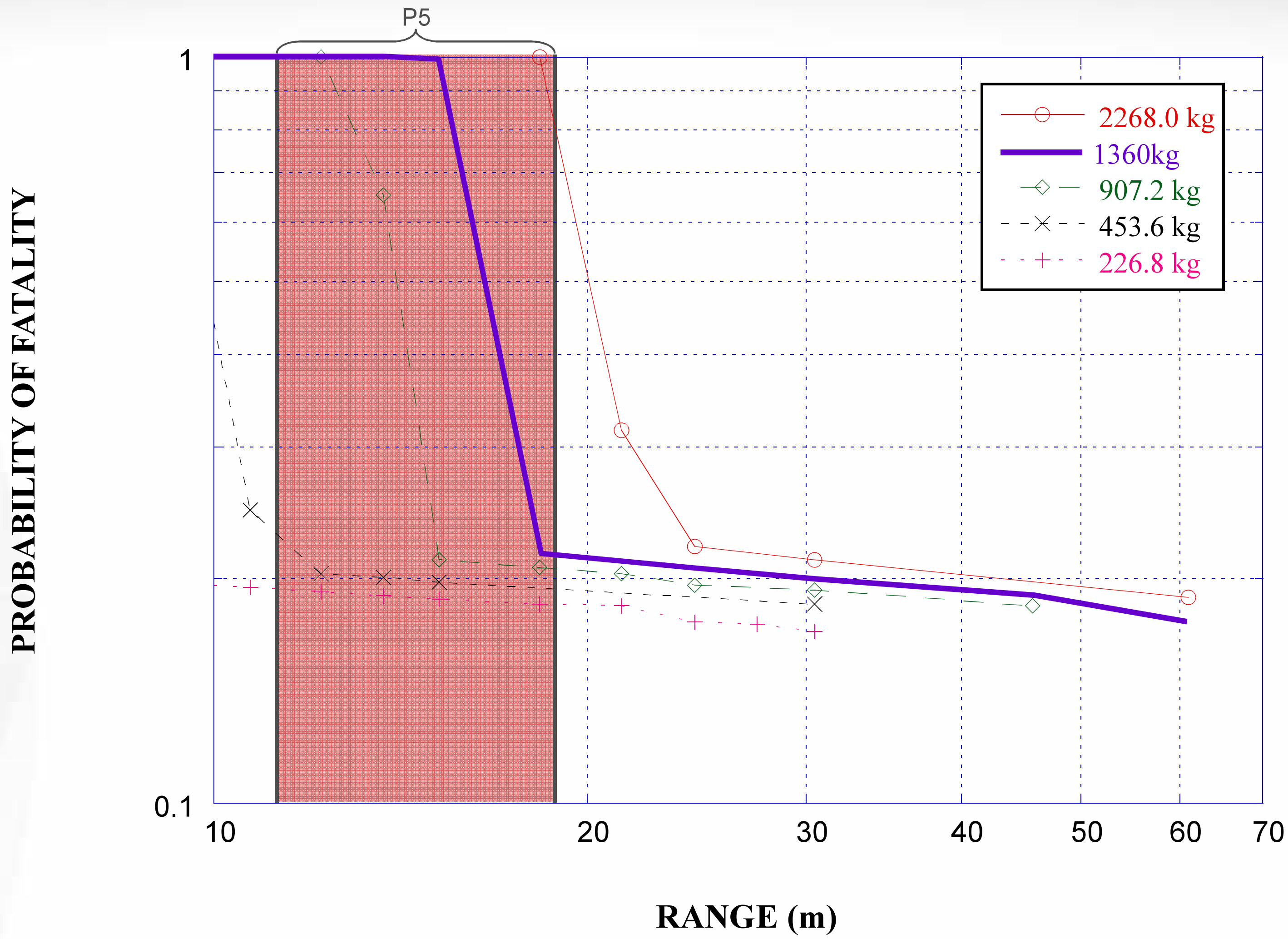
IMESAFR v1.2: Probability of Fatality Person in Open Behind Barricade



DIRE: Probability of Fatality Person in Open



DIRE: Probability of Fatality
Person in Unreinforced Masonry Structure



Summary/Conclusions

- Current QRA and consequence models are providing conservative results compared to the actual Gladstone event (which is consistent with past comparisons to tests, accidents, and terrorist events)
- Exact details of accident (event size, personnel placement, etc.) can be questioned, but it appears that the models are firmly conservative when predicting consequences at such close ranges
- Some of the model conservatism is due to the recognized assumptions about the debris distribution
  - Error applies mostly at short ranges and is not optimistic, so program sponsors have not treated the issue as a high priority
  - Conservatism mostly caused by high-angle debris distribution
  - It is important to note the (undue?) conservatism and prepare to address the issue in the future