Flyrock Model Validation

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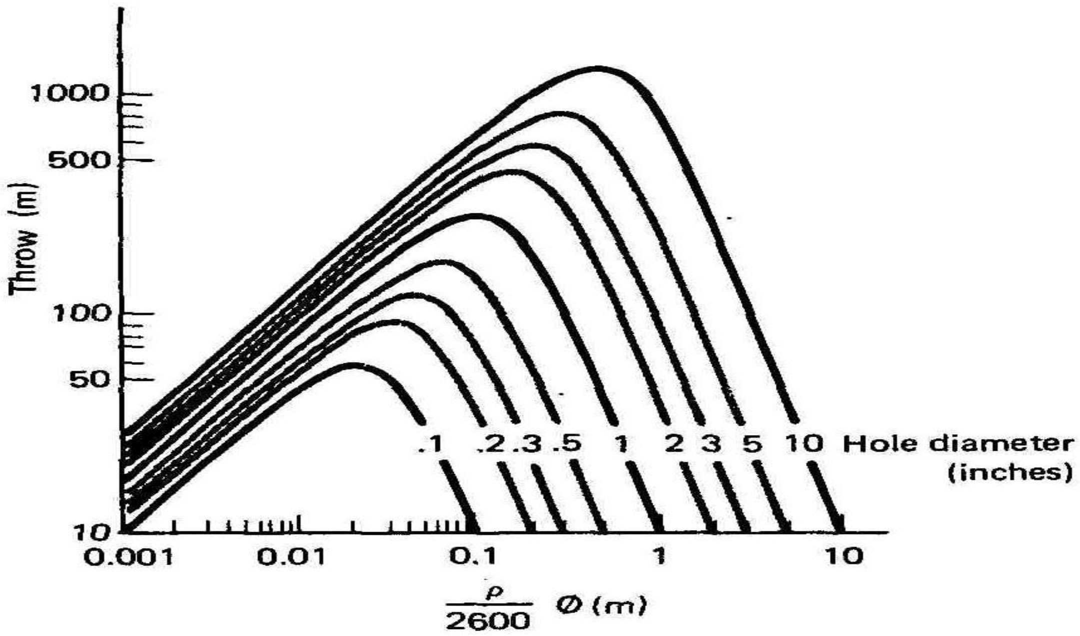
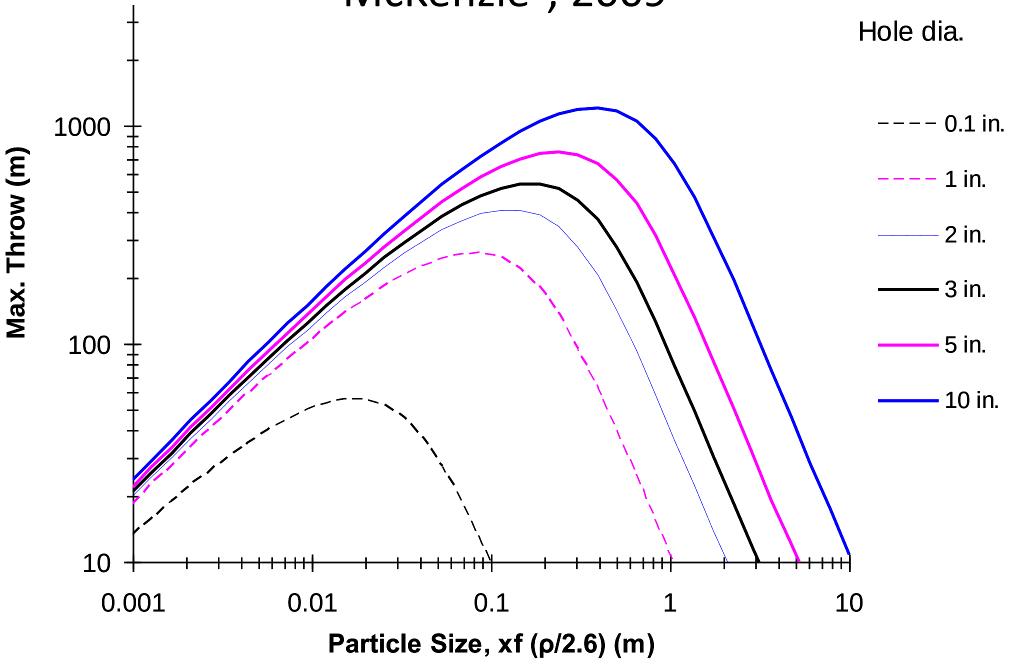
Flyrock Footprint & Hole Diameter

Lundborg[1], 1974



McKenzie[2], 2009



[1]Lundborg, N., 1974. "The hazard of flyrock in rock blasting", Swedish Rock Blasting Committee, Stockholm, Sweden.

[2]McKenzie, C.K., 2009. "Flyrock Range & Fragment Size Prediction", 35th ISEE Annual Conference, Denver, CO, USA.

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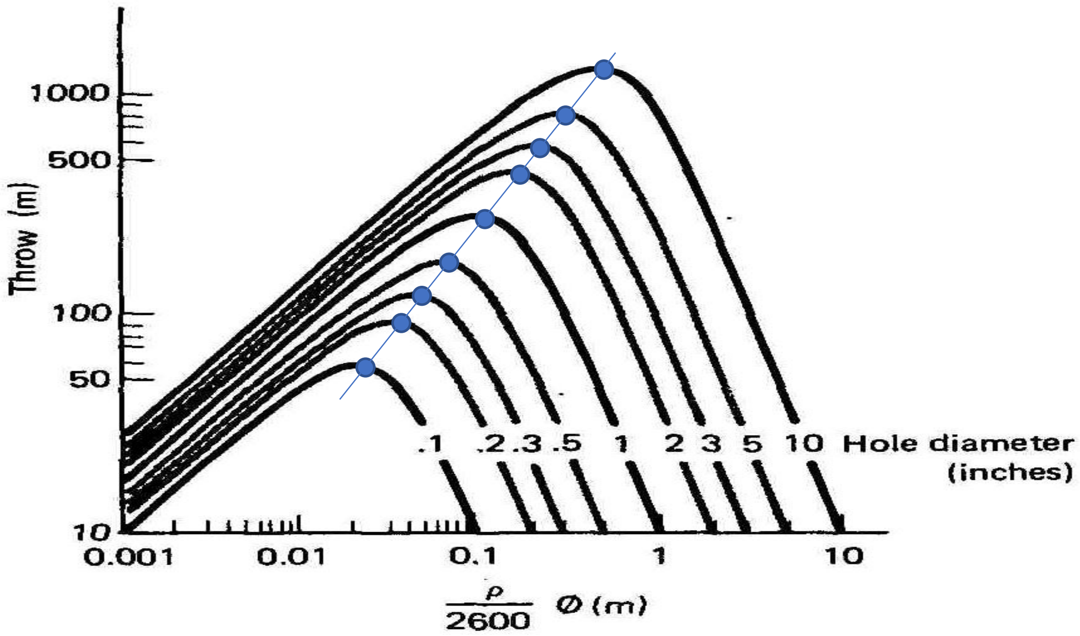

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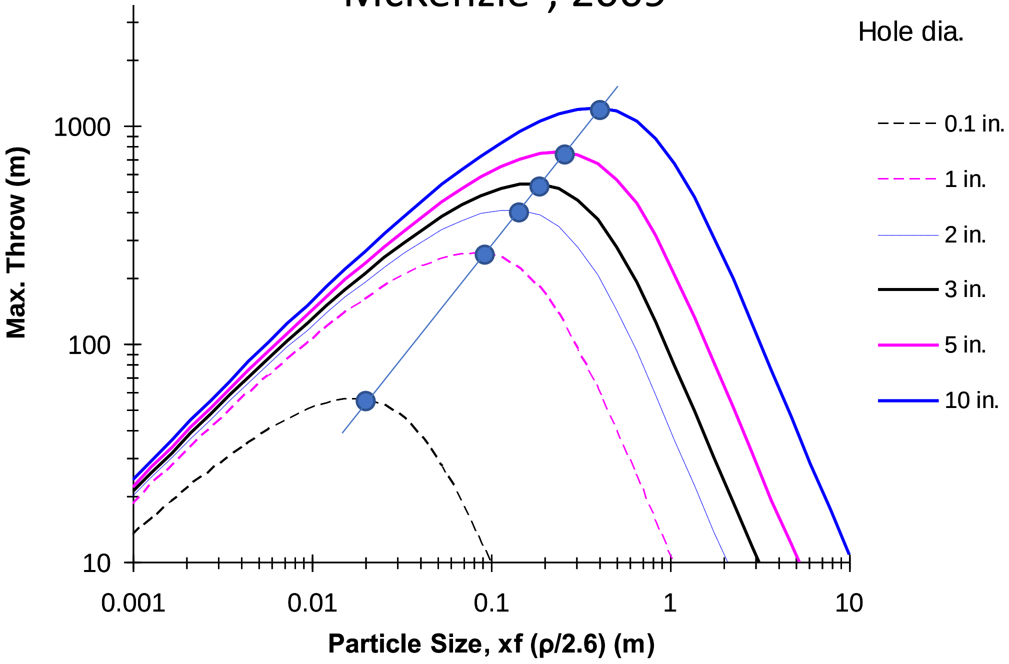

$$\text{Range} = 260 \times \text{Dia}^{2/3}$$

In Lundborg's equations, Dia is expressed in inches, and Range in metres

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Seminal Work & Findings by Lundborg

- Under crater-blast conditions $Max\ Range = 260 \times HoleDia^{0.667}$
- Under bench-blast conditions $Max\ Range{\sim}40 \times HoleDia^{0.667}$
- Under extreme confinement conditions, *Max Range ~ metres*

In Lundborg's equations, *HoleDia* is expressed in inches, and *Max Range* in metres

For Crater Blasting (Lundborg)

- Impulse equations used to determine ejection characteristics
- Launch velocity of fragments depends on fragment size and density

$$V_0 = K_v \times \left(\frac{\emptyset}{x_f}\right) \times \left(\frac{2.6}{\rho_r}\right)$$

Ø = Hole dia (in)
x_f = fragment size (m)
ρ_r = rock density (g/cc)

- Launch velocity must be lower for bench blasting and heavily-confined charges, back-calculated to be:
  - K_v = 10 (crater blasting)
  - K_v = 0.65 (bench blasting)
  - K_v = 0.11 (heavily confined, stem = 40*Dia)

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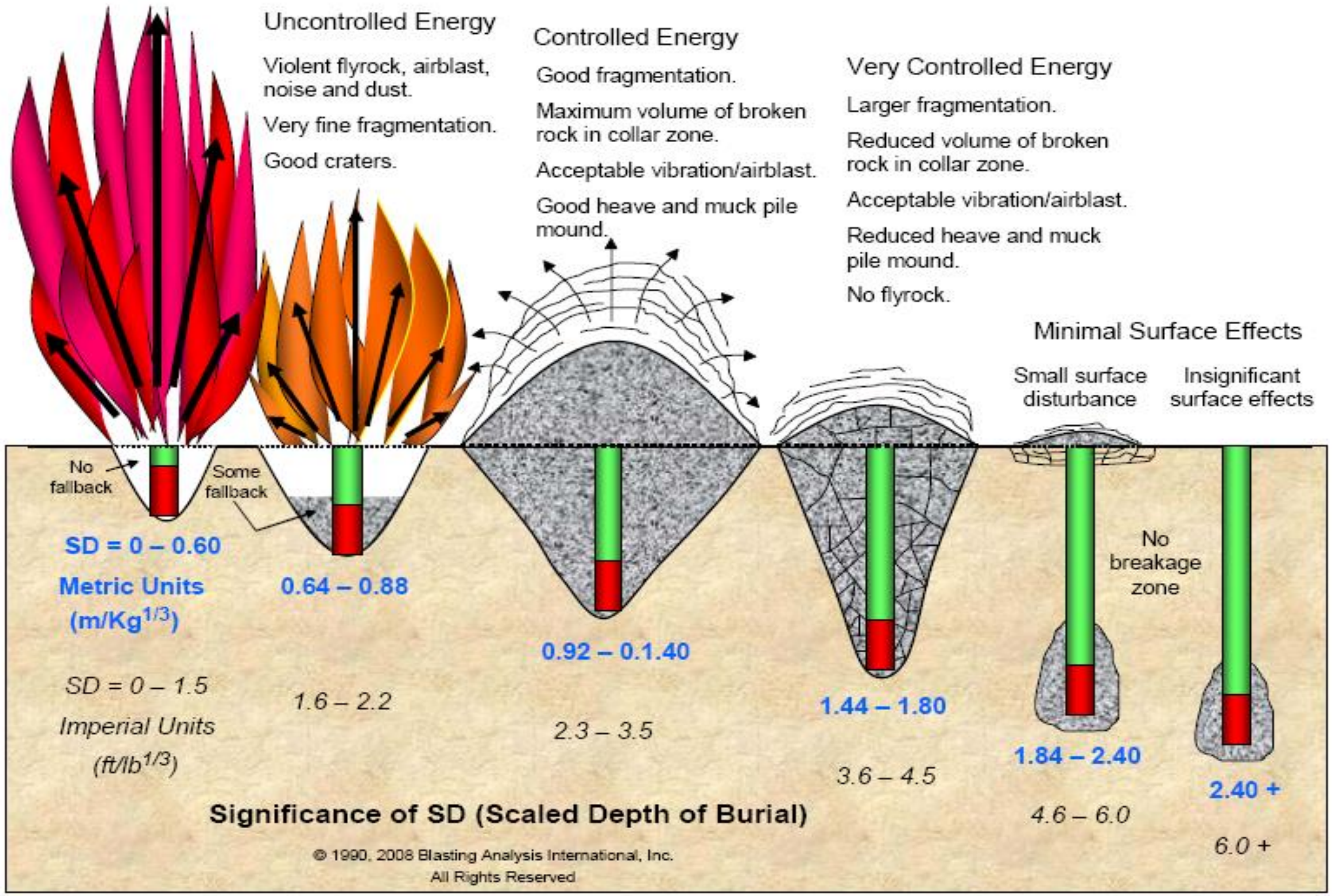
From McKenzie (2009)

Scaled Depth of Burial: Driver for Launch Velocity



EXPANSION OF THE PANAMA CANAL

by

R. Frank Chiappetta
Blasting Analysis International Inc.
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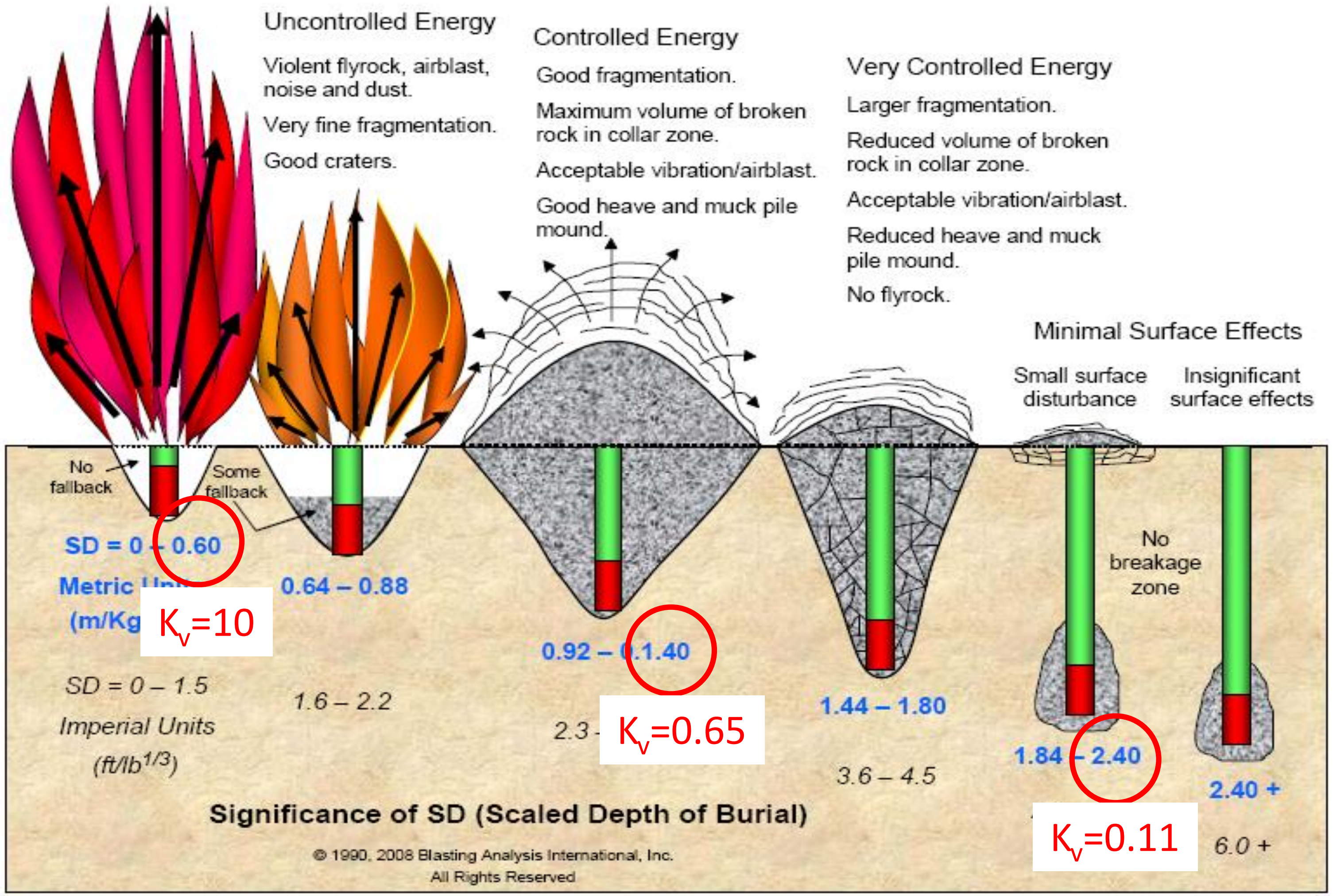

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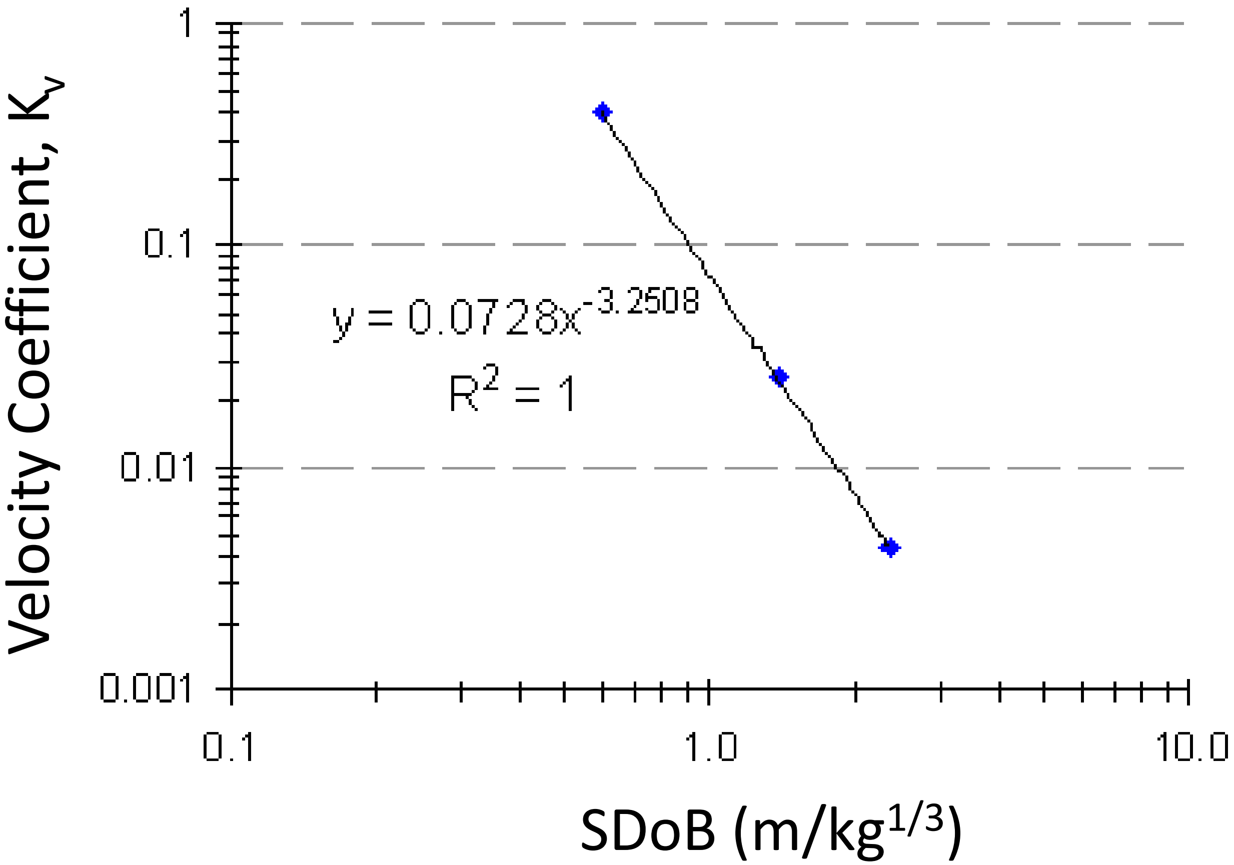
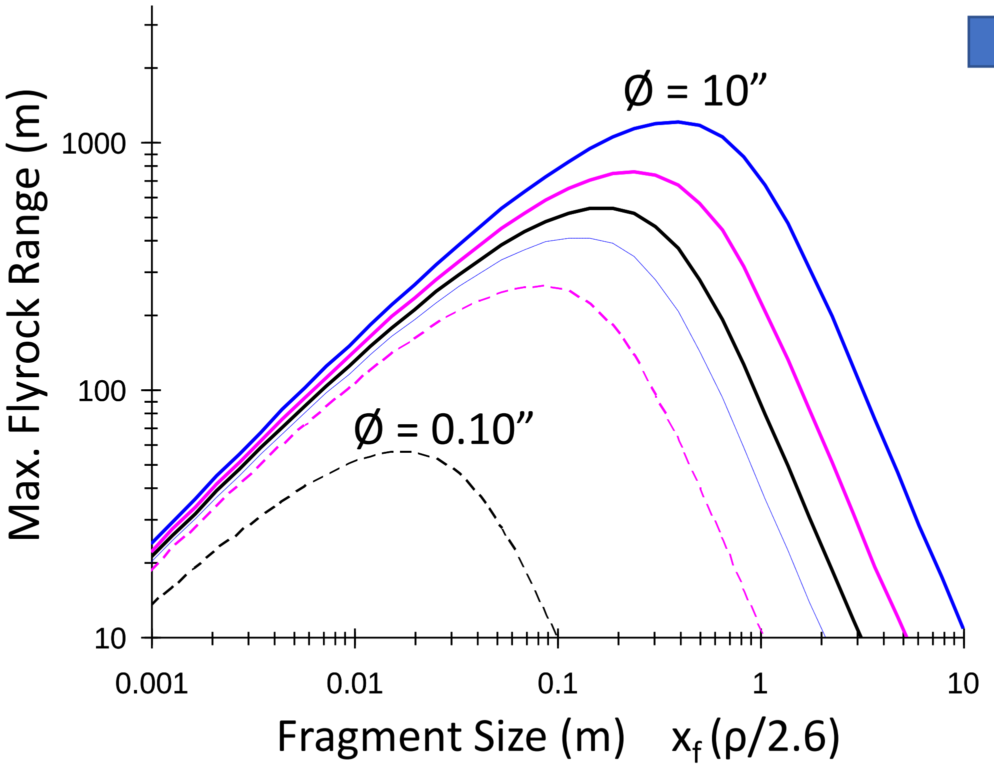
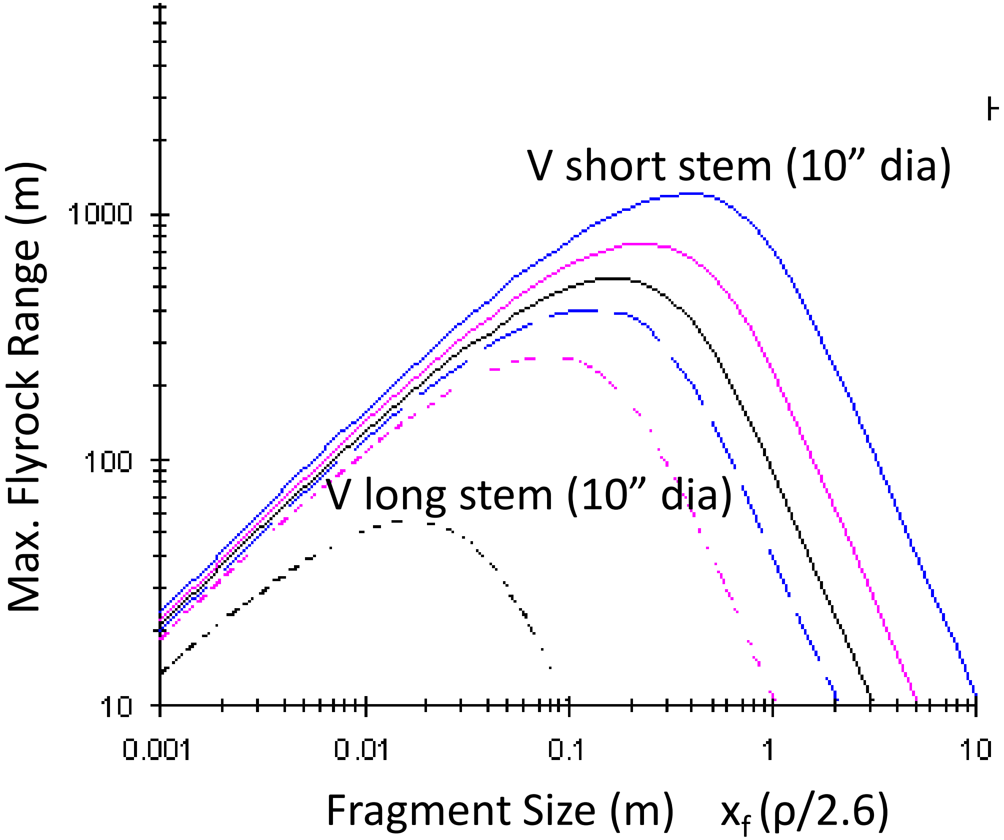
Relating Launch Velocity to SDoB



After conversion from mixed to metric units

Flyrock Footprint & SDoB (Stem Length)





Flyrock Model Summary

- Maximum flyrock range easily calculated: $$Range_{max} = 10 \times SDoB^{-2.167} \times \emptyset^{0.667}$$

  $\emptyset$ = hole dia (mm), SDoB = Scaled Depth of Burial (m/kg$^{1/3}$)

- Safe Clearance Distance easily calculated: $$Dist_{clearance} = FoS \text{ x } Range_{max}$$

  FoS = Factor of Safety

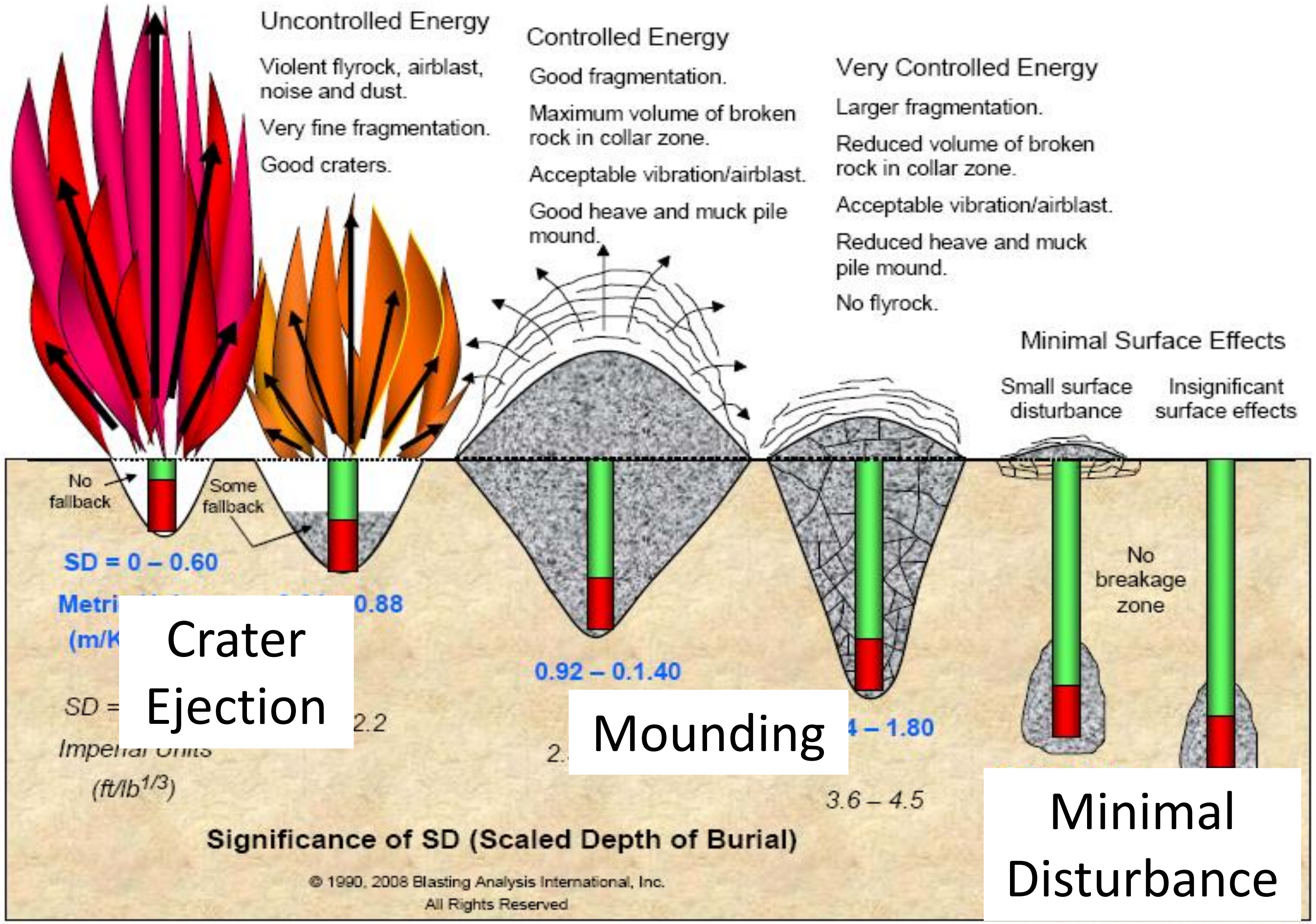
- Size of fragment easily calculated: $$x_f^* = 3.1 \times SDoB^{-2.167} \times \emptyset^{0.667} \times \left(\frac{2.6}{\rho_r}\right)$$

  ρ_r = rock density (g/cc)

- Min. stem length easily calculated: $$St_{min} = 0.03 \times \frac{\left(m\rho_{exp}\right)^{0.333} \times \emptyset^{1.31}}{\left(\frac{Range_{max}}{FoS}\right)^{0.46}} - 0.0005 \times m \times \emptyset$$

  ρ_{exp} = explosive density (g/cc)

Chiappetta's Scaled Depth of Burial (SDoB)

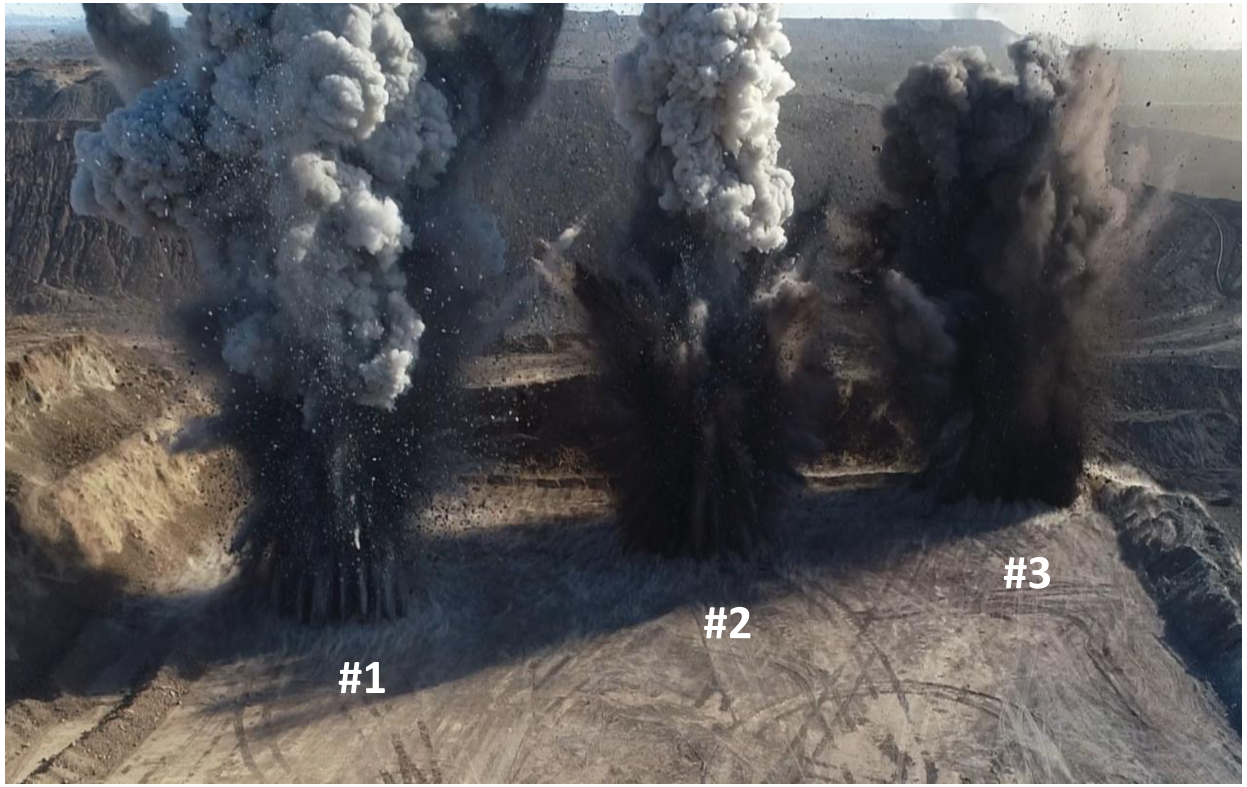


Minimal Disturbance

Mounding

Partial Cratering

Complete Crater Ejection



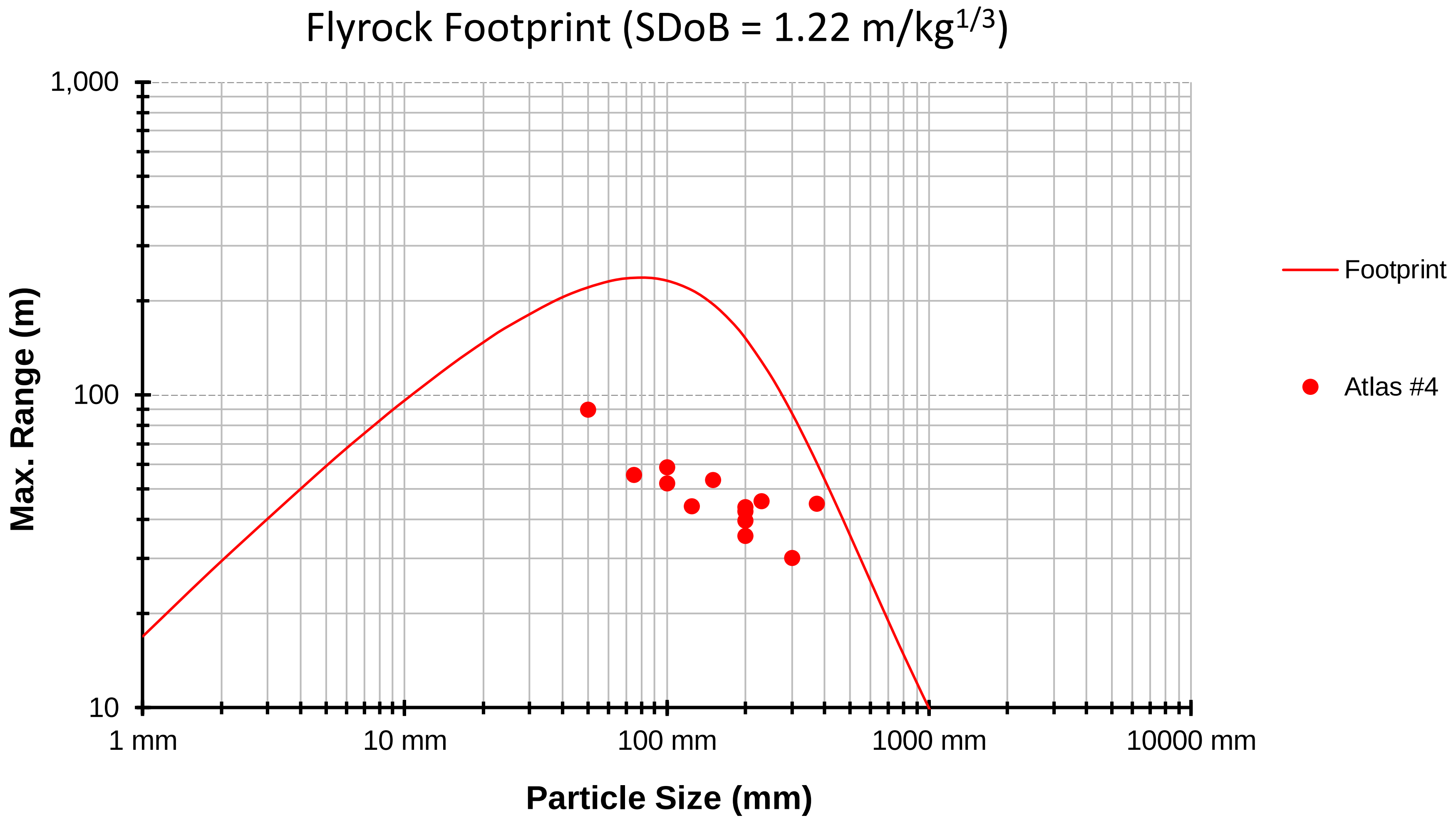
Challenge: Model Validation

- Impractical/impossible to find the fragment that is projected the maximum distance
- Need to relate projection distances to specific holes of known charge configuration
- Need a procedure that allows development of a statistically robust validation over a broad range of conditions (charging, rock)

Single Hole Test

Single Hole Test

Validation: Overlaying Surveyed Fragments



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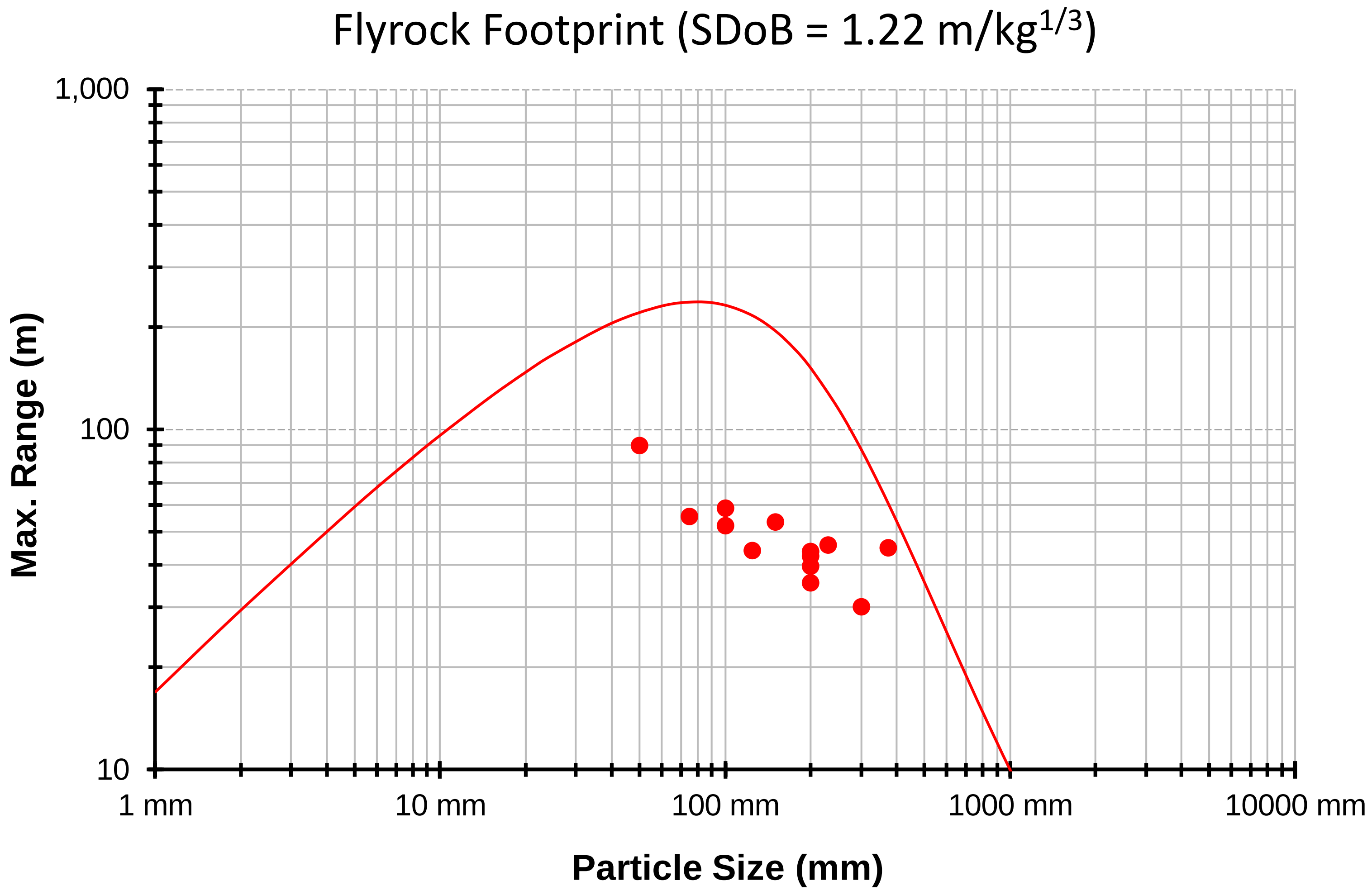

Note:
All data points must lie inside their respective footprint

Footprint curve is SDoB dependent

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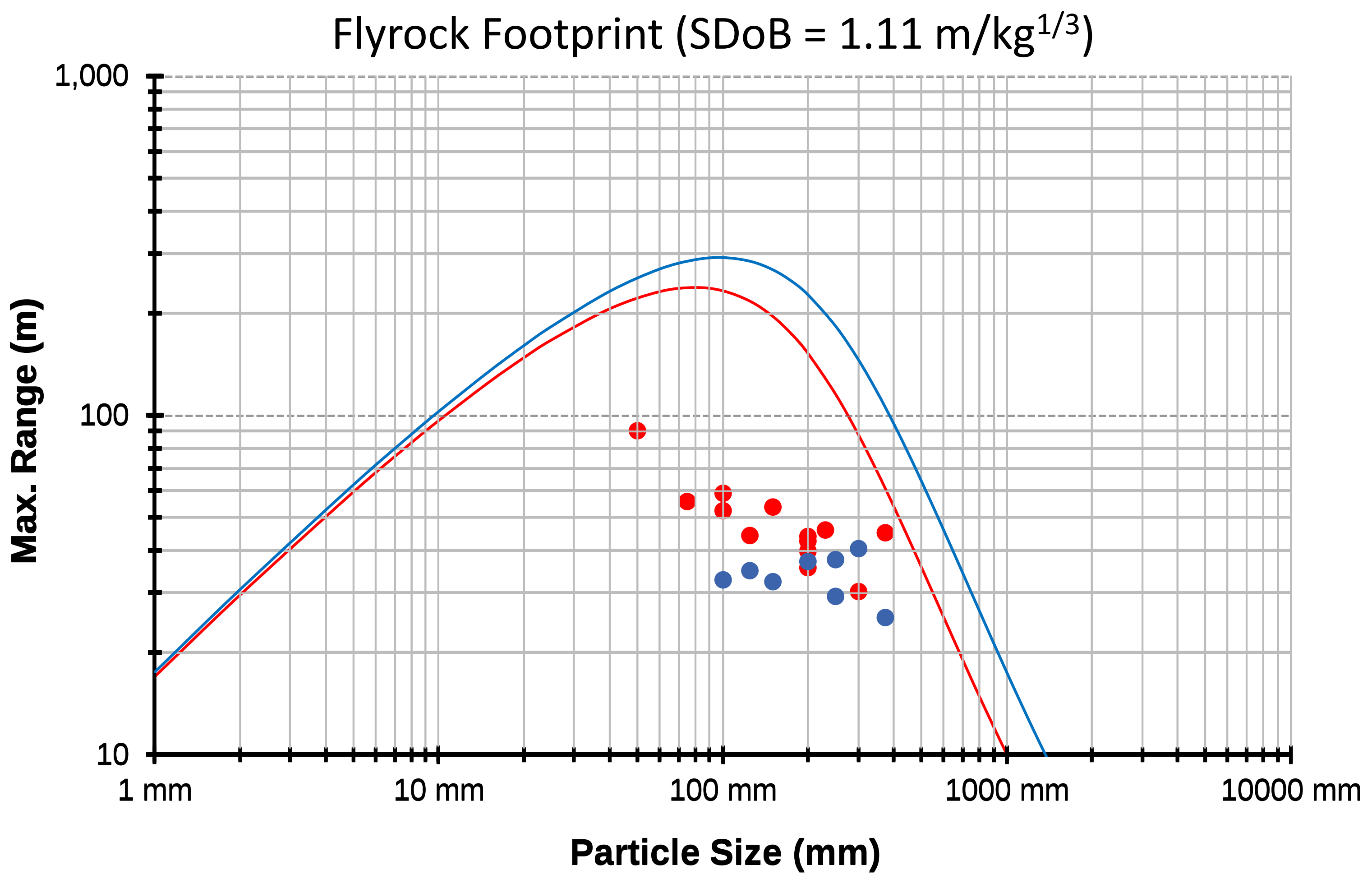

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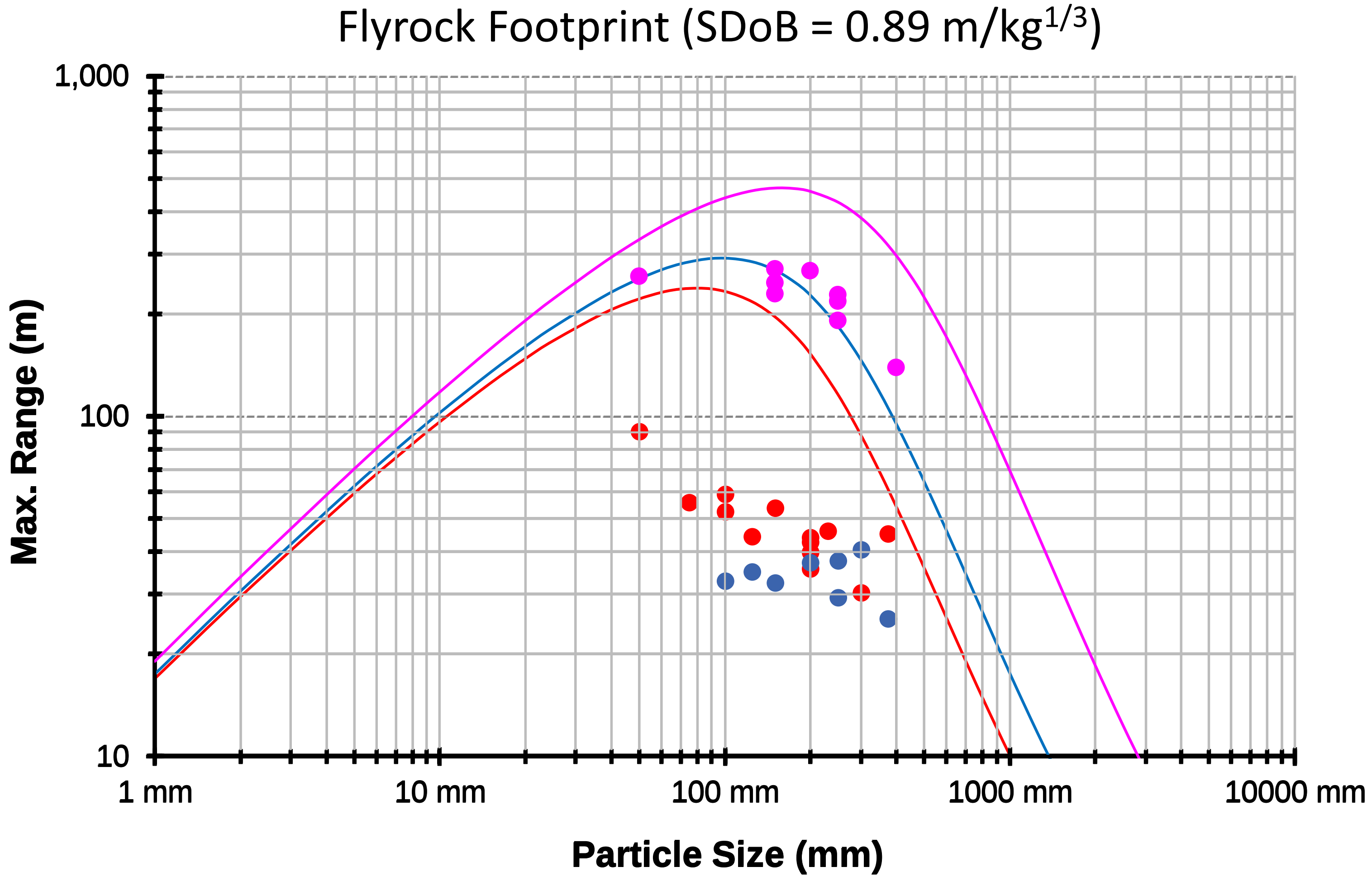

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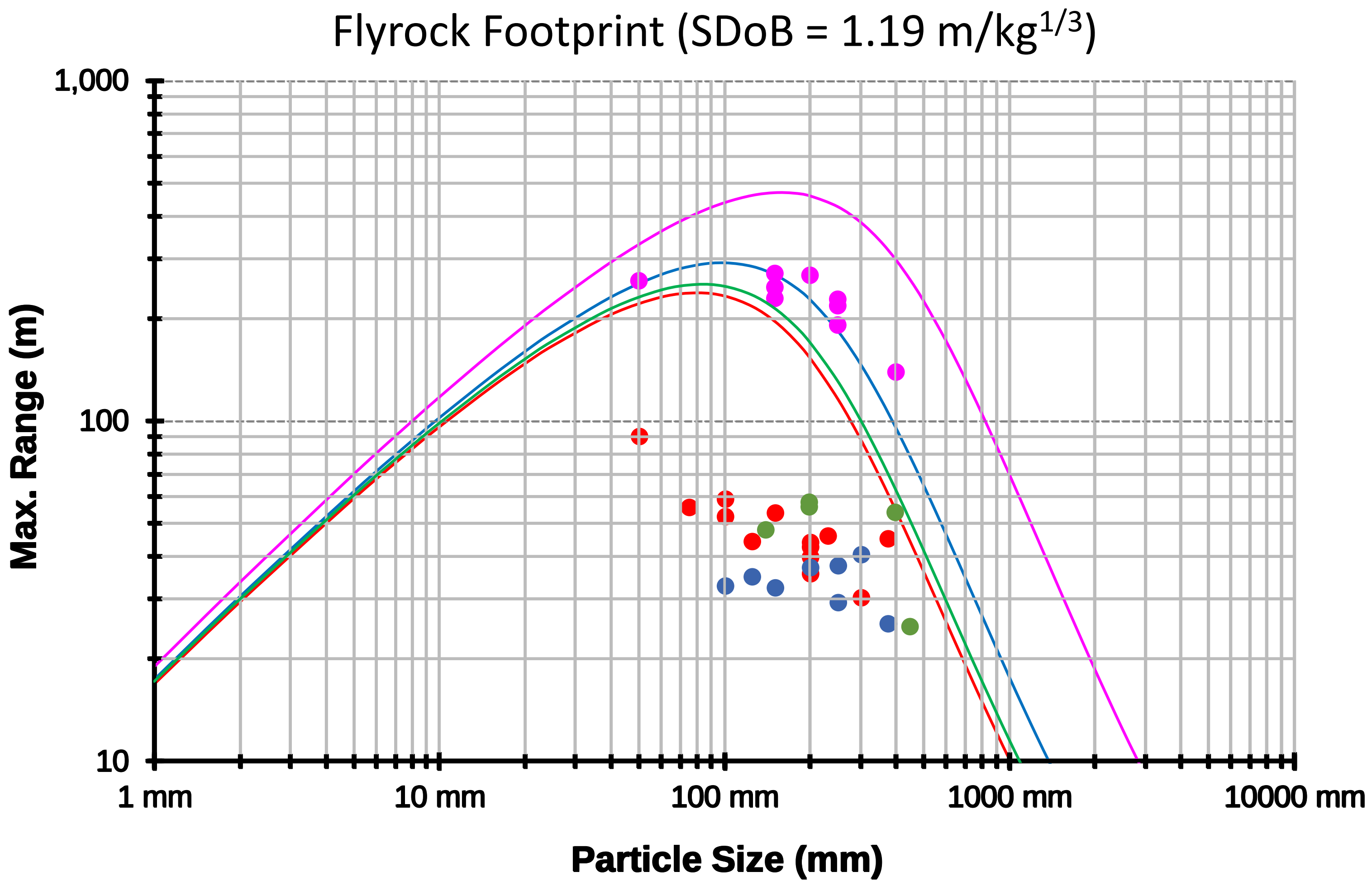

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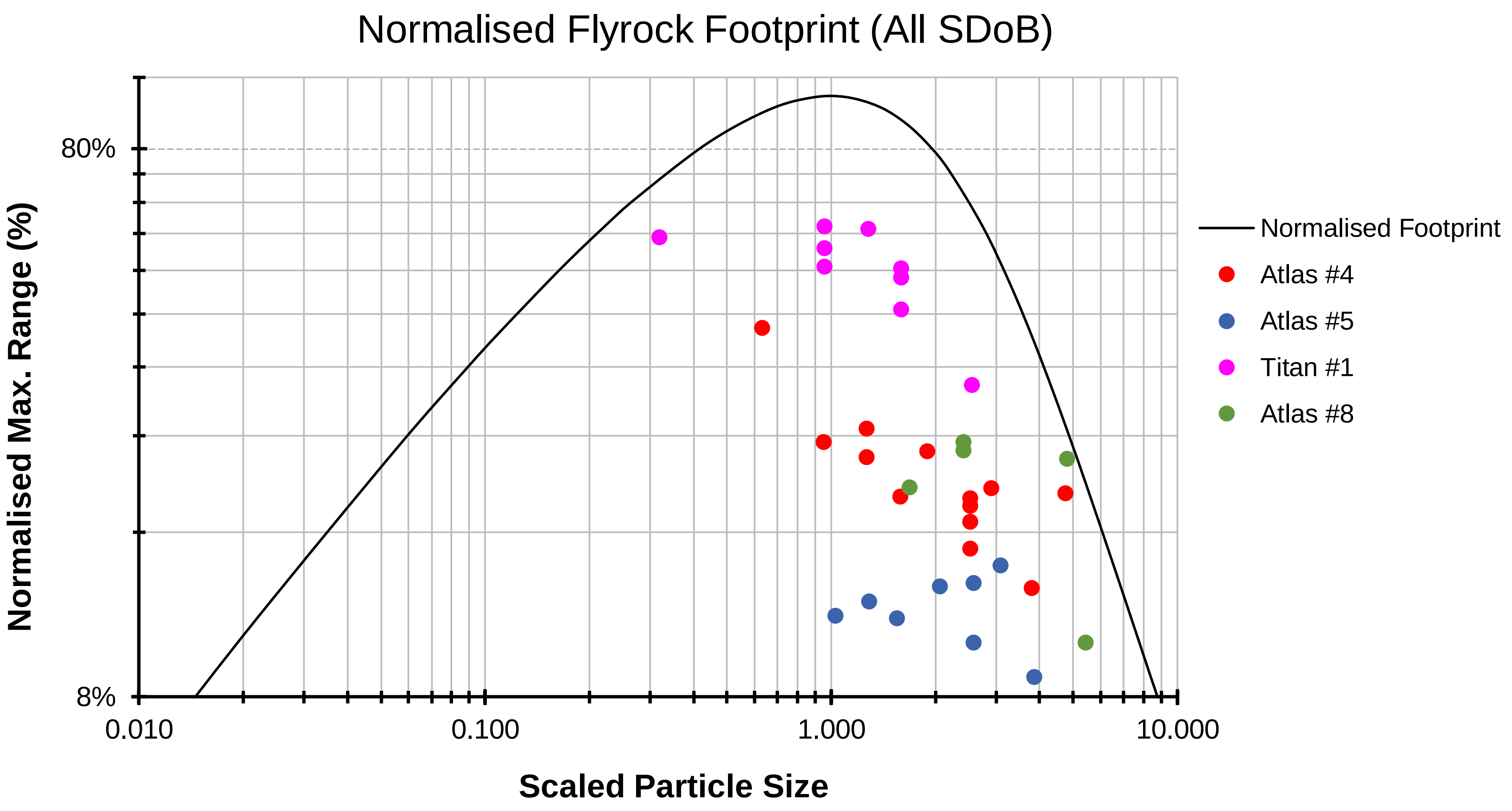
Flyrock Footprint Normalisation

For Launch Elevation = Impact Elevation



Flyrock Footprint Normalisation

$$\frac{Range}{10 \times SDoB^{-2.167} \times \emptyset^{0.667}}$$

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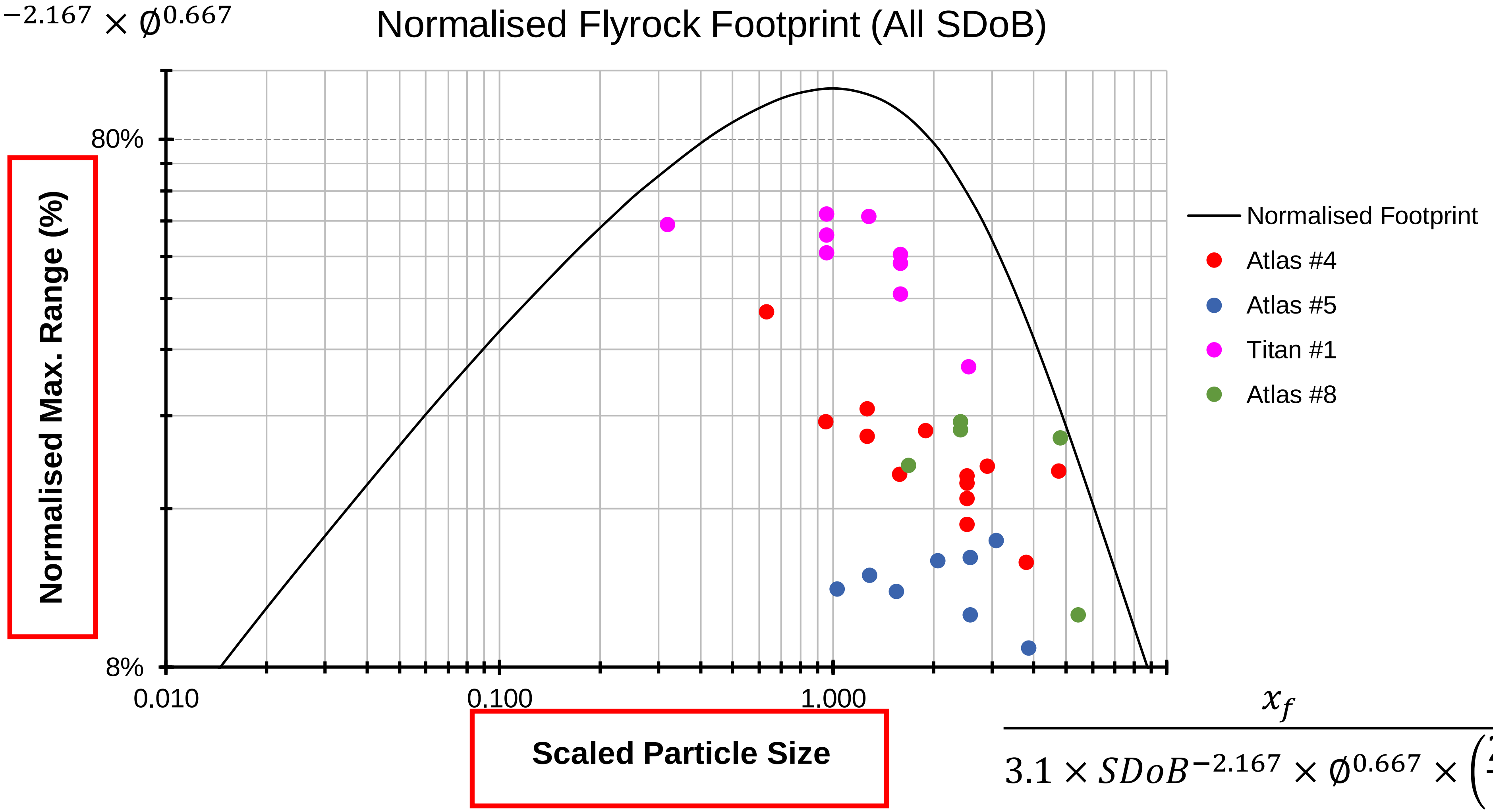
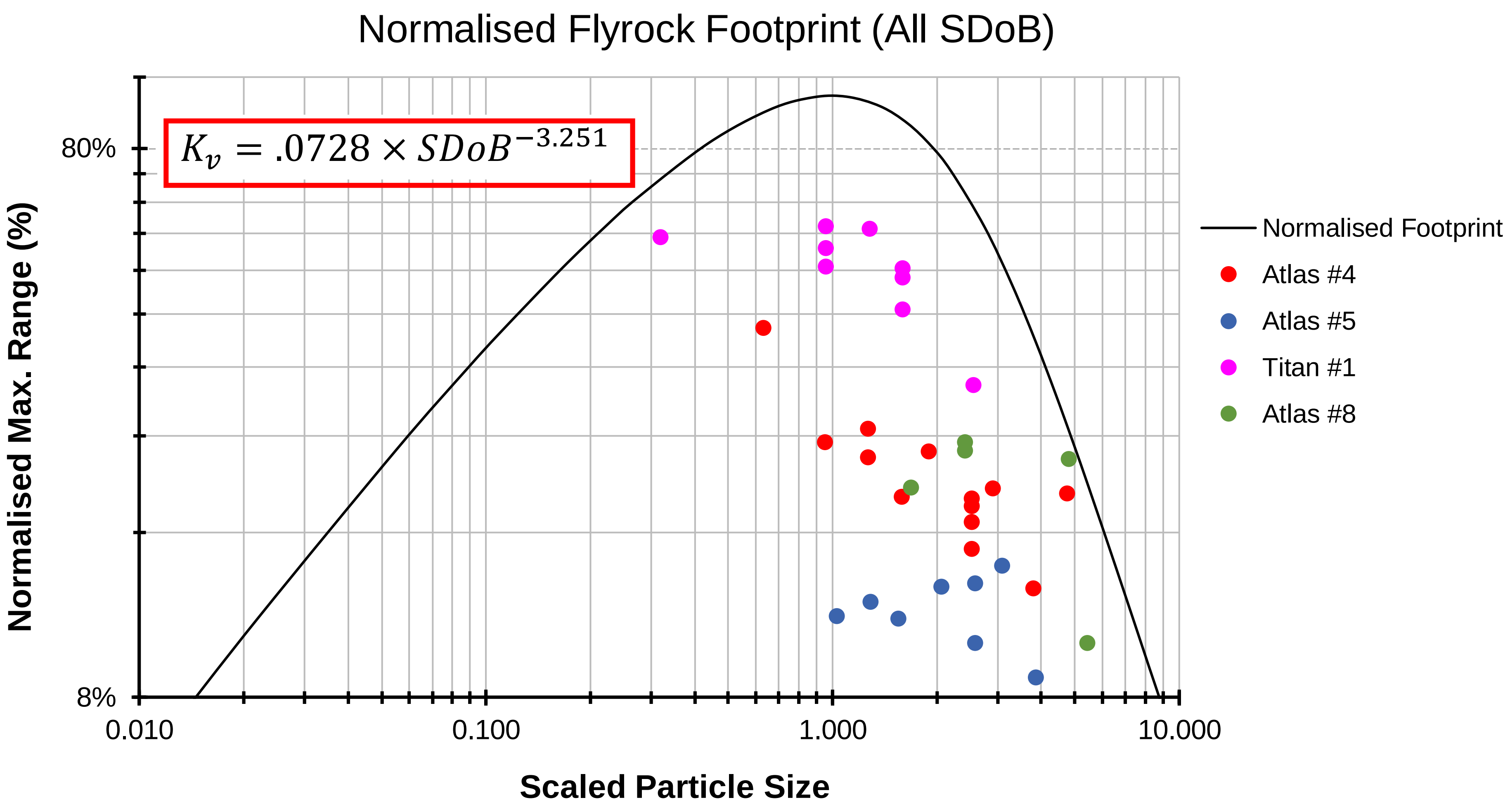


$$\frac{x_f}{3.1 \times SDoB^{-2.167} \times \emptyset^{0.667} \times \left(\frac{2.6}{\rho_r}\right)}$$

Adjusting Model Parameters



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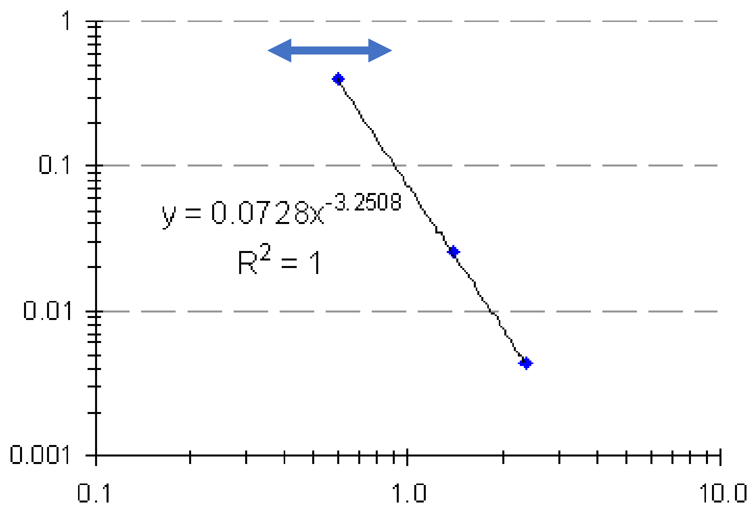

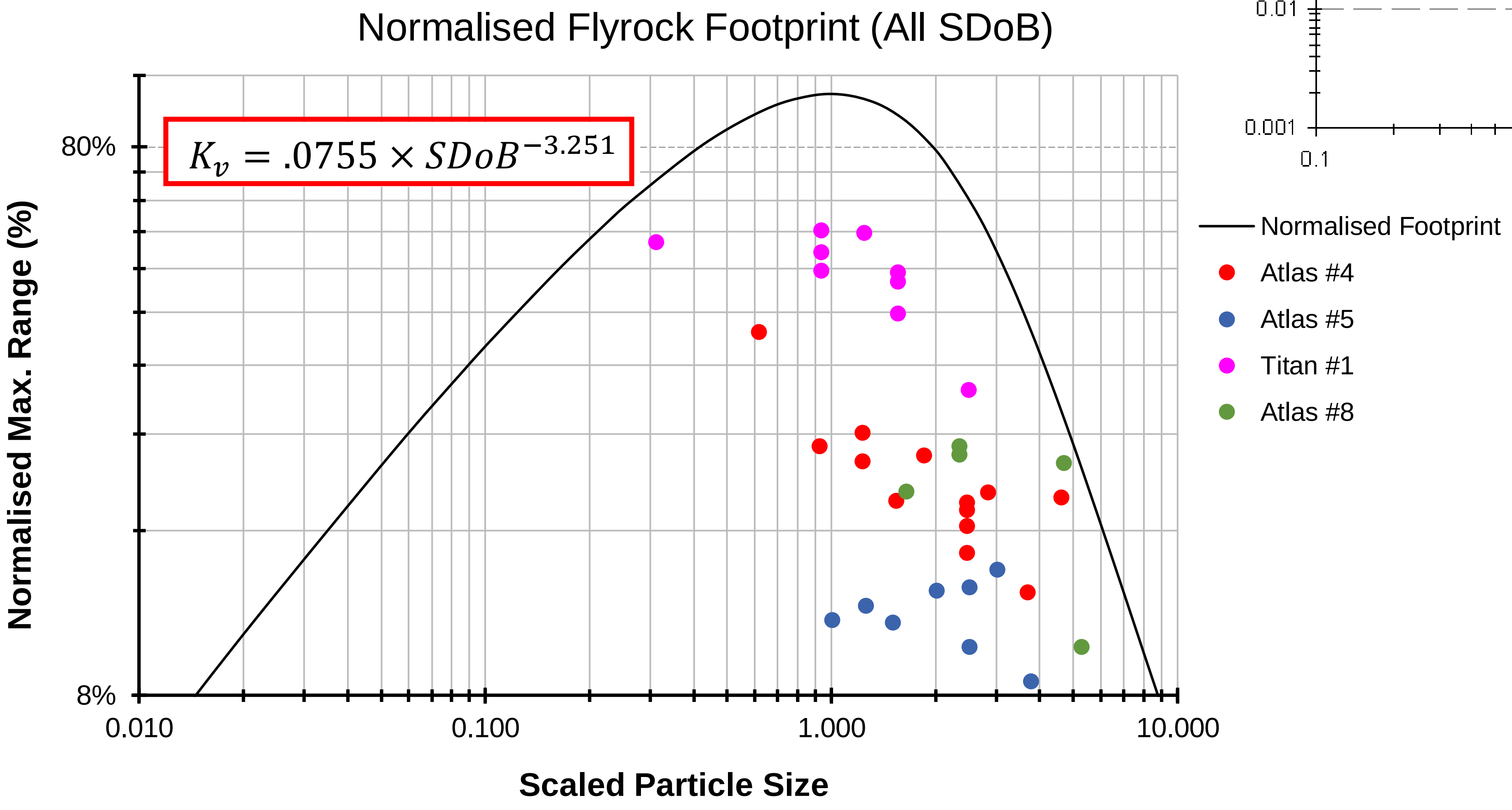

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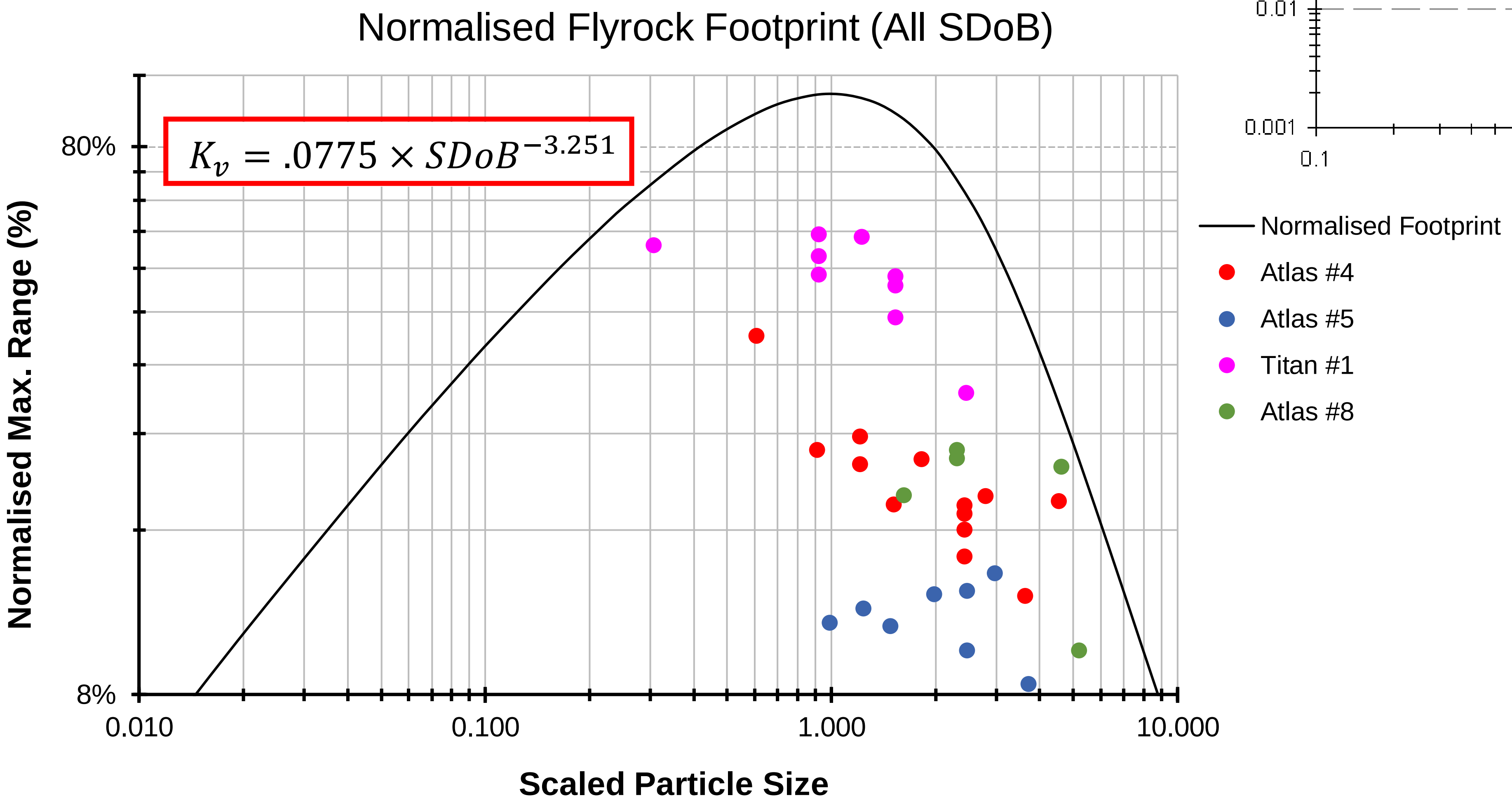

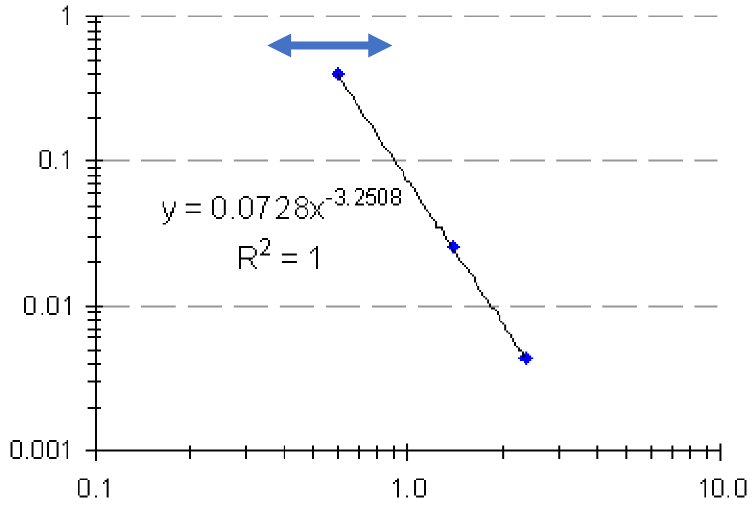

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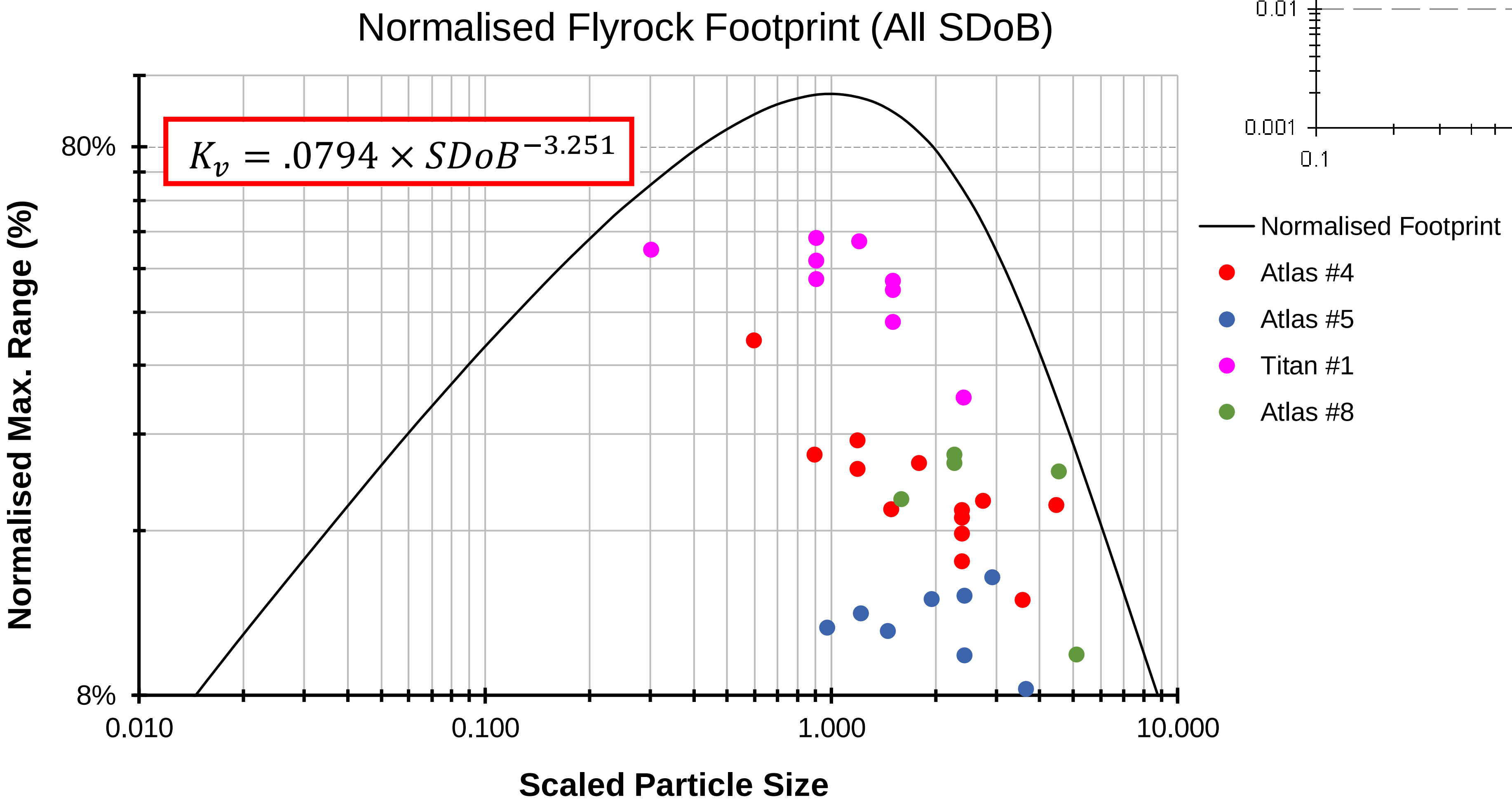

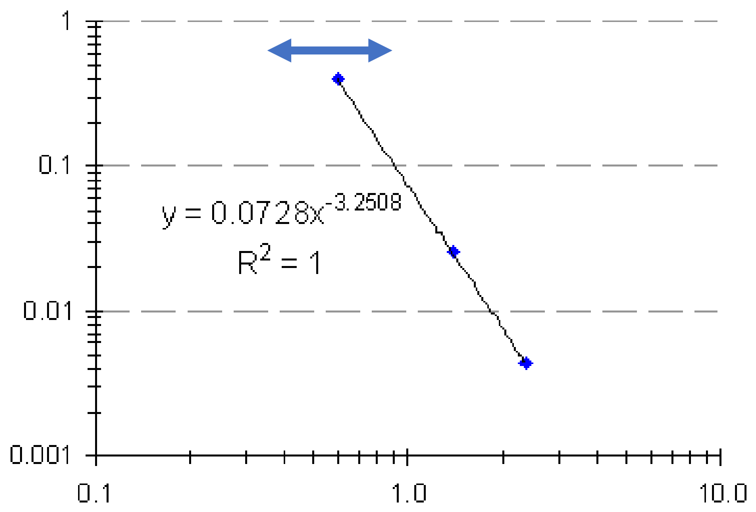

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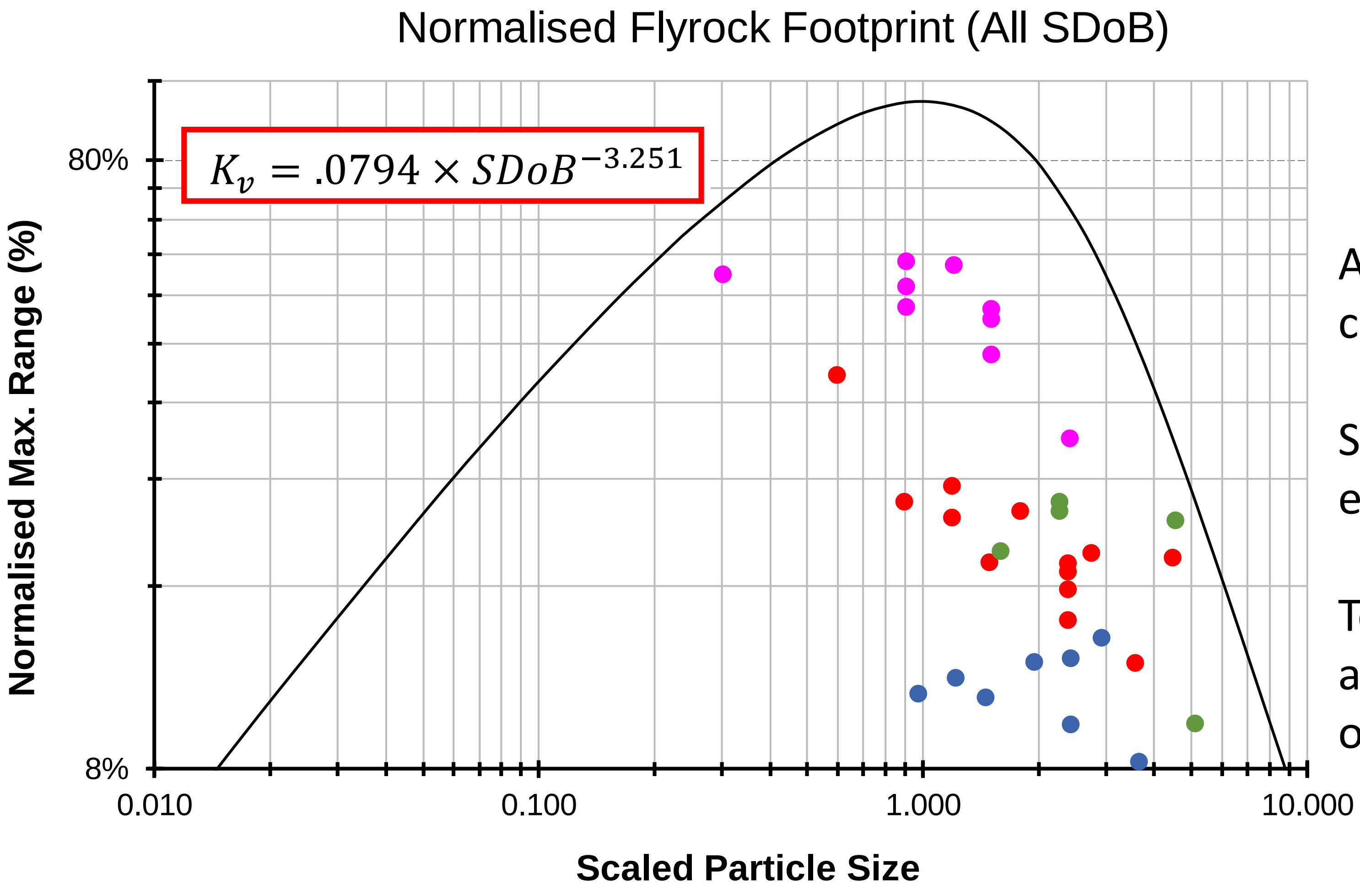
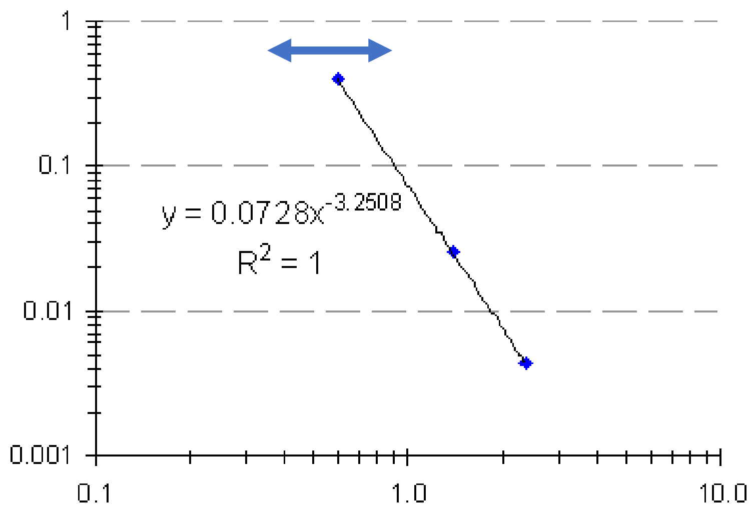




Adjustment involves the K_v v SDoB correlation

Should only be considered after extensive site measurement

To date, there is insufficient data available to justify adjustment to the original model parameters

What Factor of Safety is Appropriate?

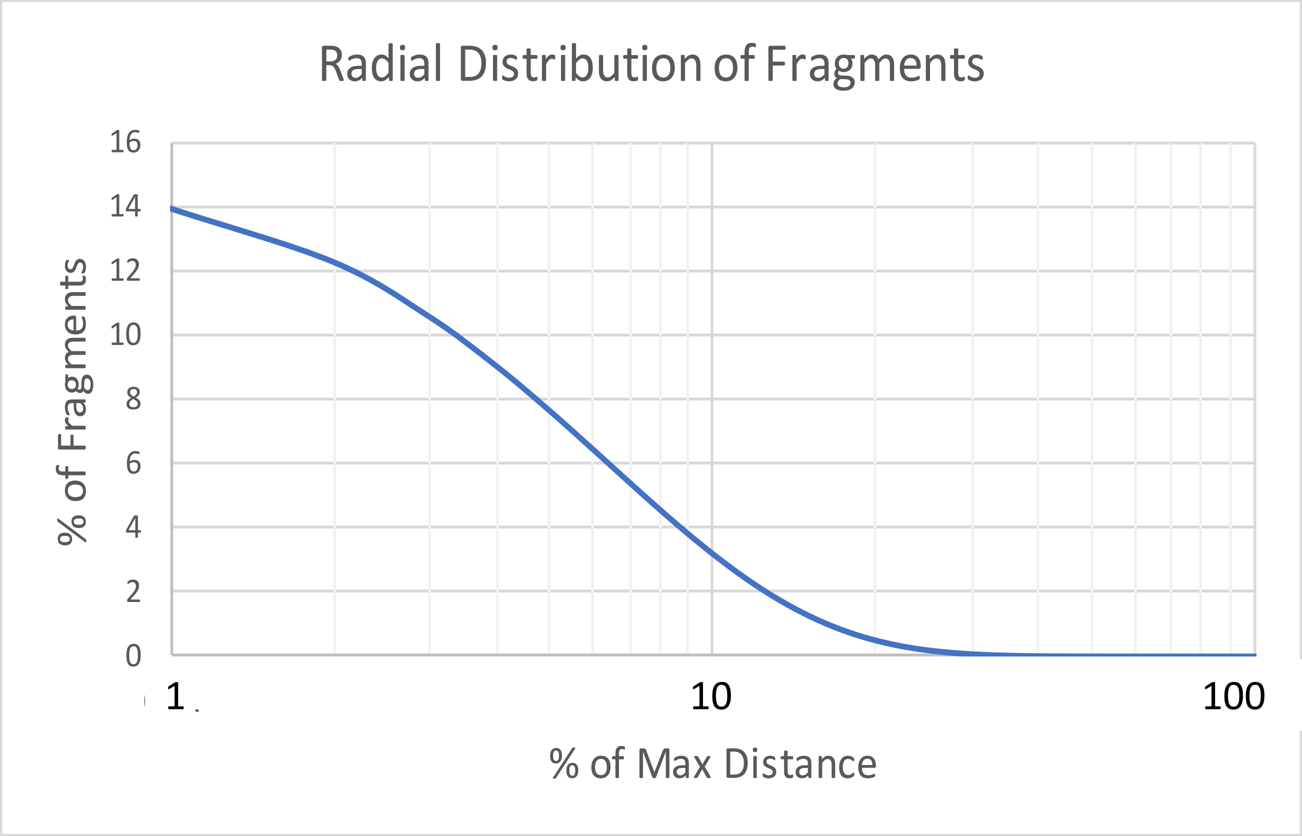
Lundborg showed that the distribution of the number of particles as a function of projection distance, R, is described by the cumulative Weibull function:

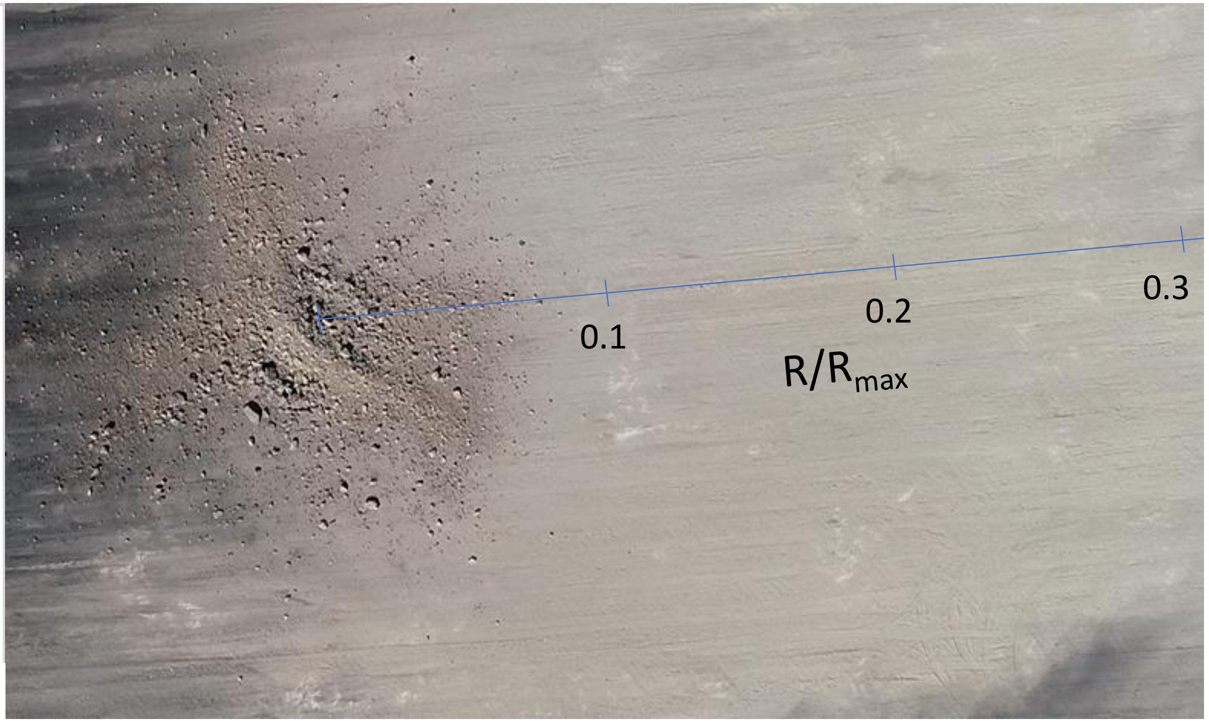
$$No\ of\ Fragments = 1 - Exp\left(-\left(\frac{R}{R_0}\right)^m\right),$$

where R_0 and m are the Weibull parameters, found by Lundborg to have values 15.3 and 1.056 respectively for field studies of flyrock fragments from a hole of 1 inch diameter. It is applied to all blasthole diameters by scaling R and R_0 to the maximum calculated projection distance for a charge of known Scaled Depth of Burial.

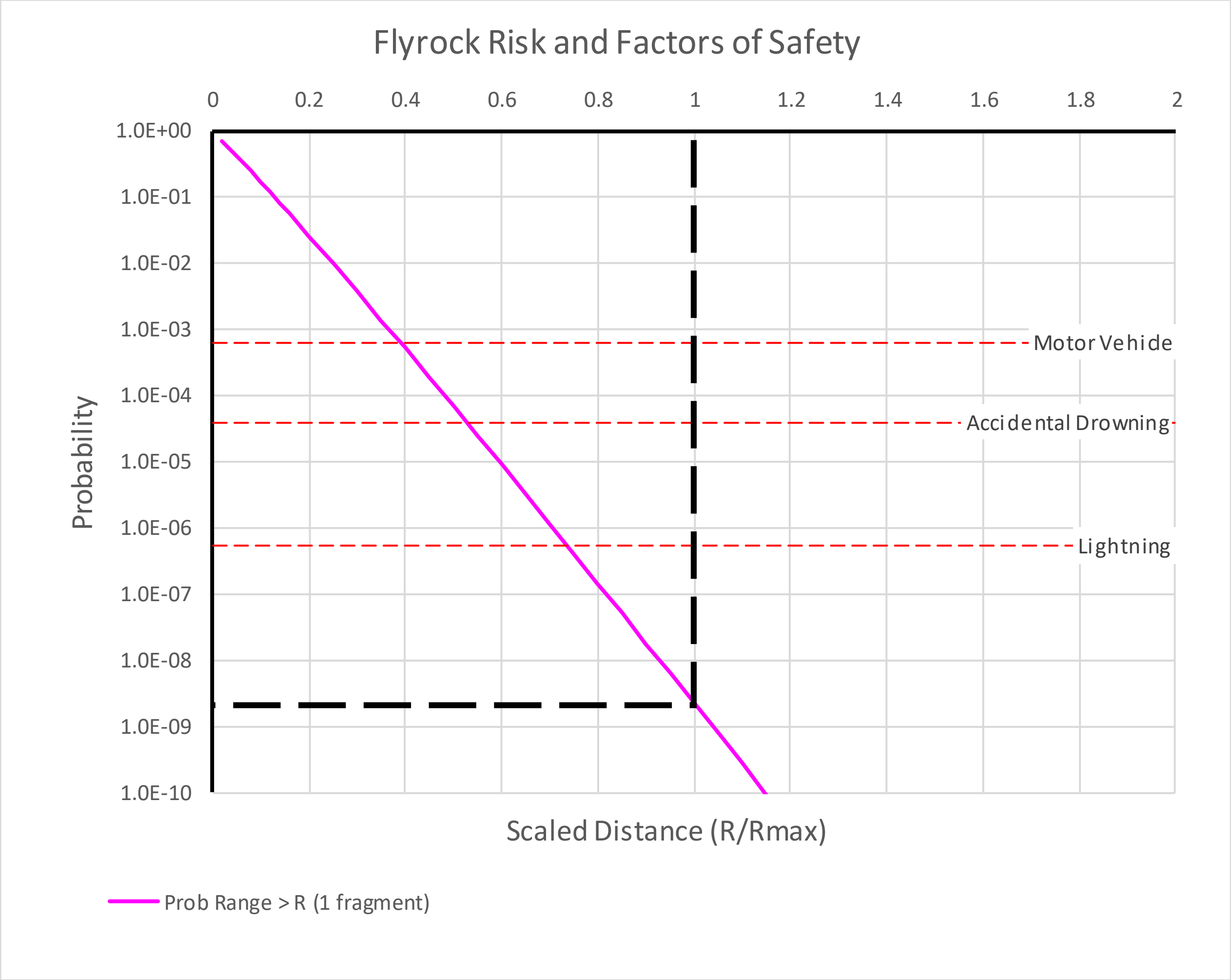
From: Lundborg, N., 1979. The probability of flyrock damage, SveDeFo report DS 1979: 10

Radial Distribution of Fragments (Weibull)





Fragment Projection Probabilities



According to Lundborg's studies and reports, the probability that a single rock will be ejected and projected more than the maximum calculated distance, R_{max}, is ~ $2x10^{-9}$

Mortality statistics from: https://www.iii.org/fact-statistic/facts-statistics-mortality-risk

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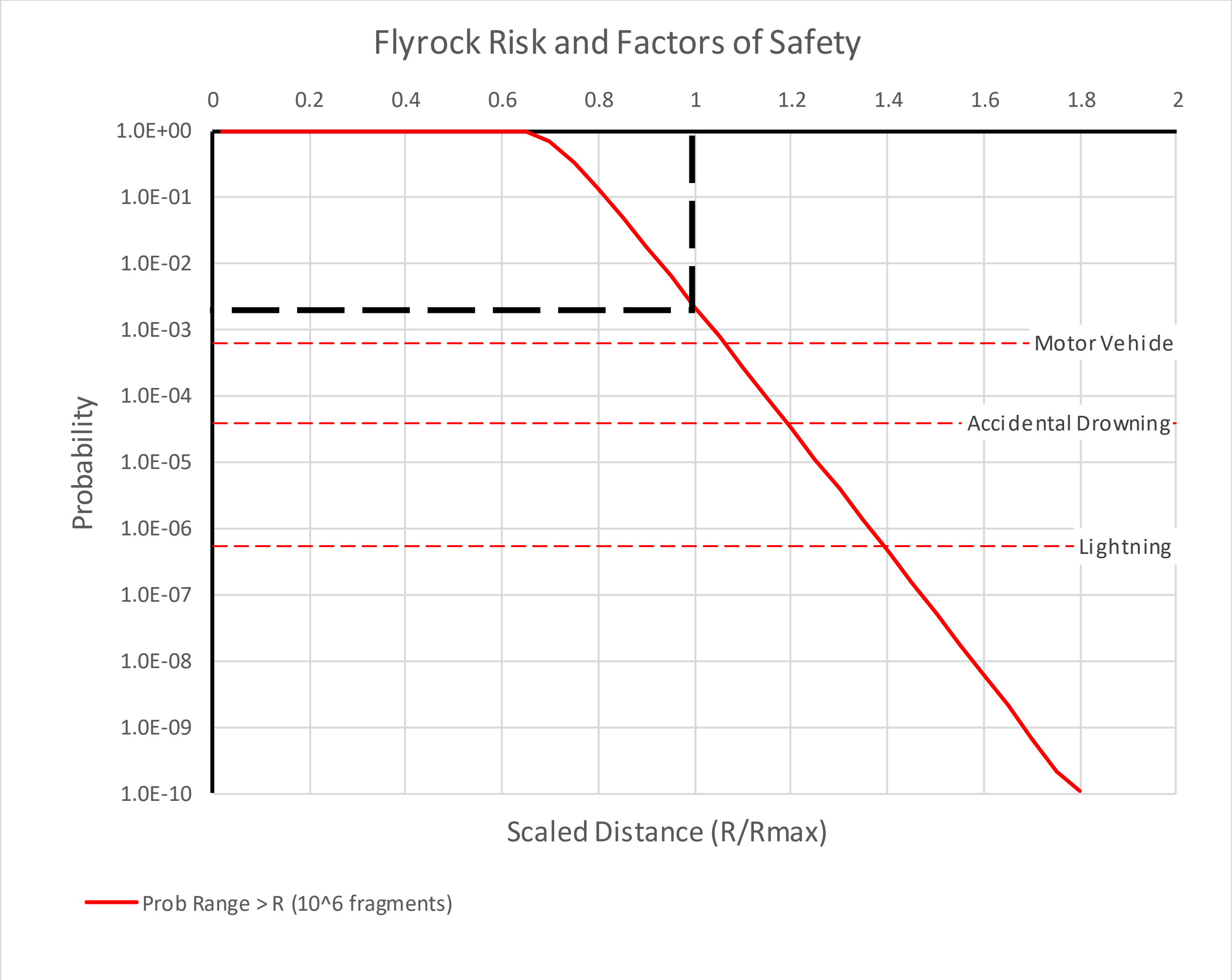

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If the hole ejects 1 million flyrock fragments, the probability that at least 1 fragment will be projected more than R_{max} is ~ $2x10^{-3}$

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Probability

Assumes 1 million fragments ejected

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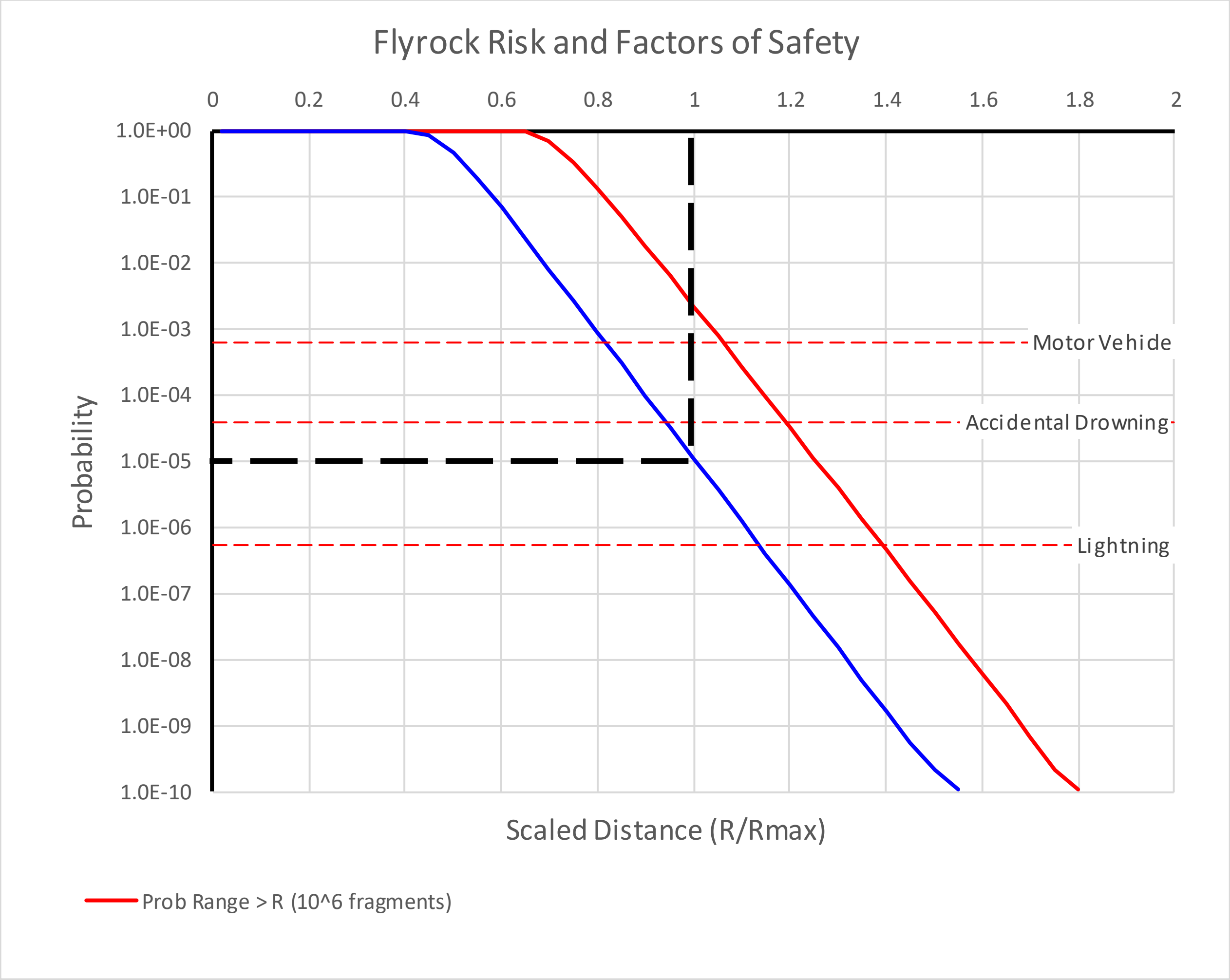

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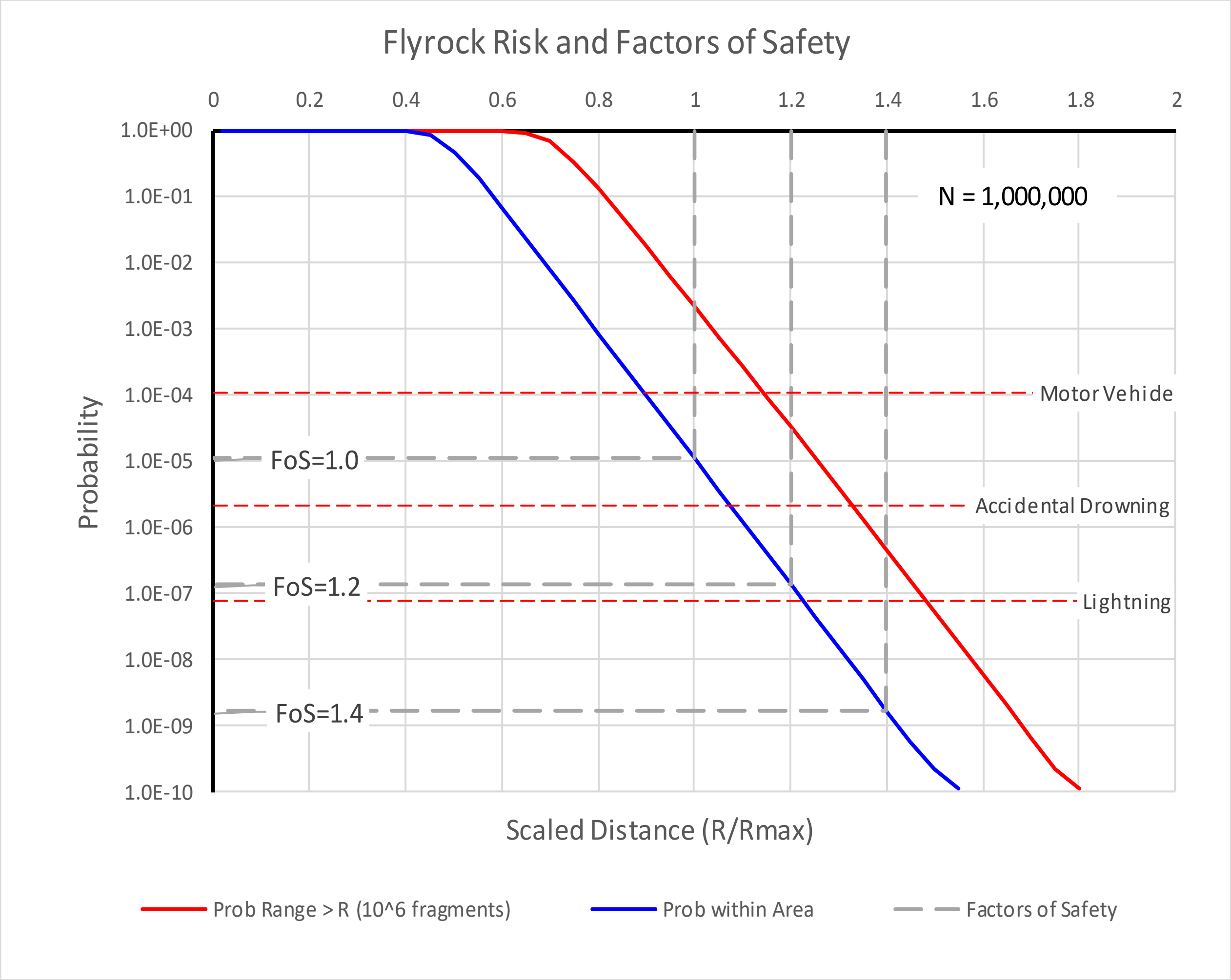
If a hole ejects 1 million rock fragments the probability that at least 1 fragment will strike an area of 10 m^2 (cab area of LV or truck) at R_{max} is ~ 1:100,000, or 13 times more likely than a fatal lightning strike. A FoS is needed.

Fragment Projection Probabilities



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For every 20% FoS added to R_{max}, the probabilities reduce by a factor of ~100

Conclusions (1)

- It is not straightforward to generate flyrock. Worst case conditions appear to be for a single hole in which the charge is well-confined in solid rock and the stemming is in disturbed or broken material.
- The flyrock model of McKenzie (2009) appears to predict maximum projection distances, for worst case conditions, over a wide range of fragment sizes, to within 10%. No data has been collected to suggest the model is under-predicting maximum projection distances, but much more testing is required.
- The model can be quite easily validated for site-specific conditions from field tests, though many tests are required for a reliable validation.

Conclusions (2)

- Flyrock fragments from any diameter hole, any blasting operation, with any length of stemming and any type of explosive can be added to the universal footprint to test the model's validity.
- Safe clearance distances can be calculated for blasts of any known charging configuration.
- Modelling must use actual charge configurations for every hole, and a Factor of Safety determined from a formal Risk Analysis. This requires a strict and verifiable quality control process.
- Factors of Safety do not need to be large to make very substantial reductions in Risk Factor.

Thank you for your interest. Are there any questions?