A Physics-Based Cordon Model for Explosive Ordnance Disposal:
Scaled-Distance Standoff, Air-Blast Decay, and Fragment Hazard Range

Bomb Doctor
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Abstract

Setting a cordon is the first irreversible decision at an explosive ordnance disposal (EOD) incident, yet field practice often reduces it to a single lookup distance read from a card. A single distance hides the reasoning behind it, and reasoning that cannot be inspected is hard to defend after the fact and hard to refine in the moment. This paper develops and documents the cordon model that drives The Long Walk system. The model is a transparent combination of three established components: scaled-distance quantity-distance criteria, a far-field air-blast overpressure correlation, and an empirical fragment hazard range. Each component is expressed in closed form, the assumptions behind each are stated explicitly, and each is implemented once in a single shared software library that both the planning application and the wrist-worn field display call. Every figure in this paper is generated directly from that library rather than redrawn from the equations, so each curve traces to the code that runs in the field. For any net explosive weight the model recommends an inner working line and an outer evacuation line, each taken as the greater of the computed physics distance and the published doctrinal floor, and it reports which of the three components governed the recommendation. We show how the governing hazard shifts from the doctrinal floor at small charges, to fragmentation at intermediate charges, to scaled distance at large charges, and we quantify how the recommended cordon responds to error in the charge-weight estimate. We argue that exposing this structure, rather than collapsing it into one number, is what makes a cordon both defensible and improvable. The model is offered as a documented engineering tool, not as operational doctrine, and every recommendation is floored at the published evacuation distance so that estimation error can never produce a cordon smaller than regulation allows.

Model status and limitations

The quantitative models in this paper are open-literature engineering correlations implemented in software. Fragment-distance and injury correlations are *illustrative* estimates for cordon sizing, not guarantees; real outcomes depend on casing, terrain, geometry, and orientation not known in the field. All distances default to the greater of the computed value and the published doctrinal floor. Nothing here is operational guidance or a substitute for command explosive-safety authority.

Contents

1 Introduction

The cordon is the geometry of safety at an EOD incident. It separates the people who must be close to the hazard from those who must not, and it does so before the device is understood. A cordon that is too small exposes responders and the public. A cordon that is too large can be impossible to hold with the personnel on scene, blocks more of the surrounding area than necessary, and erodes the cooperation a team depends on the next time. The decision is made early, under time pressure, and with incomplete information about the charge, its fill, and its casing.

Doctrine answers this with quantity-distance criteria. These are scaled-distance rules that convert a net explosive weight into a standoff distance, floored by published minimum evacuation distances (U.S. Department of Defense, 2008, 2019). The rules are sound, they are authoritative, and nothing in this paper supersedes them. What a single tabulated distance does not do, on its own, is tell the responder which hazard is actually governing that distance, how the recommendation would change if the charge estimate moved by a factor of two, or how the underlying physics of overpressure and fragmentation relate to the number on the card. When the only output is a distance, the reasoning behind it is invisible. Invisible reasoning is difficult to defend in an after-action review and difficult to refine while the incident is still developing.

1.1 Contribution

This paper documents a cordon model that keeps the reasoning visible. The model combines three established components, the scaled-distance (K-factor) standoff, a far-field air-blast overpressure correlation, and an empirical fragment hazard range, and it reports not only the recommended distance but which component drove it. The contribution is not a new physical theory. It is the careful assembly, explicit documentation, and end-to-end software traceability of known correlations into a single auditable cordon recommendation, together with two analyses that a single lookup cannot offer: a decomposition of which hazard governs the cordon across the charge-size range, and a sensitivity study of how the recommendation responds to error in the charge estimate.

1.2 Roadmap

Section 2 reviews the physical scaling, the air-blast parametrisations, the quantity-distance doctrine, the fragmentation criteria, and the TNT-equivalence methods on which the model rests. Section 3 derives each component of the model with its assumptions stated, then defines the combiner that produces the final recommendation. Section 4 presents results: the overpressure field, a comparison between two air-blast parametrisations, the recommended rings, the fragment distances, the governing-hazard decomposition, and the sensitivity analysis, with a summary table of representative cordons. Section 5 describes the implementation and the figure-to-code traceability. Section 6 states the limitations and threats to validity. Section 7 outlines future work, and Section 8 concludes.

2 Background and Related Work

2.1 Hopkinson-Cranz scaling

Practical blast estimation rests almost entirely on the Hopkinson-Cranz cube-root similarity. Two charges of the same explosive but different mass produce, at geometrically scaled distances, the same peak overpressure and a positive-phase impulse that scales with the cube root of the mass ratio (Baker et al., 1983; Cooper, 1996). The similarity collapses an otherwise two-parameter family of blast curves onto a single charge-independent curve in the scaled distance

$$Z = \frac{R}{W^{1/3}}, \tag{1}$$

where R is range and W is charge mass. The cube root appears because the energy released scales with mass while the volume into which it expands scales with the cube of a length, so equal effects occur at ranges proportional to $W^{1/3}$. Equation 1 is the backbone of every component that follows. The quantity-distance rules in explosive-safety regulation are themselves expressions of the same similarity, written as $D = K\,W^{1/3}$ with K chosen for the required level of protection (U.S. Department of Defense, 2008, 2019).

2.2 Air-blast parametrisations

Peak incident overpressure as a function of scaled distance has a long history of parametrisation. Brode (1955) produced numerical solutions of the spherical blast wave that are still used as a compact analytic form across a wide scaled-distance band. Kingery and Bulmash (1984) fit high-order polynomials in the logarithm of scaled distance to a large body of measured and computed data for spherical air bursts and hemispherical surface bursts, and these fits, often accessed through the simplified coefficients of Swisdak (1994), are the de facto reference for blast parameters in safety engineering. Mills (1987) gives a compact closed-form correlation that is convenient for embedded computation. These parametrisations agree closely in the far field, where the blast wave is well into its decay, and they diverge near the charge, where the overpressure curve is nearly vertical and small errors in range produce large errors in pressure. Section 4 quantifies that agreement and divergence directly.

2.3 Quantity-distance and K-factor doctrine

Explosive-safety regulation expresses safe separation through scaled-distance, or K-factor, criteria (U.S. Department of Defense, 2019). A K-factor distance is the scaled-distance form $D = K\,W^{1/3}$ evaluated for a posture-specific constant K. Two postures matter for the cordon problem. The inner posture protects essential personnel who must be present, against an unintentional detonation, and corresponds to a low value of K and a modest overpressure at the line. The outer posture protects non-essential personnel who can be withdrawn, against an intentional detonation, and corresponds to a large value of K where the overpressure at the line is harmless and fragmentation becomes the controlling hazard (U.S. Department of Defense, 2019; U.S. Navy, 2017). Each posture also carries a published minimum distance, a floor below which the cordon is never set regardless of the computed scaled distance.

2.4 Fragmentation hazard

Cased charges throw fragments well beyond the air-blast hazard, and for the outer cordon fragmentation, not overpressure, usually governs. Safety practice distinguishes the maximum fragment distance, the farthest any fragment is thrown, from the hazardous fragment distance, the range at which the areal density of hazardous fragments falls to the accepted criterion of one hazardous fragment per $600\,\mathrm{ft}^2$ (Department of Defense Explosives Safety Board, 2009). A hazardous fragment is conventionally one carrying at least 58 ft-pound of kinetic energy. Both distances are commonly estimated from net explosive weight, refined by the casing type, since a heavily cased item throws farther than a lightly cased one of the same fill.

2.5 TNT equivalence

Field charges are rarely TNT, and the blast correlations are written in terms of TNT. The standard remedy is TNT equivalence, a multiplicative factor that converts the mass of a given explosive into the mass of TNT that produces the same blast effect (Cooper, 1996; U.S. Department of Defense, 2008). Equivalence is not a single number. It differs for peak pressure and for impulse, and it varies with charge geometry and standoff, so any equivalence factor carries an inherent spread that should be propagated rather than hidden.

3 Model

This section derives each component, states its assumptions, and defines the combiner. Throughout, distances are computed internally in the unit native to each correlation and converted to metres for output.

3.1 Scaled-distance standoff

For net explosive weight W in pounds and posture constant K, the K-factor distance is

$$D_K = K\,W^{1/3} \quad (\mathrm{ft}), \tag{2}$$

which is Equation 1 rearranged for the range at a fixed scaled distance $Z = K$. The model uses two postures. The inner working line takes $K = 50$, which corresponds to an overpressure at the line of roughly 0.90 psi, attenuated and behind cover, appropriate for essential personnel facing an unintentional function. The outer evacuation line takes $K = 328$, where the overpressure at the line is on the order of hundredths of a psi and is therefore harmless, so fragmentation governs the outer posture (U.S. Department of Defense, 2019; U.S. Navy, 2017).

The assumption embedded in Equation 2 is pure cube-root scaling with no floor. That assumption fails at small charges, where the scaled distance shrinks below the distance a responder must keep for reasons unrelated to blast physics, such as the working room the team needs and the published evacuation minimum. The model therefore floors each posture,

$$D_{\mathrm{floor}} = \begin{cases} 200\,\mathrm{ft} & \text{inner posture,} \\ 1250\,\mathrm{ft} & \text{outer posture,} \end{cases} \tag{3}$$

and never recommends less than the applicable floor. Equation 3 is a regulatory minimum, not a physical result, and it is stated separately for exactly that reason.

3.2 Air-blast overpressure decay

The model evaluates peak incident overpressure $p_s(Z)$ from a far-field parametrisation valid over a stated scaled-distance band. Two practical issues shape the implementation. First, every parametrisation has a validity range, and below its lower bound the fit is undefined. Second, the curve is nearly vertical close to the charge, so a small error in range, or in a smoothed position fix on a wearable device, swings the reported pressure by a large factor. The model addresses both with a near-field clamp: below the validity floor of the parametrisation in Z, the model holds the overpressure at the value implied by the floor rather than extrapolating the fit toward a singularity. The clamp keeps the reported pressure stable and bounded, and it never reduces the cordon, because the cordon is governed by distance criteria, not by the clamped pressure value.

Figure 1 shows the overpressure decay for three charge sizes. The cube-root scaling of Equation 1 is visible as a near-constant horizontal offset between the curves on logarithmic axes, since multiplying the charge by a factor shifts the whole curve by that factor to the one-third power in range.

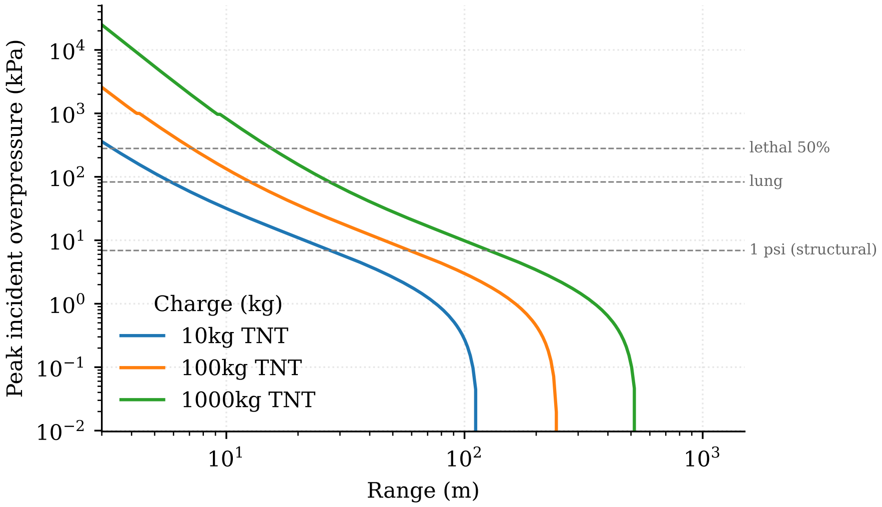

Figure 1. Peak incident overpressure versus range for 10, 100, and 1000 kg TNT, generated from the shipped air-blast model. Horizontal references mark the structural (≈1 psi), lung, and 50 % lethal overpressure levels.

3.3 TNT equivalence and uncertainty propagation

The model converts net explosive mass m of an explosive with peak-pressure equivalence factor η to a TNT-equivalent mass before applying the blast correlation,

$$W_{\text{TNT}} = \eta\, m, \tag{4}$$

and it carries a spread on the result rather than implying false precision. The implementation uses a nominal band of roughly ±12% around the central equivalence, which reflects the spread between equivalence methods and the sensitivity of the factor to geometry (Cooper, 1996; U.S. Department of Defense, 2008). Because the blast correlation is monotone in W_{TNT}, the equivalence band maps directly to a band on overpressure at a fixed range, and to a band on the standoff at a fixed overpressure. The equivalence factor enters the pressure-governed parts of the model; the scaled-distance criteria of Equation 2 use net explosive weight directly, as the regulation specifies.

3.4 Fragment hazard range

Maximum fragment distance (MFD-H) and hazardous fragment distance (HFD) are estimated from net explosive weight by a log-polynomial regression,

$$\ln D_{\text{frag}} = a + b\,\ln W + c\,(\ln W)^2 + d\,(\ln W)^3, \tag{5}$$

with a separate coefficient set per casing category, ordered from a non-robustly cased item through a robustly cased item to a heavily cased item. When the casing is unknown, the model takes the maximum across categories, which produces the most conservative, that is the largest, cordon. A companion vertical estimate (MFD-V) bounds the overhead hazard but does not enter the horizontal cordon.

Figure 2 shows MFD-H and HFD against charge size. HFD is always less than MFD-H, since the hazardous-density criterion is reached before the absolute maximum throw, and both grow sub-linearly with charge because Equation 5 is concave in $\ln W$ over the range of interest.

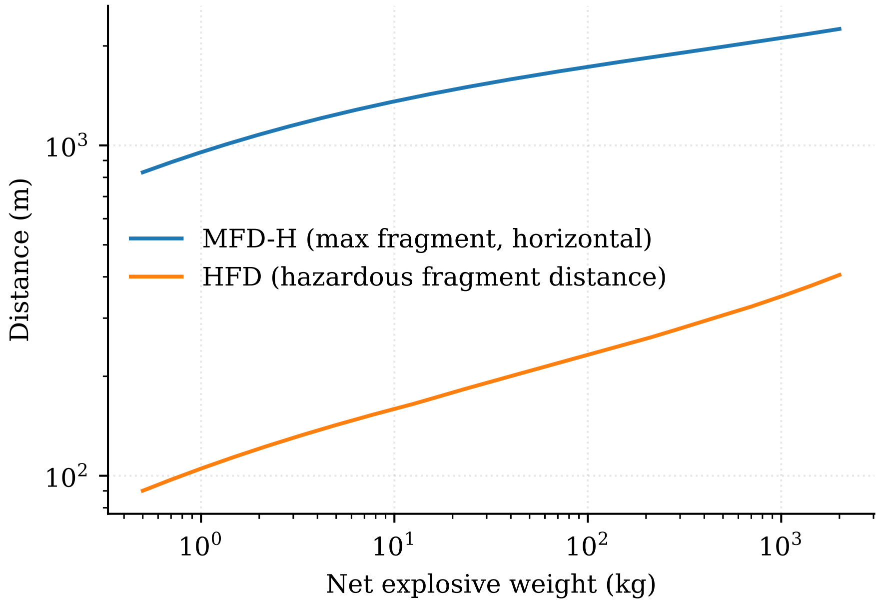

Figure 2. Maximum fragment distance (MFD-H) and hazardous fragment distance (HFD) versus net explosive weight, conservative maximum across casing categories, generated from the shipped fragment model.

3.5 The cordon combiner

The recommended standoff for each posture is the most protective of the three inputs,

$$D_{\text{rec}} = \max(D_K,\ D_{\text{floor}},\ D_{\text{frag}})\,, \tag{6}$$

and the model records which term attained the maximum. The inner posture uses HFD as its fragment input, the outer posture uses MFD-H, so each line grows to its fragment distance whenever fragmentation outranges the scaled-distance and floor terms. Equation 6 is deliberately a maximum and not an average. A cordon must protect against the controlling hazard, so the most protective term wins, and averaging would let a small term pull the recommendation below a real hazard line. Recording the governing term costs nothing and turns the single output into an explanation, which is the central design choice of the model.

4 Results

4.1 Air-blast model comparison

Figure 3 compares two air-blast parametrisations, the compact Mills correlation and the Brode form, across scaled distance. The two agree closely through the far and intermediate field, which supports using either for cordon-scale standoffs, and they separate near the charge, exactly the regime the near-field clamp is designed to manage. The agreement in the cordon-relevant band is the practical justification for the model's choice of a single far-field fit with a clamp, rather than a more elaborate piecewise scheme.

4.2 Recommended rings

Figure 4 shows the inner and outer recommended lines across charge size from the scaled-distance and floor terms. At small charges both lines are flat, held at their respective floors, since the scaled-distance term has not yet reached the regulatory minimum. As charge size grows, each line lifts off its floor and follows the cube-root scaling of Equation 2, appearing as a straight line of slope one-third on logarithmic axes.

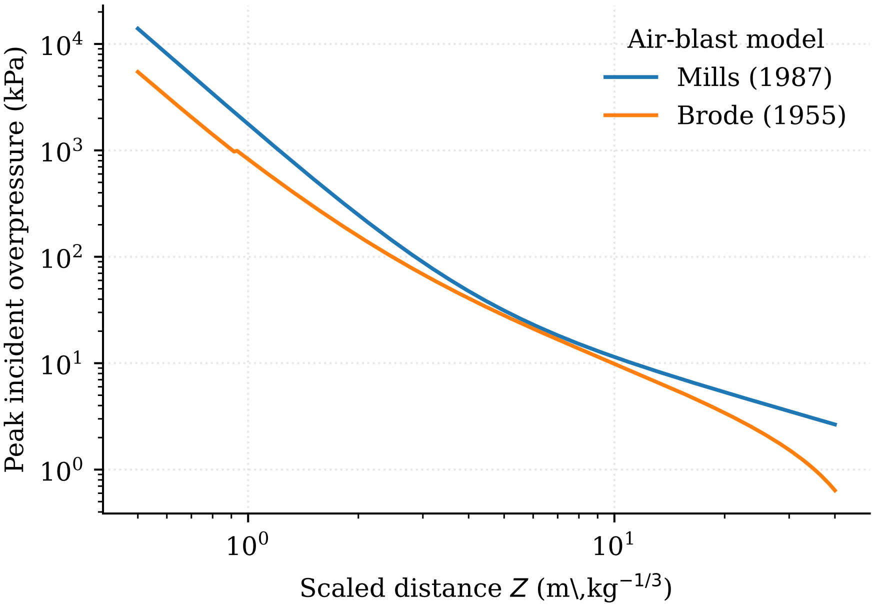

Figure 3. Peak incident overpressure versus scaled distance for the Mills and Brode parametrisations, generated from the shipped models. The two agree across the cordon-relevant band and diverge only near the charge.

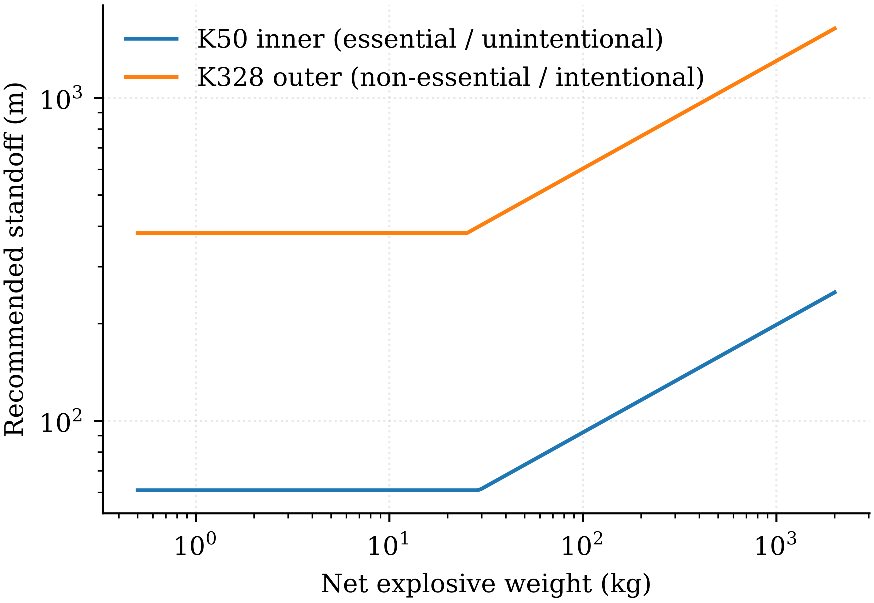

Figure 4. Inner (K50) and outer (K328) recommended standoff versus net explosive weight. At small charges the doctrinal floor governs; the scaled-distance term overtakes it as charge size grows.

4.3 Which hazard governs

The value of reporting the governing term is clearest in Figure 5, which colours the outer recommended cordon by the term that attained the maximum in Equation 6. The figure is computed for a lightly cased (non-robustly cased, NROB) item, because that is the case in which all three regimes are visible. At the smallest charges the published floor dominates, because neither blast nor fragment physics has reached the minimum evacuation distance. Across the broad middle of the range fragmentation governs, because even a lightly cased item throws fragments past the harmless outer-posture overpressure. At large charges, where the cube-root scaled distance finally overtakes the sub-linear fragment growth of Equation 5, the scaled-distance term governs.

The casing assumption matters here, and the model is explicit about it. With the casing unknown the model takes the conservative maximum over casing categories (Section 4, Table 1), and in that default the fragment term governs the outer line across the entire charge range, because the maximum-throw envelope exceeds both the scaled-distance and floor terms everywhere. A responder who sees only a distance cannot tell which regime they are in. A responder who sees the governing term knows immediately whether a better charge estimate, a casing observation, or simply holding the floor would change the answer, and can direct limited reconnaissance effort accordingly.

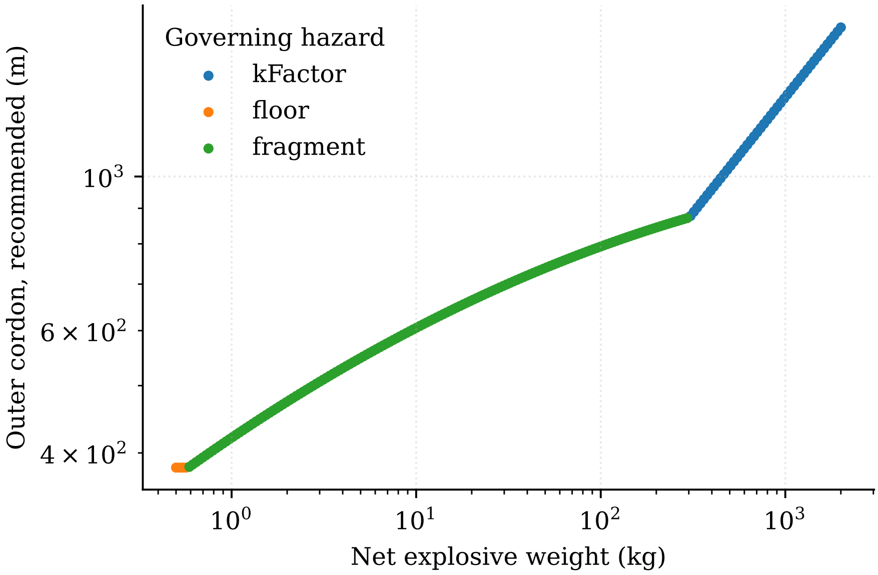

Figure 5. Outer recommended cordon versus net explosive weight for a lightly cased (NROB) item, coloured by the governing hazard. The transition from floor to fragment to scaled distance is a property of the combiner in Equation 6, not an input. Under the conservative maximum-over-casing default, fragmentation governs the outer line throughout.

4.4 Comparison with conventional calculators

A cordon model is only trustworthy if it reproduces the standard references in the regime where those references apply, and departs from them only for stated physical reasons. This section closes that loop against the two conventional tools an EOD team already carries: the bare K-factor calculator, which returns the pure scaled distance $D = K\,W^{1/3}$ with the floor applied by hand, and the published DHS/ATF bomb-threat standoff card, which gives a mandatory evacuation distance and a larger preferred distance as a function of charge mass (U.S. Department of Homeland Security & Bureau of Alcohol, Tobacco, Firearms and Explosives, 2016).

Figure 6 overlays the shipped recommendation on both references. On the inner working line the shipped value tracks the bare K50 calculator but sits above it, because the inner line is lifted by the hazardous fragment distance and the working-area floor that a bare calculator leaves to the operator. On the outer evacuation line the shipped value sits above the bare K328 calculator and above both DHS card distances across the whole range. The reason is physical and is the central point of the comparison: the bare K-factor and the DHS card are overpressure-referenced, so neither accounts for the maximum fragment throw of a cased item, whereas the shipped combiner does through Equation 5. Where the references are overpressure-driven, the shipped model agrees with their shape; where fragmentation is the controlling hazard, the shipped model is deliberately more conservative.

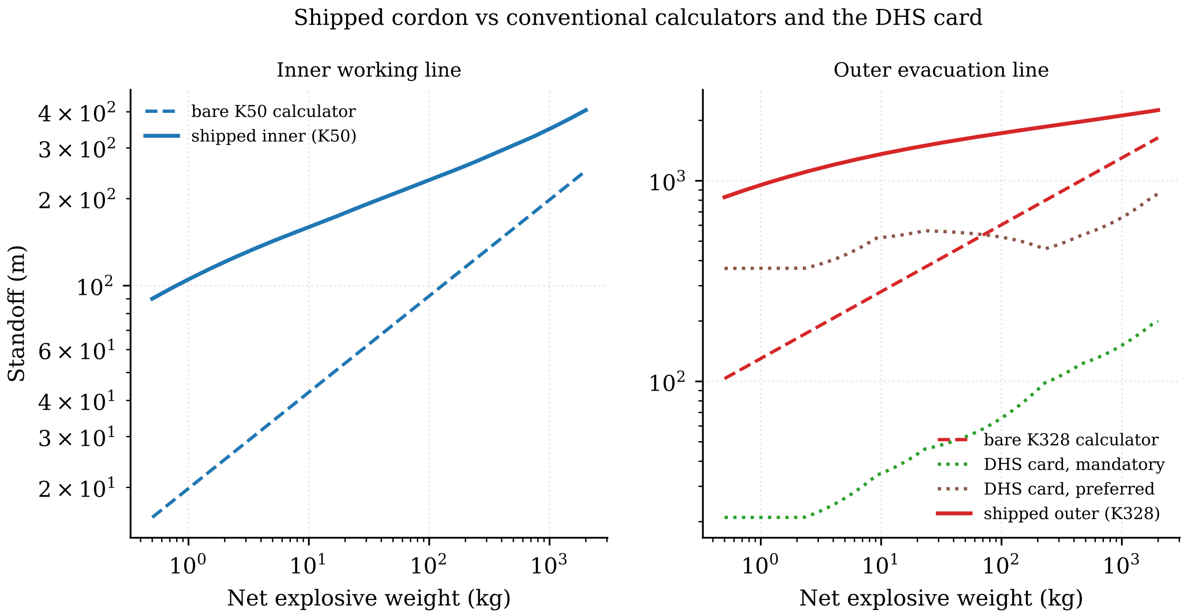

Figure 6. Shipped cordon against conventional calculators. Left: inner working line versus the bare K50 calculator. Right: outer evacuation line versus the bare K328 calculator and the DHS/ATF standoff card (mandatory and preferred). All curves are generated from the shipped library. The shipped outer line exceeds the overpressure-referenced baselines because it adds the maximum fragment throw.

Table 1 gives the same comparison at the DHS card anchor charges, with exact values produced by the shipped library. The outer line is fragment governed at every row under the conservative maximum-over-casing default, which is why it stands well clear of the overpressure-referenced references. The table is the quantitative form of the claim that the model reproduces the standard tools in their own regime and extends them where fragmentation dominates.

Table 1. Shipped cordon versus conventional references at the DHS card anchor charges (conservative maximum-over-casing). Bare K328 is the pure scaled-distance calculator output; DHS values are the standoff card. All distances in metres, produced by the shipped library and rounded for presentation. The outer line is fragment governed in every row.

NEW (kg)	Bare K328	DHS mand.	DHS pref.	Shipped inner	Shipped outer
9.1	272	34	518	157	1343
23	370	46	564	183	1497
227	794	98	457	266	1859
454	1000	122	534	301	1972
1814	1587	195	838	397	2231

4.5 Sensitivity to charge-estimate error

The charge weight is the least certain input at most incidents, so the model's response to error in it matters as much as its central value. Figure 7 plots the outer recommended cordon against a multiplicative error in the charge estimate, for three nominal charges. The error factor is the ratio of the true charge to the estimated charge, so a factor of two means the charge is twice what was assumed. Two features stand out. In the floor-governed regime the recommendation is flat, so estimation error has no effect at all until the error is large enough to lift the cordon off the floor. In the scaled-distance and fragment regimes the recommendation grows as roughly the cube root of the error factor, so even a large multiplicative error in the charge produces a comparatively gentle change in the cordon. A charge estimate that is wrong by a factor of two moves the cordon by only about a quarter, because the cube root of two is close to 1.26. This cube-root insensitivity is a structural property of scaled distance and is one reason quantity-distance criteria remain useful despite poor charge knowledge.

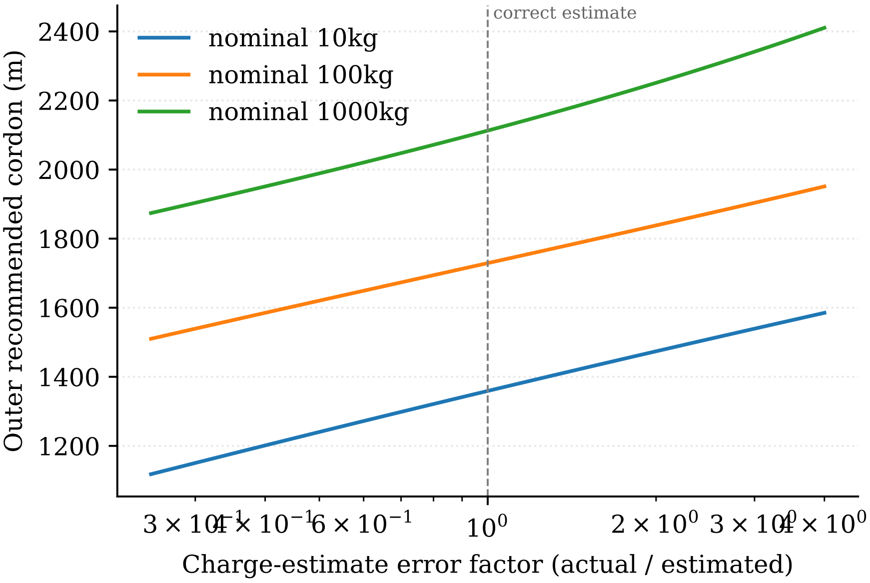

Figure 7. Outer recommended cordon versus multiplicative charge-estimate error, for three nominal charges, generated from the shipped combiner. The flat region is floor-governed and insensitive to error; elsewhere the cordon grows as the cube root of the error factor.

5 Implementation and Traceability

Every model component is implemented once, in a shared software library, and is consumed unchanged by both the planning application and the wrist-worn approach display. The figures in this paper were not redrawn from the equations by hand. They were produced by an export routine that calls the same library functions the field application calls, writes the resulting series to a data file, and renders them. A curve in this paper and the ring drawn on the responder's display therefore originate in the same code path. This is a deliberate design choice. It removes the gap between what a paper claims and what the deployed tool computes, so a reviewer can audit the figures and, by extension, the field behaviour, from a single source of truth.

6 Limitations and Threats to Validity

The blast correlation is a far-field fit and is clamped, not extrapolated, near the charge, so reported pressures very close to the charge are conservative placeholders rather than precise values.

This does not affect the cordon, which is distance-governed, but it does bound the interpretation of the near-field pressure readout discussed in the companion paper. TNT equivalence carries a composition and geometry spread that the model propagates as a band but cannot remove, so a single recommended distance should be read together with that band. The fragment regression is an illustrative estimate that does not know casing precisely, terrain, or launch orientation, and it is therefore used only to size a cordon, never to certify safety; when casing is unknown the model takes the conservative maximum across categories. The model floors every recommendation at the published doctrinal distance precisely so that estimation error cannot produce a cordon smaller than regulation allows, which means that in the floor-governed regime the physics is intentionally inert. Finally, the model addresses the steady-state hazard geometry; it does not model structural shielding, reflection, channelling, or focusing, all of which can locally increase or decrease overpressure and none of which replace command explosive-safety authority.

7 Future Work

Three extensions follow naturally. First, the equivalence band could be carried all the way to the displayed cordon as an explicit uncertainty ring rather than a single line, so the responder sees the confidence interval, not only the point estimate. Second, the fragment model could ingest a casing observation directly, narrowing the conservative maximum to the observed category once reconnaissance provides it. Third, the steady-state geometry could be augmented with a terrain and structure mask, so that the cordon reflects line-of-sight occlusion for fragmentation and diffraction for blast. The companion papers extend the same engine to live exposure during approach and to assignment across simultaneous incidents.

8 Conclusion

A cordon is more defensible when the reasoning behind it is visible. By combining scaled-distance standoff, air-blast decay, and fragment hazard range into a single recommendation that also reports its governing term, by quantifying how that recommendation responds to the charge-estimate error that dominates field uncertainty, and by deriving every figure from the same software that runs in the field, the model turns the cordon from a lookup into an auditable decision. The companion papers in this series extend the same engine to the responder's live approach exposure (Bowen et al., 1968) and to the assignment of attention across multiple simultaneous incidents.

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