Probabilistic Asteroid Impact Risk Model

- **Asteroid Characterization**
- **Input Parameter Distributions**
- **Monte Carlo Sampling**

**PHA Measurements**
- H-magnitude
- Albedo
- Orbital trajectory
- Asteroid class
- Composition

**Impact Parameters**
- Diameter
- Density
- Strength
- Luminous efficiency
- Velocity
- Entry angle
- Azimuth angle
- Impact coordinates

**Flight Integration**
(meteor equations of motion, ablation)

**Airburst Altitude**
(peak energy deposition)

**Initial Conditions**

**Fragment-Cloud Model**
(breakup and energy deposition)

**Blast and Radiation Propagation**

**Thermal Damage**
(3rd degree burns)

**Overpressure Damage**
(Peak overpressure ≥ 4 psi)

**Impact Coordinates**

**Local Land Impact Casualties**
(Gridded population within largest damage area)

**Global Effects Casualties**
(Percentage world population killed by climatic effects)

- H-magnitude
- Albedo
- Orbital trajectory
- Asteroid class
- Composition

- Diameter
- Density
- Strength
- Luminous efficiency
- Velocity
- Entry angle
- Azimuth angle
- Impact coordinates

- Fraction of grid cell population killed

PDC 2019
Ensemble Lornado (Total Casualties, All Hazards)

Ensemble, $H \ 21.7 \pm 0.4 \ (1-\sigma)$

Full Variation

Size

Location

Velocity

Density

Entry Angle

Ablation

Strength/$\alpha$

Lum. Eff.

Affected Population
Day 1 Swath Lornado (Total Casualties, All Hazards)

Day 1 Swath, $H = 21.7 \pm 0.4 (1-\sigma)$

Total Casualties

- Full Variation
- Size
- Swath Location
- Swath Location & Entry
- Density
- Entry Angle
- Ablation
- Strength/$\alpha$
- Velocity
- Lum. Eff.

Affected Population

$10^2$  $10^3$  $10^4$  $10^5$  $10^6$  $10^7$  $10^8$  $10^9$
Comparison of Rotated Swaths

Conditional Damage Risk

Conditional Damage Exceedance Probabilities

Baseline
+10 deg
+45 deg
+90 deg
+180 deg

Probability

Exceedance Probability

Affected Population

Affected Population Threshold

PDC 2019
Hazard Breakdown

- Ensemble impacts most likely to cause no ground damage.
- Day 1 corridor impacts most likely to cause local blast damage.
- Tsunami risk ~10% of blast risk.
- Thermal and global effects unlikely drivers in current results.
Ensemble Risk Assessment

- Uncertainty in scenario specific details swamp modeling fidelity related to
  - Blast overpressure
  - Asteroid Generated Tsunami
- Thermal radiation damage appears bounded by blast overpressure, but luminous efficiency values highly (100x) uncertain.
  - Need to quantify luminous efficiency uncertainty relative to thermal damage
- Global effects models for ensemble risk assessment are ad hoc and need basis in higher fidelity modeling.
- Regional impacts (local weather, flight pattern disruption, etc.) completely unrepresented in current ensemble risk modeling.

The NEO SDT report (2017) showed that long-term expected casualties driven by large impact scenarios.
Scenario Risk Assessment

- Initial uncertainty dictates that scenario assessments begin like ensemble assessments.
  - Balance of modeling accuracy versus state of knowledge (inputs) is key.
- Once scenario evolves, higher fidelity tools exist but best practices need to be established
  - Blast overpressure
  - Asteroid Generated tsunami
  - Thermal radiation
- Regional/global impact consequences have been assessed for specific cases, but broader analysis requirements need to be defined.
Mitigation Uncertainty for Risk Assessment

**EXERCISE**

**PDC2019 Hypothetical Example—Day 3 Example**

- Earth impact probability reduced to 30.7% (from 100% in the non-deflected case)
- Remaining possible impacts shift from Denver to Africa
- Average affected population reduced by 52.0% from 302,000 to 145,000
- Risk of largest affected population numbers increases greatly
Summary

• Ensemble hazard assessment models adequately bound risk for sub-global impacts.
• Scenario specific assessment techniques exist but require establishment of current best practices
  • Blast overpressure
  • Asteroid generated tsunami
• Thermal radiation appears bounded by blast overpressure, but uncertainty of luminous efficiency needs quantification.
• Regional/global effects models need development
  • Link impact/ejecta and climate models for scenario assessment
  • Create new set of reduced order models for ensemble risk assessment
• Link between mitigation uncertainty and impact risk in initial stages and needs development to inform mission design.
Impactor Property Distributions

- Diameter (m):
  - Mean: 203
  - Median: 161
  - 5th/95th%: 93 - 431

- Density (g/cm³):
  - Mean: 2.260
  - Median: 2.171
  - 5th/95th%: 1.322 - 3.270

- Energy (Mt):
  - Mean: 887
  - Median: 207
  - 5th/95th%: 35 - 4027

HYPOTHETICAL EXERCISE ONLY