2021 PDC Hypothetical Impact Exercise: Probabilistic Asteroid Impact Risk

Scenario Day 1

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HYPOTHETICAL EXERCISE

Asteroid Impact Threat Assessment

Probabilistic Asteroid Impact Risk (PAIR) Model

Asteroid Properties & Entry Parameters

Entry & Breakup Modeling

Surface Hazards
- Thermal
- Blast
- Population
- Tsunami

Impact Threat Scenario

Asteroid Property Distributions

Orbital Entry Parameters (JPL/CNEOS)

Probabilistic Risk and Damage

Orbital Entry Parameters (JPL/CNEOS)
Impact Risk Summary

Characterization Summary & Updates
- Assessment date: 26 April 2021 (initial discovery)
- Potential impact date: 20 October 2021 (6 mo.)
- Earth impact probability: 5%
- Diameter: 35–700 m, ~150 m average
- Energy: 1 Mt – 13 Gt, 256 Mt average
- Properties: unknown type or physical properties

Hazard Summary
- Potential damage sizes, severities, and locations remain very uncertain
- Primary hazard: airburst/impact causing blast overpressure, from minor structural damage to potentially unsurvivable levels
- Damage radii: 0–470 km, ~90 km average
- Affected Population: 0–86M, 6k average
- 97% chance of no damage, with small chances of affecting thousands to millions of people
Entry Parameters & Locations

5% chance of Earth impact with potential impact regions spanning most of the globe, centered around mid-Atlantic

- Entry parameters vary across the globe, but are well-known for given impact points
- **Entry Angle:**
  - Vertical (90°) entries near mid-Atlantic
  - Shallow/skimming entries near edges
- **Entry Velocity:**
  - 15-16 km/s
  - Little variation across points
- Velocity determines impactor energy and entry angle affects burst altitude ranges for damage models

[Impact entry data: P. Chodas, CNEOS/JPL]
https://cneos.jpl.nasa.gov/pdl/cs/pdc21/
Asteroid Properties

- Asteroid sizes and properties are highly uncertain, ranging from small objects that would pose little threat to objects hundreds of meters across with gigatons of impact energy.

- Maximum sizes are very large, but also very unlikely

- Averages are ~150 m, 250 Mt

- Likelier size ranges are smaller

- Type and properties are unknown, ranging from more common stony types to rare iron types

### Asteroid Size Ranges

<table>
<thead>
<tr>
<th></th>
<th>Diameter (m)</th>
<th>Energy (Mt)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full range</td>
<td>35–700</td>
<td>1–13,000</td>
<td>4.4e7–4.4e11</td>
</tr>
<tr>
<td>Average</td>
<td>150</td>
<td>250</td>
<td>9.1e9</td>
</tr>
<tr>
<td>Median</td>
<td>118</td>
<td>52</td>
<td>1.8e9</td>
</tr>
<tr>
<td>Most likely</td>
<td>~65–125</td>
<td>~20–50</td>
<td>~1e9</td>
</tr>
<tr>
<td>5th–95th %</td>
<td>65–350</td>
<td>~8–1280</td>
<td>3e8–4.5e10</td>
</tr>
</tbody>
</table>

(Property inference model: J. Dotson PDC 2021)
Affected population ranges from 0 to tens of millions across the globe, depending on population density and damage ranges

- Average affected population range: 0–10M across entry points (117k overall avg.)
- Max affected population range: 0–86M across entry points (1M avg. max among all points)
- Worst case maximum is at very edge of potential impact zone (unlikely skimming entry)

Maps of average and maximum affected population for each sampled impact entry point, given the potential range in asteroid properties and resulting damage
(ocean points represent tsunami damage to surrounding coastal regions)
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Hazard Sources
(relative hazard risks among 5% Earth-impacting cases)

- Blast damage is the predominant hazard source in ~50% of impact cases
- Thermal damage also occurs in ~16% of cases, but is smaller and less severe than blast damage in nearly all cases
- Risk of tsunami is low, occurring in ~3% of impact cases, but the largest impacts could cause significant inundation
- No global effects are expected, but potential for regional environmental effects from larger impacts is unknown
- No damage occurs in 48% of cases

<table>
<thead>
<tr>
<th>Hazard Source</th>
<th>% Cases Hazard Occurs</th>
<th>% Cases Hazard Drives Damage</th>
<th>Average Affected Population</th>
<th>Affected Population Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast</td>
<td>50%</td>
<td>49%</td>
<td>117,000</td>
<td>0–86M</td>
</tr>
<tr>
<td>Thermal</td>
<td>16%</td>
<td>0.2%</td>
<td>8,000</td>
<td>0–48M</td>
</tr>
<tr>
<td>Tsunami</td>
<td>3.5%</td>
<td>2.8%</td>
<td>940</td>
<td>0–1.8M</td>
</tr>
<tr>
<td>No Damage</td>
<td>48%</td>
<td>48%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Sample Blast Damage Sizes
(regional sizes for an entry point near Alexandria, Egypt)

**Median** (bigger than 50% of damage areas)

- 60 km

**Average**

- 90 km

**Max**

- 300 km

- 600 km

**25th %** (bigger than 25% of damage areas)

- 40 km

**75th %** (bigger than 75% of damage areas)

- 140 km

**95th %** (bigger than 95% of damage areas)

- 190 km
HYPOTHETICAL EXERCISE

Total Affected Population Risks
(Total Risk with 5% Earth Impact Probability)

- **Average affected population:** ~6k total (with 5% impact probability), ~117k among Earth-impacting cases (~50% of which cause some population damage)
- **No damage most likely:** >97% chance of no people affected (with 5% impact probability)
- **Maximum affected population:** 86 million people (but very unlikely)
- **Only 0.14% total chance of affecting over 1M people, 0.004% chance of >10M people**
Impact Risk Summary

- Object size, potential impact location, and resulting damage all remain highly uncertain
  - Earth impact probability is still low (5%)
  - Maximum impactor sizes and damage consequences are very large, but also very unlikely
- Affected Population Risks:
  - Range 0–86M people, average total population risk of 6,000 people
  - No population damage is most likely (97% total chance, 48% chance among impacting cases).
  - ~2% chance of affecting >1000 people, 1.3% chance of >10,000 people, 0.14% of >1 million people
- Hazard Summary:
  - Blast damage is the predominant hazard source, with potential ground damage radii up to several hundred kilometers
  - Thermal and tsunami damage are also possible, but less likely and less severe
  - No large-scale global effects expected, but potential for regional environmental or economic effects remains unknown.

<table>
<thead>
<tr>
<th></th>
<th>Asteroid Diameter (m)</th>
<th>Impact Energy (Mt)</th>
<th>Damage Radius (km) (given impact)</th>
<th>Affected Population (given impact)</th>
<th>Affected Population (5% impact)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full range</td>
<td>~35–700</td>
<td>~1–13,000</td>
<td>0–470</td>
<td>0–86M</td>
<td>0–86M</td>
</tr>
<tr>
<td>Average</td>
<td>150</td>
<td>250</td>
<td>90</td>
<td>117k</td>
<td>6k</td>
</tr>
<tr>
<td>Most likely</td>
<td>~65–125</td>
<td>~20–50</td>
<td>~20–60</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5th–95th %</td>
<td>65–350</td>
<td>8–1280</td>
<td>25–190</td>
<td>0–550k</td>
<td>0–0</td>
</tr>
</tbody>
</table>
Risk Assessment Next Steps

• Continuing Threat Assessment:
  • Updated risk assessments will be performed as additional information is gained about the object and potential impact
  • More detailed risk analysis and damage simulations can be performed for critical hazards as impact location and object size are refined

• Risk Information for Decisions and Response Support:
  • Probabilistic risks enable response decisions to consider both the severity and relative likelihood of potential impact consequences, given large uncertainties
  • Asteroid property distributions will be provided to mission designers to inform mitigation capability requirements
  • Risk assessments can be performed to evaluate the benefit of proposed mitigation or reconnaissance mission options
  • Damage area probabilities can support preliminary disaster response planning to prepare for potentially large damage within short warning time
REFERENCES
Related PDC 2021 Presentations

Asteroid Property Inference

- Dotson et al., “Bayesian Inference of Asteroid Physical Properties: Application to Impact Scenarios” (Impact Effects Session 9b)
- Kelley et al., “IAWN Planetary Defense Exercise: Apophis Observing Campaign 2020-2021” (Apophis Session 13)

Impact Effects – Hazard Modeling & Simulation

- Wheeler et al., “Probabilistic Blast Damage Modeling Uncertainties and Sensitivities” (Impact Effects e-lighting talks)
- Mathias et al., “Interaction of Meteoroid Fragments During Atmospheric Entry” (Impact Effects e-lighting talks)
- Coates et al., “Comparison of Thermal Radiation Damage Models and Parameters for Impact Risk Assessment” (Impact Effects e-lighting talks)
- Berger and LeVeque, “Towards Adaptive Simulation of Dispersive Tsunami Propagation from an Asteroid Impact” (Impact Effects Session 9b)
- Titus et al., “Asteroid Impacts – Downwind and Downstream Effects” (Impact Effects Session 9b)
- Boslough, “Airburst Consequence Modeling Using Artificial Ablation” (Impact Effects e-lighting talks)

Mitigation & Mission Design

- Barbee et al., “Risk-Informed Spacecraft Mission Design for the 2021 PDC Hypothetical Asteroid Impact Scenario” (Mission & Campaign Design Session 8b)
References

Probabilistic Asteroid Impact Risk (PAIR) Model

Entry & Breakup Energy Deposition Modeling

Blast Simulations and Modeling

Tsunami Simulations

Thermal Radiation Modeling and Simulation