Implementation of the MPOG
(Mission Planning and Operations Group)

Rusty Schweickart
ASE-NEO Committee
Dia = ~ 7 meter
Vinf = 17.1 km/sec
Min miss = ~ 45K km (8.3 Earth radii)
Energy imp = ~ 250 KT

ΔV imparted = ~1.5 km/sec

Association of Space Explorers
A Decision Program re NEO threats, submitted to the UN by the ASE and its international Panel on Asteroid Threat Mitigation

Presented to STSC in February 09 & full COPUOS in June 09. Being coordinated within COPUOS by Action Team-14
Members of the ASE Committee on Near Earth Objects
Rusty Schweickart, Chair
Sergei Avdeev (Russia)
Chris Hadfield (Canada)
Thomas Jones (USA)
Edward Lu (USA)
Dumitru Prunariu (Romania)
Viktor Savinykh (Russia)
Franklin Chang-Diaz (USA/Costa Rica)

Members of the Panel on Asteroid Threat Mitigation
Adigun Ade Abiodun, Nigeria
Vallampadugai Arunachalam, India
Roger-Maurice Bonnet, Switzerland
Sergio Camacho-Lara, Mexico
James George, Canada
Tomifumi Godai, Japan
Peter Jankowitsch, Austria
Sergey Kapitza, Russia
Paul Kovacs, Canada
Walther Lichem, Austria
Gordon McBean, Canada
Lord Martin Rees, United Kingdom
Karlene Roberts, United States
Michael Simpson, United States
Sir Crispin Tickell, United Kingdom
Richard Tremayne-Smith, United Kingdom
Frans von der Dunk, Netherlands
James Zimmerman, United States
Key Recommendations
Defined functional responsibilities

United Nations Security Council

MAOG
Mission Authorization and Oversight Group

IAWN
Information, Analysis, and Warning Network

MPOG
Mission Planning and Operations Group
Agenda

1) Early Warning
2) Orbital Dynamics
3) Deflection Options
Early Warning

1) NEO Inventory
2) Statistical size-frequency distribution
3) Future discovery rate
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Known Near-Earth Asteroids
1980-Jan through 2010-Jun

- > 1,000,000 Total by ~2025
- > 300,000 Tunguska or larger

16 July 2010
Alan B. Chamberlin (JPL)
Near-Earth Asteroids
Total Discovered per Size Bin

<table>
<thead>
<tr>
<th>Estimated Diameter (m)</th>
<th>Total Discovered</th>
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<tbody>
<tr>
<td>&lt;0.5%</td>
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<td>1000</td>
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</tr>
</tbody>
</table>

16 July 2010
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Thousands of objects that could take 10 to 20 years to see from Earth

- Poor detection efficiency from Earth
- Nominal search region available from Earth

- 0.71 AU (Venus' Orbit)
- 1 AU (Earth's Orbit)
- ~0.70 AU (Spacecraft Orbit)

NEO Survey Observatory

Search region available for the NEO Survey Observatory

Represented orbits are to scale.
These results were computed on Oct 07, 2009

99942 Apophis (2004 MN4)
Earth Impact Table

<table>
<thead>
<tr>
<th>Date</th>
<th>Distance</th>
<th>Width</th>
<th>Sigma Impact</th>
<th>Sigma LOV</th>
<th>Stretch LOV</th>
<th>Impact Probability</th>
<th>Impact Energy</th>
<th>Palermo Scale</th>
<th>Torino Scale</th>
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<td>(r_Earth)</td>
<td>(r_Earth)</td>
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</table>

Analysis based on 2 radar delay, 5 Doppler, and 633 optical observations spanning 1395.6 days (2004-Mar-15.10789 to 2008-Jan-09.665088)

Energy | 5.1e+02 MT
all above are mean values weighted by impact probability

Orbit diagram and elements available [here](#).
### Orbital Elements at Epoch 2455400.5 (2010-Jul-23.0) TDB Reference: JPL 144 (heliocentric ecliptic J2000)

<table>
<thead>
<tr>
<th>Element</th>
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<th>Uncertainty (1-sigma)</th>
<th>Units</th>
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</table>

### Orbit Determination Parameters
- # obs. used (total): 640
- # delay obs. used: 2
- # Doppler obs. used: 5
- data-arc span: 1395 days (3.82 yr)
- first obs. used: 2004-03-15
- last obs. used: 2008-01-09
- planetary ephem.: DE405
- SB-pert. ephem.: SB-BIG16-1
- condition code: 0
- fit RMS: 0.48956
- data source: ORB
- producer: Steven R. Chesley
- solution date: 2009-Oct-23 11:54:34

### Additional Information
- Earth MOID = 8.12667E-5 AU
- T_jup = 6.467
Orbital Dynamics

1) Geometry
2) Line of Variations (LOV)
3) Keyholes
4) Risk corridor & implications
MOID – minimum orbit intersection distance
LOV – line of variation
Apophis

Close Encounter Geometry

- **V\text{inf}** = 5.87 km/sec
- DeltaV = 2.83 km/sec
- Angle = 28\(^\circ\)

**Incoming Period**
- \(P = 323.588\) days
- = 0.886 yrs

**Outgoing Period**
- \(P = \approx 426.125\) days
- = 1.167 yrs
Resonances & Keyholes
Early Apophis situation as example

Note: all calculations based on JPL data as of 4/11/05.

Return date: 2048
Orbital period, days: 408 (currently 323 days)

Centroid:
- 3-sigma error ellipse:
  - 2.96 Re
  - 18,960 km

Period calculation:
(426.125 days − 3.4 minutes) = Period = 426.12499 days
Both strength **AND** precision are needed for a successful deflection campaign.

Total impulse required:
- $1.15 \times 10^8$ newton seconds
- 10,900 kilometers ($5,140 \times 2.12$)

Primary Deflection = Miss the Earth

Shepherding = Guide between keyholes

Total impulse required:
- $1 \times 10^4$ newton seconds
- 0.6 kilometers

12,840 kilometers
Risk Corridor, Apophis, 13 Apr 2036
Deflection Options
(characteristics & capabilities)

1) $\Delta V$ required (1 Earth radius)
2) Targetting (minimum miss?)
3) Precision to avoid Keyholes
4) Kinetic Impact & Nuclear
5) Gravity tractor (or equivalent)
6) Deflection Campaign
Δv plot: NEO 2004 MN4

Along track positive Δv: thick line
Along track negative Δv: thin line

Impact date: 2036 Apr. 13, 08:51:40 UT

Keyholes and ΔV requirement
Current Deflection Capability

Kinetic Impact

Pushes the asteroid via direct impact
(KI = robust but imprecise)

Gravity Tractor

Pulls the asteroid using mutual gravity as a tow-rope
(GT = weak but precise)
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Nuclear Explosion
Explodes surface off NEO
to create impulsive push
Keyholes and $\Delta V$ requirement

Gravity Tractor
1 metric ton
1 year
x10
Kinetic Impactor
1 metric ton @ 5 km/sec
x1

Impact date: 2036 Apr. 13, 08:51:40 UT

12.4 days @ 0.4n = 42,160 ns
Key Parameter
– Total Impulse –
(= NEO momentum change)
(Units = n-sec or kg-m/sec)

Kinetic Impact*
\[ M\Delta V_{NEO} = \beta mV_{IMP} \]
\[ \Delta V_{NEO} = \beta (m/M)V_{IMP} \]
\[ 2 < \beta < 10 \]

Gravity Tractor
\[ F = GMm/r^2 \]
\[ \Delta V_{NEO} = tGm/r^2 \]
Independent of M

* Nuclear standoff explosion subject to different but comparable uncertainties.
Primary Deflection

Multiple keyholes within uncertainty zone
Secondary Deflection or Shepherding the NEO error ellipse

Step 1
- collapse the primary deflection error ellipse

Step 2
- shepherd the error ellipse between adjacent keyholes

Probability of success goal
1:1,000 - ~ 3\sigma error ellipse
1:1,000,000 - ~ 5\sigma error ellipse
Discussion
Association of Space Explorers

Oct. 12, 2010
Association of Space Explorers

Earth Distance: 4.0E-4 AU
Sun Distance: 0.998 AU

Oct 12, 2010