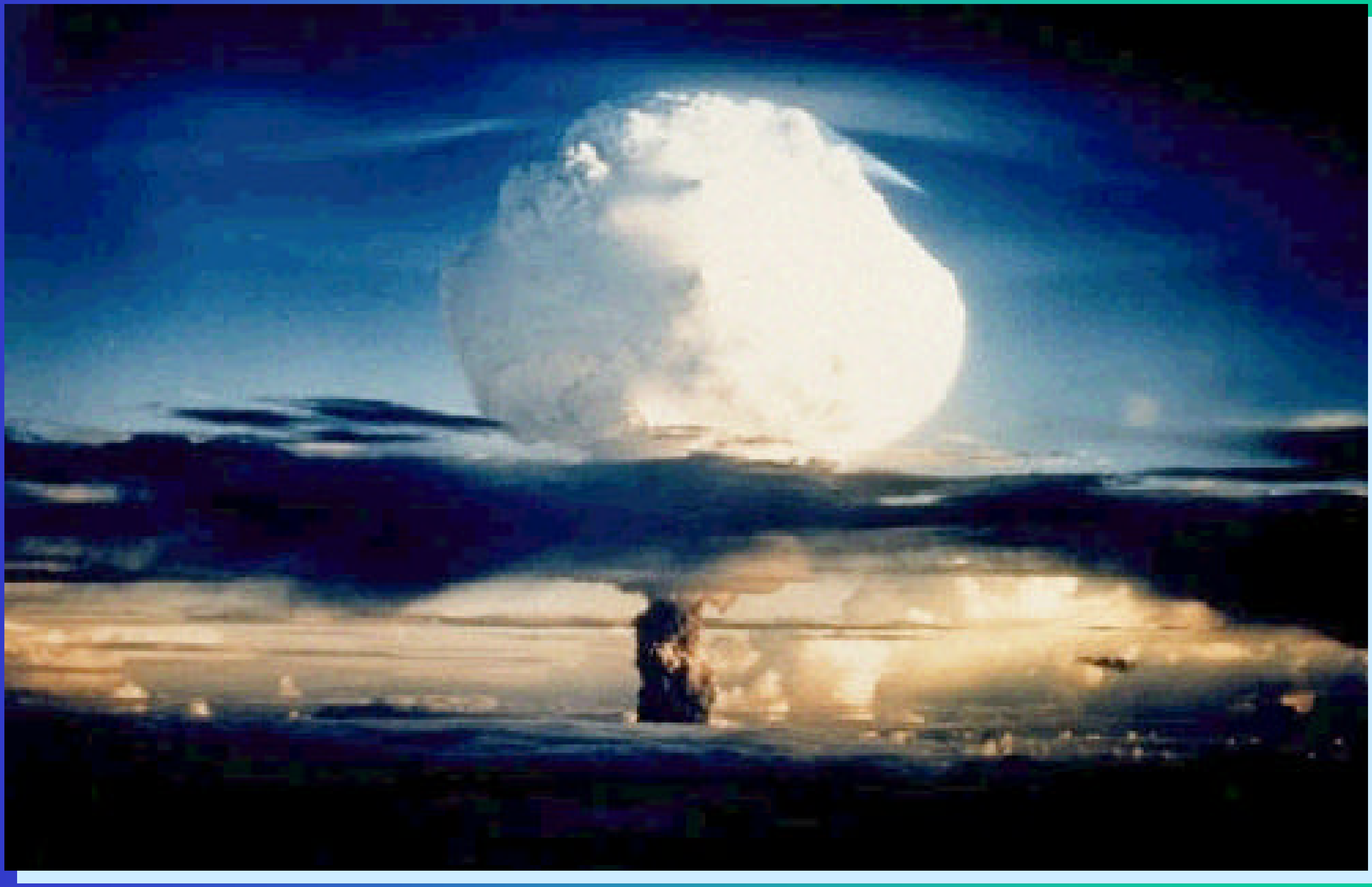
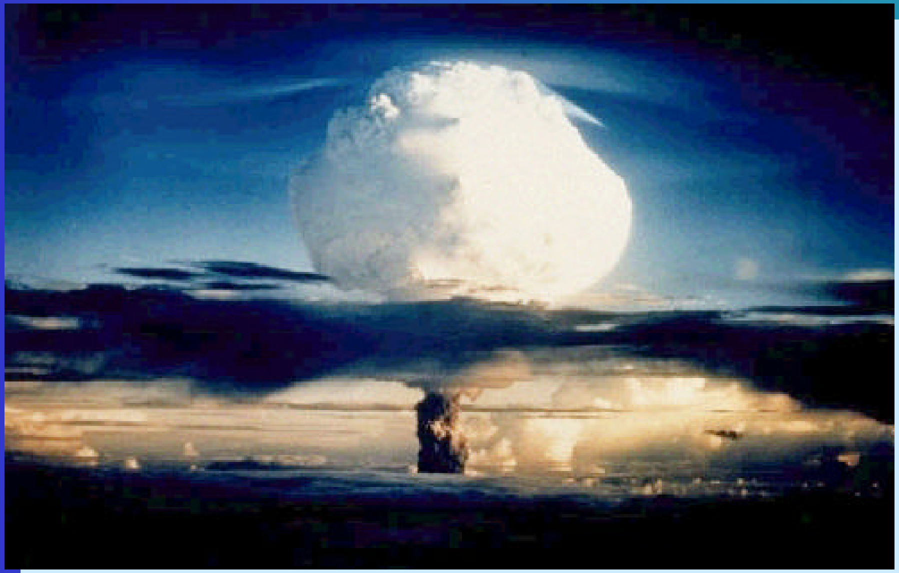
Earth Sterilizing Impact

Mass Extinction Impact

Civilization Threatening Impact



Civilization Threatening Impact

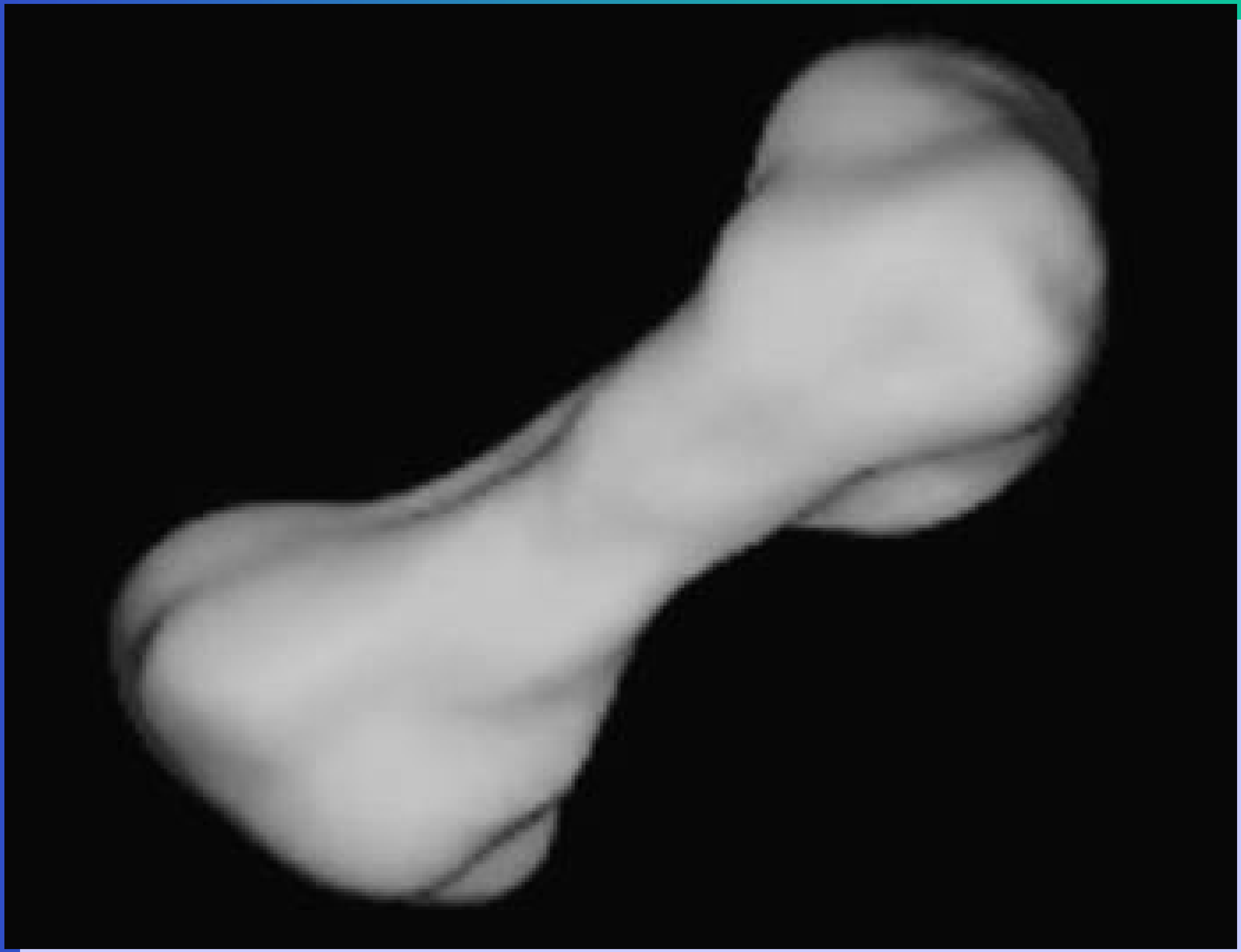


Mass Extinction Impact

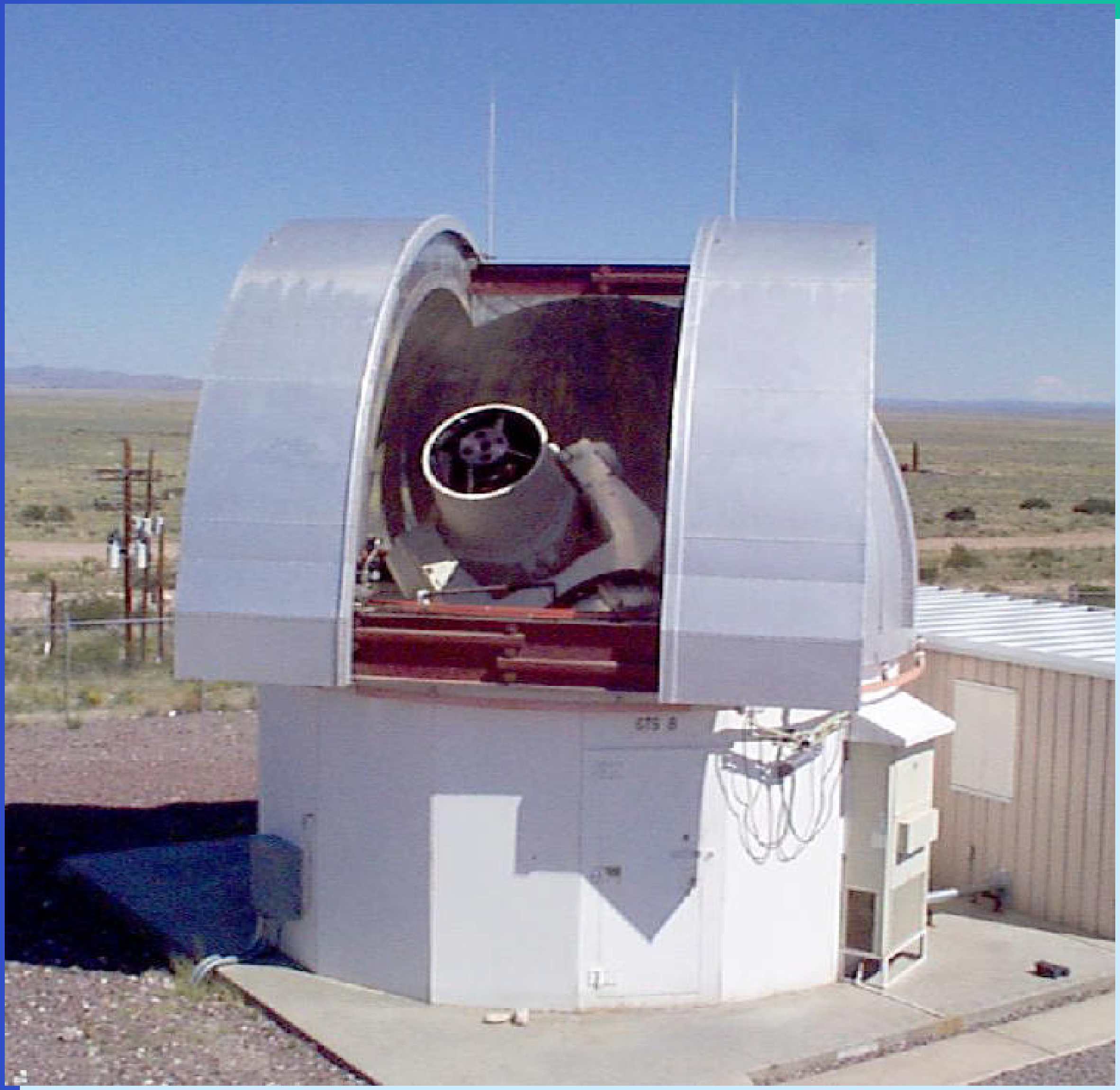
Earth Sterilizing Impact

EROS Asteroid 433

KLEOPATRA Asteroid 216



LINEAR NEO Search Systems



What Happens When an Impact Takes Place?

Bolides (up to 5 MT)

- Great fireworks display, no damage

Tunguska-class (15 MT) impact

- Damage similar to large nuclear bomb (city-killer)
- Average interval for whole Earth: 100 yr.
- Minor risk relative to other natural disasters (earthquakes, etc.)

Larger local or regional catastrophes (*e.g.* 10,000 MT)

- Destroys area equivalent to small country
- Average interval for whole Earth: 100,000 yr.
- Moderate risk relative to other natural disasters

Global catastrophe (> 1 million MT)

- Global environmental damage, threatening civilization
- Average interval for whole Earth: 1 million years
- Major risk relative to other natural disasters

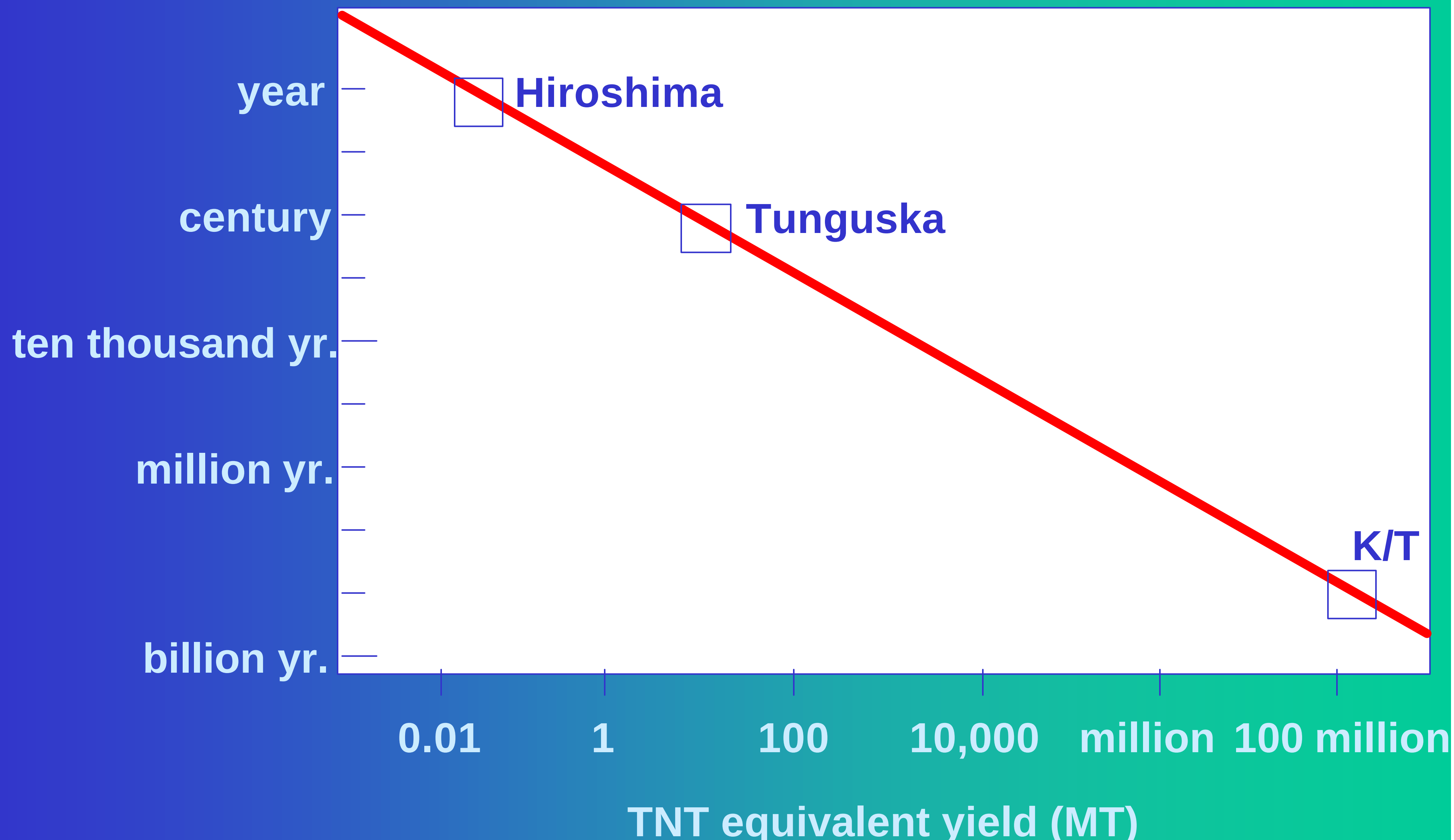
Hazard of Globally Catastrophic Impacts

Kills more than 1.5 billion people
- We define "globally catastrophic" this way

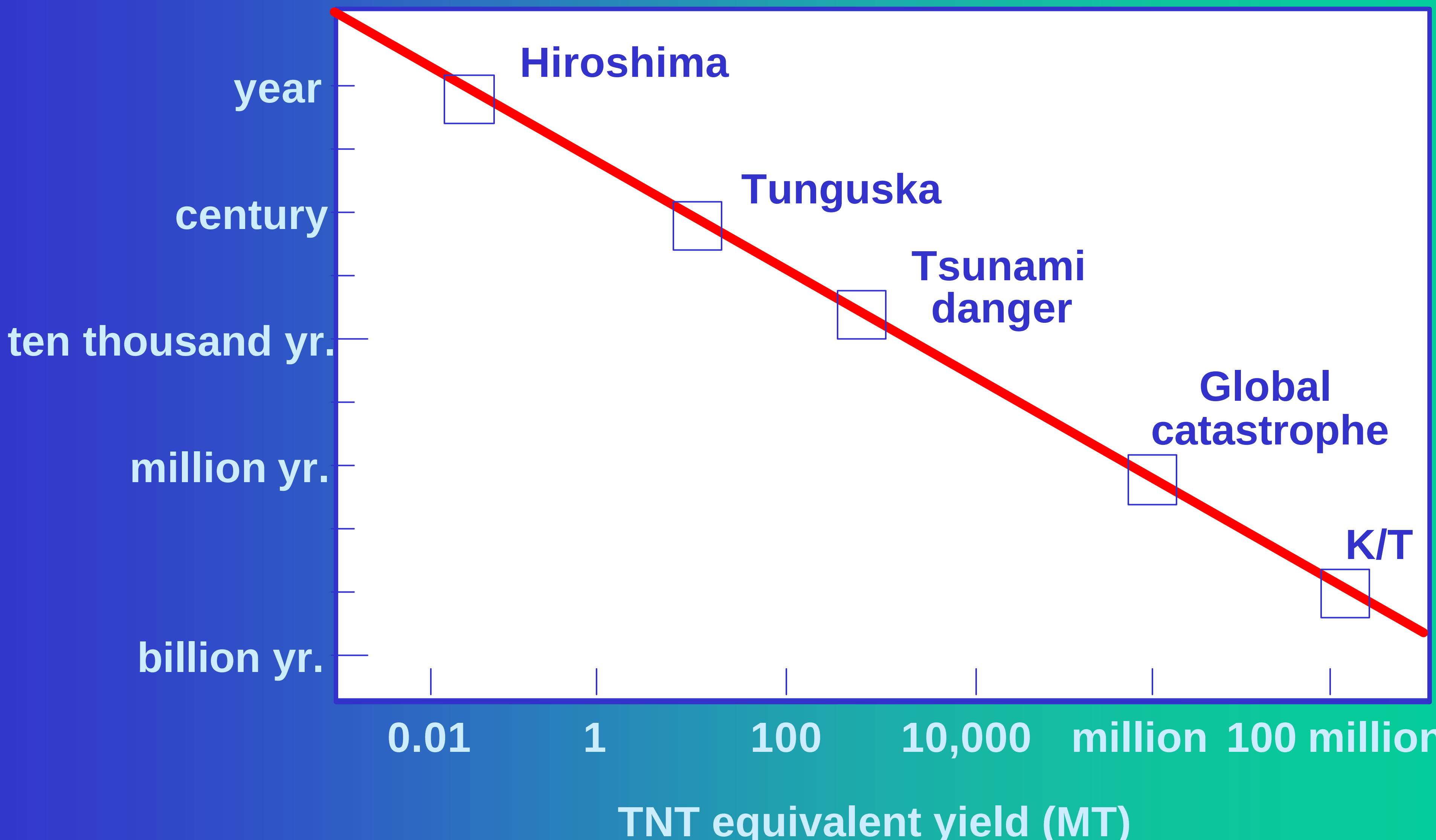
Energy threshold calculated to be near 1 million MT
- Primary global effect is from stratospheric dust and smoke
- Average interval 500,000 to 1 million yrs.
- Risk order-of-magnitude greater than that of smaller impacts
- Risk similar to other natural hazards (earthquakes, severe storms)

Unique in capacity to destabilize civilization
- Qualitatively different risk from that of other natural hazards
- Can be compared with global nuclear war
- Only known natural hazard that can destroy civilization

Terrestrial Impact Frequency



Terrestrial Impact Frequency



Comparison with Other Risks

Statistical risk of death from impacts is about 1 in a million per year, or about 1:20,000 lifetime risk

- Much less (in U.S.) than auto accidents, shootings
- Comparable with other natural hazards (*e.g.* earthquakes, floods)
- Near threshold for hazards most people are concerned about
- Well above threshold for U.S. governmental or regulatory action

Severity of disasters (billions of people killed) is greater than any other *known* hazard we face

- Apparently unique in its threat to civilization
- Places this disaster in a class by itself

Average interval between major disasters (hundreds of millennia) is larger than for any other hazard we face

- Causes some to question credibility of hazard

Comparative Risk from Natural Disasters

AVERAGE ANNUAL RISK OF DEATH IN PARTS PER MILLION

1	Total Impact Risk
0.1	Risk from Local/Regional Impacts (<2 km)
0.01	Risk from Tunguska-like impacts (<300 m)
50	Bangladesh (primarily floods)
25	China (primarily floods & earthquakes)
20	Turkey/Iran/Turkestan (primarily earthquakes)
15	Japan (primarily earthquakes)
10	Caribbean & Central America (storms, earthquakes, volcanoes)
<1	Europe
<0.1	USA/Canada

Comparative Risks for USA & Canada

AVERAGE ANNUAL RISK OF DEATH IN PARTS PER MILLION

300	Accidents (not motor vehicle)
200	Homicide & suicide
160	Motor vehicle accidents
10	Fire
5	Electrocution
1	Airplane accidents
0.5	**TOTAL IMPACTS (global threshold = 1 million Mt)**
0.3	Storms and floods (declining)
0.1	**LOCAL / REGIONAL IMPACTS**
0.1	Earthquakes (poor statistics)
0.01	**TUNGUSKA-TYPE IMPACTS**
<0.01	Nuclear accidents (design goals)

Robust Conclusions from the Hazard Analysis

- Cosmic impacts represent an extreme example of the class of hazards with low probability but high consequences.
- The statistical risk from impacts is substantially larger than the one-in-a-million lifetime risk of death often used as a threshold for governmental or regulatory interest.
- Unlike other natural hazards, impacts can kill billions of people and endanger the survival of civilization.
- The total risk increases with the size (energy) of the projectile; thus any effort at hazard reduction naturally focuses on the rare events associated with the larger impacting bodies.
- Unlike other natural catastrophes, large impacts can, in principle, be avoided by deflection to alter the orbit of the projectile.
- The initial step in any mitigation scheme is to survey the near-Earth asteroids and determine their orbits.

Reality Checks

How can this risk be credible when no one has been killed?
- The small, frequent events (such as meteorite falls) are not a significant hazard; only the large rare events are important.

If Tunguska size impacts take place every few hundred years, why are there no historical records (except for Siberia in 1908)?
- Most such impacts will be in the ocean or unpopulated areas. Our history covers just a small fraction of the Earth's surface for a few millennia; it is no surprise that only one event has been recorded.

If global ecological catastrophes take place one or more times in a million years, why are intervals between mass extinction's typically tens of millions of years in the fossil record?
- A mass extinction means every member of many species is killed; it requires collapse of global ecosystems. The global catastrophe we have defined requires only crop loss, no extinctions.

If the interval between major impacts is hundreds of millennia, we don't need to worry; let later generations deal with it.
- Spacing between impacts is random; hence the probability of impact is as great for next year as any later year.

Spaceguard Survey Progress

Spaceguard Survey originally proposed by NASA panel in 1992

- Additional support from US Congress in 1995
- Adopted as NASA goal in 1998 (in collaboration with USAF)

Survey Objective: Discover and track 90% of the Near Earth Asteroids (NEAs) with diameter greater than 1 km within ten years (by 2008)

- Estimated number of NEAs larger than 1 km: approximately 900
- Number discovered through end of 2000: approximately 430
- Estimated completion date (to 90%): 2012

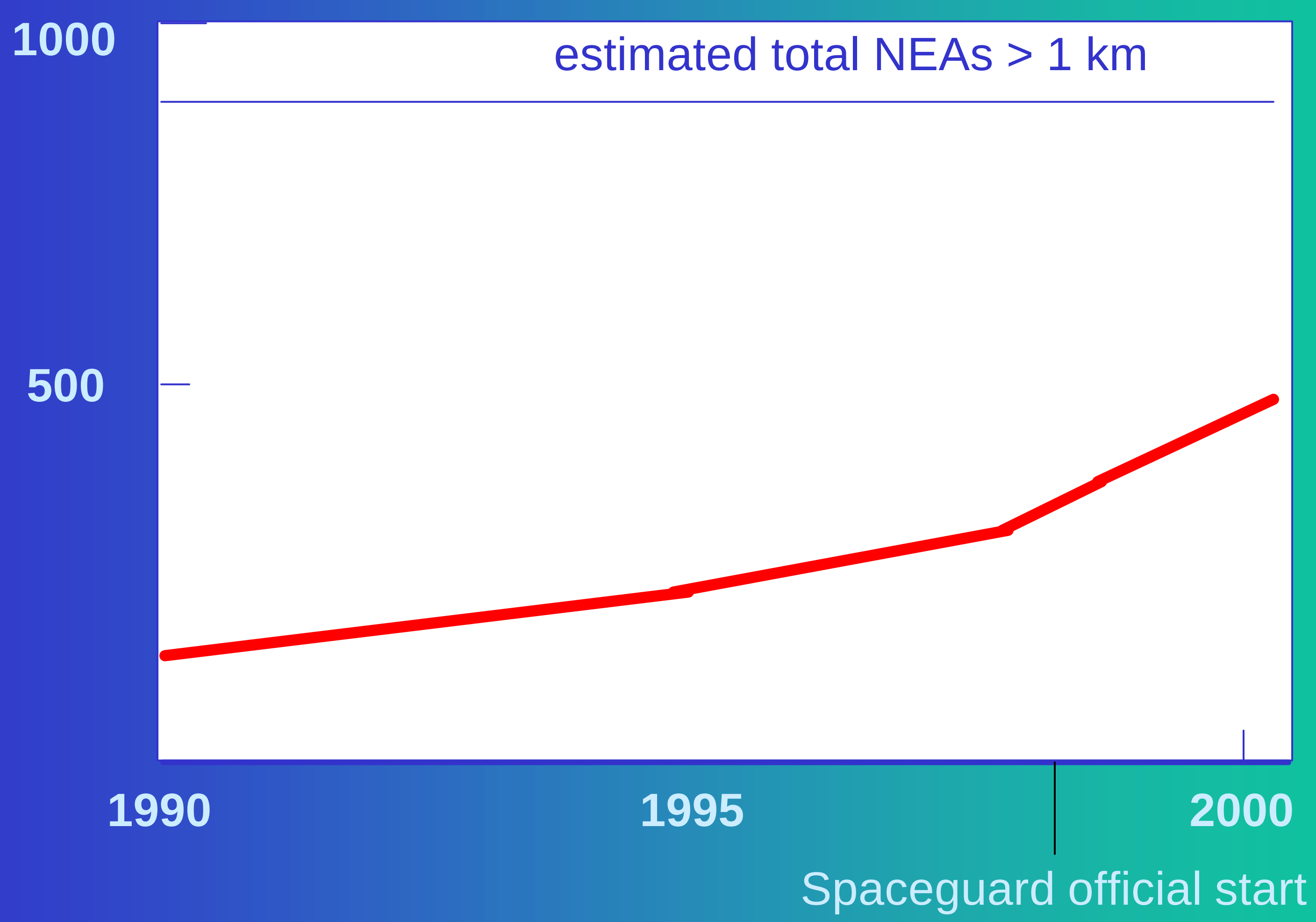
Most NEAs discovered by MIT-Lincoln Lab LINEAR search system

- Two USAF 1-m telescopes with NASA operating funds
- Discovery rate approximately 5 / month

International program for follow-up and orbit determination

Threatening NEAs (if any) should be identified decades before impact

Known Kilometer-Size Near Earth Asteroids



Protecting Against Impacts

Impacts are preventable natural disasters

- Modern technology can deflect or disrupt an incoming object
- Long lead time is required (as provided by Spaceguard)

Deflection (change of orbit) is preferred approach

- Imparts slight change in velocity (few cm/s) years in advance
- Requires advanced warning (decade or more)
- Requires rendezvous spacecraft (like NASA NEAR mission)
- Requires one or more nuclear explosives (up to MT yield)

Disruption may be possible if warning time is less

- Requires greater yield explosives to ensure no large fragments
- Requires advanced command and control
- Requires fully-developed defense system (on the pad)

Subject of studies by US Air Force, US weapons labs (Livermore, Los Alamos), Russian defense industry, United Nations

Congressional Statement 1991

The House Committee on Science and Technology believes that it is imperative that the detection rate of Earth-orbit-crossing asteroids must be increased substantially, and that the means to destroy or alter the orbits of asteroids when they do threaten collisions should be defined and agreed upon internationally. The chances of the Earth being struck by a large asteroid are extremely small, but because the consequences of such a collision are extremely large, the Committee believes it is only prudent to assess the nature of the threat and prepare to deal with it.

NASA Authorization Bill, 1991

NASA Spaceguard Report 1992

- Impacts by Earth-approaching asteroids and comets pose a significant hazard to life and property. Although the annual probability of the Earth being struck by a large asteroid or comet is extremely small, the consequences of such a collision are so catastrophic that it is prudent to assess the nature of the threat and prepare to deal with it. The first step in any program for the prevention or mitigation of impact catastrophes must involve a comprehensive search for Earth-crossing asteroids and comets and a detailed analysis of their orbits.

- Current technology permits us to discover and track nearly all asteroids or short-period comets larger than 1 km diameter that are potential Earth-impactors… What is required … is a systematic survey that effectively monitors a large volume of space around our planet and detects these objects as their orbits repeatedly carry them through this volume of space… The international survey program described in this report can be thought of as a modest investment to insure our planet against the ultimate catastrophe.

NASA Spaceguard Survey Working Group, January 1992

UK NEO Task Force Report 2000

- Impacts represent a significant risk to human and other forms of life. Means now exist to mitigate the consequences of such impacts for the human species. The largest uncertainty in risk analysis arises from our incomplete knowledge of asteroids whose orbits bring them near to the Earth...
- We recommend that the Government should seek partners, preferably in Europe, to build in the southern hemisphere an advanced new 3-metre-class survey telescope for surveying substantially smaller objects than those now systematically observed by other telescopes...
- We recommend that the Government should help promote multi-disciplinary studies of the consequences of impacts from Near Earth Objects on the Earth...
- We recommend that the Government, with other governments, set in hand studies to look into the practical possibilities of mitigating the results of impact and deflecting incoming objects…

UK NEO Task Force Report, September 18 2000

FOR MORE INFORMATION

NASA Impact Hazard Website

http:// impact.arc.nasa.gov

NASA NEO Program Website

http:// neo.jpl.nasa.gov