The Disposal of Spacecraft and Launch Vehicle Stages in Low Earth Orbit

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Presentation Outline

- **Rationale for LEO Satellite Disposal Procedures**
- **National and International Space Debris Mitigation Guidelines**
  - Passivation
  - Disposal Orbits
- **LEO Spacecraft Disposals**
- **LEO Launch Vehicle Stage Disposals**
- **Compliance and Challenges**

The Need for Proper Disposal Guidelines

- **Historically, derelict spacecraft and launch vehicle stages represent future debris sources due to explosions and collisions.**

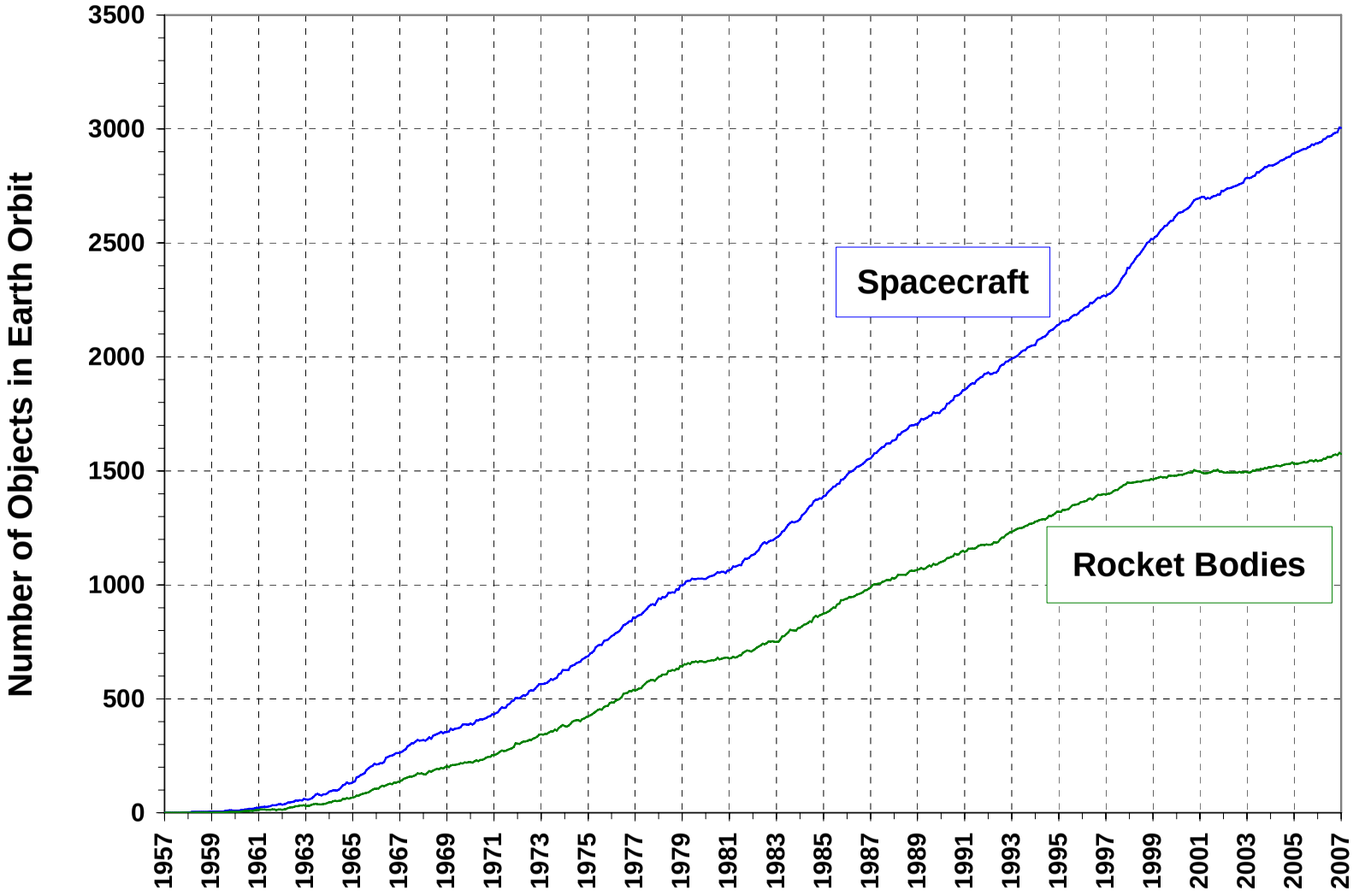
- **~90% of known accidental satellite breakups have originated with spacecraft and launch vehicle stages left in orbit after mission termination.**

- **The majority of mass in Earth orbit resides in non-operational spacecraft and launch vehicle stages. This mass also represents the largest segment of cross-sectional area, i.e., collision hazard, for future debris generation.**

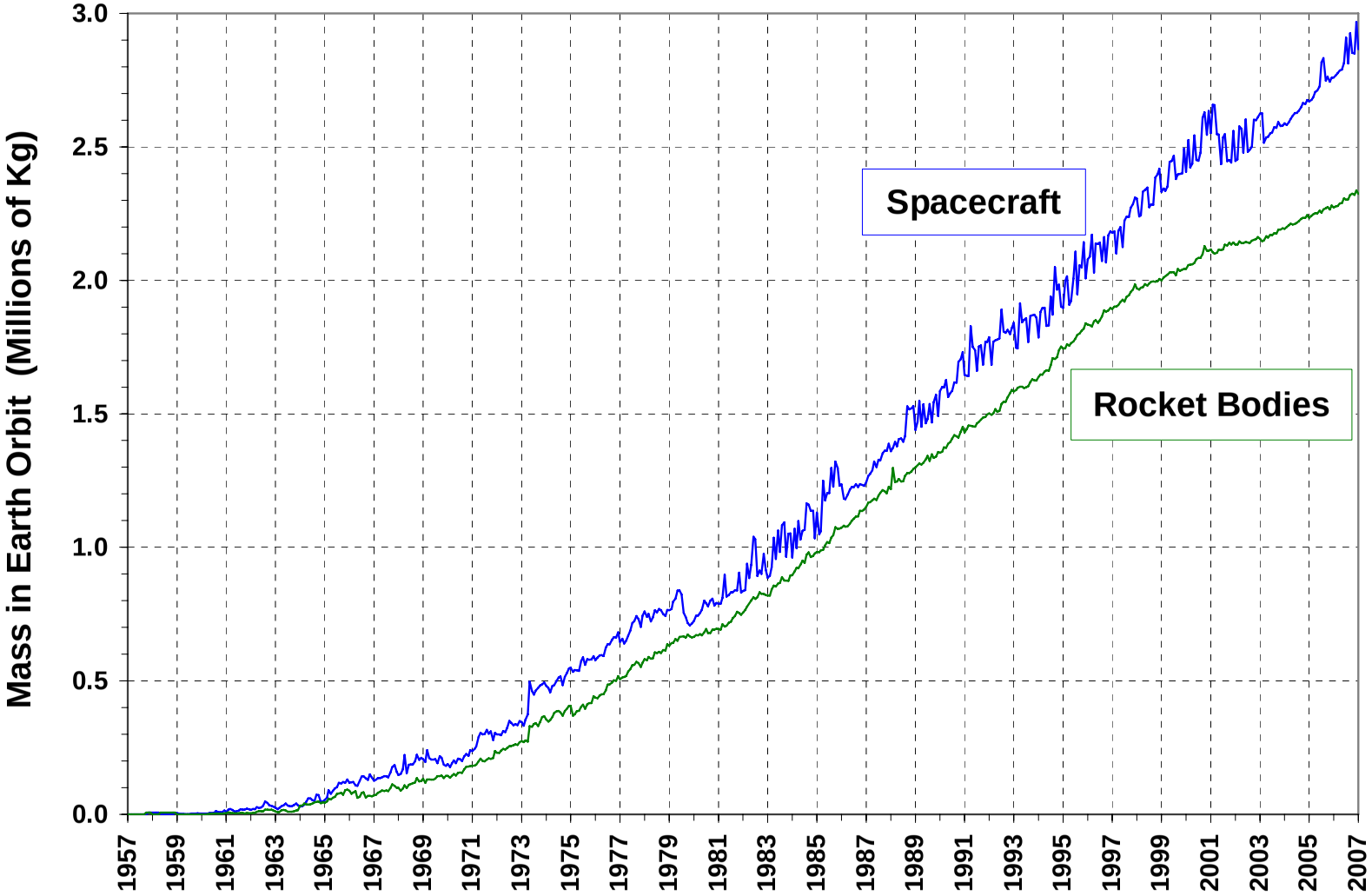
- **87% (55 out of 63) space missions conducted in 2006 left at least one spacecraft or launch vehicle stage in or passing through LEO.**

Proper disposal of non-operational spacecraft and launch vehicle stages is essential for the safety of future space systems.

Growth of Spacecraft and Launch Vehicle Stage Populations



Accumulation of Mass in Earth Orbit



NASA Orbital Debris Mitigation Guidelines for LEO Space System Disposal

- **In 1995 NASA issued a comprehensive set of orbital debris mitigation guidelines.**
  - Guideline 4-2: All on-board sources of stored energy will be depleted when they are no longer required for mission operations or postmission disposal. Depletion will occur as soon as such an operation does not pose an unacceptable risk to the payload.
  - Guideline 6-1: A spacecraft or upper stage with a perigee altitude below 2000 km in its final mission orbit will be disposed of by one of three methods:
    - atmospheric reentry within 25 years of end of mission,
    - maneuver to a storage orbit between LEO and GEO, or
    - direct retrieval within 10 years.
- **ESA and space agencies of other countries now have similar guidelines.**

US Government Orbital Debris Mitigation Guidelines for LEO Space System Disposal

- **In 2001 the US Government issued a set of orbital debris mitigation standard practices, based upon the NASA orbital debris mitigation guidelines.**
  - Standard Practice 2-2: All on-board sources of stored energy of a spacecraft or upper stage should be depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as such an operation does not pose an unacceptable risk to the payload…
  - Standard Practice 4-1: A spacecraft or upper stage may be disposed of by one of three methods:
    - atmospheric reentry option within 25 years of end of mission,
    - maneuver to a storage orbit between LEO and MEO, or
    - direct retrieval as soon as practical after end of mission
- **Standard practices are applicable to all US Government-sponsored space missions.**

IADC Debris Mitigation Guidelines for LEO Space System Disposal

- **In 2002 the Inter-Agency Space Debris Coordination Committee (IADC) issued a set of space debris mitigation measures. IADC members include the space agencies of 10 countries plus the European Space Agency.**
  - Measure 5.2.1: In order to limit the risk to other space systems from accidental break-ups after completion of mission, al on-board sources of stored energy of a space system should be depleted…Depletion should occur as soon as this operation does not pose an unacceptable risk to the payload.
  - Measure 5.3.2: Whenever possible space systems that are terminating their operational phases in orbits that pass through the LEO region, or have the potential to interfere with the LEO region, should be de-orbited (direct re-entry is preferred) or where appropriate maneuvered into an orbit with a reduced lifetime. Retrieval is also a disposal option.
    - IADC and other studies and a number of existing national guidelines “have found 25 years to be a reasonable and appropriate lifetime limit”.

UN Space Debris Mitigation Guidelines for LEO Space System Disposal

- **In February 2007 the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space adopted a set of space debris mitigation guidelines.**
  - Guideline 5: In order to limit the risk to other spacecraft and launch vehicle orbital stages from accidental break-ups, all on-board sources of stored energy should be depleted or made safe when they are no longer required for mission operations or post-mission disposal.
  - Guideline 6: Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbit that pass through the LEO region should be removed from orbit in a controlled fashion. If this is not possible, they should be disposed of in orbits which avoid their long-term presence in the LEO region.
- **These guidelines are expected to be endorsed by the full COPUOS in June 2007.**

NASA Space Missions of 2006

- **Seven NASA space missions were undertaken in 2006.**

Mission	Launch Date	Destination	Other Objects Produced
New Horizons	19 January	Pluto	No objects left in Earth orbit
ST-5 (A, B, C)	22 March	Elliptical Earth Orbit	One rocket body and one mission-related debris in short-lived orbits
Cloudsat / Calipso	28 April	LEO	Rocket body decayed; one mission-related debris to decay within 25 years
STS-121	04 July	LEO (ISS)	No debris left in Earth orbit
STS-115	09 September	LEO (ISS)	No debris left in Earth orbit
STEREO A and B	26 October	Heliocentric Orbit	One rocket body and one mission-related debris in short-lived orbits
STS-116	10 December	LEO (ISS)	Six small payloads and three mission-related debris in short-lived orbits

- **All spacecraft, rocket bodies, and mission-related debris residing in or passing through LEO have already reentered or will reenter within 25 years.**

Disposal of ERBS Spacecraft in 2005

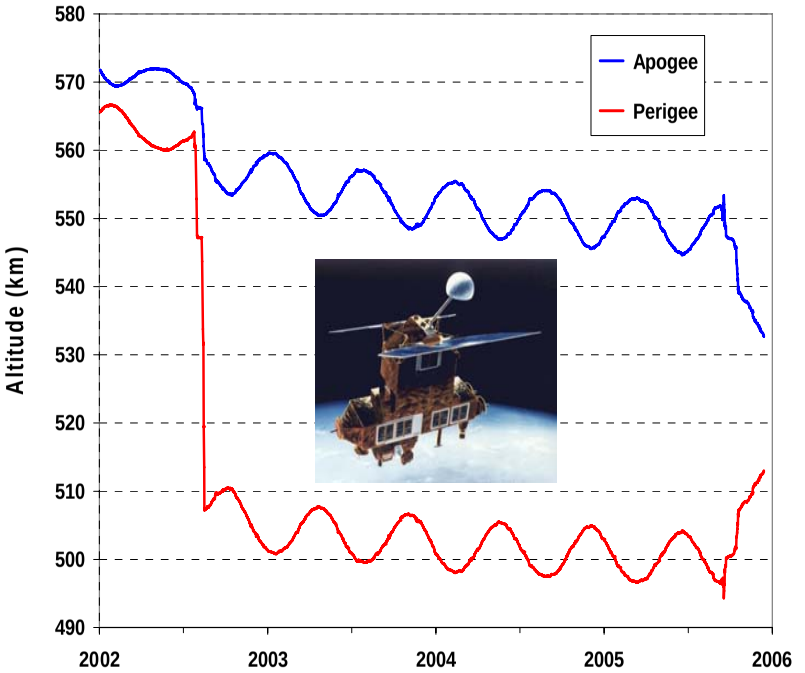
- **Earth Radiation Budget Experiment (ERBS) [1984-108B]**

- **Operated near 600 km for almost 18 years**

- **Perigee lowered more than 50 km in 2002 to ensure orbital reentry in less than 25 years after end of mission**

- **Support system degradation prevented further reduction in perigee in 2005; however, all residual propellant was expended during maneuvers in September and October**

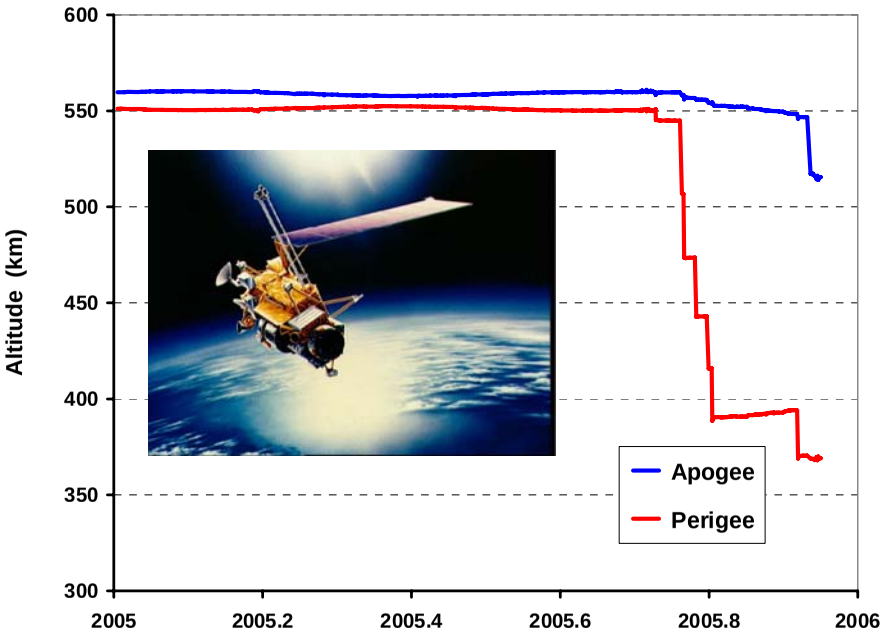
- **Remaining orbital lifetime is expected to be less than 17 years**



Disposal of UARS Spacecraft in 2005

Upper Atmosphere Research Satellite (UARS) [1991-063B]

- **Operated between 550 and 600 km for 14 years**
- **During October and December 2205 all residual propellant was expended in a series of 8 maneuvers**
- **Mean orbital altitude was reduced more than 100 km**
- **Remaining orbital lifetime is expected to be less than 5 years**

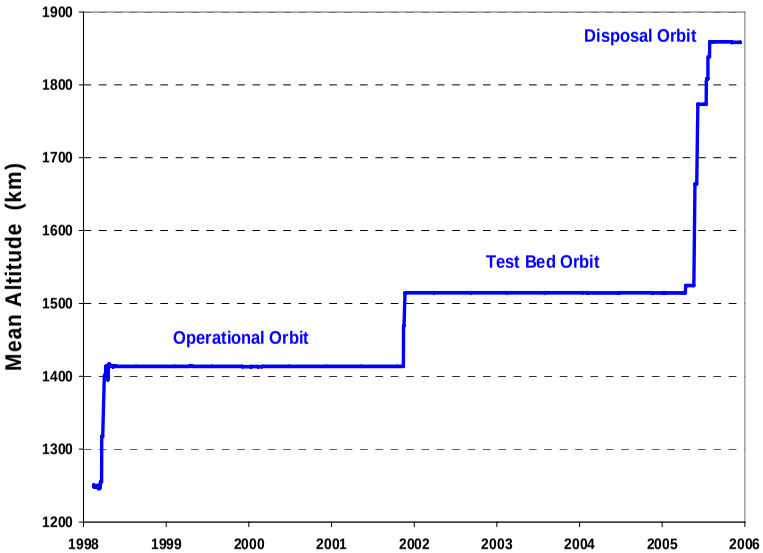


Disposal of Globalstar Spacecraft

- **The Globalstar commercial communications network consists of 48 primary spacecraft in orbits near 1415 km altitude. The spacecraft were designed in the early 1990's before disposal recommendations for LEO satellites.**

- **Disposal orbits 100 km above the operational orbits were originally envisioned. However, in October 2005 Globalstar LLC declared to the USA Federal Communications Commission its intent to dispose of Globalstar vehicles in orbits as high as 2000 km, in accordance with current USA disposal options.**

- **One of the first group of four spacecraft was transferred to a disposal orbit near 1900 km in 2005. Two other spacecraft in a temporary post-mission test orbit are expected to reach 2000 km.**



Globalstar M002

Solar Dynamics Observatory (SDO)

- **NASA's SDO is a case study in the implementation of NASA orbital debris mitigation efforts and processes.**

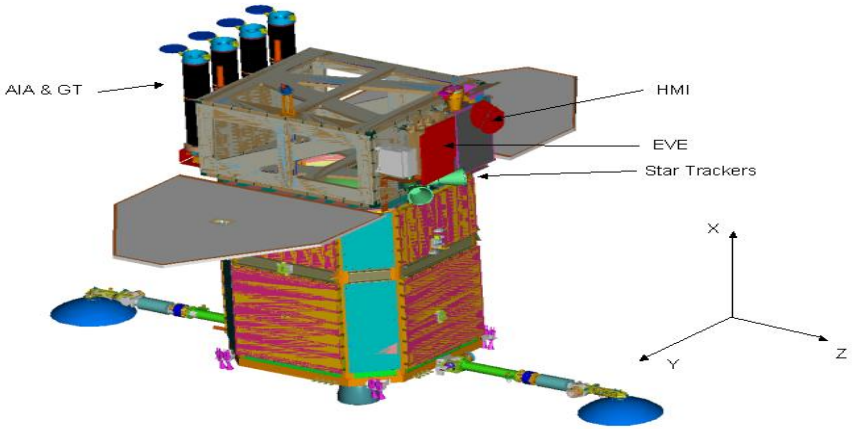
- **The 3200-kg SDO will be launched in 2008 by an Atlas V launch vehicle for a five-year scientific mission in an inclined geosynchronous orbit.**

- **Review of the orbital debris assessment report submitted in March 2004 at the Preliminary Design Review noted potential non-compliance issues:**

  – Venting of helium pressurant at end of mission

  – Disconnect of battery from charging circuit at end of mission

  – Disposal of launch vehicle upper stage, including reentry risk



Solar Dynamics Observatory (continued)

- **Design and operational changes adopted by time of the Critical Design Review in April 2005 included:**
  - Bypass valve added to permit venting of helium pressurant
  - Battery disconnect relay control added to power subsystem
  - Centaur upper stage to be left in storage orbit between LEO and GEO.
- **Cost-effective solutions were found to meet orbital debris mitigation objectives without impacting spacecraft reliability or program schedule.**

Disposal of Launch Vehicle Stages for LEO Communications Constellations

- **Iridium**
  - 88 spacecraft launched in 25 months (1997-1999) using three different launch vehicles from three countries
  - 26 orbital stages inserted, but only one remains in orbit due to malfunction
    - Proton orbital stages de-orbited over Pacific Ocean
    - Delta and Long March orbital stages moved to lower disposal orbits

- **Globalstar**
  - 52 spacecraft launched in 24 months (1998-2000) using Delta and Soyuz launch vehicles
  - 17 of 19 orbital stages have already decayed
  - Six Soyuz-IKAR stages were de-orbited into Pacific from altitude near 900 km

- **Orbcomm**
  - 35 spacecraft launched as primary or secondary payloads
  - Eight orbital stages used for dedicated missions (31 spacecraft); only one orbital stage remains in orbit due to lower stage malfunction

- **Only 4 of 53 launch stages used to orbit 175 spacecraft will fail to meet 25-year rule (two due to launch vehicle malfunctions).**

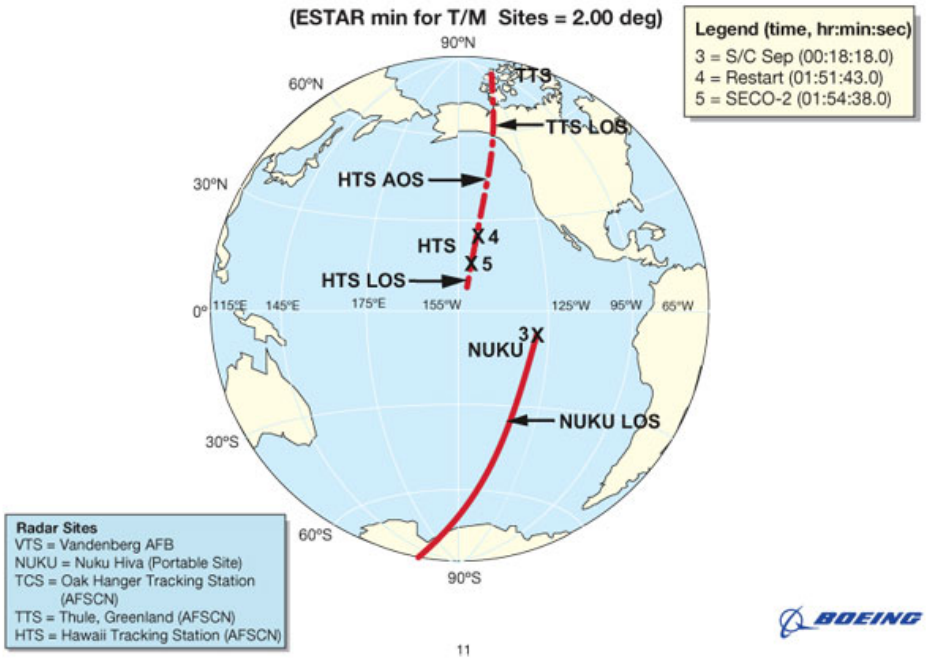
U.S. Promotion of Short Orbital Lifetimes for Launch Vehicle Stages in LEO in 2004

- **Seven Delta 2 launch vehicles were employed for LEO and MEO missions, leaving 10 stages in short-lived Earth orbits.**
  - Six reentered before the end of the year; remainder will reenter in less than 8 years
  - All stages had perigees of 215 km or less after propellant depletion burn
  - Three missions reduced perigees 400 km or more
- **Four Atlas 2AS and 3A launch vehicles were flown on commercial GEO missions, leaving all Centaur stages in GTOs with lifetimes of less than 25 years.**
  - All stages had perigees of 220 km or less

Controlled Reentry of Delta IV Second Stage

- **In 1996 the U.S. demonstrated the ability to significantly reduce the altitude of a launch vehicle stage to limit its time in low Earth orbit.**
  - The MSX Delta II second stage was maneuvered from a payload delivery orbit of 900 km to a disposal orbit of 225 km by 870 km; reentry occurred only 9 months later.

- **In 2006 the DMSP 5D-3 F17 Delta IV second stage was completely de-orbited from a circular orbit of 850 km.**



Compliance and Challenges

- **Compliance with the both passivation and LEO orbital lifetime limitation guidelines is improving.**

- **LEO spacecraft inserted into operational orbits above 650 km with no maneuver capability are normally unlikely to meet orbital lifetime guideline.**

  – Spacecraft with masses less than 500 kg often have no significant maneuver capability

- **Solid-propellant upper stages inserted into orbits above 650 km rarely meet orbital lifetime limitation guidelines.**

- **Spacecraft and launch vehicle passivation and LEO orbital lifetime issues are best considered early in the initial system definition phase.**

  – U.S. LEO communications constellations are excellent examples of how spacecraft and launch vehicles design and operational trades can be highly effective.