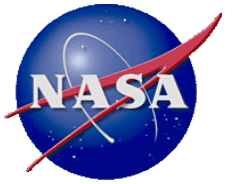
National Aeronautics and Space Administration



NASA Upper Atmosphere Research Satellite (UARS) Re-entry Prediction and Analysis

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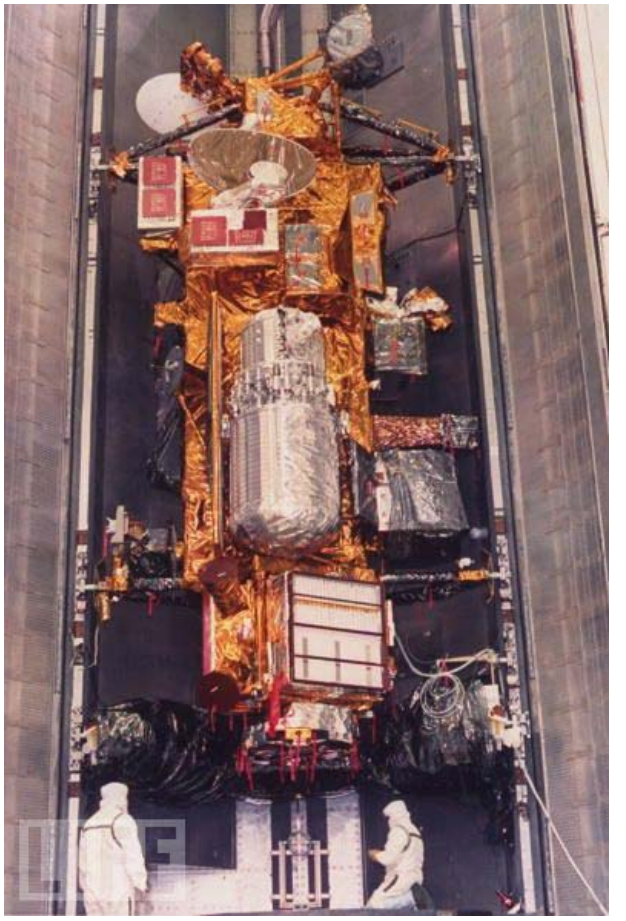
INTERNATIONAL SYMPOSIUM ON
SUSTAINABLE SPACE DEVELOPMENT AND UTILIZATION FOR HUMANKIND
ORBITAL SPACE DEBRIS – CHALLENGES & OPPORTUNITIES

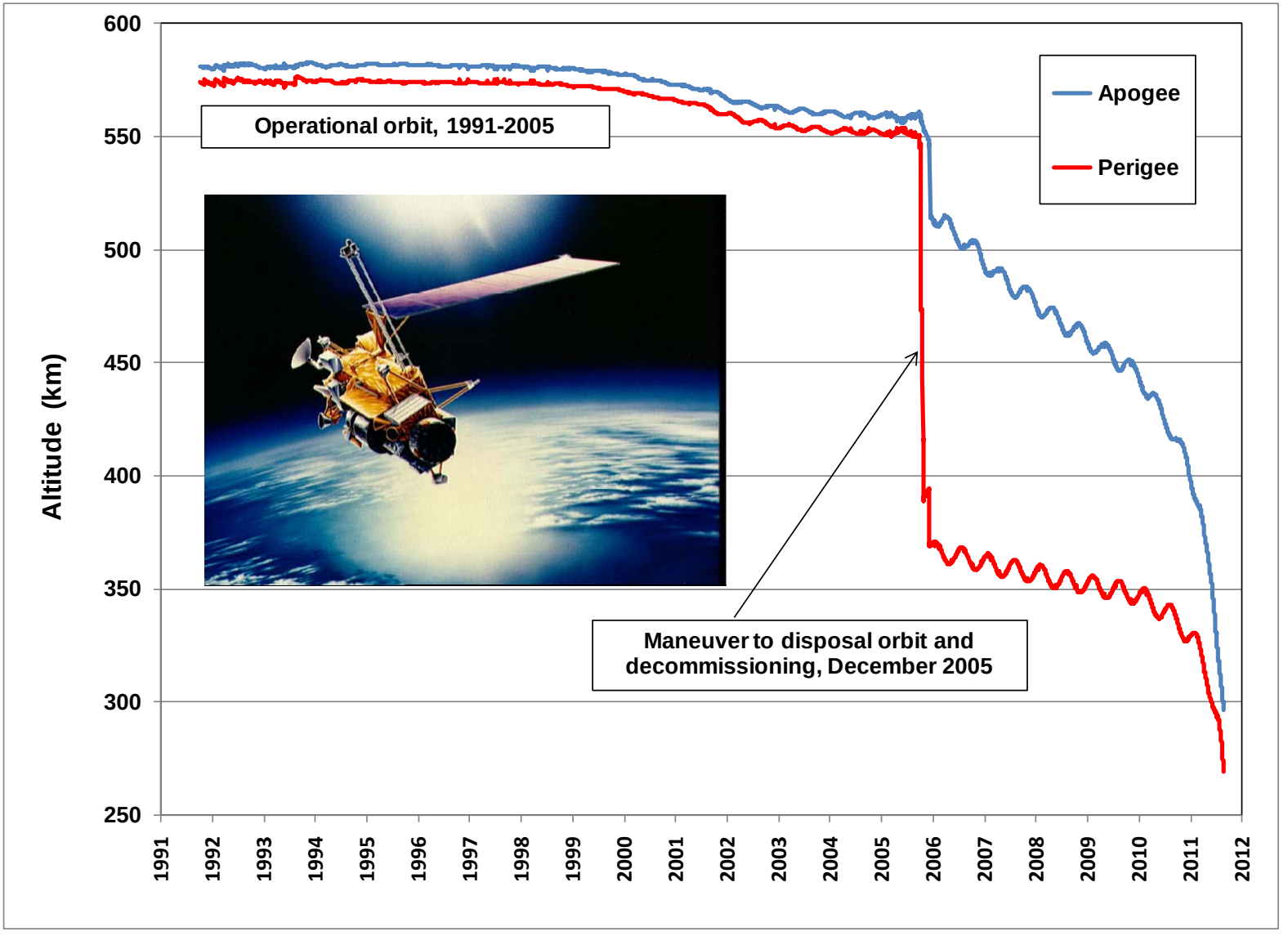
1-2 March 2012

Upper Atmosphere Research Satellite

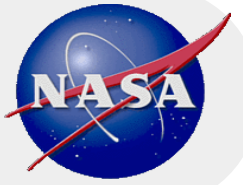


- **Launched: 12 September 1991 inside STS-48**
- **Deployed: 15 September 1991**
- **International Designator: 1991-063B**
- **U.S. Satellite Number: 21701**
- **Dry mass: 5668 kg**
- **Initial Operational Orbit: 575 km by 580 km, 57 deg inclination**
- **Decommissioned: 15 December 2005 after maneuvering into a shorter-lived disposal orbit**
  - Residual orbital lifetime reduced by ~ 20 years

Orbital History of UARS



Time of Reentry Inherent Prediction Limitations



- **The two principal and not completely independent influences on reentry prediction accuracy are atmospheric density and vehicle stability.**

- **Atmospheric density varies over the planet and can be significantly affected by solar activity within a short period.**
  - Solar activity can also adversely affect the operation of ground-based radars, leading to less accurate tracking information.

- **Changes in vehicle stability are not uncommon during the final days prior to reentry due to increased average atmospheric density.**
  - The initiation or change of tumbling modes can result in a change in the vehicle's drag profile, which, in turn, can affect the time and location of reentry.

U.S. Reentry Predictions

- **The official source of reentry predictions for uncontrolled space objects is USSTRATCOM's Joint Space Operations Center (JSpOC).**

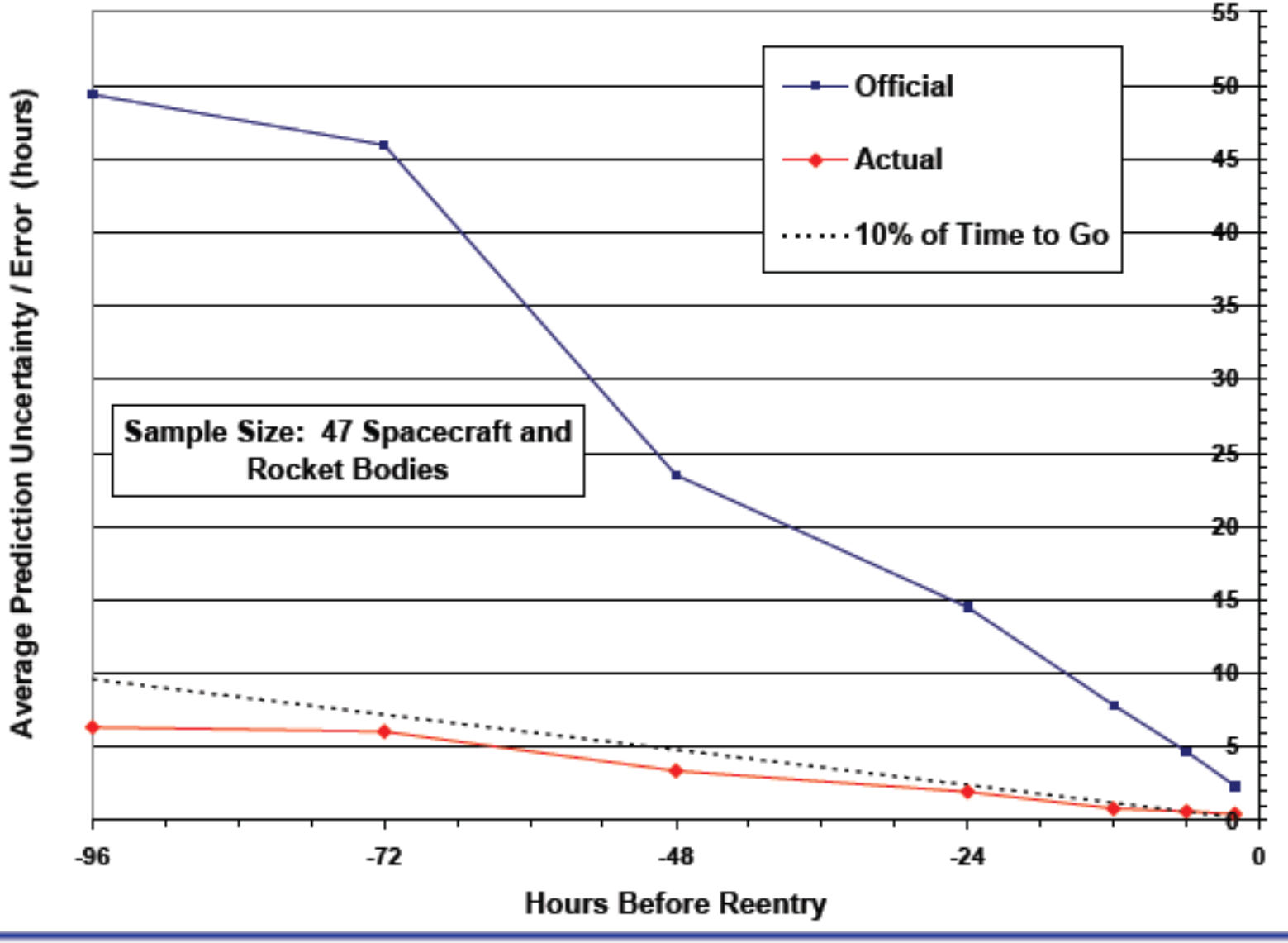
- **Normal procedure is for TIP (Tracking and Impact Prediction) messages to be prepared and released to the public (via the Space-Track.org website) at the following intervals:**

  – T – 4 days, T – 3 days, T – 2 days, T – 1 day, T – 12 hours, T – 6 hours, and T – 2 hours

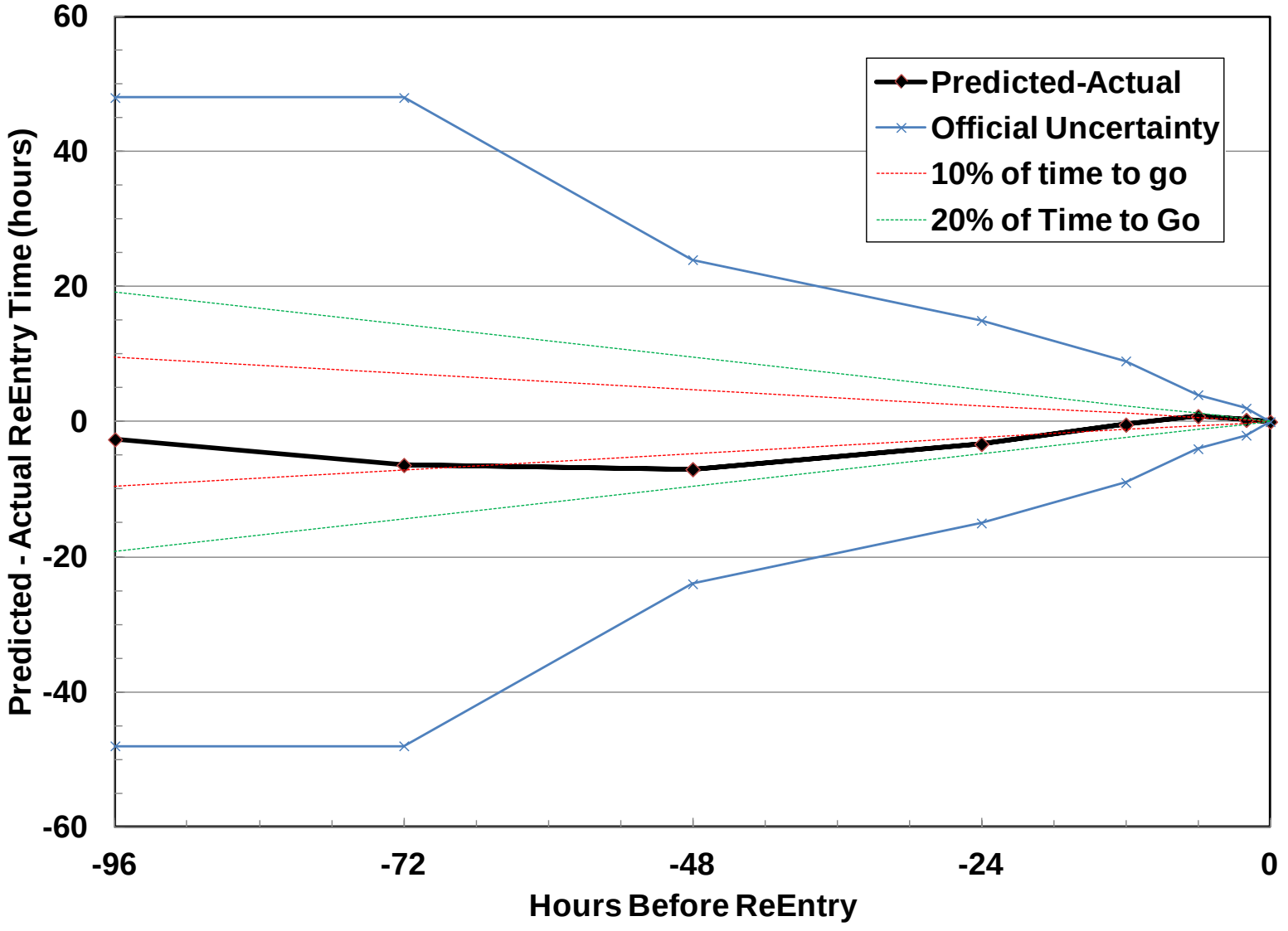
- **TIP messages provide the best estimates of reentry time and location but have large uncertainties. Even at T – 2 hours, the uncertainty of reentry time is on average +/- 25 minutes for nearly circular orbits. This equates to +/- 12,000 km on the Earth.**

- **A final, post-reentry assessment message is normally issued within a few hours of reentry.**

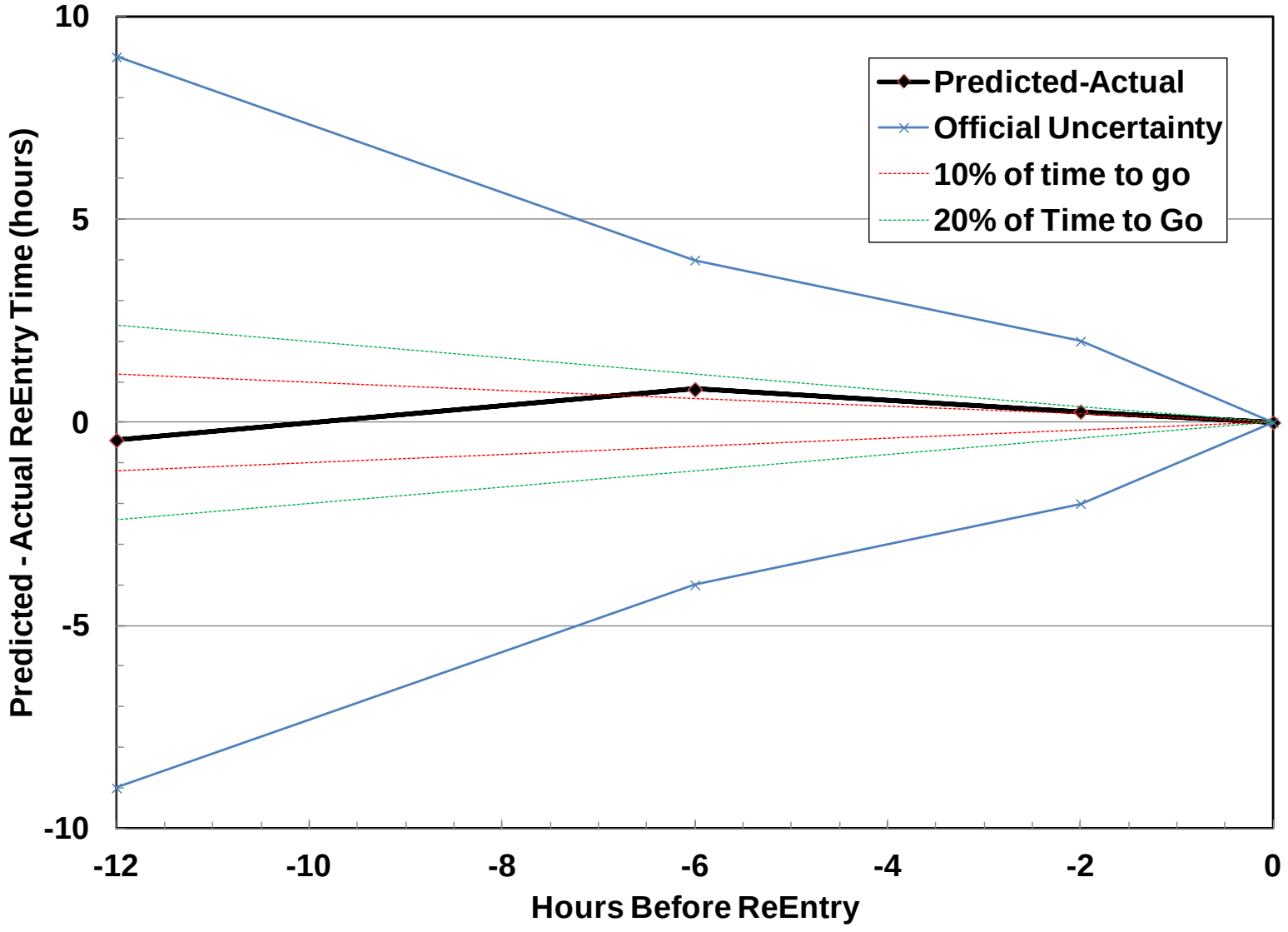
Average of 47 Objects Reentering from Near Circular Orbits



UARS Reentry Predictions

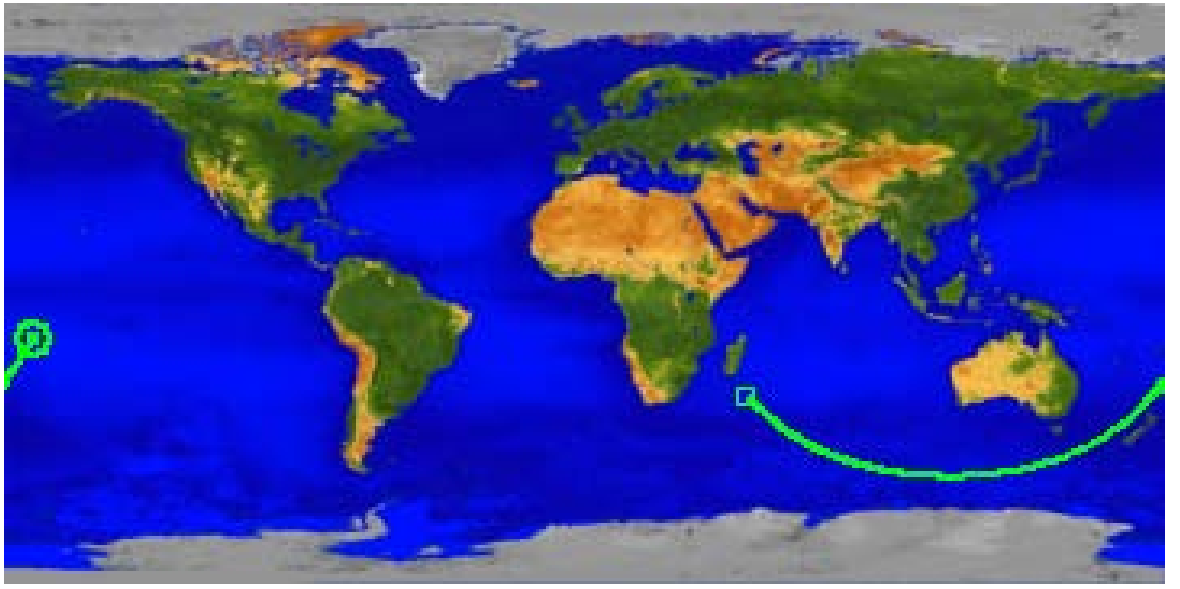


UARS Reentry Predictions



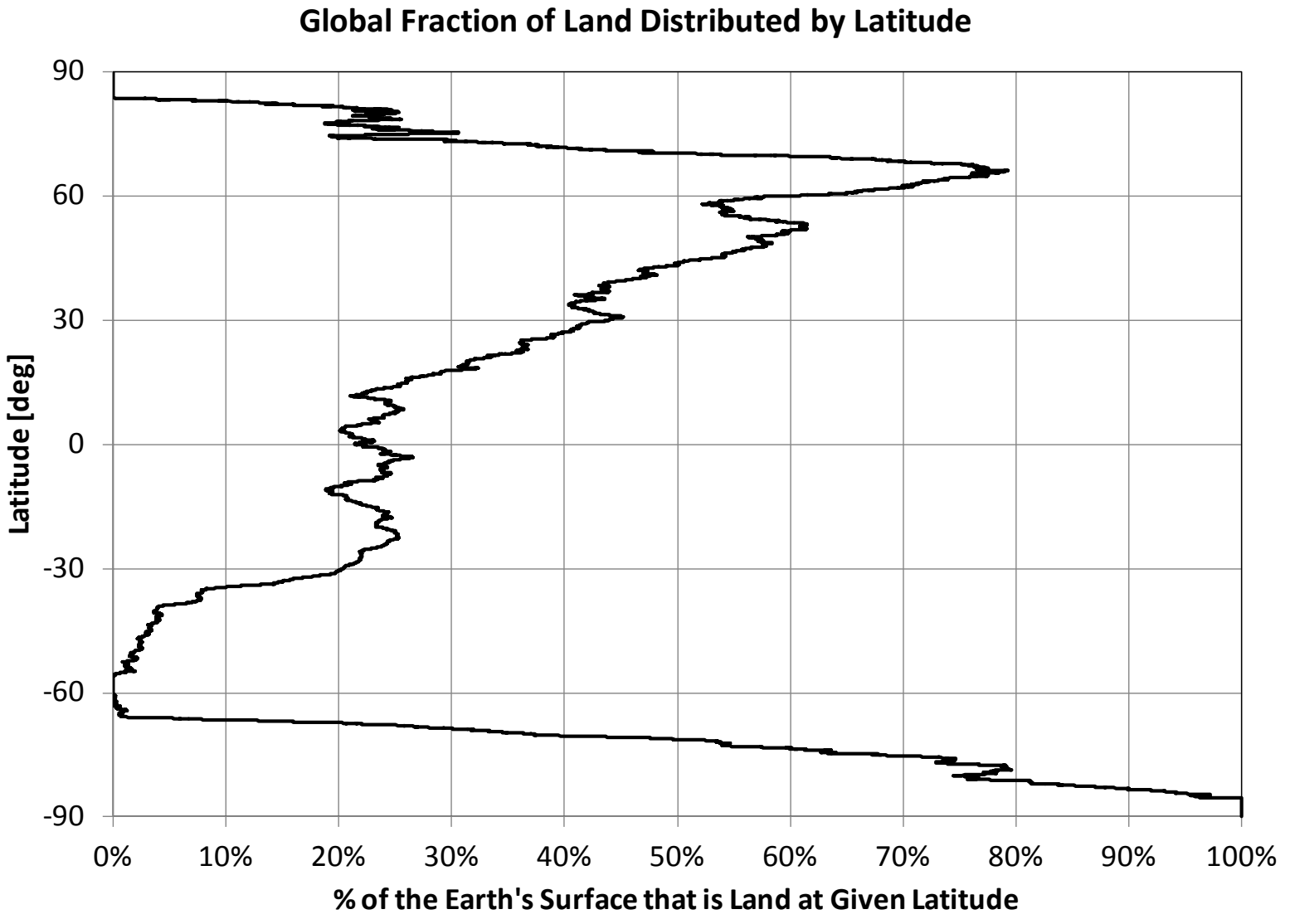
Post-Flight Assessment of UARS Reentry

- **High confidence post-flight assessment is that UARS reentered the Earth's atmosphere at 14.1° S and 170.1° W at 04:00 GMT on 24 September 2012.**

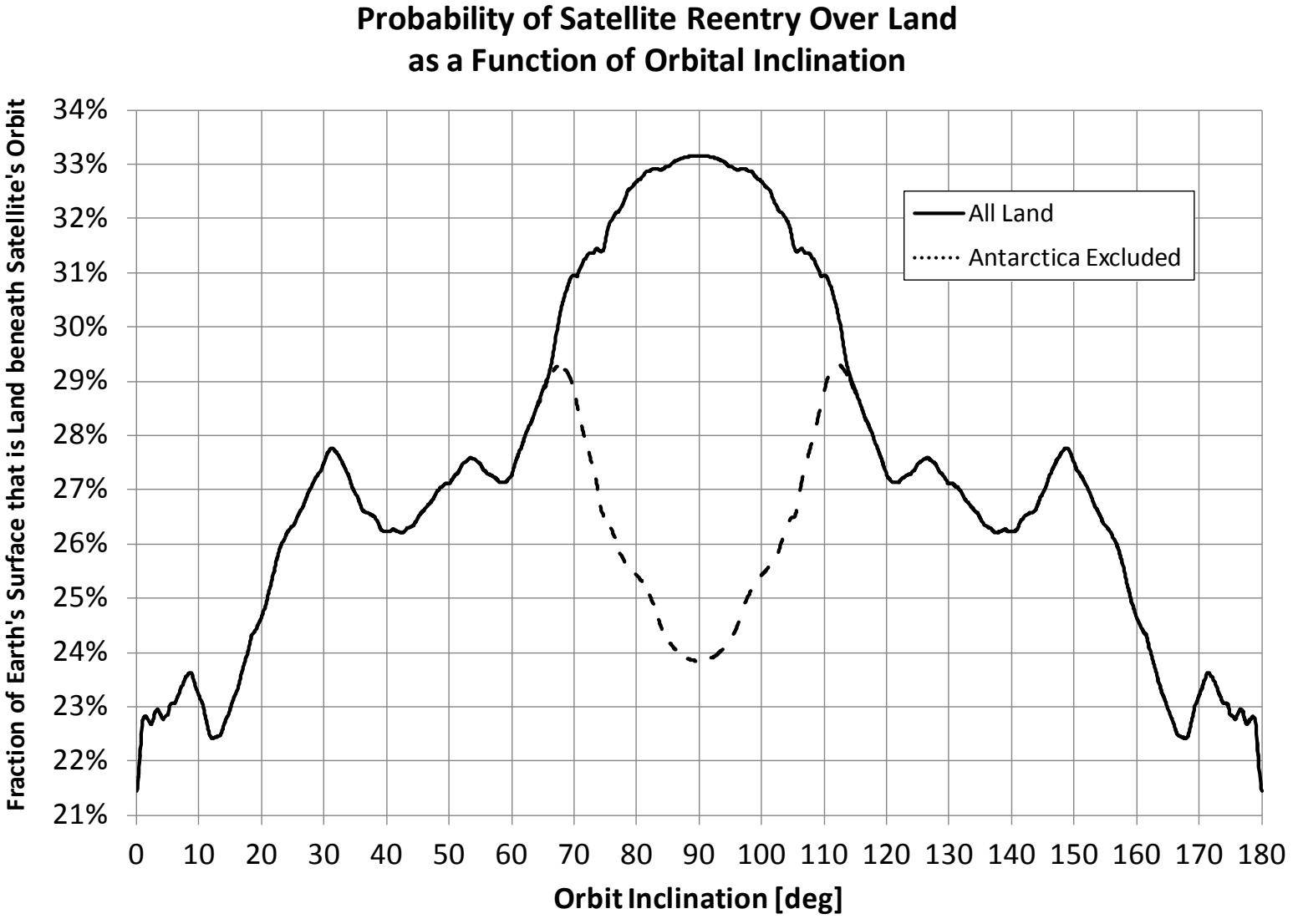


UARS Groundtrack, 03:30 – 04:00 GMT, 24 September 2011

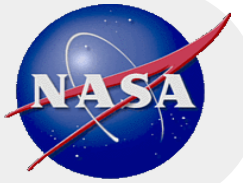
Probability of Reentering Over the Ocean



Probability of Reentering Over the Ocean

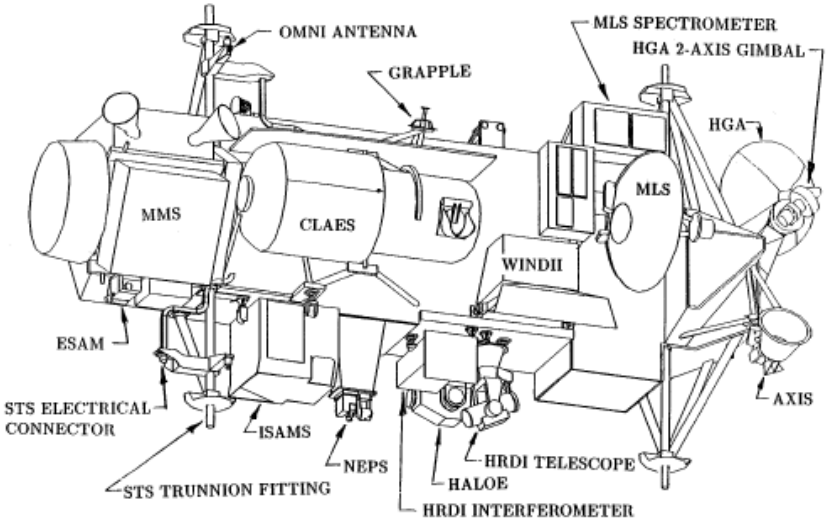


NASA Reentry Risk Capability



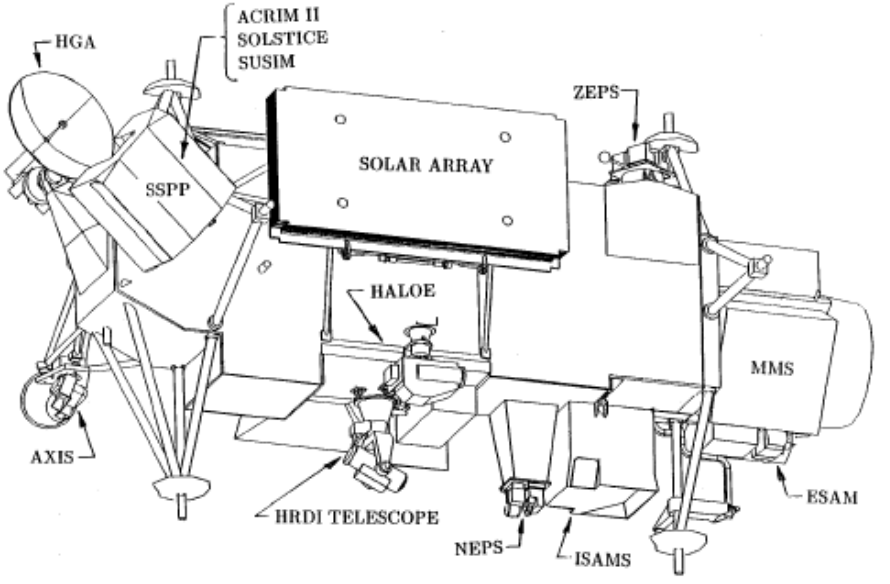
- **NASA's highest fidelity software program for reentering satellites is called ORSAT: Object Reentry Survival Analysis Tool. The program:**
  - Assesses spacecraft, launch vehicle stage, and other man-made space object component survivability during atmospheric entry from sub-orbital, orbital, and deep space trajectories.
  - Assesses human casualty risk associated with uncontrolled reentries.
  - Characterizes surviving debris footprints associated with controlled reentries for the purpose of avoiding inhabited regions and the Antarctic permanent ice pack.
- **ORSAT has supported many NASA, DoD, and other domestic and foreign programs during the past two decades.**

Basic Components of UARS



Starboard View

Port View



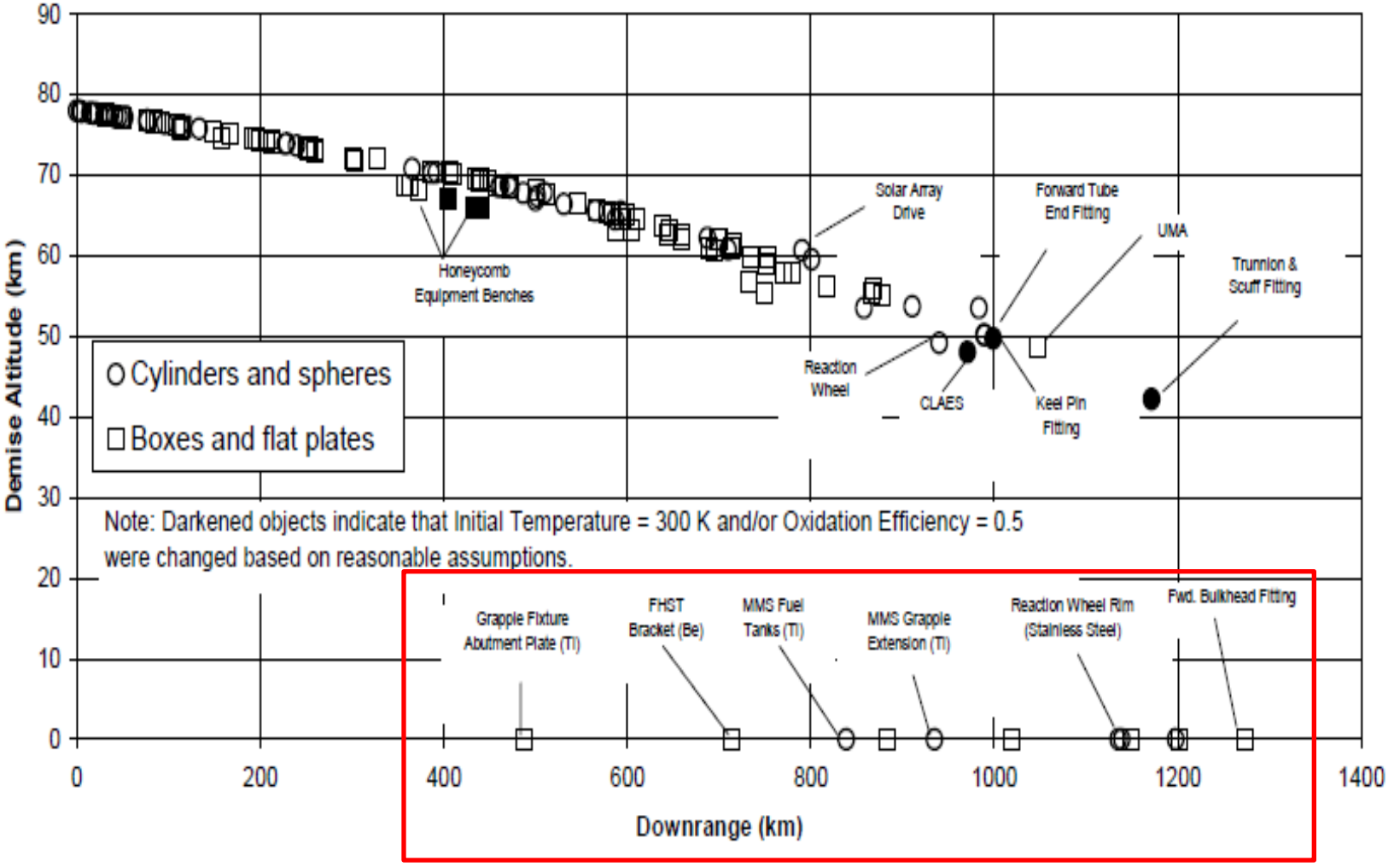
UARS Casualty Risk Assessment

- **NASA conducted a detailed reentry risk assessment for UARS in 2002.**
  - Number of potentially hazardous objects expected to survive: 26
  - Total mass of objects expected to survive: 532 kg
  - Estimated human casualty risk (updated to 2011): ~ 1 in 3200

Object Description	Material	Qty.	Type	Initial mass (kg)	Impacting mass (kg)	Impacting vel. (m/s)	Impacting K. E. (kJ)	Downrange (km)	Debris casualty area (m^2)	Impacting cross section area (m^2)	Mass/CS area (kg/m^2)	Impacting ballistic coeff. (kg/m^2)
HGA gimbal & reten.	Titanium	1	Cyl.	98.81	27.03	43.91	26.07	1197.56	1.32	0.301	89.80	119.58
Fwd bulkhead fitting	Titanium	4	Box	24.91	24.91	79.07	77.88	1274.16	0.66	0.0463	538.60	379.30
SSPP gimbal	Titanium	1	Cyl.	60.65	60.65	58.10	102.36	1138.72	1.36	0.322	188.47	207.80
SSPP structure	Al 2024-T8	1	Box	158.30	158.30	44.02	153.38	1019.70	2.44	0.928	170.59	120.13
MMS fuel tanks	Titanium	4	Sphere	5.17	5.17	25.55	1.69	838.55	0.94	0.138	37.48	40.74
MMS MPS batteries	SSteel 304L	3	Box	45.78	45.78	64.57	95.43	1149.34	0.91	0.126	362.97	255.61
Reaction wheel rims	SSteel 304L	4	Cyl.	2.04	2.01	107.26	11.54	1134.95	0.43	0.0028	710.02	678.79
FSS housing	Beryllium	1	Box	3.13	3.13	78.02	9.53	1201.73	0.46	0.0060	524.74	369.54
FHST bracket	Beryllium	2	Box	1.09	1.09	18.26	0.18	713.20	0.63	0.0368	29.60	20.85
G. F. abutment plate	Titanium	2	Flat pl.	2.30	2.30	14.28	0.23	486.58	1.22	0.255	9.02	12.76
G. F. base plate	Titanium	2	Flat pl.	5.51	5.51	35.80	3.53	883.43	0.83	0.098	56.35	79.70
G. F. extension	Titanium	1	Cyl.	3.39	0.64	21.40	0.15	934.93	0.56	0.0215	29.95	28.59
TOTALS		26		607.92	532.38				22.38	3.49		

Note: Totals account for quantity while the value listed in the table accounts for only one object.

Downrange Spread of Surviving Debris



Surviving Components

Summary

- **No NASA or USG human casualty reentry risk limits existed when UARS was designed, built, and launched.**
- **Time of reentry estimates were within normal limits**
- **NASA, the USG, and some foreign space agencies now seek to limit human casualty risks from reentering space objects to less than 1 in 10,000.**
- **UARS was a moderate-sized space object. Uncontrolled reentries of objects more massive than UARS are not frequent, but neither are they unusual.**
- **Since the beginning of the space age, there has been no confirmed report of an injury resulting from reentering space objects.**