Satellite Reentry Risk Assessments at NASA

Nicholas L. Johnson
Chief Scientist for Orbital Debris
NASA Johnson Space Center

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Outline

- **Origin of Reentry Risk Metrics**
- **Reentry Risk Criterion**
- **Reentry Risk Evaluation Process**
- **Sample Assessments**
  - Compton Gamma Ray Observatory
  - Tropical Rainfall Measuring Mission
  - Hubble Space Telescope
- **Summary**

Origin of Reentry Risk Metrics

- **NASA Safety Standard 1740.14 (August 1995) first established the guideline for all LEO spacecraft and launch vehicle orbital stages to remain in orbit for no more than 25 years after end of mission for the purpose of protecting the space environment for future operations.**
  - This guideline is now accepted by the US Government and many foreign space agencies and international bodies.
- **The most practical and cost-effective strategy for compliance is disposal of the vehicle in a low altitude orbit from which a natural, uncontrolled reentry will occur within the allotted time.**
- **However, such uncontrolled reentries shift on-orbit satellite collision risks to human casualty risks on Earth. To limit human casualty risks from surviving satellite debris, NASA developed a specific risk criterion and risk assessment process.**

Reentry Risk Criterion

- **In NASA Safety Standard 1740.14, a total debris casualty area metric was established:**

$$D_A = \sum_{i=1}^{N} \left(0.6 + \sqrt{A_i}\right)^2$$

where N is the number of objects that survive reentry and A_i is the area of the surviving piece in m^2. The term 0.6 represents the square root of the average cross-sectional area of a standing person, as viewed from above. Debris with impacting kinetic energies less than 15 Joules are no longer considered.

- **Total human casualty expectation, E, can then be defined as**

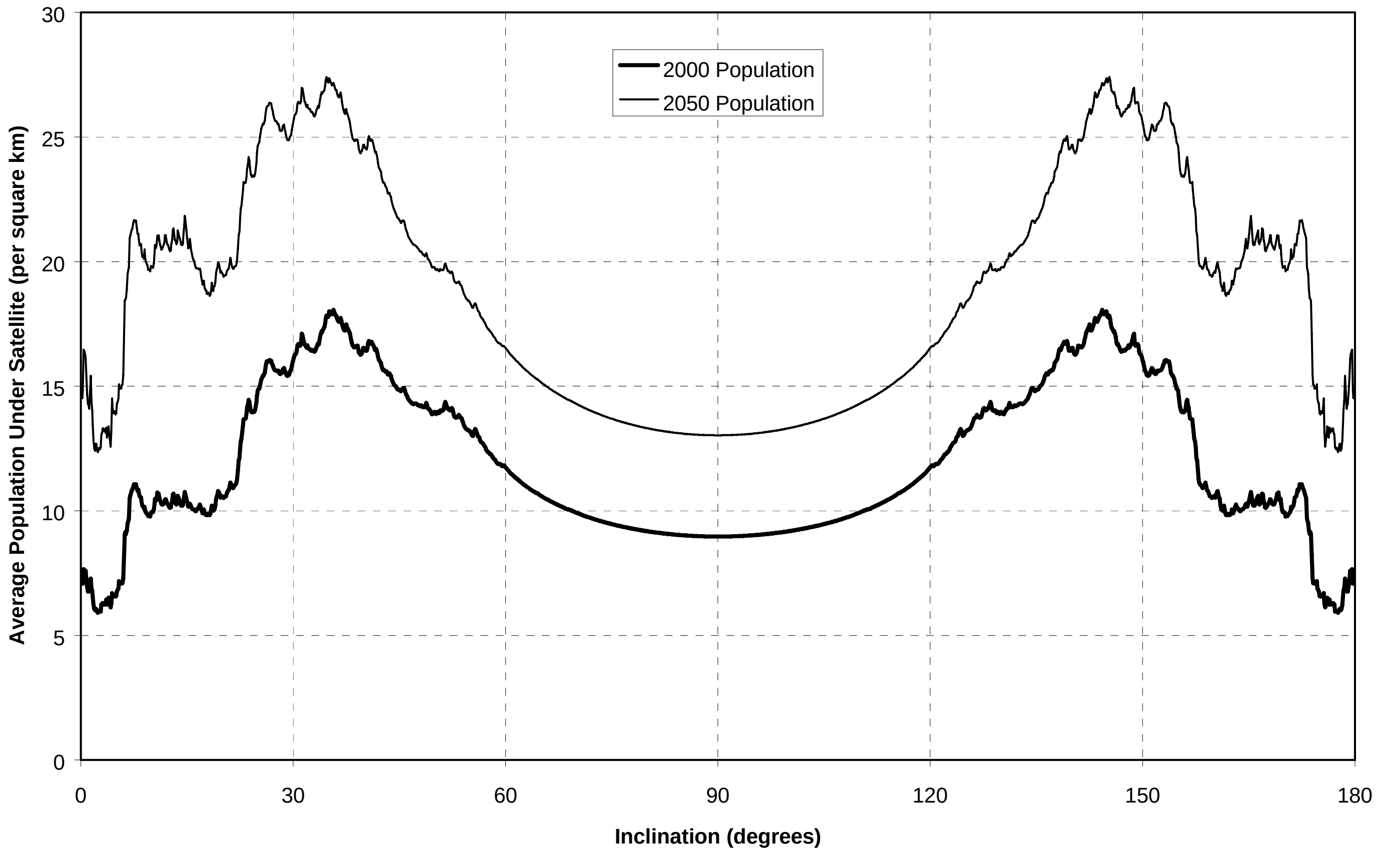
$$E = D_A \times P_D$$

where P_D is equal to the average population density for the particular orbital inclination and year of reentry.

- **A fundamental human casualty risk threshold of 1 in 10,000 per reentry event was adopted by NASA in 1995, which was equivalent to a debris casualty area of no more than 8 m^2 averaged over all inclinations for that year.**
  - Debris with impacting kinetic energies less than 15 Joules are no longer included in this calculation.

World Population Evolution

- Using internationally recognized sources for the 2000 world population and its expected evolution through 2050, average population densities weighted by the fraction of time a satellite spends a different latitudes as a function of orbital inclination have been developed.



Reentry Risk Evaluation Process

- **Reentry risk assessments are required for all NASA programs and projects in conjunction with the Preliminary Design Review (PDR) and Critical Design Review (CDR) milestones.**

- **NASA maintains two levels of reentry risk assessment software:**

DAS (Debris Assessment Software)

and

ORSAT (Object Reentry Survival Analysis Tool)

- **DAS is publicly available and can be used by program/project personnel.**

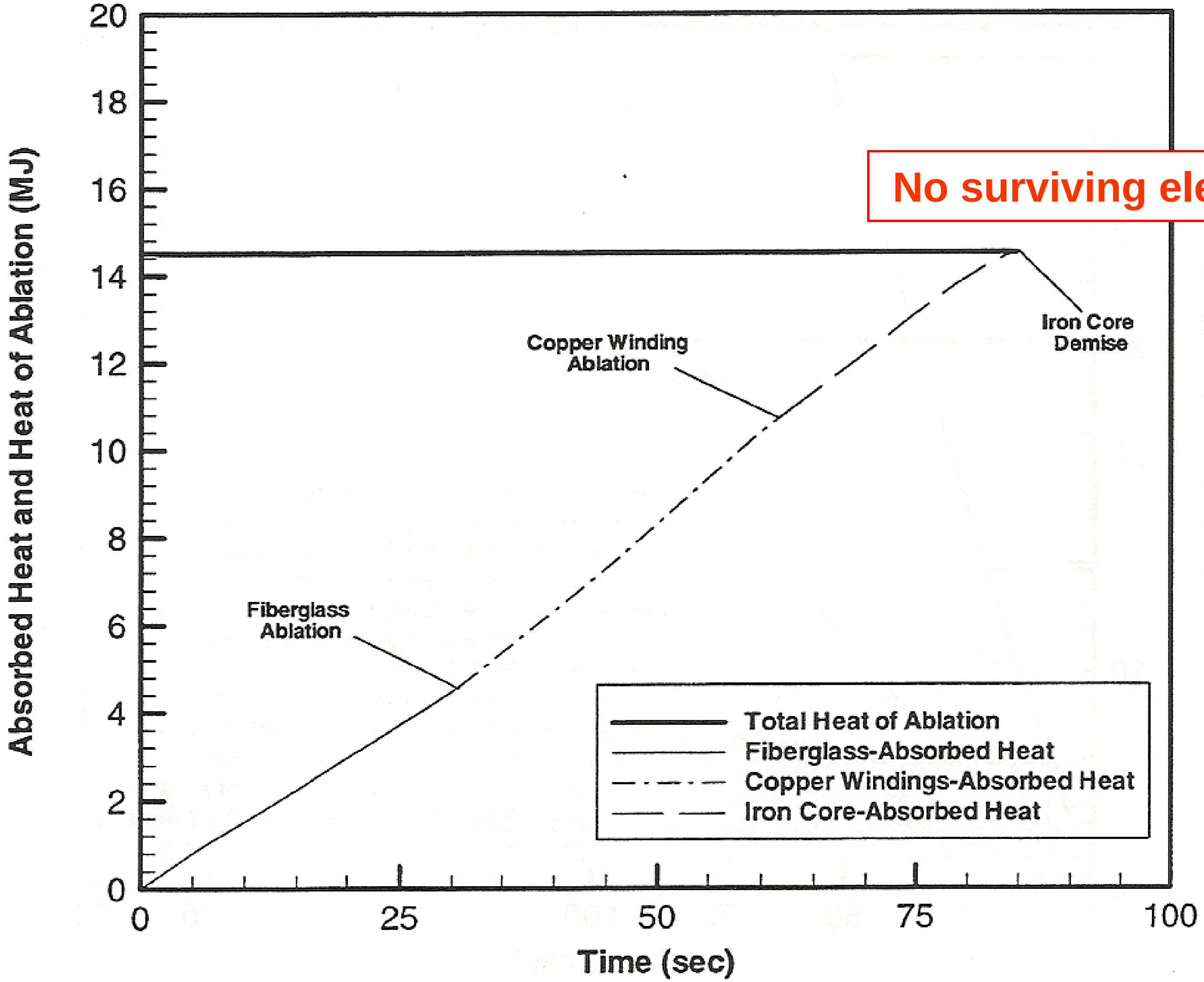
- **ORSAT is a higher fidelity, more capable model run by trained specialists at the NASA Johnson Space Center.**

ORSAT Summary Table for Terra Spacecraft: Surviving Components

#	Object Name	Qty	**Thermal Mass (kg)**	**Material**	Max. Demise Factor (%)	Downrange (km)	Debris Casualty Area (m^2)	Impact Mass (kg)	Kinetic Energy (J)
1.4	Bay 1 Nodes	6	9.48	Ti-6Al4V	97	1173	0.63	1.66	776.3
2.4	Bulkhead 2 Sleeve Fittings	6	0.76	Ti-6Al4V	99	708	0.48	0.07	5.4
2.6	Bay 2 Nodes - Large	4	7.77	Ti-6Al4V	98	1053	0.64	0.69	128.3
3.7	Bay 3 Nodes	4	6.98	Ti-6Al4V	99	1078	0.60	0.59	126.8
5.4	Bulkhead 5 Sleeve Fittings	8	0.69	Ti-6Al4V	99	826	0.46	0.06	6.6
5.8	Bay 5 Nodes - Large	2	7.20	Ti-6Al4V	99	1090	0.59	0.60	134.6
6.5	Bulkhead 6 Sleeve Fittings	8	0.67	Ti-6Al4V	99	871	0.44	0.06	7.4
9.1.3	DMU	2	69.91	Al 6061-T6	94	1097	1.15	13.13	5872.3
9.1.5	SFE	1	21.09	Al 6061-T6	97	513	3.10	4.21	114.4
10.3.4	Power Distribution Unit	1	37.73	Al 6061-T6	95	561	1.19	7.23	1982.7
11.1.2	Base Panel (w/fittings)	1	21.03	Al 5056-H39 core, M46J/7714A FS	97	465	2.94	13.70	1675.6
11.3	Propellant Tank	1	31.94	Ti-6Al4V	66	816	2.13	31.94	13410.7
12.1.8.1	Rotor Assembly	4	9.40	Stainless Steel	73	1160	0.59	9.40	21800.1
13.1.10.3	Kinematic Mount 3 Axis	1	0.77	Ti w/ teflon lined stainless bearings	99	894	0.47	0.10	13.4
20.1	CERES Panel	1	27.88	Al 5056-H39 core, M46J/7714A FS	90	541	2.71	14.02	2004.8
21.1.2	MOPITT Power Module	1	28.00	Al 6061-T6	99	963	1.01	5.30	1568.9
21.3.1	corner fittings	6	1.00	Ti-6Al4V	30	814	0.44	1.00	2078.1
21.3.2	MAGE fitting (1)	1	0.80	Ti-6Al4V	33	803	0.44	0.80	1328.0
21.3.3	MAGE fitting (2)	2	0.30	Ti-6Al4V	42	755	0.44	0.30	185.9
21.5	1 Axis KM Ftg	1	2.44	Ti-6Al4V	88	992	0.64	2.44	2445.2
21.9	3 Axis KM Ftg	1	4.63	Ti-6Al4V	73	944	0.81	4.63	3908.6
22.1.1	MISR Power Module	1	34.00	Al 6061-T6	87	921	1.17	13.18	6852.2
22.1.2	Electronics Module	1	18.00	Al 6061-T6	94	807	1.10	3.50	572.4
23.1	Instrument	1	115.37	Al 6061-T6	95	885	2.20	22.56	5974.2
25.1	Instrument	1	148.48	Al 6061-T6	95	908	2.46	29.04	8244.1
26.1	Instrument (w/alignmnet plate)	1	230.66	Beryllium	26	1046	3.40	230.66	301213.5
27.2	Release Mechinism Brackets	4	2.48	Ti-6Al4V	99	1029	0.46	0.39	177.0
27.3.1	HGA Gimbal	2	21.77	Ti-6Al4V	59	1304	0.63	15.43	64144.5
27.3.2	ACON	1	16.78	Ti-6Al4V	62	937	1.08	16.78	13302.9
28.1.1	SAD Shaft and bearings	1	8.20	Ti and Stainless	17	1313	0.88	8.20	6021.3

Total DCA for Objects Impacting < 15 J = 48.48

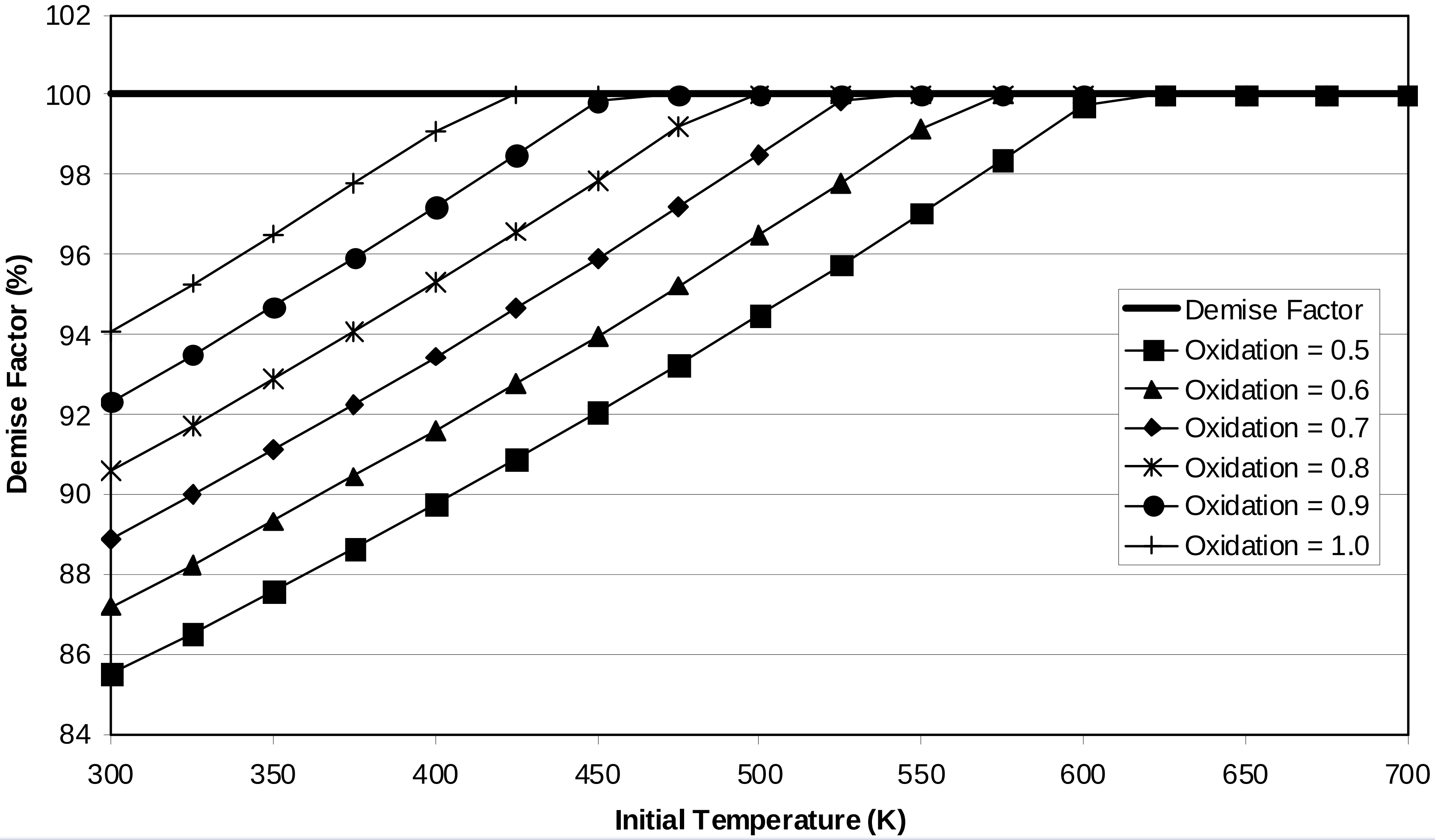
Example ORSAT Output: Sequential Demise of Portions of the Magnetic Torquer rod assembly from UARS Spacecraft



No surviving elements

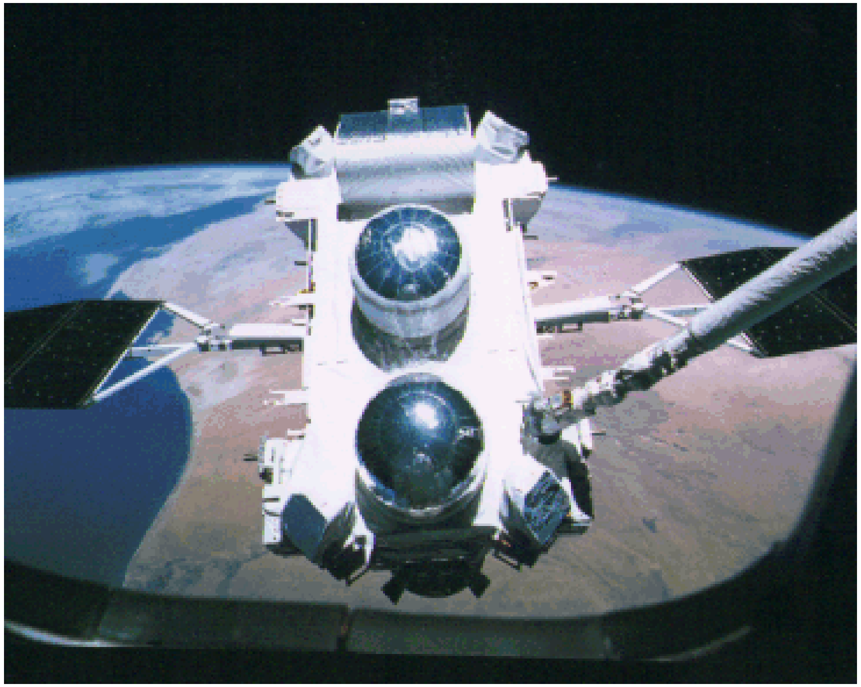
Parametric ORSAT Analysis of Different Initial Temperatures and Oxidation Heating Efficiencies

Survivability Factor vs. Initial Temperature for UARS Forward Bulkhead Fitting

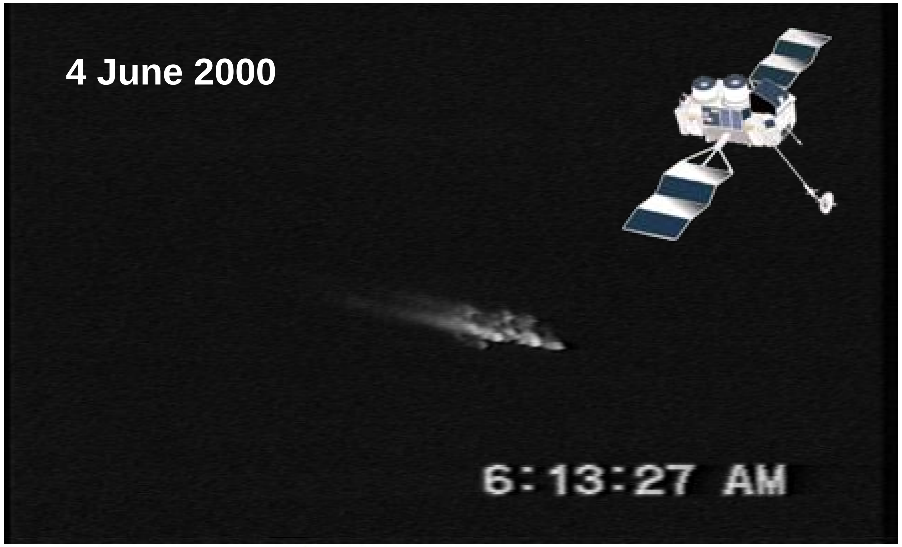


Sample Assessment: Compton Gamma Ray Observatory

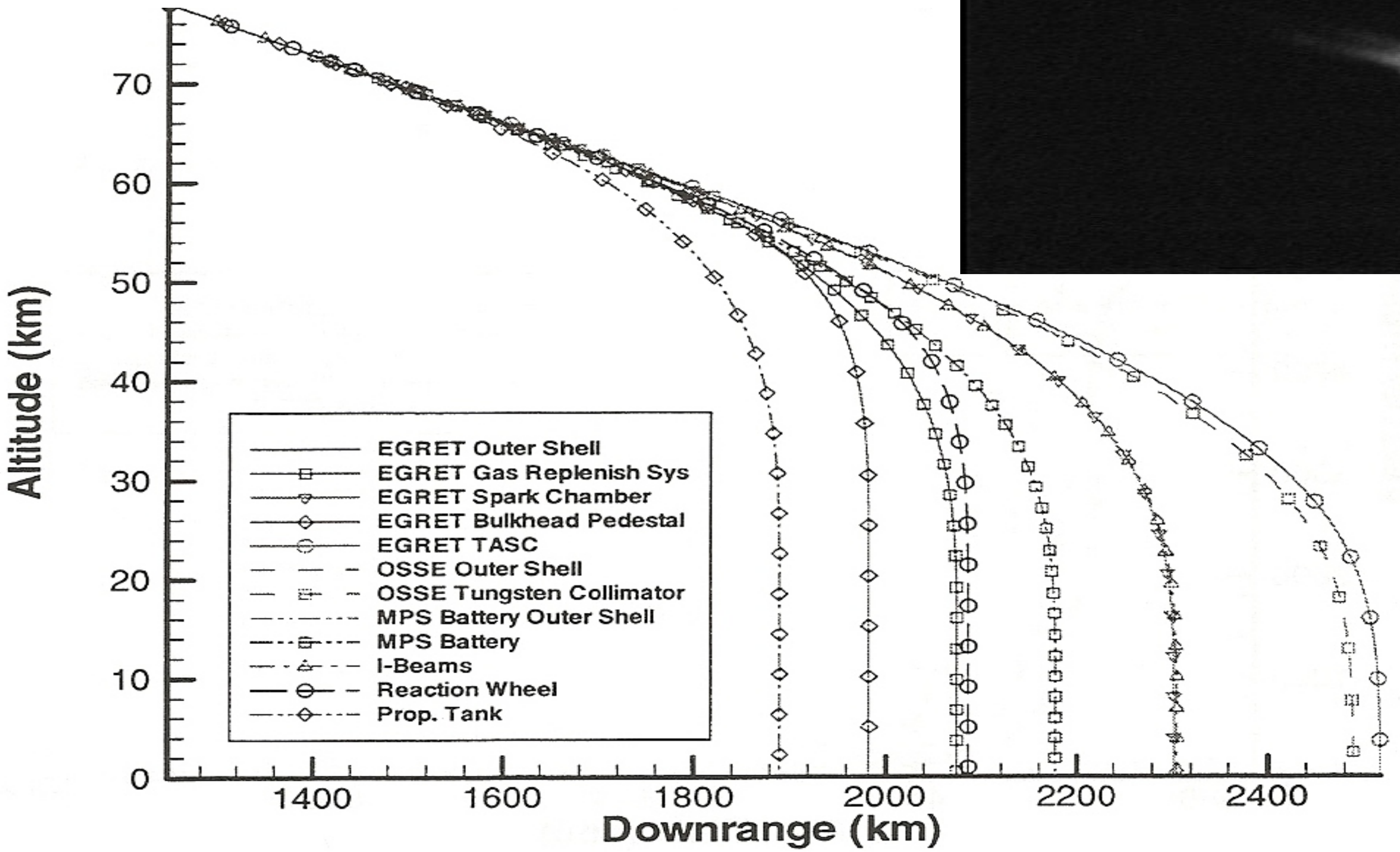
- **CGRO was deployed by the Space Shuttle in April 1991.**
- **Failure of a gyro on CGRO in December 1999 left the spacecraft zero-fault tolerant for a planned controlled reentry.**
- **A re-evaluation of the human casualty risk for CGRO using ORSAT yielded a total debris casualty area of 52.5 m2, *i.e.*, a human casualty risk of 1 in 1200.**
- **Consequently, CGRO was commanded to controlled reentry over the Pacific Ocean on 4 June 2000.**



CGRO Reentry



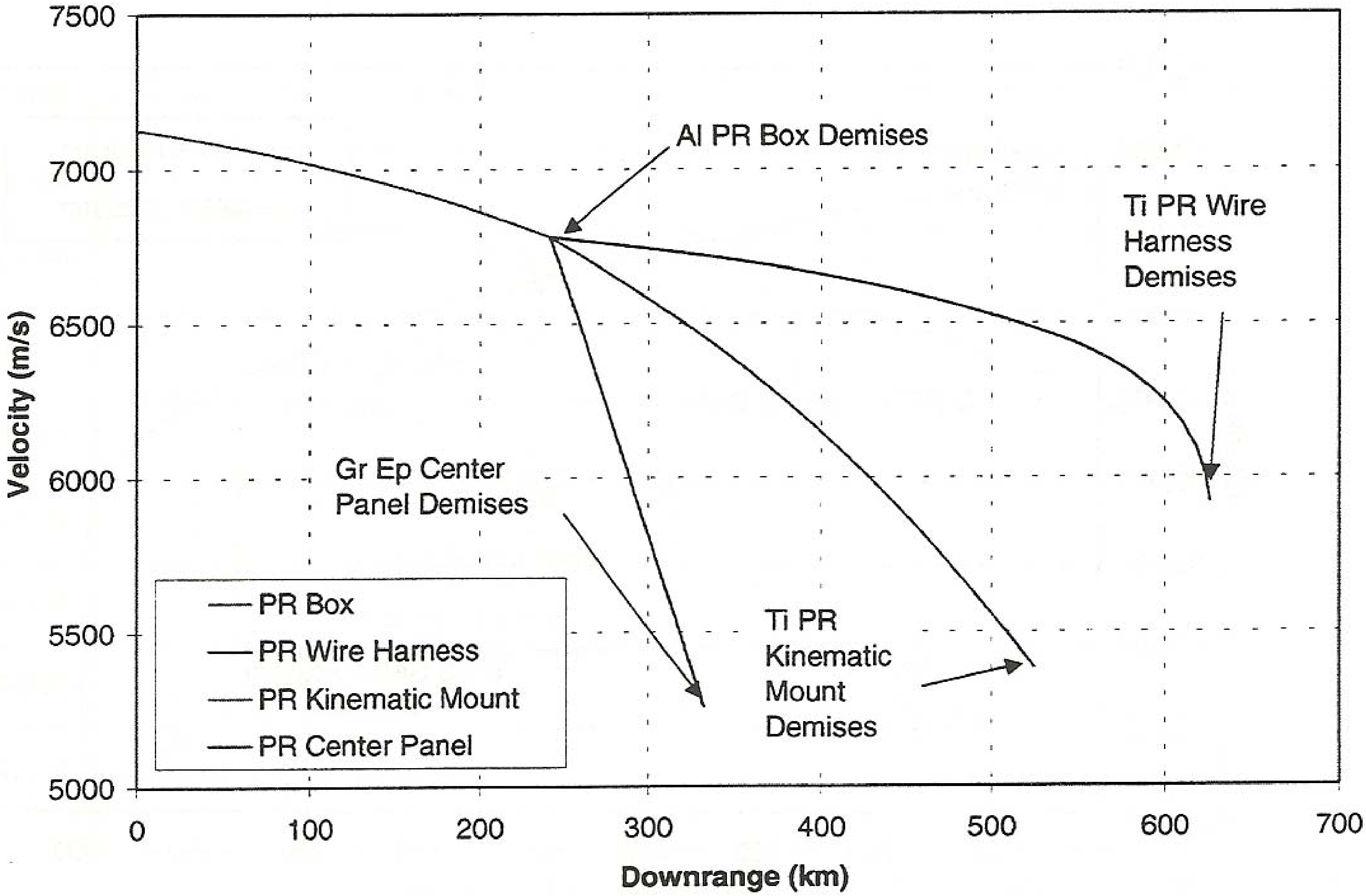
4 June 2000



Sample Assessment: Tropical Rainfall Measuring Mission

- The TRMM spacecraft was designed for a controlled reentry to avoid risk to people on Earth.
- An updated ORSAT assessment of human casualty risks following an uncontrolled reentry was commissioned as the spacecraft’s propellant supply approached the minimum level required for a controlled deorbit.
- ORSAT calculated a human casualty risk of ~ 1 in 5,000, i.e., a factor of two greater than the desired minimum risk of 1 in 10,000.
- However, due to the potential benefit of operating TRMM for several more years, NASA decided to no longer require a controlled reentry.

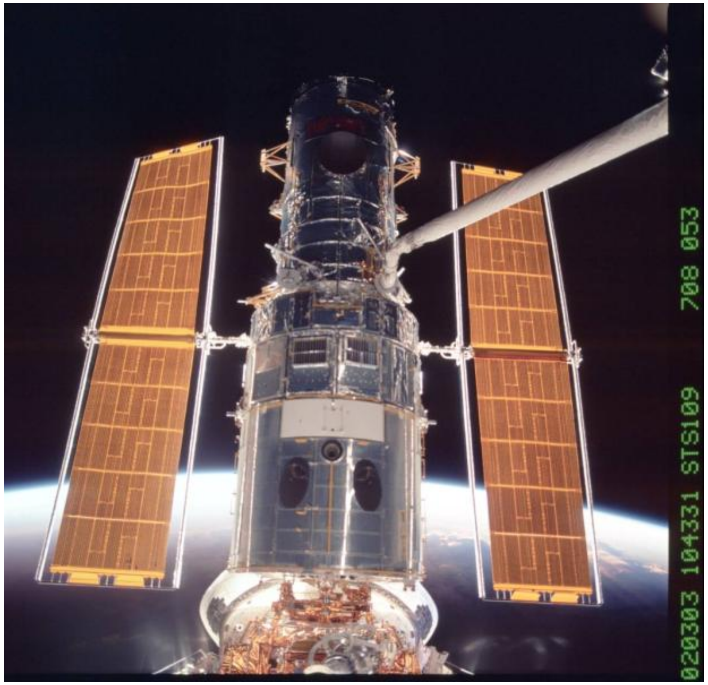
Predicted Demise of TRMM Precipitation Radar



Sample Assessment: Hubble Space Telescope

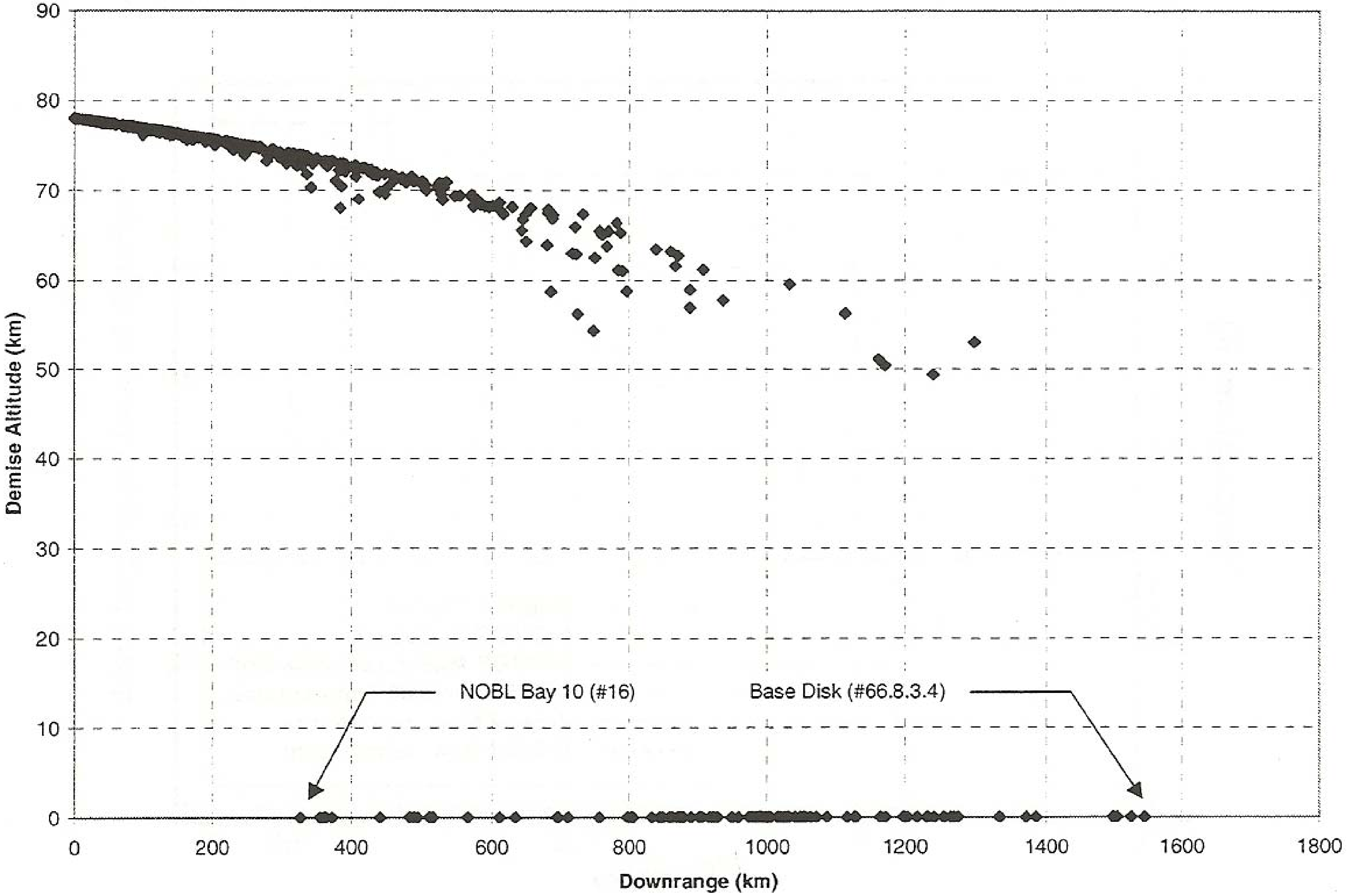
- **HST has a mass of ~11 metric tons and no maneuver capability.**

- **An ORSAT assessment of the human casualty risk arising from an uncontrolled reentry of HST found a casualty area of more than 150 m^2 and a risk on the order of 1 in 250 for a reentry in 2020.**



- **Consequently, NASA has reiterated its intention of conducting a controlled reentry with the future attachment of a specialized propulsion unit.**

Predicted Demise Altitudes and Impact Locations for HST Components: Uncontrolled Reentry



Future Challenges

- **Large launch vehicle orbital stages, *e.g.*, Delta IV and Atlas V, are often non-compliant with U.S. Government and NASA directives on limiting potential human casualty risks following uncontrolled reentries.**
  - Redesign of stages is not a practical solution.
- **Controlled deorbits from LEO are feasible (demonstrated by Delta IV second stage in 2006).**
  - These are more attractive if stages are left in low parking orbits and spacecraft insert themselves into higher, operational orbits.
- **For GTO missions, an alternative is to leave stages in long-lived orbits with perigees above 2000 km, *e.g.*, GOES 13 in 2006.**
- **Design-to-Demise techniques offer solutions for new spacecraft.**

Summary

- **NASA has established the policies, requirements, and technical tools for evaluating and limiting human casualty risks from satellite reentries.**
- **Each reentry event should pose a human casualty risk no greater than 1 in 10,000.**
- **Reentry risks are evaluated explicitly at PDR and CDR.**
- **Design-to-Demise techniques and controlled reentries will remain the principal means of limiting human casualty risks, particularly for large spacecraft and launch vehicle orbital stages.**