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Meteoroids and Meteor Storms: A Threat to Spacecraft?

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B. Jeffrey Anderson

Electromagnetics and Aerospace Environments Branch

NASA

Marshall Space Flight Center

Huntsville, Alabama, 35812

b.jeffrey.anderson@msfc.nasa.gov

Meteoroid Flux in Geosynchronous Orbit

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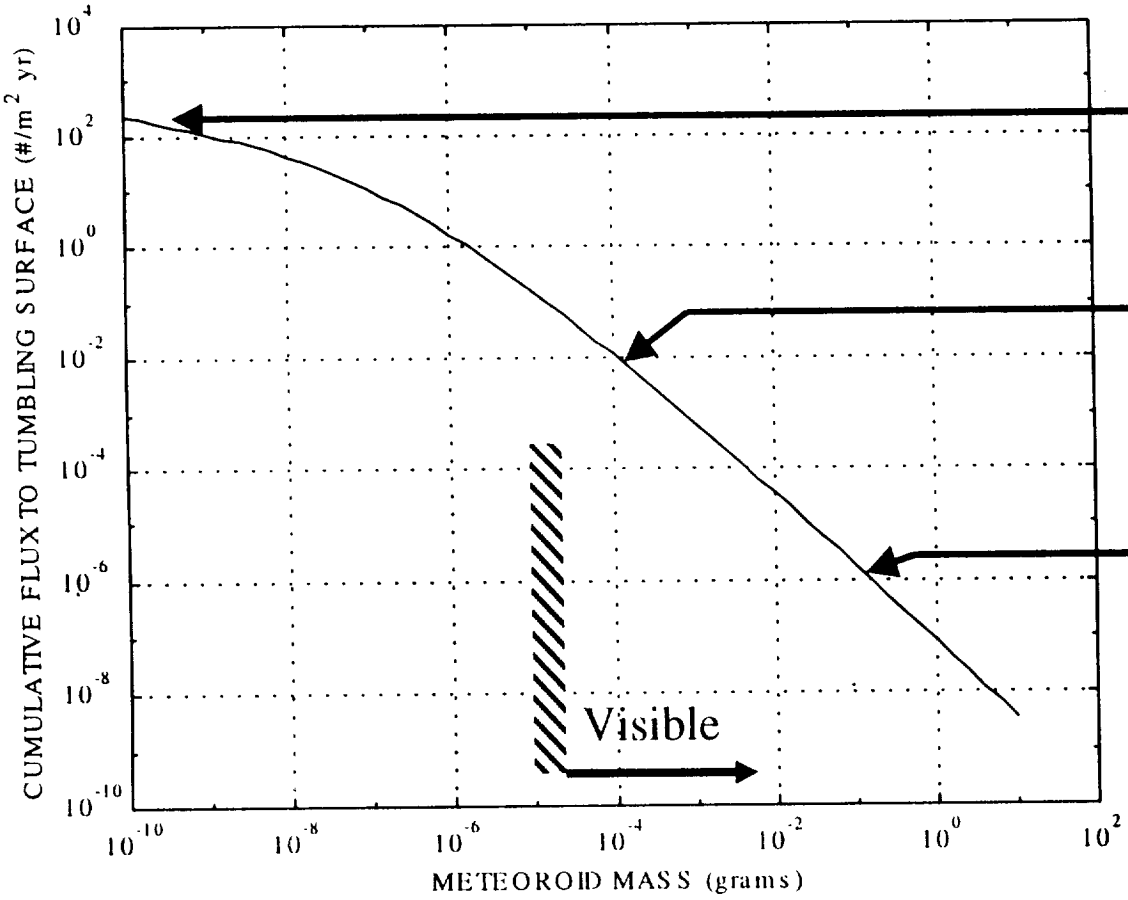

# m^{-2} yr^{-1}	Size
200	0.008 m
1/100	0.7 m
1/1,000,000	8 m

Hypervelocity Impact Phenomena

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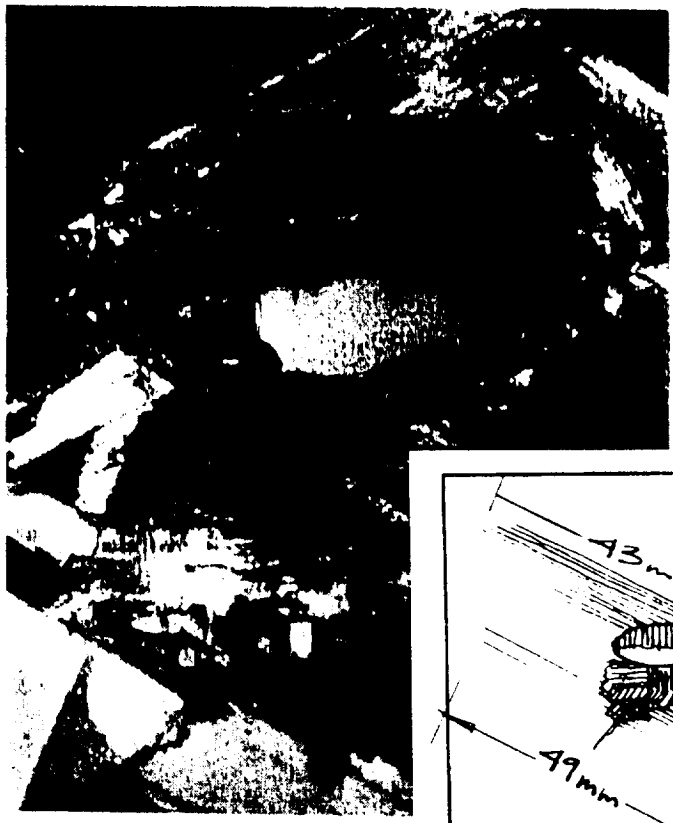

Courtesy Johnson Space Center

Left: Flash x-ray sequence. **Right:** Impact Damage to Graphite Epoxy Honeycomb
{1/16" (5.82 mg) Al impact at 6.81 km/s on 24 layer MLI, M60J/954 Honeycomb, 0.040"/0.40"}

Impacts on LDEF Thermal Surfaces

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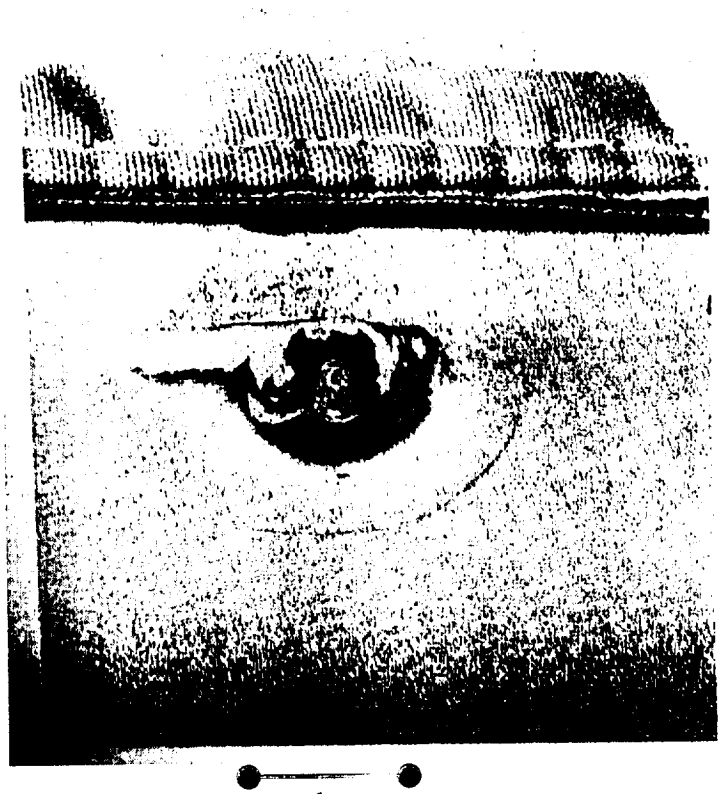

≈1 cm

...blanket backed by vapor deposited silver/inconel, paint (Exp. A01...
...coated with 125 μm teflon film, silver & adhesive backed (Exp. S1005).

Impact Related Failure Modes

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• Cables Short	MSTI-2 (9/94) ??
• Cables Cut	
• Pressure Vessels (explode/unzip)	
• Structure Failure	CERISE (7/96)
• Tethers Cut	SEDS-2 (after mission)
• Window Damage	Shuttle (3 replaced / 2 missions)
• Light Leakage	
• Electromagnetic Pulse (Meteoroids only)	Olympus (8/93) ??
• Fluid Line and Heat Pipe Leaks	Shuttle Threat
• Operator Error	

Zenith Hourly Rate (ZHR)

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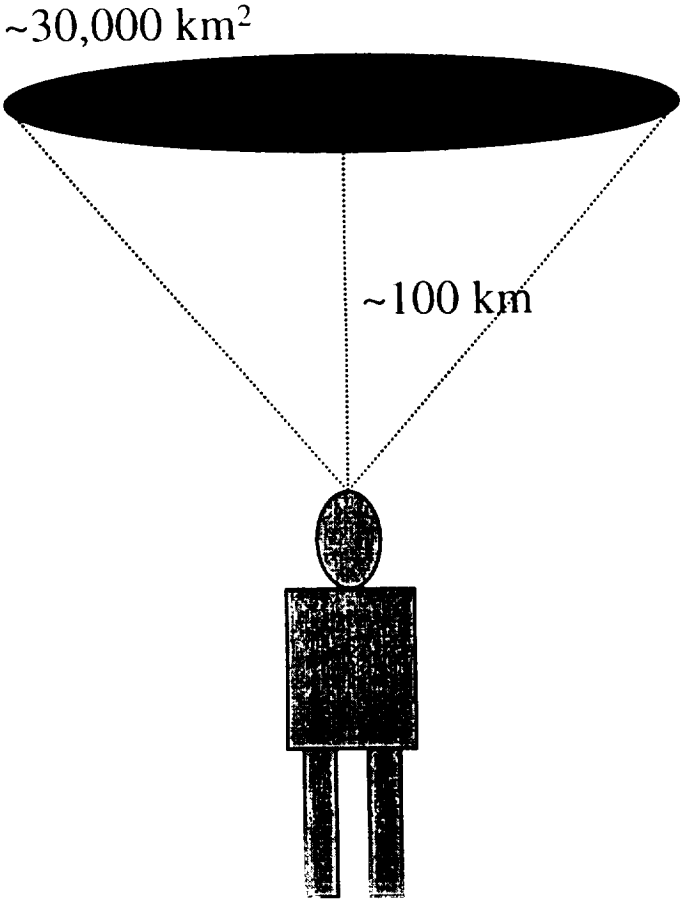

- Meteor altitude is about 100 km.
- "Standard" Observer.
- Dark, clear sky
  - Magnitude 6.5 stars visible.
- Radiant of shower directly overhead.
- **Zenith Hourly Rate is the number counted per hour.**
- Background: ZHR ~ 8.
- Typical "Shower": ZHR ~ tens.
- Meteor "Storm": ZHR > 1000.
- **For a 300 m^2 Satellite, storm conditions risk is ~ 0.00001 hr^{-1} from visible-size meteoroids.**

Meteor Showers

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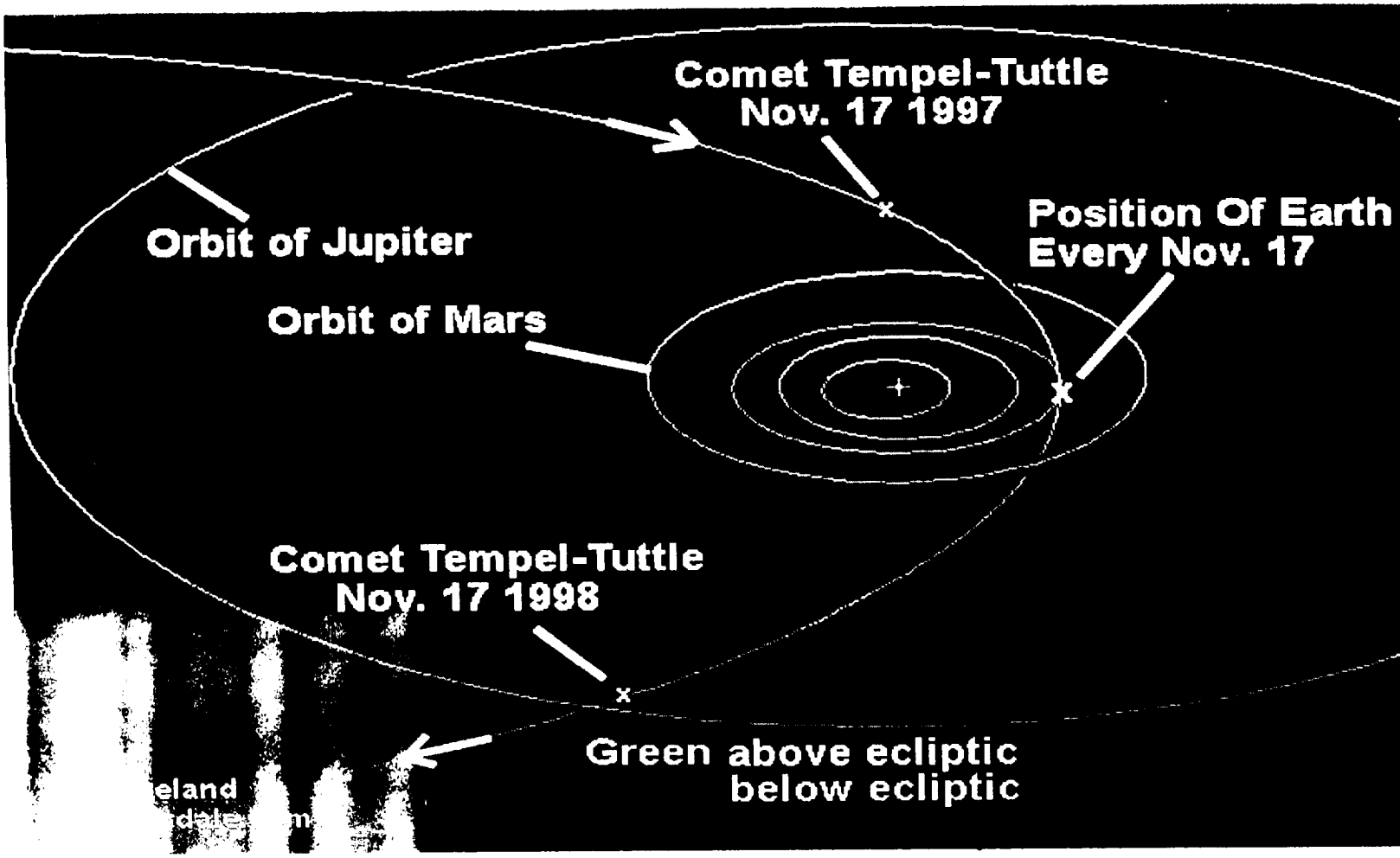
Meteors	Dates	ZHR Peak	Comet
Sporadic Background		8	
Quadrantids	Jan 1-6	80	unknown
April Lyrids	Apr 19-25	15	Thatcher 1861 I
Pi-Pullids	Apr 21-26	40	Grigg-Skjellerup
Eta-Aquarids	Apr 24-May 20	35	Halley
Day Beta-Taurids	Jun 23-Jul 5	20	Encke
Perseids	Jul 15-Aug 21	75	Swift-Tuttle
October Draconids	Oct 7-10	20	Giacobini-Zinner
Orionids	Oct 16-30	25	Halley
Taurids	Oct 20-Nov 30	12	Encke
Leonids	Nov 15-20	10	Tempel-Tuttle
[illegible]ids	Nov 25-Dec 17	60	3200 Phaethon (asteroi
	Dec 20-24	5	Tuttle

Orbital Mechanics of Leonid Generating Comet Tempel-Tuttle



Courtesy of Peter Brown, University of Western Ontario

1998 Leonid Visual Observations

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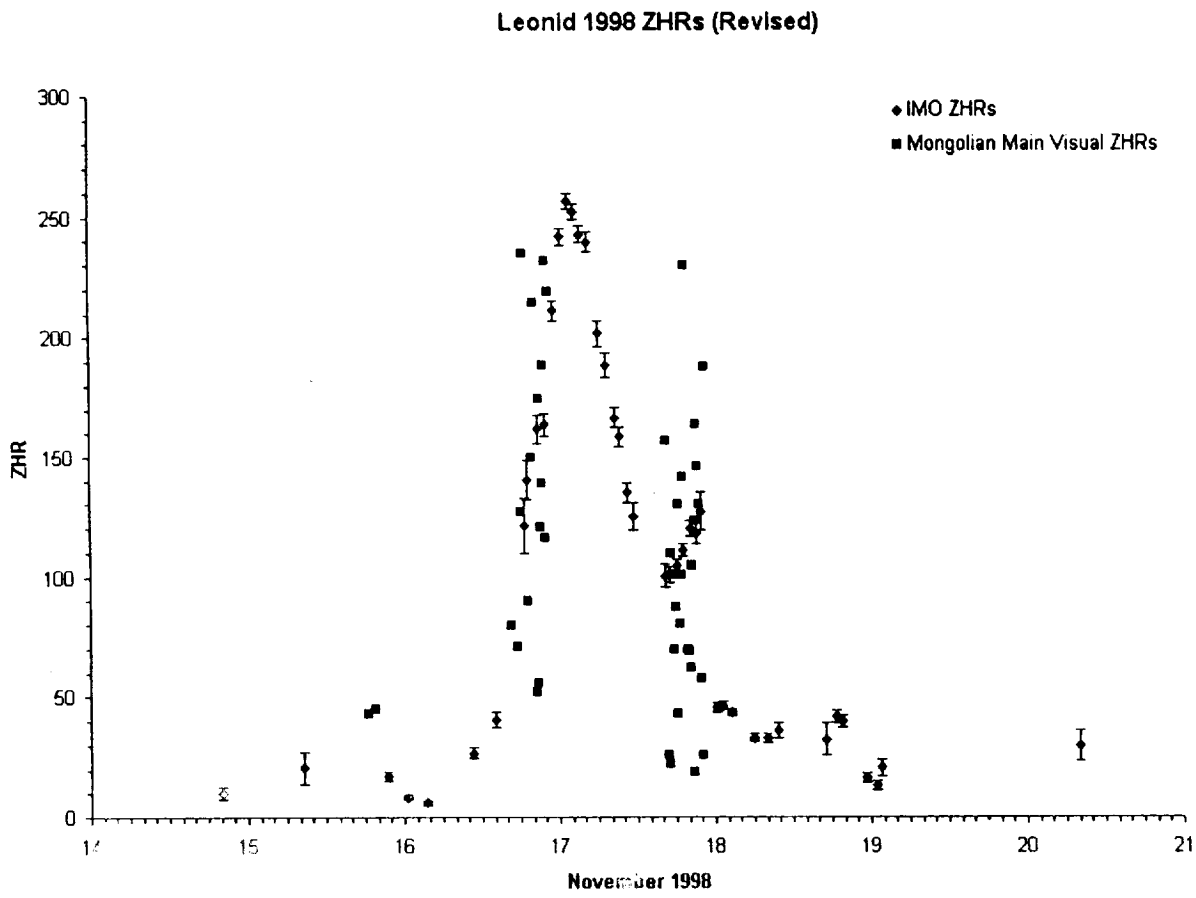

Courtesy of W. Cooke and P. Brown

1999 Leonid Encounter

Orbit Analysis by P. Brown, UWO; Threat Analysis by W. Cooke, CSC Inc./ MSFC

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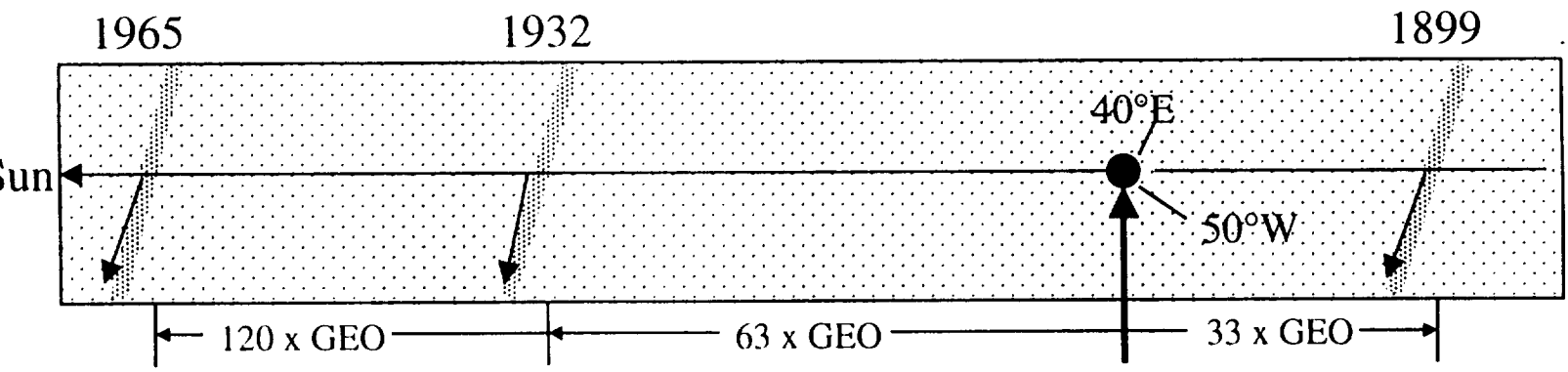

- Encounter Velocity = 72 km/s.
- Peak Time = 02:20 UT on Nov. 18, 1999.
- Estimated Peak ZHR = 1000 to 2000.
- Width of Peak: Less than 2 hours, but with enhanced activity for several days.

Risk to Satellite Surfaces

Meteoroid Mass (grams)	1.E-07	1.E-06	1.E-05	1.E-04	1.E-03
Flux (m^{-2} hr^{-1})	~ 3 E-5	~ 5 E-6	~ 9 E-7	~ 1 E-7	~ 2 E-8

Leonid Storm Mitigation Strategies

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- Robust Design (Minimize exposed cables and fluid lines. Assure a well grounded system.)
- Understand your system's weaknesses --- plan accordingly.

November 18, 1999, 02:20 UT ± 3 hours:

- Orient satellite to minimize cross-sectional area and vulnerable surface exposure to the stream.
  - No problem for solar arrays since radiant is about 82° from sun.
- Notify system controllers of the enhanced likelihood of spacecraft anomalies. Keep the "Starting Team" on duty.
- Minimize operational changes, software uploads, and complex operations during this period.
- Configure to minimize high voltages on board.

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BACK UP SLIDES

Double Wall Penetration
Leonid Storm Peak

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Assumptions:

Zenith Hourly Rate = 5000

Flux = 2.8e-19 (zhr) $m^{-1.3}$ [m^{-2} s^{-1}]

One Square Meter at Random Orientation, One Hour Exposure

0.020 Inch Al Back Wall

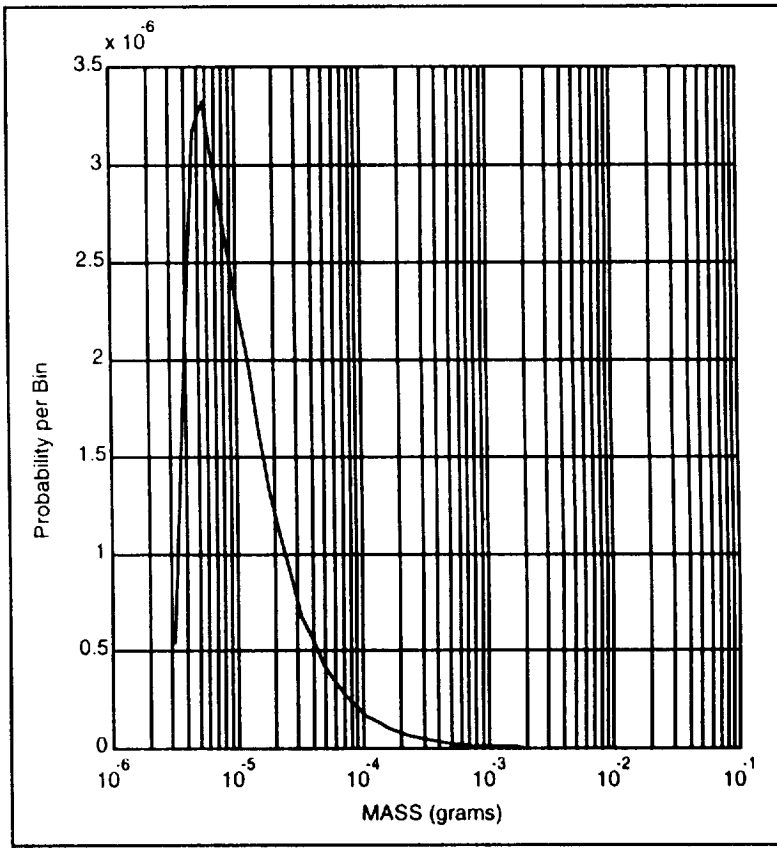
0.25 Inch Spacing to Bumper

No Earth Shielding

Total Probability of Penetration

2.7e-5 [m^{-2} hr^{-1}]

Critical Mass = 3.6e-6 g.



Double Wall Penetration

Taylor-McBride Velocity Distribution

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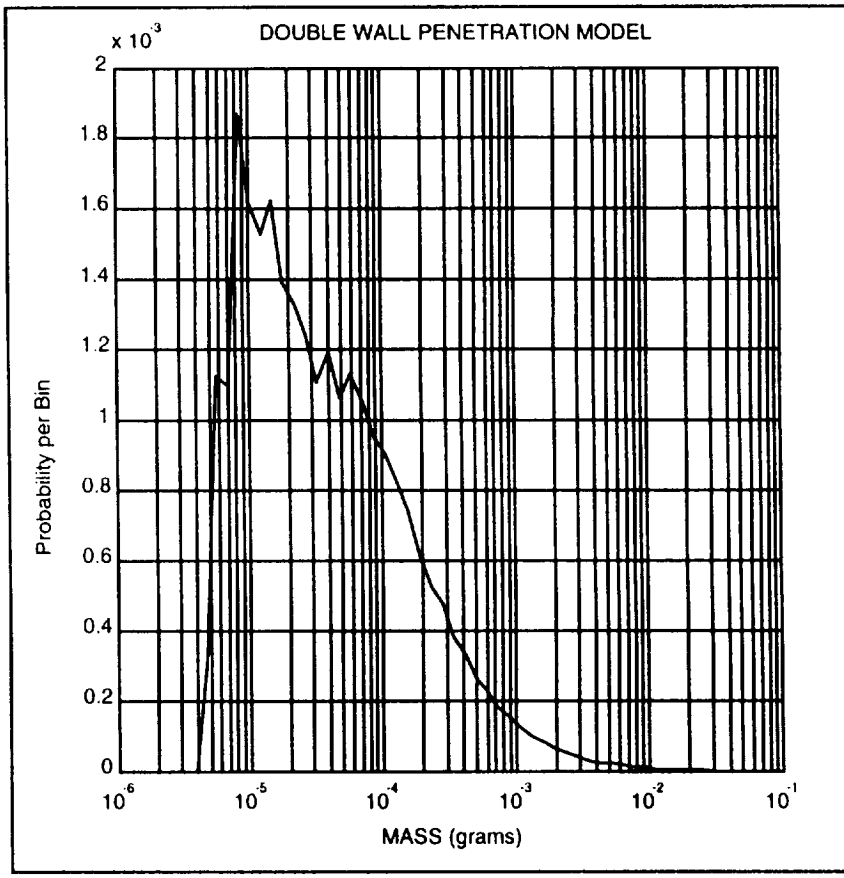
Assumptions:

- 0.020 Inch Al Back Wall
- 0.25 Inch Spacing to Bumper
- One Square Meter, One Year Exposure
- 1000 km Altitude
- Grün / Space Station / TM 4527 Flux
- Taylor & McBride Velocity Distribution (3/97 Darmstadt Conf.)

Total Probability of Penetration = 0.026



Conclusions

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- Robust system design is the best protection against meteoroid damage.
- Impacts by small meteoroids are common on satellite surfaces, but impacts by meteoroids large enough to damage well designed systems are very rare.
- Estimating the threat from the normal meteoroid environment is difficult. Estimates for the occasional "storm" are even more uncertain.
- Common sense precautions are in order for the 1999 Leonids, but wide-spread catastrophic damage is highly unlikely.
- Strong Leonid showers are also expected in 2000 and 2001, but these pose much less threat than 1999.

Results of half inch Al projectile impacting on 0.040 inch Al plates at 6.1 km/s; 4 in. spacing; 0.125 in. back plate.