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Mitigation Guidelines for Extreme Electron Events

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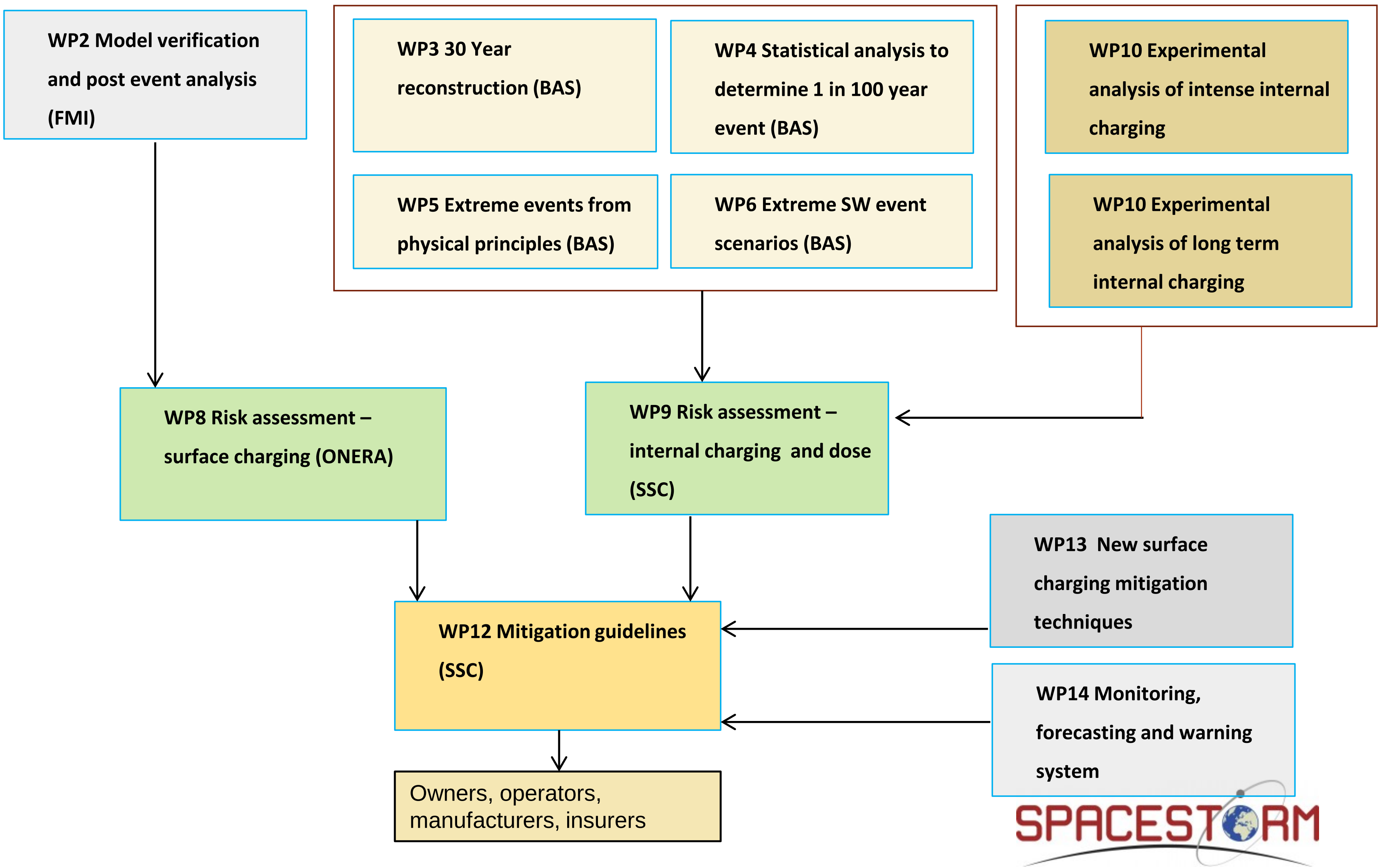
Close Out Meeting, Cambridge, UK, 23 March 2017

Mitigation guidelines (WP12)

Objectives

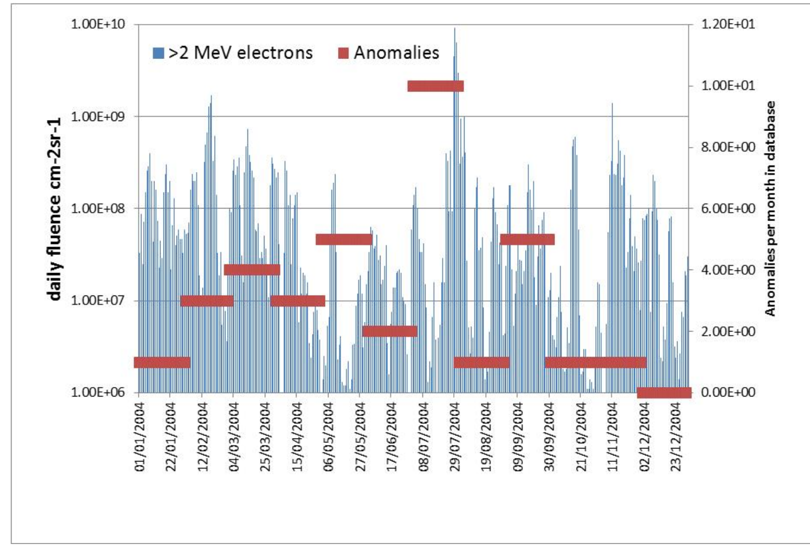
- Aid exploitation of Spacestorm research
- Practical guidance on extreme events in context of current design practice (for GEO and MEO)
- Determine/quantify the feasibility of mitigation if possible
- Advise on mitigation options

Spacestorm Overview

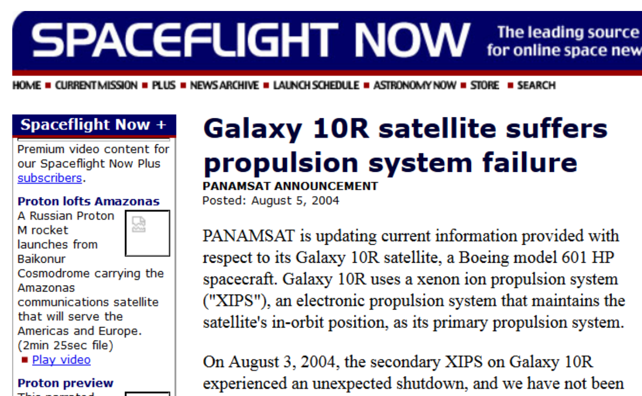


Experience of severe storms to date

- Satellites have specifications which account for ‘severe’ space weather
  - many space weather failures do not occur in the most severe events
- Overall performance of global fleet is actually good
  - even in largest of space weather events there have been only a few failures
  - sign of successful engineering
  - but reliable anomaly data is hard to obtain
  - severe events to date appear to cause ‘stress’
  - conservative design practices and hidden safety margins
- An extreme electron event would be outside of current engineering specifications
  - leads to risk but not necessarily instant failures



Anomalies per month in 2004 (Sources: Atrium insurance database and GOES/NOAA SEM)



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Proton lofts Amazonas

A Russian Proton M rocket launches from Baikonur Cosmodrome carrying the Amazonas communications satellite that will serve the Americas and Europe. (2min 25sec file)

▪ Play video

Proton preview

This narrated

Galaxy 10R satellite suffers propulsion system failure

PANAMSAT ANNOUNCEMENT

Posted: August 5, 2004

PANAMSAT is updating current information provided with respect to its Galaxy 10R satellite, a Boeing model 601 HP spacecraft. Galaxy 10R uses a xenon ion propulsion system ("XIPS"), an electronic propulsion system that maintains the satellite's in-orbit position, as its primary propulsion system.

On August 3, 2004, the secondary XIPS on Galaxy 10R experienced an unexpected shutdown, and we have not been able to restart the system. This event has not affected service

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Perspectives from stakeholders

- Owners/operators
  - Aware of ‘Carrington events’ but uncertain of implications
  - Commercial systems
    - Normally accept manufacturers existing products on basis of track record
    - Insurers carry the (financial) risk for extreme events
  - Critical systems (navigation, security) can impose bespoke specifications
    - Natural environment specifications still ‘severe’ rather than ‘extreme’
    - Some unusual specifications (e.g. military)
- Insurers
  - Watching brief on extreme space events at present – aim to quantify risk
  - Concern about multiple claims from one event - update the ‘realistic disaster scenario’
- Manufacturers
  - Point to a long track record of success
  - Any further protection depends what is specified by customers
  - Need to understand the engineering implications and feasibility

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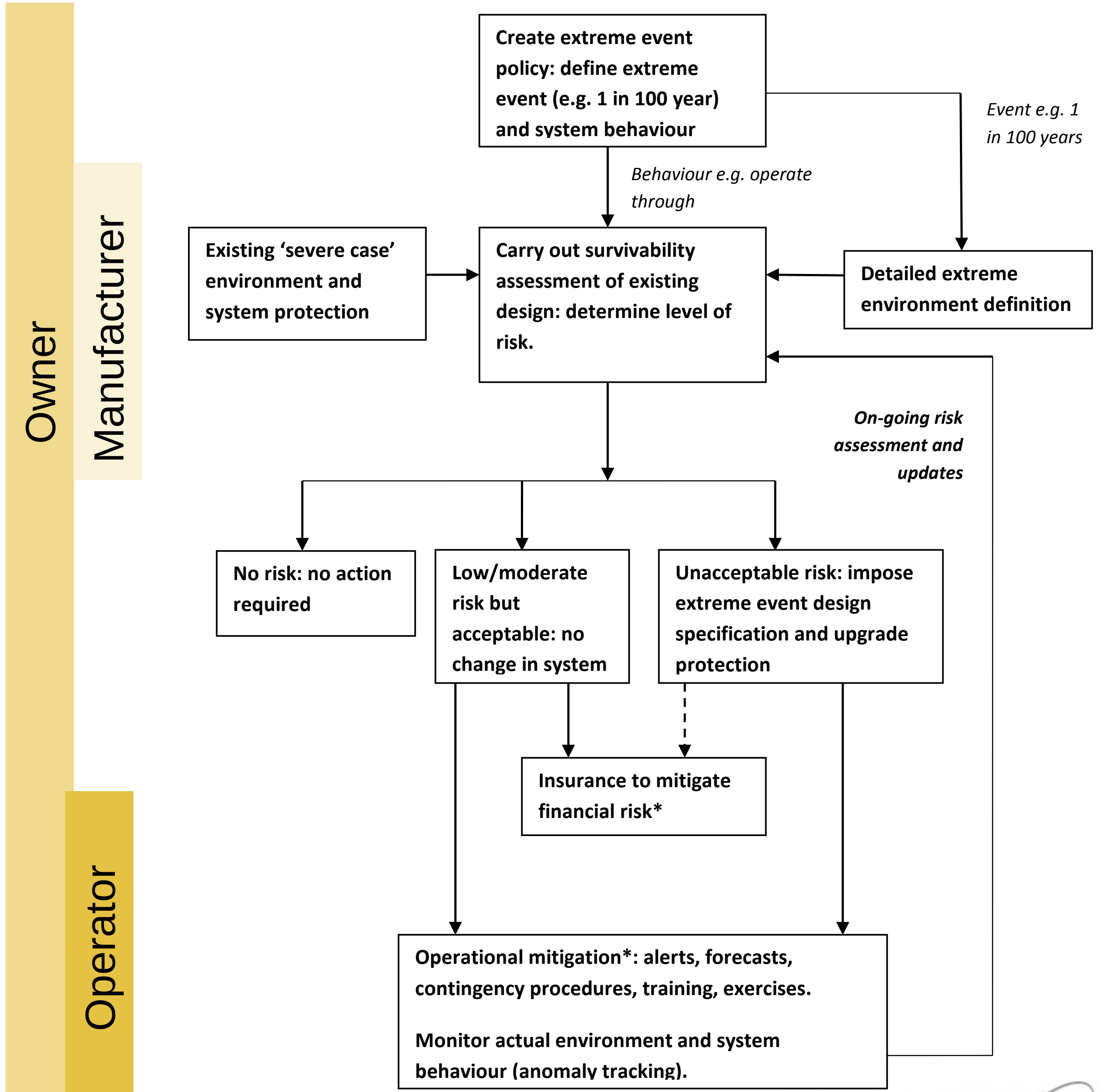
Mitigation process

To proceed the owner/customer needs a policy for extreme events.



*Operational procedures and insurance should also address environments more extreme than those which the system is formally required to survive. e.g.to enable best chance of recovery.

Engineering effects of extreme electron events

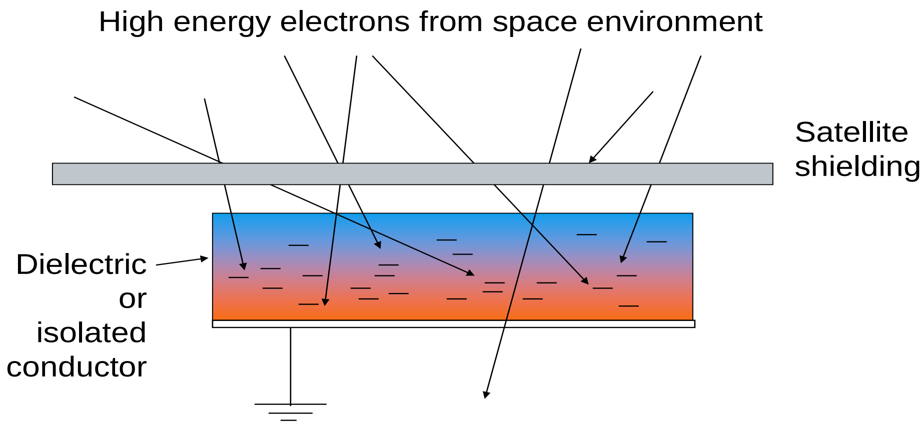
- Internal charging
- Ionising dose
- Solar cell damage

Energetic (MeV) electrons

- Surface charging – low energy (keV) electrons and protons

Internal charging and mitigation (1)

- Affects dielectrics / isolated metals all around the spacecraft
- Engineering responsibility is not always clearly defined
- Testing is difficult
  - methods are poorly-defined
  - few test facilities
- Materials (conductivity) parameters poorly known
- NASA and ECSS define ‘severe’ environments for engineering
  - also define a charging current limit ($0.1pAcm^{-2}$ daily average) for ‘safety’



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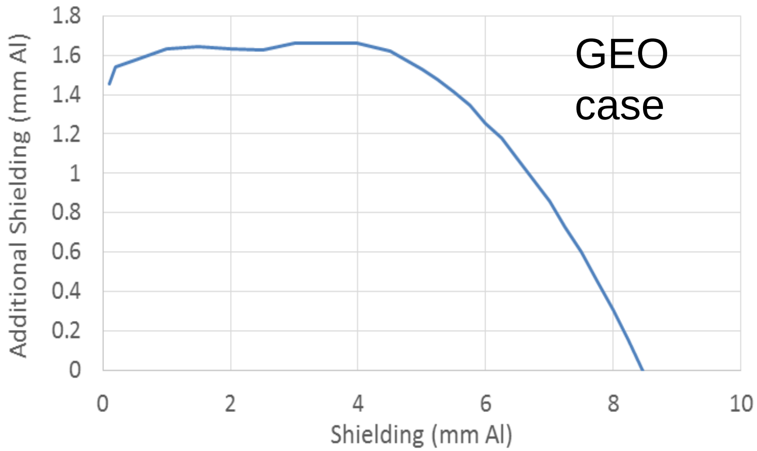
Internal charging mitigation (2)

- 1 in 150 year event ‘Spacestorm’ event in GEO: how much extra shielding is needed?
- Assume spacecraft type has excellent track record with no anomalies under standard severe conditions
- Simple approach is to apply shielding to restore internal charging currents back to ‘severe’ levels
  - If applied at satellite body level need ~1.6mm Al extra
    - Requires ~80kg of mass for a medium GEO (dry mass 1200 to 1500 kg)
    - Upper estimate
  - Not an likely approach



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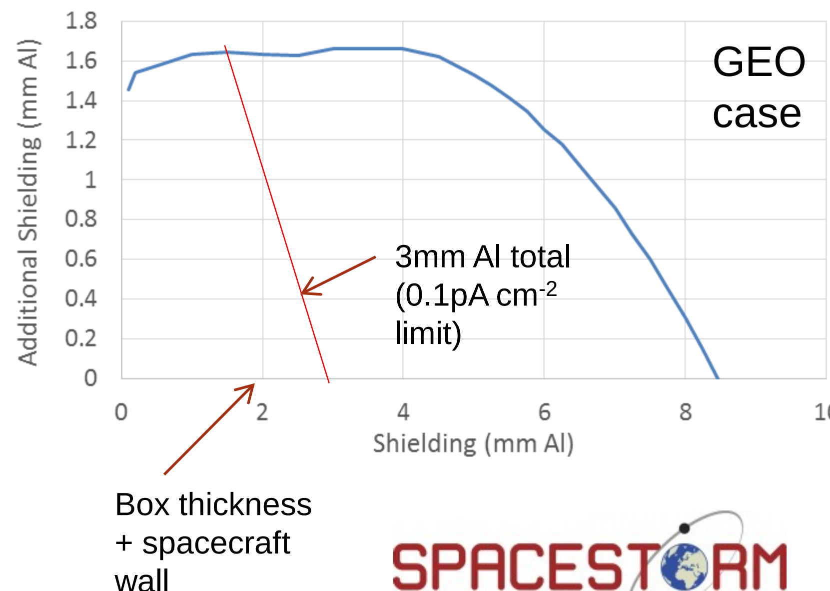
Internal charging mitigation (3)

- In practice the harness is not usually specifically shielded (just via outer panels ~0.5mm Al eq).
- Acceptable if:
  - dielectrics are thin (true for most cables)
  - equipment boxes are robust to ESD events (and tested)
- Thus we just add extra shielding at box level
  - We assume initially 1.5mm Al thick boxes + 0.5mm Al outer structure
  - But no need to increase beyond 3mm total (0.1pAcm^{-2} ECSS/NASA limit)
  - Thus need extra 1mm Al on boxes
  - Extra ~**50kg** shielding required (upper limit estimate)
- For Galileo-type spacecraft (700kg dry mass) we need ~20kg extra mass.



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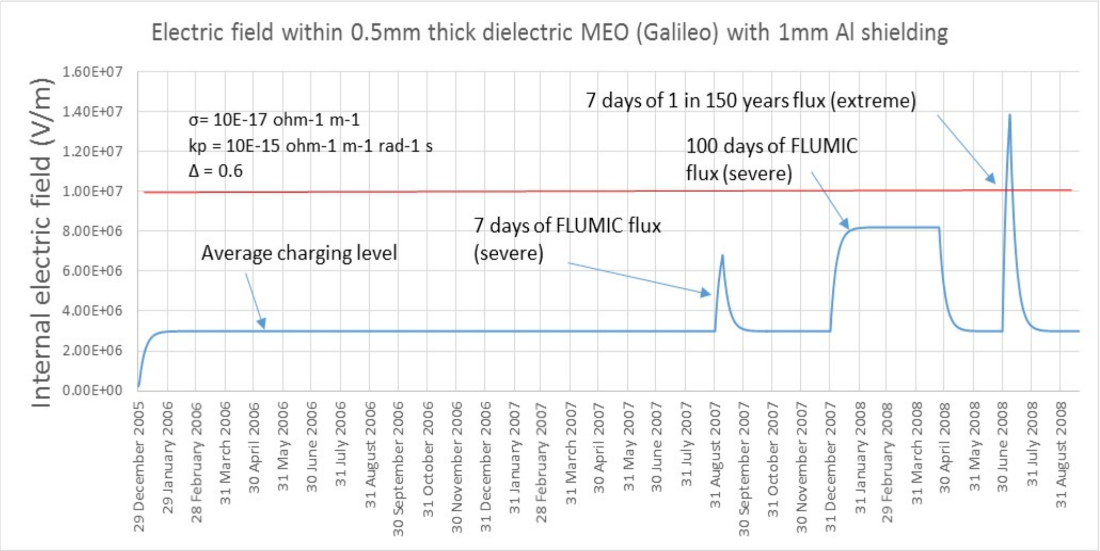
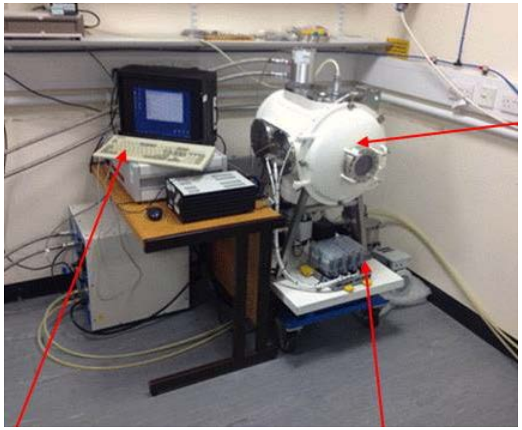
Electric field modelling and testing

- Reduce the shielding requirement by modelling internal electric fields
  - MCICT, DICTAT, ELSHIELD, NUMIT, CBIESD
  - Need materials parameters
- Specific extreme event modelling (time evolution)
- Testing
  - Test facilities
    - o ONERA: GEODUR and SIRENE – accelerated and low flux
    - o SSC: REEF – realistic flux, long term tests





REEF at SSC

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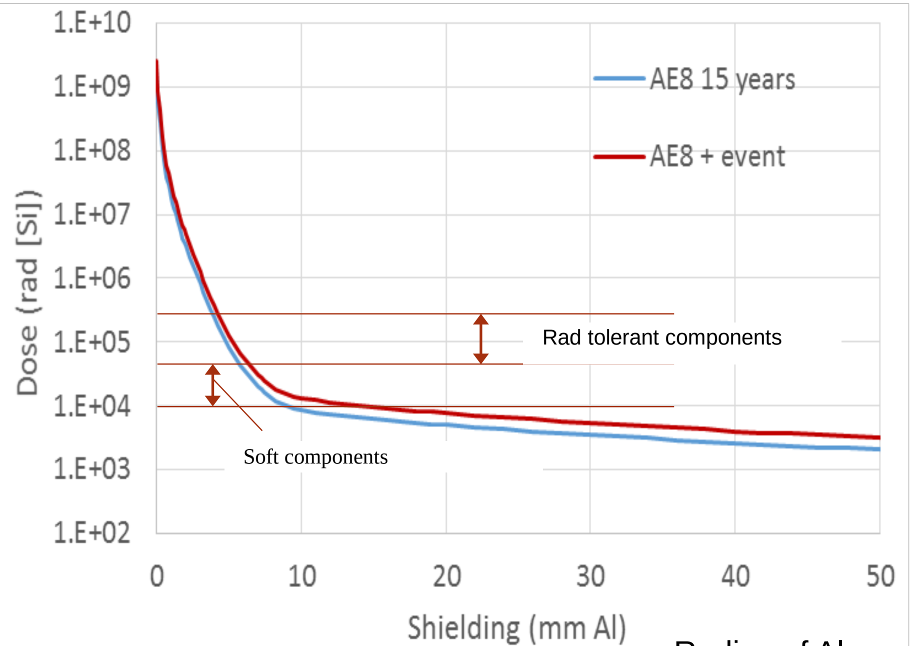
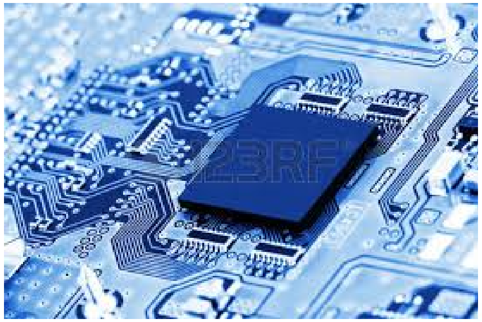
Ionising dose mitigation (1)

- 15 year GEO mission
  - One 1 in 150 year event (extreme flux lasts one week)
- Most electronic component tolerances lie in a narrow range
  - Soft components will be heavily shielded
- Additional 8 years of dose
  - ~50% of GEO spacecraft would be pushed to beyond their radiation design lifetime
  - Conservative designs may prevent sudden failures, but should prepare to replace them
- How much additional shielding is required to mitigate?

15 year GEO mission

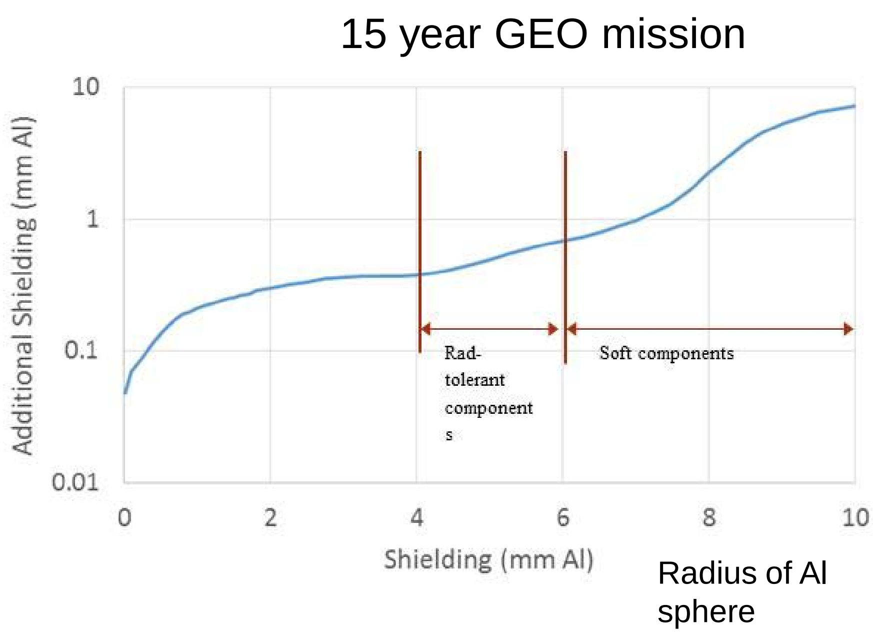


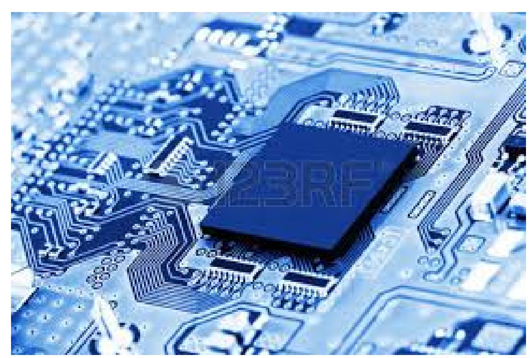
Radius of Al sphere



Ionising dose mitigation (2)

- For rad-tolerant components need <1mm Al (spherical)
  - Applied at box level
  - This is less than that required to address internal charging (thus no further mass impact)
- Note for 'soft' components the additional shielding is potentially much greater
  - Due to bremsstrahlung limit
  - Need detailed study for each case
  - However there should be only very few situations like this





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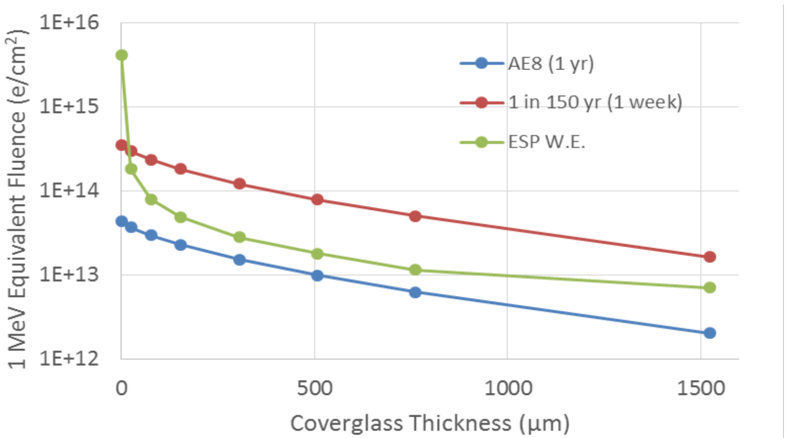
Solar array damage mitigation

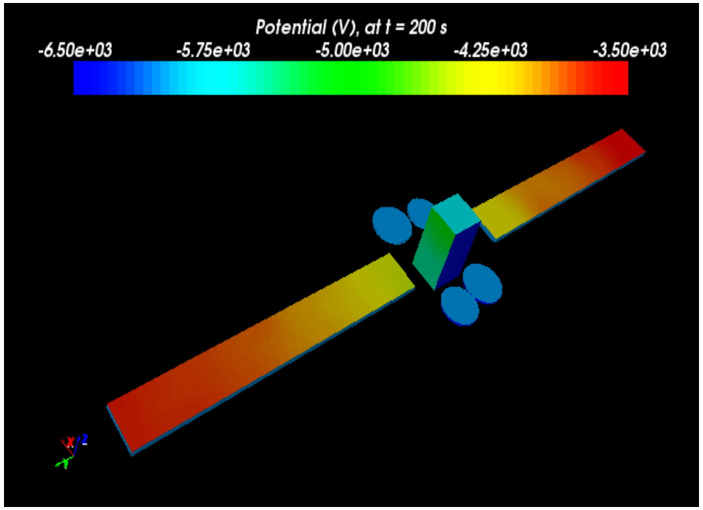
- GaAs cells, 150 micron cover glass
- GEO, 6kW BOL array
- Electron degradation is dominant
- Average electron environment causes 17% degradation over 15 years
- 1 in 150 year electron event gives a further **5%** degradation (22% total)
- To mitigate need to increase cover glass thickness to 300microns: ~**10kg** extra mass
- Can also oversize the array to compensate

For MEO Galileo size spacecraft (2.5 kW BOL) need extra **5kg**.



Surface charging mitigation

- Perform surface charging analysis
  - Use SPIS or NASCAP2K
  - Select environment: ECSS is a severe case for GEO and MEO
- What if 23 July 2012 CME had impacted Earth?
  - Very high levels of charging
  - Very preliminary result: continue to use ECSS at present
- Apply normal ECSS/NASA rules for surface charging alleviation
  - Avoid exposure of dielectrics to plasma
  - Use conductive/grounded surfaces (e.g. on blankets)
  - Ensure ‘secondary arcs’ cannot occur
  - Consider passive emitters (WP13)
- Minimal mass impact from surface charging alleviation measures



Above: ONERA example spacecraft charging analysis.

Below: results for sunlit cases

		Differential voltage with CMX cover glass (V)	
Severe: 5th April 2004	GEO	+220	Measured GEO environment
	MEO	+2800	IMPTAM modelled environment
Severe: 29th May 2003	GEO	+300	Measured GEO environment
	MEO	+1800	IMPTAM modelled environment
Extreme event: July 2012 CME Earth-directed.	GEO	+2600	IMPTAM modelled environment
	MEO	+3200	IMPTAM modelled environment
ECSS – Table 5	GEO/MEO	+2400	Engineering standard
NASA 4002A - Table 5	GEO	+1100	Engineering standard

Operational mitigation

- Often dozens of satellites are controlled from one centre
  - anomalies on multiple spacecraft could cause excessive workload
- Discussion with operators shows that there <u>are</u> mitigations which usefully reduce risk *[e.g. Haggerty et al, ESWW, 2016]*
  - re-schedule operations
  - re-configure staffing and equipment
  - ensure recovery procedures are ready and rehearsed
- Alerts and forecasts are thus important – need to develop good relationship with provider: e.g. NOAA, Met Office
  - Spacestorm has developed new risk indicators which relate closely to engineering threat
- Install (simple) on-board environment monitoring equipment
  - to help diagnose anomalies, monitor lifetime and validate survivability

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Summary of mitigation guidelines

- Owner should have an extreme event policy and then assess risks, implications and remedies
- 1 in 150 year energetic electron event would be serious
  - Internal charging and dose are major concerns
  - Anomalies and significant loss of lifespan should be expected
  - Inherently conservative designs may provide a buffer
- Engineering mitigation is feasible *(if required)*
  - Shielding requirement is moderate
    - ~60kg additional mass for a 1500kg dry mass GEO spacecraft
    - ~25kg additional mass for a 700kg Galileo-type spacecraft
  - To minimise additional mass do more internal charging/dose modelling
  - Clearly some re-design and re-qualification costs
- Operational mitigation is valuable
  - Space weather services for alerts and forecasts
  - Install simple on-board environment monitoring equipment
  - Carry out training and rehearsals