APPENDIX C

SATELLITE THREAT DUE TO HIGH-ALTITUDE NUCLEAR DETONATIONS

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CAMBRIDGE, MASSACHUSETTS

How Could It Happen?

- Collateral damage from regional nuclear war or TMD/NMD intercept:
  - Nuclear warning shot in a regional conflict;
  - Effort to damage adversary forces/infrastructure with electromagnetic pulse;
  - Detonation of salvage -fused warhead upon exoatmospheric intercept attempt.

- Deliberate effort to cause economic damage with lower likelihood of nuclear retaliation:
  - By rogue state facing economic strangulation or imminent military defeat;
  - Pose economic threat to the industrial world without causing human casualties or visible damage to economic infrastructure.

From HALEOS Study

HEMP

Early (nanosecs) -> kHz - GHz

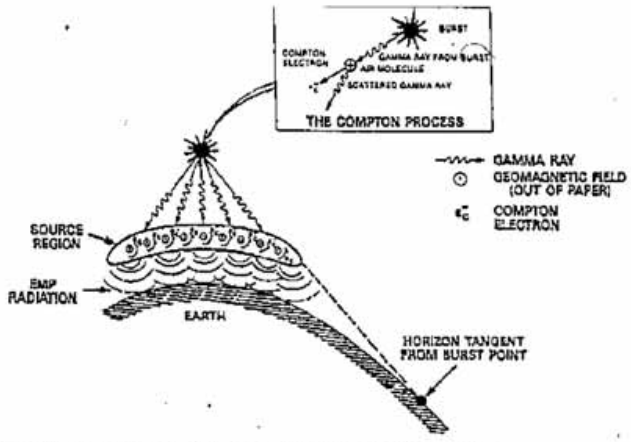


Figure 1. Mechanisms of High Altitude Emp (HEMP) Generation

- Line of Sight at 400km ->US
- Not a Threat to space assets
- Major Threat to Ground Systems and ground infrastructure

- Mitigation Hardening

High Altitude EMP (HEMP) Gamma radiation from the HANE interacts with air molecules to generate relativistic electrons (Compton electrons) that leave behind massive positive ions. The electrons trapped in the earths magnetic field constitute a giant antenna that radiates (similar to lightning) mainly towards the earth. Shielding of ground systems well understood. Adds 10% to cost if included in design or 20% if added later.

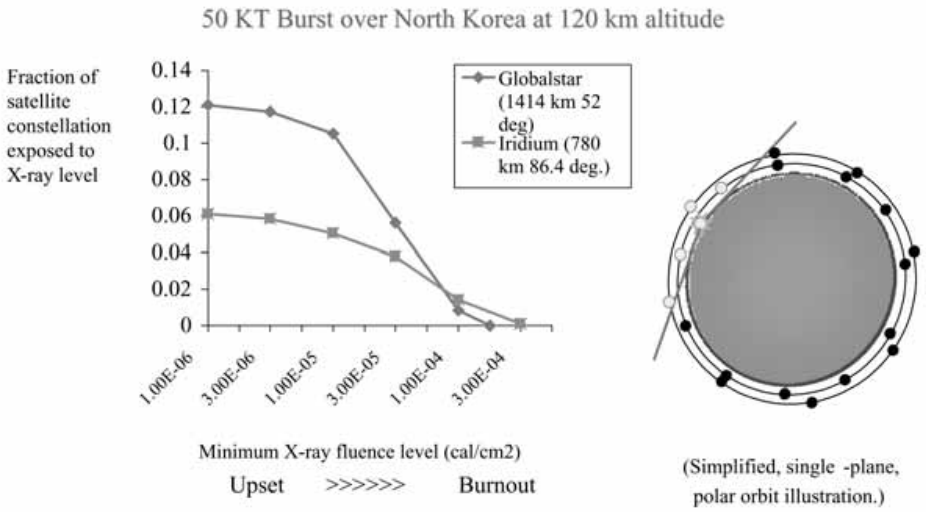
MHD EMP weak but affects long lines (power lines, telephone wires, tracking antennas including underwater cables) by inducing large potentials. Starfish resulted in major effects on power and telephones in Hawaii, 1000 km away). Push of B out by explosion and atmospheric heave. Similar effect in Solar Storms. Hydro-electric Quebec affected in 1987 by solar storm.

SGEMP

- IMPACTS SPACE SYSTEM ELECTRONICS WHEN GAMMA AND X-RAYS ENCOUNTER SATELLITE SYSTEMS AND RELEASE ELECTRONS AS THEY PENETRATE INTO THE SYSTEM INTERIOR THROUGH APERTURES, SPACECRAFT SKIN AND CABLES

- Effects Prompt – line of sight – burst dependent

SYSTEM GENERATED EMP - SGEMP



Prompt X - radiation impacts 5 - 10% of each LEO constellation.

From HALEOS Study

RADIATION BELT PUMPING
THE CHRISTOFILOS EFFECT

- Effect of a single high altitude nuclear weapon detonation on LEO satellites
  - Nuclear burst "pumps" Earth's Van Allen radiation belts with energetic electrons generated from beta decay of fission fragments
  - Satellites that fly through these enhanced belt regions will be rapidly degraded/destroyed due to a rapid accumulation of total ionizing dose on critical satellite electronic parts.

So how does a single high altitude nuclear detonation cause such havoc with all LEO satellites? The culprit is high energy "beta" electrons released from the radioactive decay of fission debris from the bomb. These electrons become trapped in the Earth's magnetic field and rapidly spread out in latitude and longitude following well known trajectories of charged particle motion in a magnetic field. The result is that all of LEO space is filled with these electrons within 30 minutes. LEO satellites now fly through this greatly enhanced electron radiation environment and these electrons penetrate through the skin of the spacecraft and deposit damaging radiation on critical microelectronic circuits causing them and the spacecraft to degrade and fail.

BASICS - THE EARTH's MAGNETIC FIELD

- Magnetic Configuration
- L - Shells
- Inner RB (1.5<L<2.2)
- Slot (2.2<L<3)
- Outer (L>3)
- Invariant Latitude

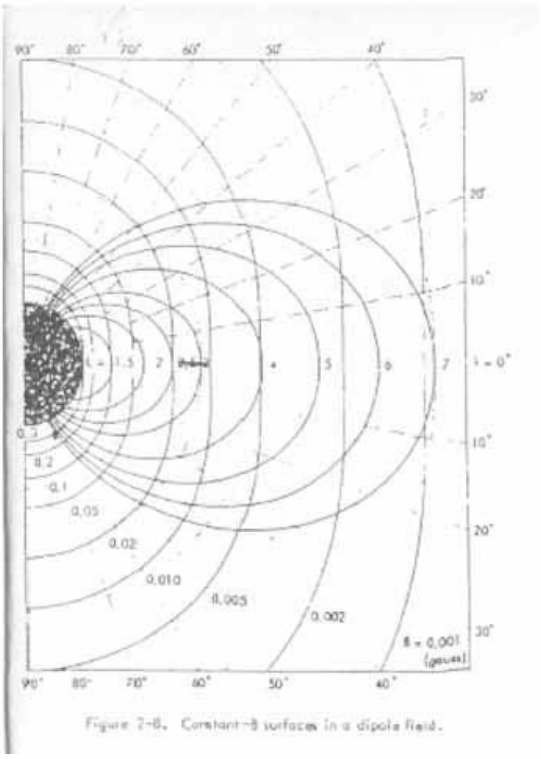
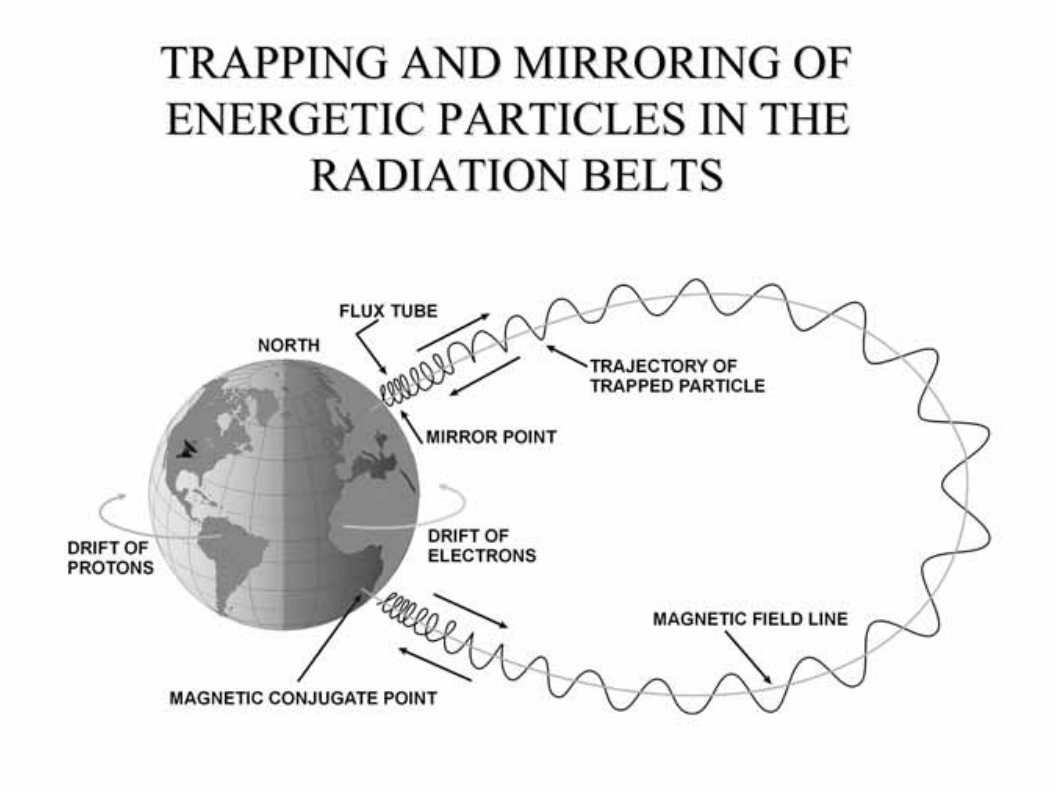


Figure 2-8. Constant-B surfaces in a dipole field.



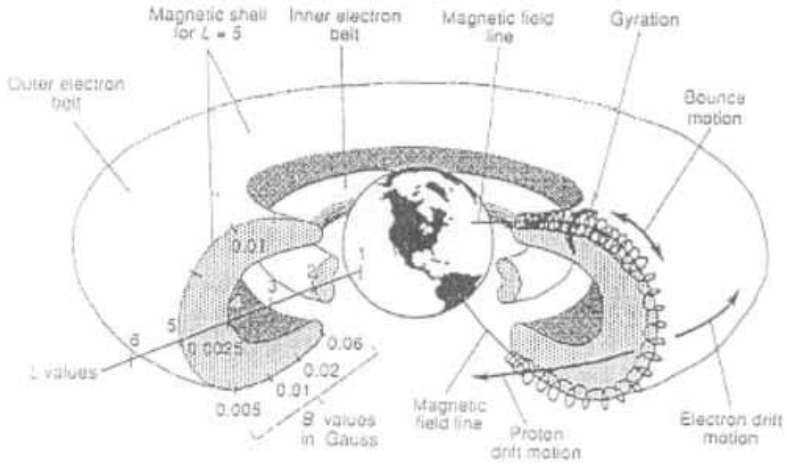
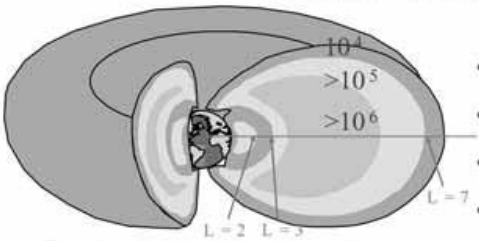
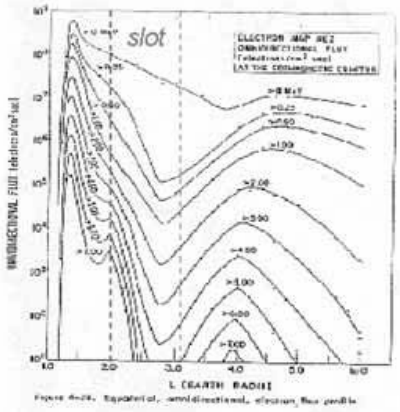


Figure 4. Sketch of a three-dimensional representation of the inner and outer radiation belts forming a ring current around Earth (after Mitchell, 1994).

RADIATION BELTS
Natural Ambient Properties

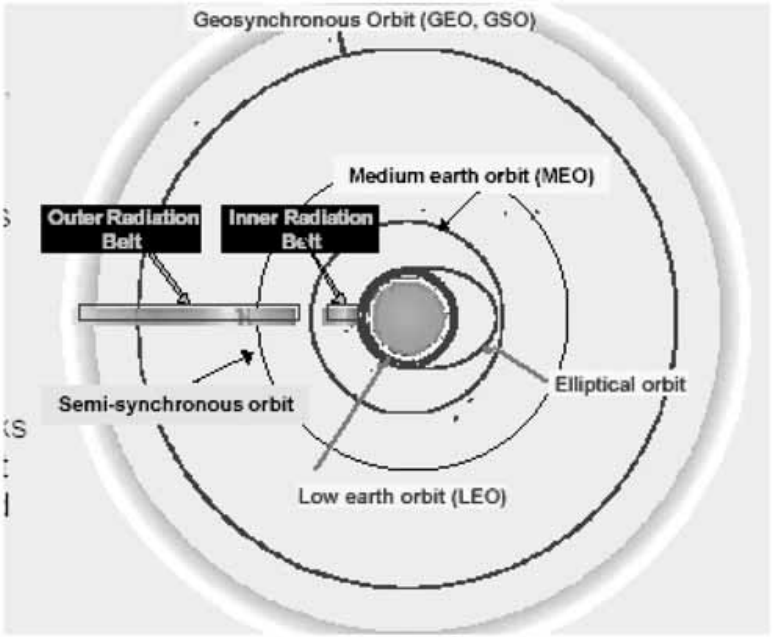


- Inner Radiation Belt (1.5<L<2.2)
- Outer Radiation Belt (L>3)
- Slot (2.2<L<3)
- $L = R/R_E$



- MEO and half-GEO (GPS location) especially challenging
- To minimize radiation dose, many commercial and military satellite orbits use the slot

SATELLITE ENVIRONMENT



THE ROLE OF MeV ELECTRONS

– MeV electrons cause internal charging of dielectric surfaces

-Cumulative radiation dose

-Loss of attitude control

•Degradation of performance

•Swelling of mirror surfaces

•Darkening of glassy surfaces

•Solar cell degradation

•Thermal control degradation

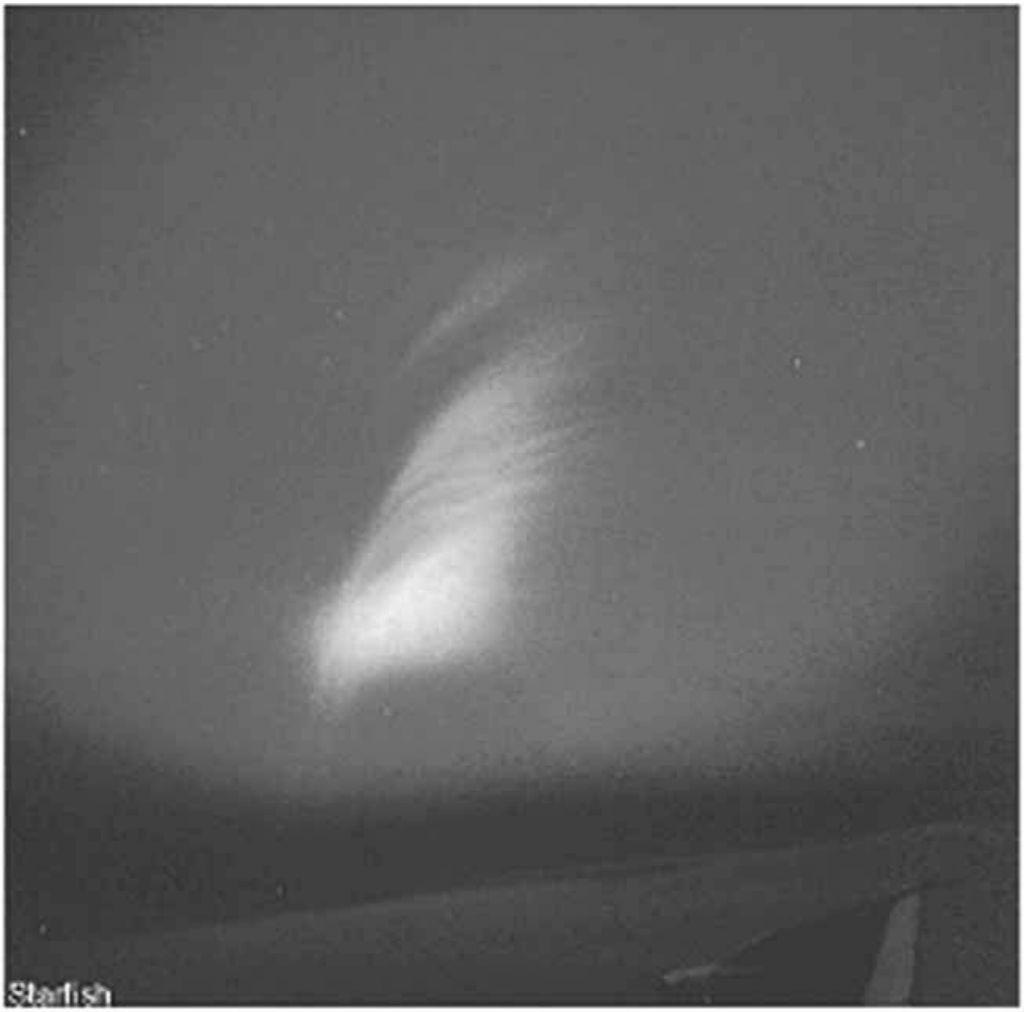
•Damage electronic components

•Limits lifetime

ESA Study 2001
Most of satellite designers identified internal charging caused by MeV electrons as their most important problem (Horne 2001)

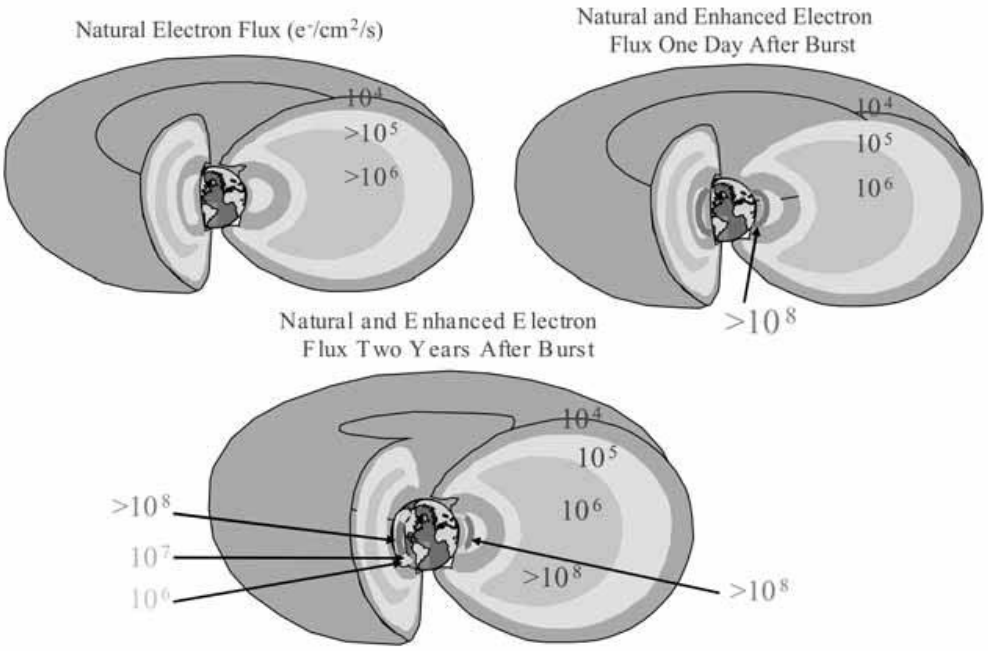
- Internal charging and ESD is related to MeV electron flux (variations)
  - more than 20 spacecraft damaged [Wrenn and Smith, 1996]
- Several examples of spacecraft damaged during storms when flux was enhanced, e.g., Baker et al. [1998]
  - 1994: Intelsat K, Anik E1, & E2
  - 1997: Telstar 401
  - 1998: Galaxy IV
- US National Security Space Architect:
  - 13 satellites lost in 16 years that can be attributed clearly to natural enhancement (flux of 10^8 #/cm^2 sec) of MeV electrons

This is not the stuff of science fiction, we know that this phenomenon is real. In the late 50's and early 60's the US and Soviet Union conducted a number of high altitude nuclear tests the most notable being the STARFISH test. STARFISH was a 1.4 MT device detonated in the South Pacific at 400 km altitude. The high energy electrons released from that explosion disabled at least seven satellites within a few months. The concern today is that more and more LEO satellites are using commercial off-the-shelf electronics, thus making them much more sensitive to this kind of threat.



RADIATION BELT PUMPING

Source: DTRA; 50KT, 120 km over the Korean Peninsula



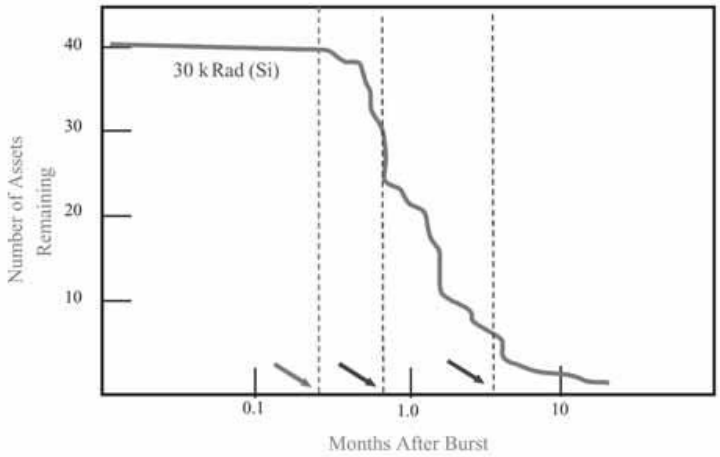
SUMMARY

- LEO constellations present tempting targets to future nuclear-missile-armed rogues, lowering the nuclear threshold.
- LEO constellations may be destroyed as a by-product of nuclear detonations with other objectives (e.g., EMP generation, salvage-fusing at nmd intercept, nuclear interceptor).
- Loss of civilian and military communications, imaging, weather forecasting, scientific infrastructure in space
- Socio-economic and political damage due to dependence on LEO constellations

Is there mitigation besides hardening ?

LIFETIME OF SATELLITES IN ORBIT

Source DTRA: Bay of Bengal 50 kT Burst At 250 km



WHAT DOES IT TAKE TO GET RID OF THE PARTICLES IN TEN DAYS