The STARFISH Exo-atmospheric, High-altitude Nuclear Weapons Test

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To study the effects of nuclear weapons, the United States conducted a series of atmospheric test in 1958, as for example the HARDTACK series in the Pacific Ocean and the ARGUS series in the South Atlantic Ocean. Additional high altitude nuclear tests were later conducted within the FISHBOWL series in 1962. During those tests, the STARFISH PRIME device, with a yield of 1.4 megatons TNT equivalent, was exploded on July 9, 1962, at a very high altitude (approximately 400 km) over Johnston Island in the Pacific, about 700 miles southwest of Hawaii. This exo-atmospheric nuclear explosion released about 10^{29} energetic fission electrons into the magnetosphere, creating an artificial radiation belt and raising the intensity levels of the natural Van Allen Belt electron population in the inner zone by several orders of magnitude. This additional radiation increased the total ionizing dose incident on spacecraft flying at that time to critical levels, resulting in the loss of seven satellites within months after the test, primarily from solar cell damage. The first such failure due to total dose was the TELSTAR satellite, which was launched a day after STARFISH. It was estimated that the spacecraft experienced a total dose from the weapon test 100 times larger than expected.

Initial predictions about the longevity of the STARFISH debris ranged from the overly optimistic of some months to the more realistic of a few years. Studies conducted in the late 1960s [1, 2, 3, 4] attempted to define the rate of decay with varying results. An in-depth evaluation performed in 1970-71 [5] using data from the 1963-38C satellite and covering the time span from September 1963 to December 1968, identified three distinct regions within the inner zone domain populated by the artificial electrons and established that their decay lifetime τ (in days) could best be presented as a complex function of three variables: magnetic shell parameter L (in Earth radii), field strength B (in gauss), and energy E (in MeV), as shown in Figure 1 for $E = 0.28$ MeV electrons. A more thorough approach a year later produced a model of the STARFISH flux for epoch September 1964 [6], based on data from several spacecraft (OGO-1, OGO-3, OGO-5, OV3-3, and 1963-38C). That model distinguished between artificial and natural electrons and provided the artificial flux as a function of equatorial pitch angle, energy, and L value. The decay times for this flux were determined by two separate methods, which were combined to yield average values that are appropriate for the evaluation of the long-term loss process of the artificials. A threshold-energy vs L-value map for decay cutoff times is presented in Figure 2.

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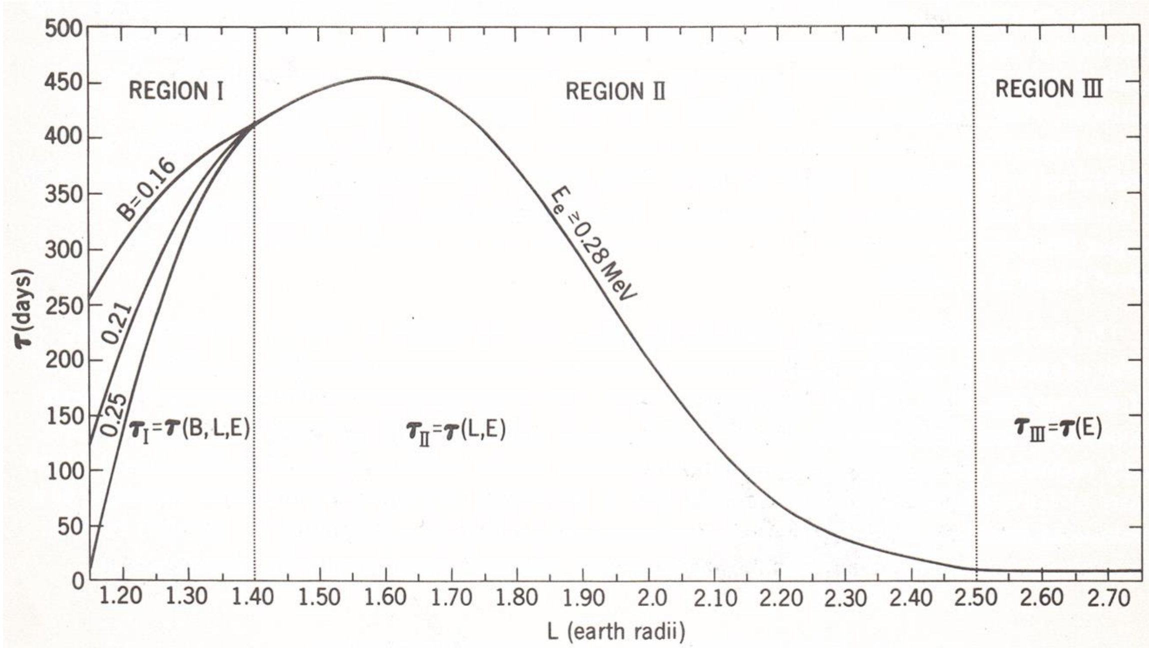

Figure 1: Domains of functional dependence of the decay lifetime τ on B, L, and E for E > 0.28 MeV

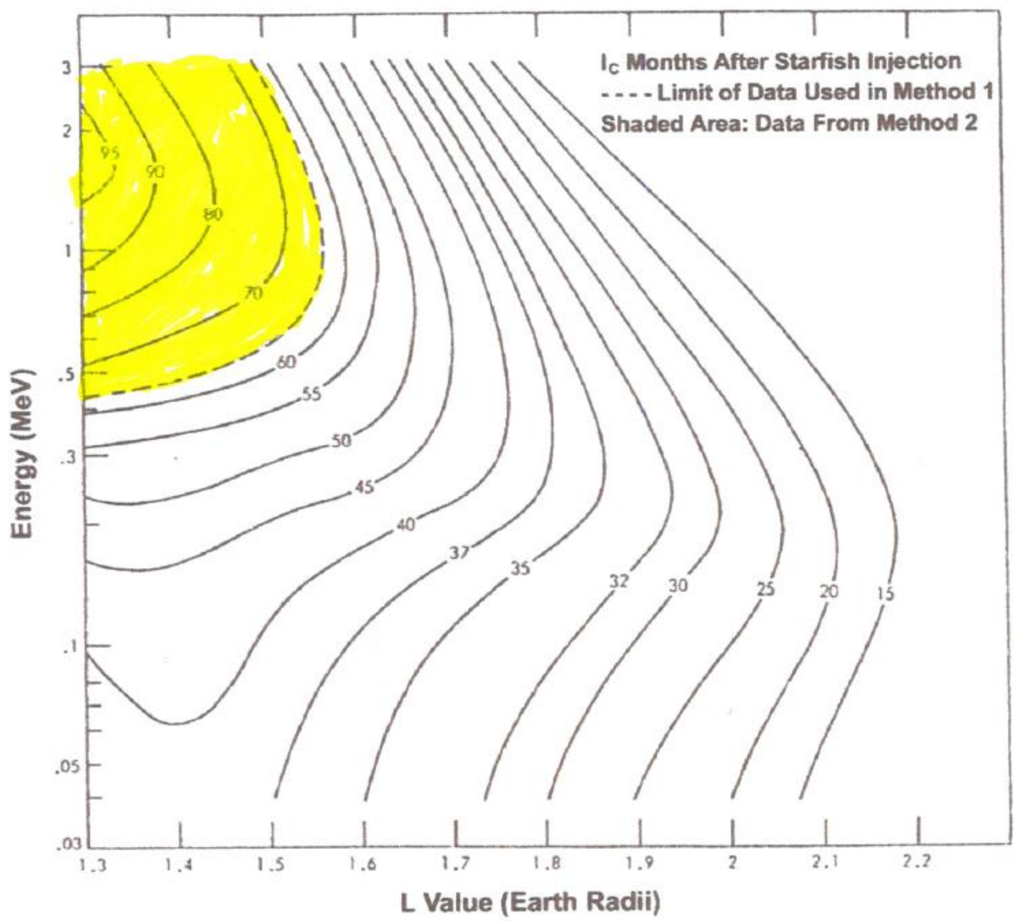

Figure 2: Threshold-energy vs. L-value map for decay cutoff times.

A note of caution regarding limitations: numerical values relating to nuclear explosions are not, and cannot be exact. They must inevitably include a substantial margin of error. Apart from difficulties in making measurements of such events and their effects at the time of their occurrence, the results are often dependent upon circumstances which cannot be predicted. Furthermore, two nuclear weapons of different design may have the same explosive energy yield, but the effects could be markedly different.

It is interesting to compare the STARFISH effects with those of a Soviet high-altitude test of a low-yield weapon performed on October 28, 1962, over Semipalatinsk in Kazakhstan. Figure 3 shows the integral Van Allen belt R_E to about -10 R_E for particles with energies of E > 0.5 MeV and E >1.9 MeV. This region covers the end of the inner zone, the slot region, and the beginning of the outer zone. The bulk of the fusion electrons are concentrated between L -1.8 and L -2.7, which is to be expected because their injection occurred at a high latitude location (Semipalatinsk: L ~2.1 R_E). In contrast, the STARFISH debris, was concentrated in the inner zone on account of the low latitude of the test site (Johnston Island: L ~1.13 R_E). A schematic of the distribution of the fission electrons from these two tests in magnetic space is shown in Figure 4 in terms of magnetic shell parameter L and magnetic latitude. Figure 5 is an attempt to display the average apparent lifetimes of the E > 2 MeV electrons from the STARFISH and the Soviet experiments. Although it is difficult to draw final conclusions from only two isolated tests, the data suggest that longevity is maximum at low L values (years), decreases rapidly towards the slot region, and settles into months and probably weeks thereafter.

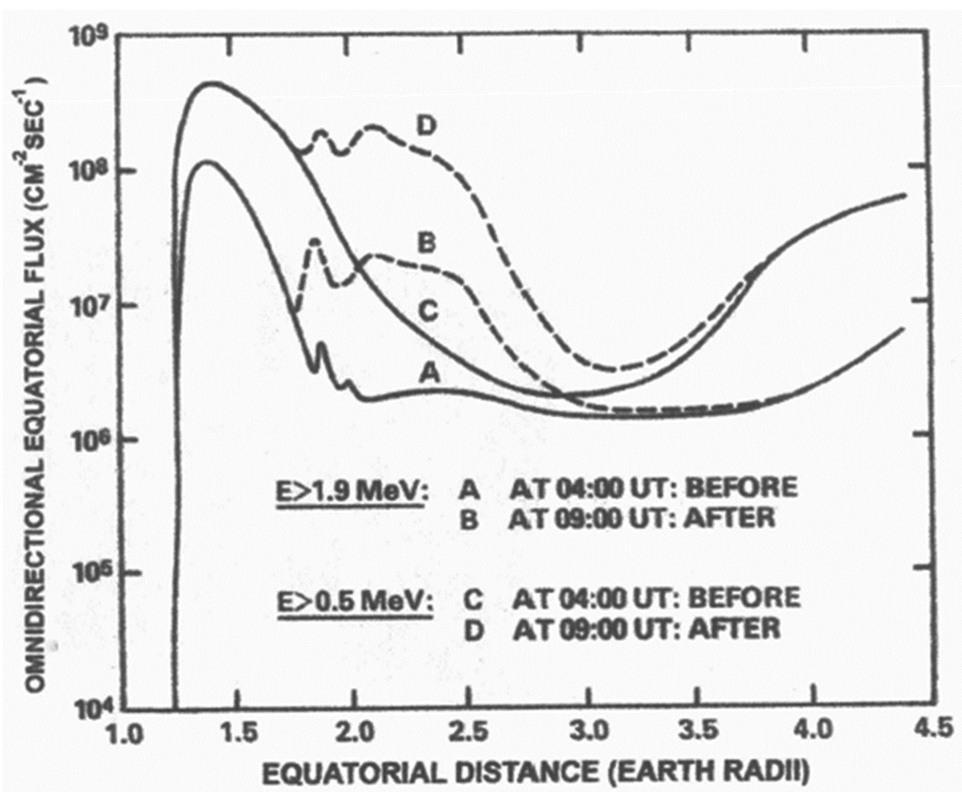

Figure 3: Integral Van Allen belt electrons before and after the Soviet event.

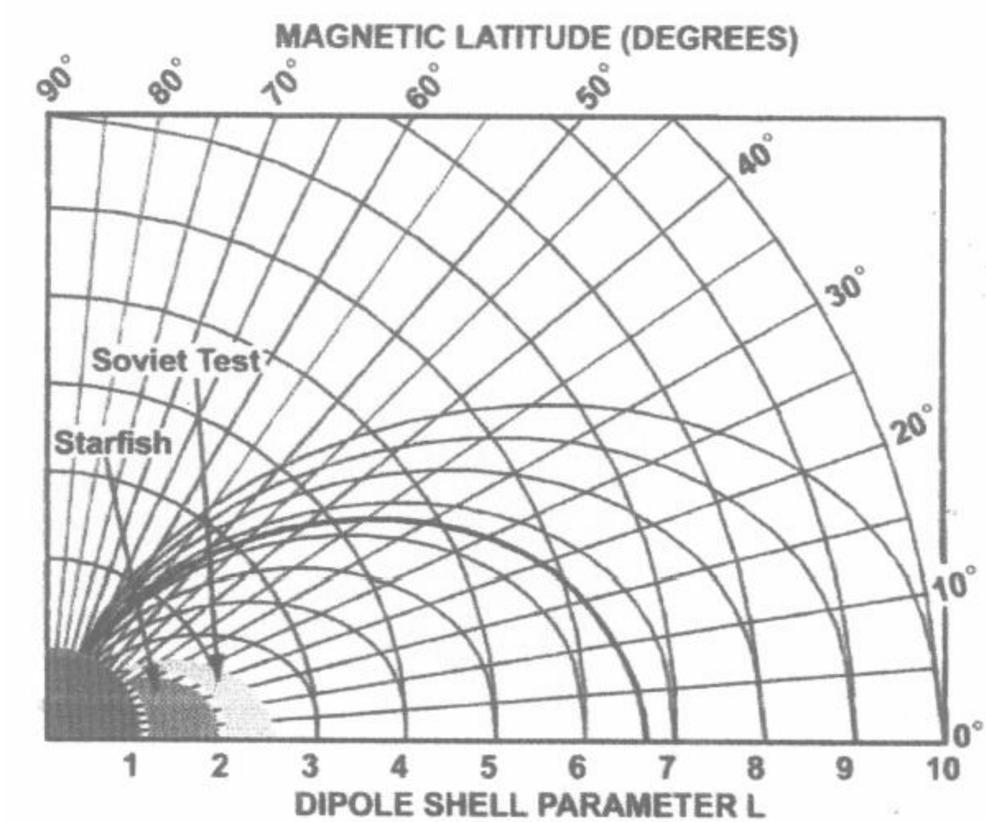

Figure 4: Schematic of the distribution of fission electrons from the STARFISH and Soviet tests in magnetic coordinates.

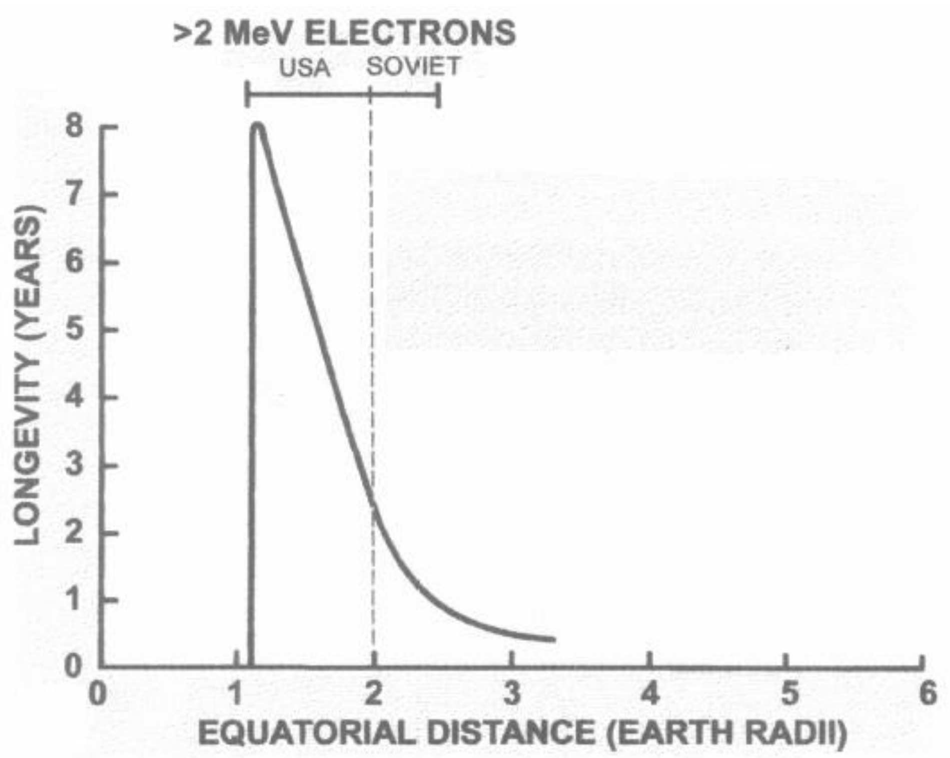

Figure 5: Comparison of the average lifetimes of >2 MeV electrons for the STARFISH and Soviet tests.

References

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