LIFETIMES OF GEOMAGNETICALLY TRAPPED ELECTRONS OF SEVERAL MeV ENERGY

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THE loss of charged particles from trapped orbits in the magnetosphere is a complex physical process, which is not characterized by any simple law. Hence it is not possible, in the strict sense, to define a single parameter which characterizes their lifetime. Nevertheless, there is now a large body of observational knowledge of the monotonic decrease with time of the intensities of trapped particles following a natural or artificial injection of such particles. The most definitive knowledge on the loss of energetic electrons comes from investigations of the time history of nine artificial radiation belts which have been produced by U.S. and U.S.S.R. high-altitude nuclear explosions in 1958 and 1962. In Fig. 1 is shown a sample set of curves of intensity versus time for the fission-decay electrons from the *Starfish* nuclear explosion of July 9, 1962, as observed with satellites *Injun* I and III. The counting rate is that of a small, heavily shielded Geiger tube (designated *SpB*) which detects the trapped electrons via their intermediate bremsstrahlung in the shield. The response of the *SpB* detector[1] is due primarily to electrons the energies of which lie in the range 1·5–5 MeV. The curves of Fig. 1 are for a particular value, 1·25, of the McIlwain magnetic shell parameter L and for a succession of values of the scalar magnetic field B within that shell. It is clear that there is a relatively rapid decrease of intensity within the first ~1,000 h after injection and that this transient period is followed by a much longer one characterized by an approximately constant slope on a semi-logarithmic plot. It is noteworthy that the value of this slope is independent of B.

For $L \lesssim 1·25$, an essentially complete theoretical understanding of the time-decay history of the *Starfish* radiation belt has been achieved by Walt[2] in terms of scattering and energy loss in the atmosphere.

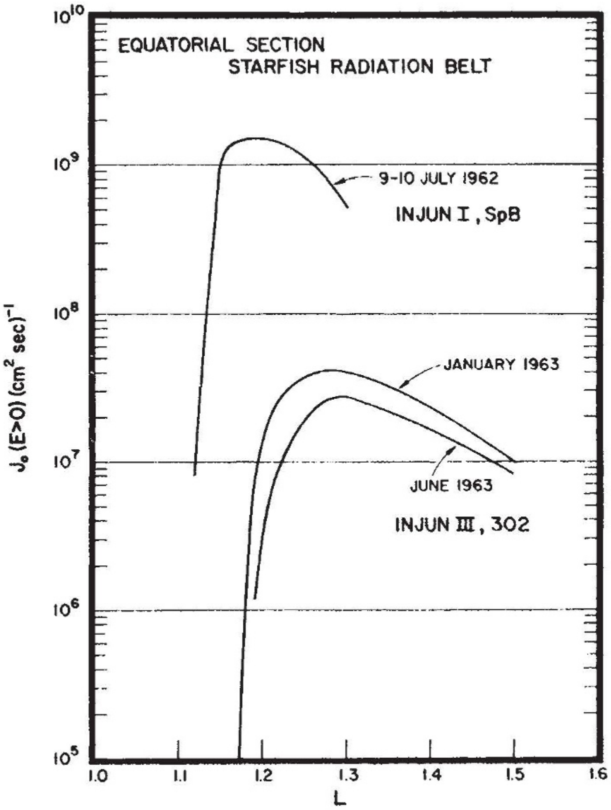

Fig. 2. An abridged summary of the time-history of the *Starfish* radiation belt. The ordinates are in absolute units

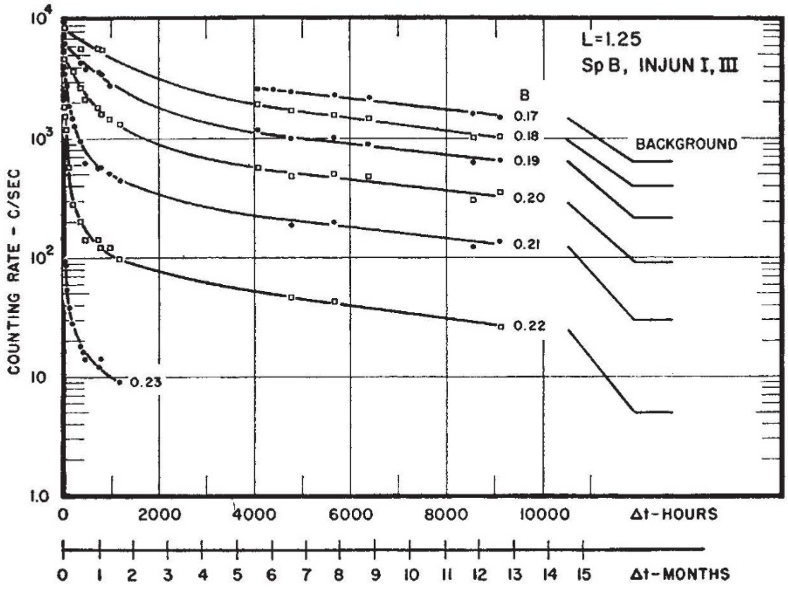

Fig. 1. A sample set of time-decay curves for a selected portion of the artificial radiation belt of energetic electrons from the *Starfish* nuclear explosion of July 9, 1962, as observed with heavily shielded Geiger tubes on the S.U.I./O.N.R. satellites *Injun* I and *Injun* III. The horizontal bars labelled 'background' show the pre-*Starfish* counting rates corresponding to the several members of the family of curves. Δt is the elapsed time after the detonation

For the purposes of this article the L-dependent quantity τ in $\exp(-\Delta t/\tau)$ is termed the 'apparent mean lifetime' of ~ 2-MeV electrons during the main decay-phase, that is, for $\Delta t > 1{,}000$ h (Fig. 1).

The overall decay of the *Starfish* radiation belt is shown in Fig. 2.

An example of the decay of the intensity of energetic electrons in the composite radiation belt produced by two Soviet nuclear detonations on October 22 and 28, 1962, is shown in the lower panel of Fig. 3, taken from *Explorer* XIV observations by Frank, Van Allen and Hills[3].

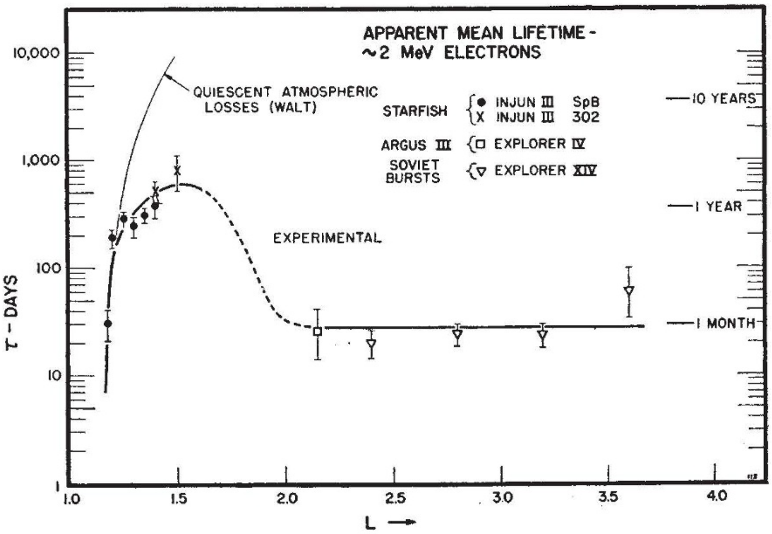

Fig. 4. The L-dependence of observed values of the 'apparent mean lifetime' of ~ 2-MeV electrons from two U.S. and two U.S.S.R. nuclear detonations at high altitudes. Note that the theory of quiescent atmospheric losses is adequate for $L < 1{\cdot}25$ but departs heroically from the experimental curve for $L > 1{\cdot}25$ (see text)

Fig. 4 gives a summary of the L-dependence of experimental values of the apparent mean lifetime of ~2-MeV electrons. The general nature of this dependence has been known for some years[4] from investigations of the time variations of the intensity of energetic electrons in the natural radiation belts. For $L \lesssim 1{\cdot}25$, the loss of electrons is dominated by 'quiescent' scattering and energy-loss processes in the outer atmosphere. For greater L values such processes become of relatively trivial importance and the loss of particles is dominated, presumably, by electromagnetic and magnetic processes in the geomagnetic field as it is subjected to perturbations by terrestrial sources (for example, whistlers, and other very-low-frequency phenomena) and by erratic buffeting by the solar wind at its outer boundary. The observed lifetime of ~2-MeV electrons has a maximum value of about 2 years at $L = 1{\cdot}5$, then declines rapidly to values of the order of one month for L from 2·0 to 3·5. Examination of time variations in the population of energetic electrons of similar energy in the natural radiation belts[3,5] shows that, even during periods of relatively low solar and geomagnetic activity, the effective lifetime declines at greater L to values of the order of a few days at $L \sim 8$. Beyond $L \sim 8$–10, durable trapping is not possible. Fragmentary investigations in the region of the 'slot' between the inner and outer radiation belts ($L \sim 1{\cdot}8$) have shown that there are large, sporadic time variations there. This fact suggests that the effective value of τ may fall considerably below the dashed portion of the experimental curve of Fig. 4 in the range $1{\cdot}6 < L < 2{\cdot}1$.

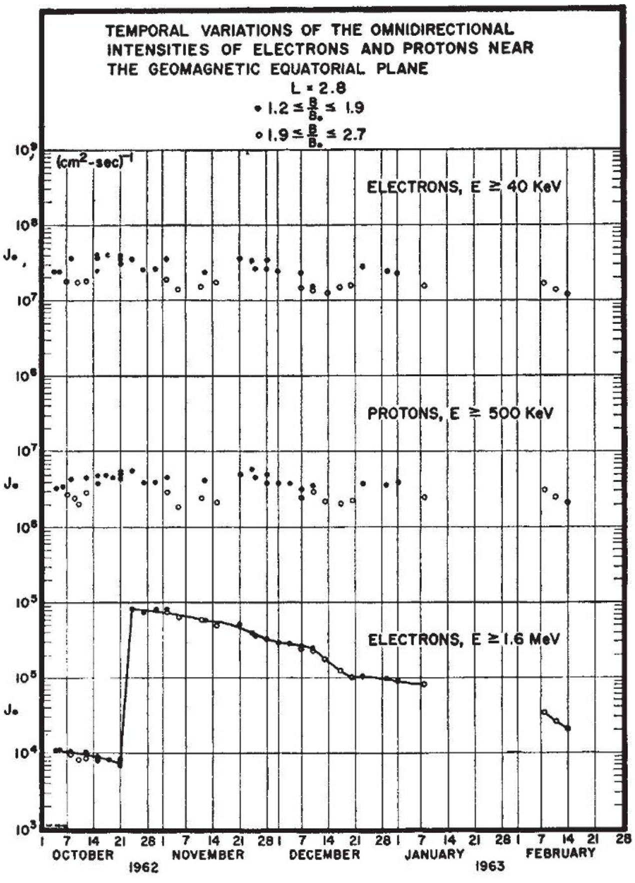

Fig. 3. In the lower panel is shown the time-decay of the intensity of energetic electrons from the U.S.S.R. nuclear detonations of October 22 and 28, 1962. Note, in the upper two panels, the negligible effect on the intensities of electrons of energy greater than 40 keV and of protons of energy greater than 500 keV (ref. 3)

Finally, it is noted that there is no established theory of the loss of trapped particles for $L \gtrsim 1{\cdot}25$. The observational evidence suggests that the time-history of the intensity of electrons at the greater L values consists of a sporadic sequence of discontinuous perturbations, some of which result in the loss of particles and some of which result in replenishment[4,5]. The overall tendency is for specifically injected electrons to lose their identity and to be assimilated into the general mêlée. Hence, effective values of τ for $L \gtrsim 1{\cdot}25$ are almost certainly dependent on the general level of solar activity and on the consequent level of geomagnetic activity, τ being expected to be less during periods of high solar activity. An incidental aspect of this line of thought is the tentative 'explanation' of the outer boundary of the inner-zone-distribution of energetic protons ($E \gtrsim 20$ MeV) which has been suggested previously[1,4].

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