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ADDITIONAL STATUS REPORT ON TRAPPED ELECTRONS FROM THE STARFISH HIGH ALTITUDE NUCLEAR TEST

A JOINT REPORT PREPARED BY THE ATOMIC ENERGY COMMISSION, DEPARTMENT OF DEFENSE AND NATIONAL AERONAUTICS AND SPACE ADMINISTRATION.

February 4, 1963

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A series of scientific articles on the artificial radiation belt in space is appearing in the February 1963 issue of the scientific publication, Journal of Geophysical Research. These articles, together with previous short communications in volume 195 of the British journal Nature, discuss the character and behavior of the artificial electron belt injected by the STARFISH high-altitude nuclear explosion over Johnston Island in the South Pacific. The articles have been contributed by scientists from university, government, and industrial laboratories. Further scientific data relative to the artificial belt will be published in a similar way in the scientific literature as the data become available and are evaluated by the scientists conducting the measurement.

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The STARFISH detonation was one of a series of high altitude nuclear tests announced on May 28, 1962, which, after careful review, were conducted during the summer of 1962 for the purpose of acquiring significant national security information. Prior to conducting the tests, possible geophysical effects were studied by a group of outstanding scientists. It was recognized that an appreciable number of electrons would become trapped along the lines of force of the earth's magnetic field as a result of high-altitude nuclear explosions. On the basis of the estimates made by this group it was considered that no hazardous effects to human beings or protracted interference with scientific observation of natural phenomena would result from the planned shots. Information concerning the individual tests was issued, in advance, by the Federal Aviation Agency and also, to assist geophysicists and other scientists, through the International World Day Service network.

The STARFISH detonation occurred at 5:00 A.M. (EDT) on July 9, 1962, at an altitude of 400 kilometers (about 250 miles), with an announced yield of 1.4 megatons. Satellite observations, and certain radio-noise measurements conducted at low latitudes immediately following the shot, indicated the presence of a new artificial belt of injected electrons. The electron fluxes following the test were sufficiently high to accelerate the deterioration of exposed solar cells on three experimental satellites which were then in orbit and which were not designed for these increased radiation levels. Preliminary information concerning the character of this belt was announced on August 20 and September 1, and a more detailed statement, "Status Report on Trapped Electrons from the STARFISH High Altitude Nuclear Test," was jointly issued by the Atomic Energy Commission, the Department of Defense, and the National Aeronautics and Space Administration on September 7. A two-day scientific symposium was conducted on September 10-11 at the NASA Goddard Space Flight Center in Greenbelt, Maryland, to discuss the measurements. A brief report of this symposium, prepared by Drs. W. N. Hess and Paul Nakada of the Goddard Center, appeared in the October 5, 1962 issue of Science, the organ of the American Association for the Advancement of Science. The series of scientific papers now appearing in the Journal of Geophysical Research is based in part on material presented at the Goddard symposium and is preceded by an introductory summary by W. L. Brown (Bell Telephone Laboratories), W. N. Hess (Goddard Space Flight Center), and J. A. Van Allen (State University of Iowa).

The necessarily preliminary data which became available shortly after the STARFISH shot were intensively reviewed by many qualified scientists in order to advise the government concerning the effects to be expected from other scheduled tests in the same series. The cooperation of scientists from the State University of Iowa, the Bell Telephone Laboratories, the Applied Physics Laboratory of Johns Hopkins University, and from several other organizations was invaluable in providing promptly the data on which those reviews were based.

On the basis of this information, each of the remaining tests was carefully scrutinized, with respect to its consequences and relevance to the acquisition of security information needed by the United States, and alternatives were considered with the object of avoiding any major additional enhancement of the radiation belt. Revisions were made in the program of the 1962 test series and subsequent observations have not shown any measurable enhancement to have resulted from the remainder of that series. Also, the shot times for these events were carefully restricted to intervals during which satellites then in orbit would not experience short-term phenomena associated with these detonations.

As previously announced by the AEC, the Soviet Union conducted high altitude nuclear tests on October 22 and 28 and November 1. Data from these Soviet tests are being collected and it is expected that after analysis the results will be submitted by the scientists concerned for publication in the technical literature.

As is indicated by the introductory paper in the Journal of Geophysical Research, it was apparent from the presentations at the Goddard symposium that the measurements existing at that time could be variously interpreted with respect to the spatial distribution of the trapped particles and, hence, to the total number of injected electrons. Specifically, however, there was agreement between results obtained at relatively low altitudes from the satellites INJUN I, TRAAC, and TELSTAR; and an omnidirectional electron flux of about 10^9 (one billion) electrons per square centimeter per second (cm^{-2} sec^{-1}) could be inferred from both the INJUN I and TELSTAR observations in the equatorial plane at about 1.23 earth radii from the earth's geomagnetic center. (It should be noted that the earth's geomagnetic center is appreciably displaced from the geographic center.)

For estimating intensities at large distances from the earth, it initially was necessary to rely entirely on observations from TELSTAR, the orbit of which extends to 5600 km altitude. This satellite was launched on July 10 and hence unfortunately did not provide comparative data before and after the STARFISH event. The TELSTAR detectors, which measure electrons of energies of about 1/2 million electron volts energy, showed fluxes of 10^9 cm^{-2} sec^{-1} to distances as great as 1.8 earth radii, whereas the INJUN I data could be interpreted to indicate that fluxes of 10^9 cm^{-2} sec^{-1} did not extend beyond 1.26 earth radii. The INJUN detector measures electrons of several Mev, but the satellite does not fly higher than 1100 km and does not directly provide equatorial data beyond about 1.28 earth radii from the earth's geomagnetic center. In interpreting the TELSTAR data, the flux was computed on the assumption that the energy spectrum of the measured particles was that of fission electrons. The total number of electrons injected as a result of the STARFISH shot thus was judged from the TELSTAR data as being as great as 2×10^{26}, electrons (as measured one week after the event) subsequently estimated as 6×10^{25}, electrons (as measured two weeks after the event) while a total of only 8×10^{24} electrons (as measured six hours after the event) could be inferred from the contours which were suggested by the State University of Iowa group on the basis of INJUN data alone. The discrepancy between these numbers arises from the uncertainty as to whether the low energy electrons at high altitudes are of natural origin or are fission electrons modified in spectrum by the injection process.

Unfortunately, the independently measured intensity of radio noise (synchrotron radiation observed at low latitudes from the circular or helical motion of the electrons about magnetic field lines) could not contribute decisively to resolution of this difference, since it was almost entirely contributed by high energy electrons moving in the stronger fields which occur at relatively low altitudes.

For planning purposes subsequent to the STARFISH shot, the larger intensities and long life times for trapped electrons were conservatively assumed. Additional information is now available concerning the time history of the trapped electron flux. Electrons having minumum altitudes below 500 km are decaying in periods of weeks to months. Once those electrons whose trajectories dip into the denser portion of the earth's atmosphere are eliminated by air scattering and energy loss, the remaining electrons may be expected to survive for some years in the absence of pronounced magnetic storms or other perturbations of the geomagnetic field.

Certain high altitude components of the observed electron distribution, however, were seen to decay by a factor of two or more in a period of a few weeks. Most notably observations, reported by W. L. Brown and J. D. Gabbe, of the Bell Telephone Laboratories, in the Journal of Geophysical Research, have shown a pronounced decrease of intensity in regions associated with flux lines extending at the equator to distances of approximately 3 earth radii. Some more recent data indicate, moreover, that these secular changes are energy dependent. It has been noted that large time fluctuations somewhat similar to this phenomena were previously observed to occur in connection with the natural belts. The observed decrease of intensity in certain regions, and the other associated changes in the electron distribution, indicate a complicated phenomenon of considerable scientific interest. The results of the present series of observations may be expected to lead to an increased understanding of phenomena which determine the origin, intensity, and character of the natural radiation belts as they are affected by geomagnetic forces and the upper atmosphere.

Specially instrumented satellites which were launched by NASA (EXPLORER XIV and EXPLORER XV) and by the Department of Defense, subsequent to the STARFISH event, acquired additional data concerning the character and evolution of the artificial electron belt. Data from these more recent flights are being analyzed and will be published in the scientific literature.

The effect of the artificial belt on increasing the noise-temperature of the sky, as observed by ground-based radiotelescopes, does not appear to be of long duration or highly troublesome. Some radio noise from synchrotron radiation certainly can be detected under favorable conditions, and was observed at low latitudes, so that the radio noise under such circumstances could constitute a temporary nuisance. There is no measurable radio noise from the July 9 test at the higher latitudes, and radio astronomy installations such as Jodrell Bank are, therefore, unaffected by this phonomenon. The intensity in the region of the magnetic equator is falling off steadily and is now comparable to the diurnal minimum of natural noise. The radio noise may continue (for some time) to be detectable, with special instrumentation, in the equatorial region by virtue of its polarization, but should have no adverse effects on work in radio astronomy. This radio noise conceivably might be somewhat more troublesome if received by sensitive detectors aboard artificial satellites such as the Top Side Sounder. In any case, the electrons which contribute appreciably to production of this radio noise are those situated at the lower altitudes, where the magnetic field strength is relatively large, and their life-times will be shorter than for many of the electrons now trapped by the geomagnetic field.

Solar-cell power sources and other similar components experience an accelerated deterioration of their performance if the satellite trajectories are such that the vehicles spend a substantial portion of their flight time in the more intense regions of the artificial electron belt. This can be serious if the systems are designed with only a small margin of safety. Improved types of solar cells (employing n-on-p silicon junctions), which are considerably more radiation resistant, are available and were employed on TELSTAR. With respect to manned missions in space, the shielding provided by normal capsule design effects a considerable reduction in the radiation exposure, and the artificial belt is not regarded as placing any significant restrictions on the conduct of current manned space flights.

Interested governmental agencies will continue to study closely the implications of the additional data which are being acquired, and new information will be made available to the scientific community through further publication in the appropriate technical journals.

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