Solar Flare Tritium in a Recovered Satellite

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Tritium and argon-37 were measured in samples of the Discoverer XVII satellite. The tritium content was unusually high, the maximum value being 163±2 tritium decays/kg min. The ratio of tritium to argon-37 atoms was 2500±300 in an iron sample and larger than 9000 in a lead sample. The tritium activity decreased rapidly with depth. The tritium content is too large by a factor of more than one hundred to be explained by nuclear interactions induced by incident protons or alpha particles. The tritium must result from a flux of incident tritons stopped in the material.

TRITIUM was measured in samples of a lead sheet one-quarter inch thick, and in samples of a stainless steel battery case from the Discoverer XVII satellite.[1] In some samples the radioactive isotope argon-37 was also measured. For comparison purposes we also made measurements on an unflown lead sheet, one-quarter inch thick, from the same source; on a similar battery case from the Discoverer XVIII satellite; and on meteorite samples.

The Discoverer XVII was launched from California at 20:42 UT, November 12, 1960, and was exposed to the intense radiation associated with the 3+ solar flare of November 12, 1960. The Discoverer XVII was in a polar orbit for 50 hours. The orbit had an apogee of 997 km and a perigee of 184 km.

The tritium content of the Discoverer XVII samples was unusually high and the activity decreased rapidly with depth. The maximum tritium activity was 163±2 decays/kg min near the surface of the lead sheet; the average depth of this fraction of the lead sheet was 1.0 g/cm². At the same location but greater depth in the lead sheet the tritium activity was 38±2 decays/kg min; the average depth of this fraction was 3.75 g/cm². The lead had been covered on the outside by an aluminum sheet of 0.43 g/cm² thickness and by a heat shield of thickness varying between 0.95 to 2.60 g/cm². The minimum kinetic energy required for a triton to reach the surface of the lead was approximately 85 Mev. The tritium content in the lead differed at different locations indicative of variations in shielding. The lowest tritium content in the lead was 6.7±0.5 decays/kg min. Even this value is fifty times more tritium than would be expected from the interaction of cosmic rays with the lead. We detected no tritium (less than 0.6 decay/kg min) in the lead sheet which was not flown. The tritium content of the stainless-steel battery case from the Discoverer XVIII satellite was one-eighth that measured in the battery case from the Discoverer XVII satellite.

We measured the tritium and the argon-37 in the satellite materials by the same technique that we have used for meteorites.[2] During the course of the satellite measurements, we also measured tritium and argon-39 in the Bruderheim meteorite. The tritium and argon-39 values that we found in the Bruderheim meteorite were quite similar to values that we have obtained for other chondrites. The tritium to argon-39 ratio in the Bruderheim meteorite is 26.[3]

Table I gives the tritium results for the Discoverer XVII materials. The letters *A*, *B*, and *C* denote the locations of the lead samples. The column labeled "thickness" is the average thickness of the material except for location *A*, where the quarter-inch thick lead sheet was chiseled into three fractions. Sample *A*-surface was 172 g of the material chiseled from the outside surface. A counting rate of 24.6±0.16 counts/min was measured in the hydrogen from this sample. Sample *A*-center was 149 g of the central material, a depth in the lead sheet from 2.0 g/cm² to 5.5 g/cm². The counting rate in the hydrogen from this sample was 5.65±0.14 counts/min. Sample *B* was a 125 g section that counted 3.68±0.06 counts/min. We divided the hydrogen from the 563 g sample *C* into two portions, one with 67% and the other with 33% of the hydrogen. The first gave a counting rate of 3.14±0.03 counts/min of tritium; the second gave 1.86±0.03 counts/min. We also divided the hydrogen from 167 g of the steel battery case into two portions, one containing 67% and the other 33% of the hydrogen. The first gave 6.17±0.16

TABLE I. Tritium in material from the Discoverer XVII satellite, which was in a polar orbit for 50 hr (apogee = 997 km, perigee = 183 km).

Material (location)	Thickness (g/cm²)	Tritium (decays/kg min)	Tritium (10^6 atoms/cm²)
Lead sheet (*A*) surface	2.0	163 ±2	3.2
Lead sheet (*A*) center	3.5	38 ±2	1.3
Lead sheet (*B*)	7.2	27 ±1	1.9
Lead sheet (*C*)	7.2	6.7±0.5	0.47
Lead sheet (*C*)	7.2	7.3±0.9	0.51
Stainless steel case	1	56 ±3	0.54
Stainless steel case	1	49 ±4	0.48
Lead sheet (unflown)	7.2	<0.6	...

[1] Dr. H. Yagoda of Air Force Cambridge Research Laboratories generously gave us the samples from the Discoverer XVII and XVIII satellites.

[2] E. L. Fireman and J. DeFelice, J. Geophys. Research **65**, 10 (1960).

[3] E. L. Fireman and J. DeFelice, presented at the American Geophysical Union 42nd Meeting, April, 1961 (unpublished).

counts/min; the second gave 2.90±0.05 counts/min. Three background measurements with tank hydrogen made during the experiment gave the values 0.71 ±0.016, 0.88±0.03, and 0.80±0.03 count/min. These background rates agree with previous background measurements on the same counter. The hydrogen from a 157 g sample of the unflown lead gave 0.80±0.03 count/min, which is identical to the background value of the tank hydrogen. The over-all efficiency of the counter and low-level system is 85%. The chemical yield is assumed to be 100%. Any lower value for the chemical yield would raise the values for the tritium. We calculated the number of tritium decays/kg min with these data.

Although the tritium content of the Discoverer XVII sample was very high, the argon-37 content in the same samples was not. The argon-37 activity in the stainless-steel battery case was 2.6±0.3 decays/kg min so that the H^3/A^{37} ratio in the sample was 2500±300. The argon-37 activity in the lead sample C with an average counting rate of 7.1±0.2 decays/kg min of tritium was less than 0.10 decay/kg min so that its H^3/Ar^{37} ratio was greater than 9000. These argon-37 values agree with more precise determinations by Stoenner and Davis.[4]

Van Allen[5] estimated from Explorer VII counter measurements that approximately 10^9 solar flare particles/cm², i.e., protons greater than 30 Mev and alpha particles greater than 120 Mev, impinged on the Discoverer XVII satellite during its time in orbit.

[4] R. W. Stoenner and R. Davis, Jr., Bull. Am. Phys. Soc. **6**, 277 (1961).
[5] J. A. Van Allen, Bull. Am. Phys. Soc. **6**, 276 (1961).

The large tritium to argon-37 ratio, if interpreted on the basis of production of both isotopes by nuclear interactions in the iron and lead, requires that most of the tritium be produced by incident particles of relatively low energy (less than 160 Mev for protons).[6] On the other hand, the very large tritium activity, particularly at the surface of the lead at location A, would require an average tritium production cross section of greater than 500 mb for the flux of particles estimated. Such a large cross section for tritium production by incident protons of low energy is inconsistent with measured cross sections.[6-8] We also believe that alpha-particle stripping cannot account for the amount of tritium observed.

We believe that the proper interpretation of our results is that tritium was present in the flare itself with an H^3/H ratio of about 0.4%. Most of the tritons that we measure have energy between 85 and 200 Mev. Freden and White[9] measured with nuclear emulsions a flux of 2±1 tritons/cm² sec between 126 and 200 Mev in the Van Allen belt. Since the flux required to explain our results is about 20 tritons/cm² sec and since the Discoverer XVII spent only a small fraction of its orbit time in the Van Allen zone, we believe that the source of the tritium was probably the solar flare itself rather than Van Allen trapped tritons.

[6] E. L. Fireman and J. Zähringer, Phys. Rev. **107**, 1695 (1957).
[7] J. Gonzalez-Vidal and W. H. Wade, Phys. Rev. **120**, 1354 (1960).
[8] L. A. Currie, W. F. Libby, and R. L. Wolfgang, Phys. Rev. **101**, 1557 (1956).
[9] S. C. Freden and R. S. White, J. Geophys. Research **65**, 5 (1960).