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ELECTRON RADIATION EFFECTS ON SILVER-ZINC CELLS

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ABSTRACT

A test has been completed to determine the effects of electron irradiation on vented silver-zinc (Ag-Zn) cells, similar to the type used in the AE-B (Explorer 32) spacecraft. Irradiation by electrons of energies up to 1.5 Mev at 10^{15}e/cm^2 caused severe deterioration of the cellophane separator material, producing catastrophic cell failures. Half of the cells irradiated at 10^{14}e/cm^2 failed after being subjected to numerous charge-discharge cycles. No cell failures occurred at 10^{13}e/cm^2. Results also indicated that a cell's state of charge during irradiation may affect its ampere-hour capacity.

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INTRODUCTION

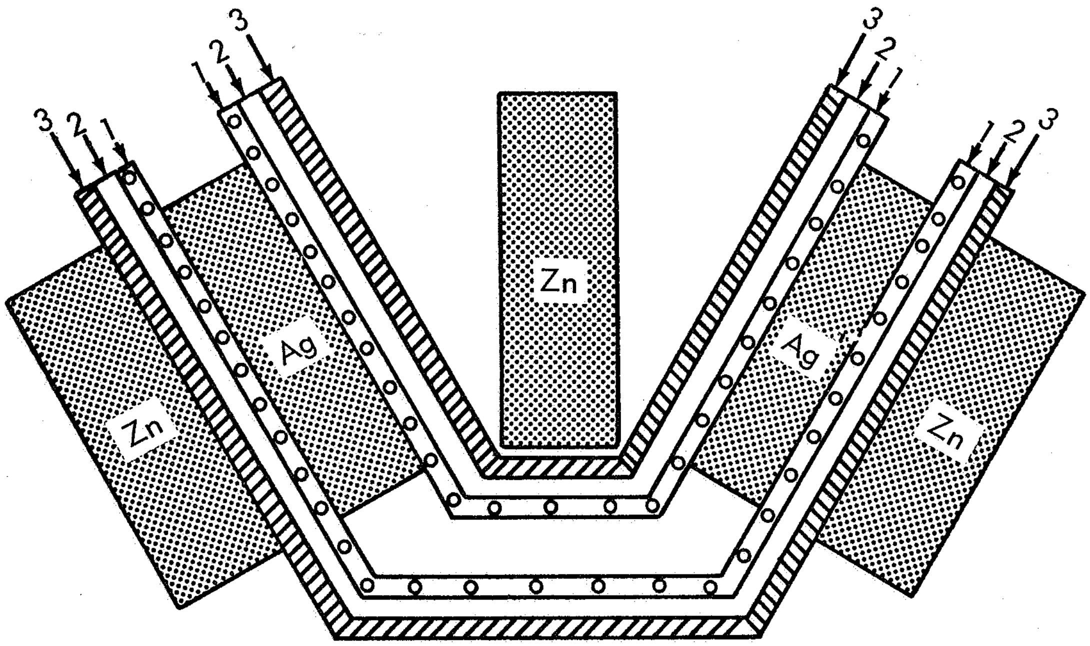
In May 1966, the AE-B spacecraft (Explorer 32) was launched. Its primary power supply comprised HR-type, Yardney silver-zinc (Ag-Zn) cells of 40-, 58-, and 200-ampere-hour capacity (Reference 1). From September 1966 through February 1967, many of these cells failed, even though neither spacecraft temperature and pressure nor battery temperatures indicated cause for the premature failures. However, because of an extended second-stage burn of the Delta rocket, the apogee altitude had been increased from 1200 to 2700 kilometers, thereby subjecting the batteries to more severe electron irradiation from the Van Allen belts than had been expected.

Because of this situation, tests were performed to determine whether radiation could cause premature failure of Ag-Zn cells. The 5-ampere-hour, HR-type, Yardney Ag-Zn cells used in the tests differed from the AE-B spacecraft cells only in ampere-hour capacity. Figure 1 illustrates the Ag and Zn electrodes and "U" fold separator configurations used in the Ag-Zn cell construction.

RADIATION PARAMETERS (PHASE 1)

It was estimated that the AE-B spacecraft was irradiated at 0.23×10^{14} e/cm^2 when cell failure first occurred.* At the time of failure, the two extreme battery capacity parameters, zero-percent and 70-percent depth-of-discharge, were evidenced. For the test run, fully charged cells and cells discharged to a 70-percent depth were irradiated with 1.5-Mev electrons at

*Private communication with R. Janda and F. Gordon, Goddard Space Flight Center.



1 - NYLON SEPARATOR
2 - CELLOPHANE SEPARATOR
3 - ALDEX SEPARATOR

<u>HR-40 dc (10 NM)</u>

Ag
- 1 - One wrap
- 2 - Four wraps
- 3 - One wrap

Zn No separator

<u>HR-58 dc (2 NM)</u>

Ag
- 1 - One wrap
- 2 - Four wraps
- 3 - One wrap

Zn No separator

<u>HR-200 dc (4 NM)</u>

Ag
- 1 - One wrap
- 2 - Four wraps
- 3 - One wrap

Zn No separator

<u>HR-5 dc (11 NM)</u>

Ag
- 1 - One wrap
- 2 - Four wraps
- 3 - One wrap

Zn No separator

Figure 1. Cross-Sectional View of Ag and Zn Plates and Separators

10^{13}, 10^{14}, and 10^{15} e/cm^2. The majority of the Ag-Zn cells in the spacecraft were positioned with their narrow sides near the spacecraft skin, thereby exposing the edges of the electrodes and separators to the highest degree of radiation. Therefore, 5-ampere-hour test cells were placed in a manner to receive comparable radiation. Figure 2 illustrates cell placement with respect to the 1.5-Mev electron source for each level of irradiation. Eight cells were irradiated at each level. Table 1 lists the three test phases, the number of cells used for the two charged states, and the radiation levels. In addition to the cells tested, samples of dry cellophane and cellophane immersed in 40-percent potassium hydroxide were subjected to the radiation source at each level.

CELL DISSECTION AND EXAMINATION (PHASE 2)

Examination of the cells after irradiation showed severe discoloration of the bakelite cell case edges positioned nearest the 1.5-Mev electron source, at 10^{15} e/cm^2. There was slight discoloration for irradiations at 10^{14} e/cm^2, but none at 10^{13} e/cm^2. Cells 7 and 8, at both 10^{14} e/cm^2 and 10^{15} e/cm^2, had less

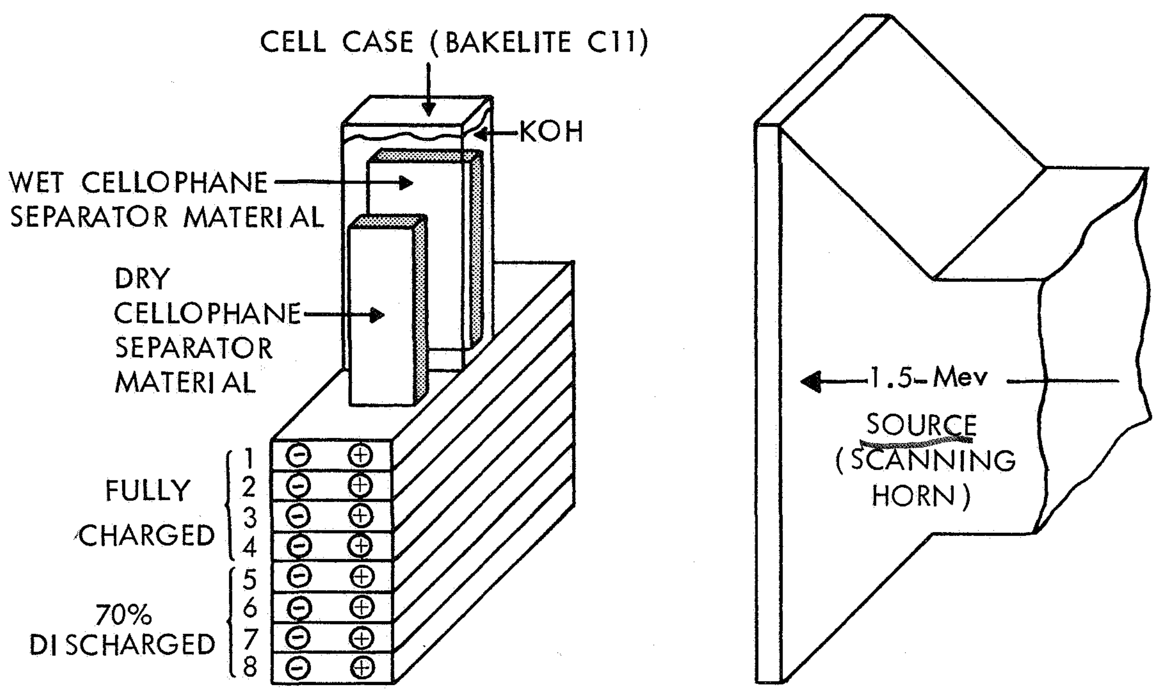


Figure 2. Cell Placement During Irradiation

Table 1

Cell Capacity, Radiation, and Test Phase Profile

Phase	Unradiated	Radiated		
		10^{13} e/cm^2 (A)	10^{14} e/cm^2 (B)	10^{15} e/cm^2 (C)
Phase 1 0% depth-of-discharge		4 cells (1A-4A)	4 cells (1B-4B)	4 cells (1C-4C)
70% depth-of-discharge	4 cells (1-4)	4 cells (5A-8A)	4 cells (5B-8B)	4 cells (5C-8C)
Phase 2 Cells to be dissected for examination	1 cell (1)	2 cells (1A, 8A)	2 cells (1B, 8B)	2 cells (1C, 8C)
Phase 3 Cells to be cycled to 70% depth-of-discharge	3 cells (2-4)	6 cells (2A-7A)	6 cells (2B-7B)	6 cells (2C-7C)

discoloration than the top six cells, indicating that the bottom two cells at each level had been irradiated to a lesser degree than anticipated. Since no discoloration was noticed at 10^{13} e/cm^2, a comparison between these eight cells could not be made.

Cells 1 and 8, irradiated at 10^{13}, 10^{14}, and 10^{15} e/cm^2, were dissected. The edges (nearest the 1.5-Mev electron source) of the cellophane separator material of cell number 1C, irradiated at 10^{15} e/cm^2, were completely deteriorated. The separator material of the number 8C cell showed no deterioration, thus supporting the fact that the bottom two cells had not been irradiated to the anticipated level. Figure 3 is a photograph of one cellophane separator from each dissected cell. Separators 1A and 8A were irradiated at 10^{13} e/cm^2; 1B and 8B were irradiated at 10^{14} e/cm^2; 1C and 8C were irradiated at 10^{15} e/cm^2; and separator 1 was unradiated. Deterioration of cellophane

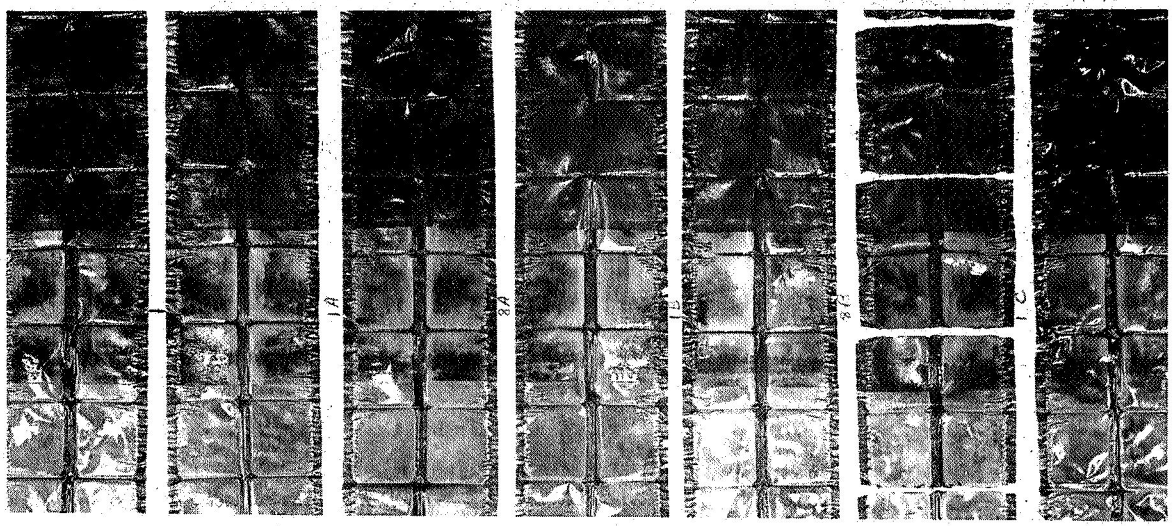


Figure 3. Photograph of Inner Surface of Cellophane Separators

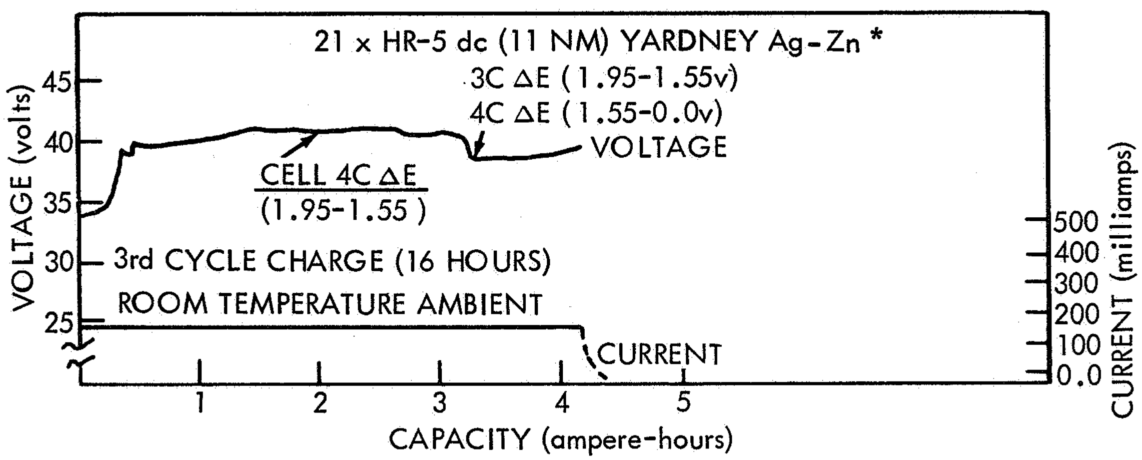
separator 1C extended through all four wraps. The nylon and aldex separators and the Ag and Zn electrodes appeared to be unaffected by irradiation at 10^{15} e/cm^2. Irradiation at 10^{13} and 10^{14} e/cm^2 appeared to have no effect on the cellophane separators. Infrared studies of the dry cellophane separator material (Reference 2) indicate that the cellophane irradiated at 10^{15} e/cm^2 had been severely oxidized, thereby attributing to the polymer structure breakdown.

CYCLE TEST (PHASE 3)

The HR-type, Ag-Zn cells have limited cycle life (approximately 70 cycles at 50-percent depth-of-discharge) and limited wet stand life (approximately 12 months). These limitations necessitated an accelerated cycle test, rather than simulation of the AE-B batteries' cycling modes (approximately two to six cycles per year), to determine possible radiation effects at the three radiation levels. The 21 cells (3 unradiated, 18 irradiated) were assembled into a battery and cycled at a 24-hour regime (8-hour 70-percent depth-of-discharge, 16-hour recharge with a battery voltage limit averaging 1.98 volts per cell).

Whenever cell failure occurred, the charge voltage limit had to be decreased to prevent the remaining cells from becoming overcharged. For example, the voltage limit for 21 cells was 41.58 volts, which equals 1.98 volts per cell. With two cell failures, the cell voltage limit increased to 2.19 volts per cell. Figure 4 is a battery voltage and current characteristic curve for the third cycle, during which time two cell failures occurred. To minimize the overcharge problem, battery cycling was discontinued during the weekends, limiting the battery charge-discharge cycling to four per week.

Five of the six cells irradiated at 10^{15} e/cm^2 developed catastrophic shorts within six cycles producing exceedingly high cell temperatures, which caused the electrolyte to boil. The sixth cell (number 7, irradiated at



*Because of cell failures, battery did not reach power supply voltage limit; and charge current remained constant. Six cells exceeded 2.0v at end of charge.

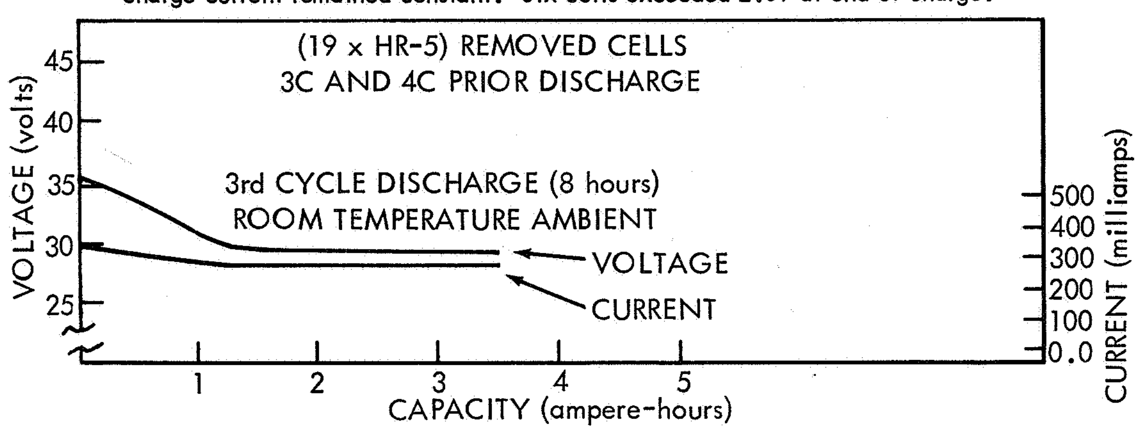


Figure 4. Voltage-Current Characteristics

$< 10^{15}$ e/cm^2) developed a high-impedance short (slow self-discharge) during the 35th cycle. No appreciable temperature change was evidenced.

Three of the six cells irradiated at 10^{14} e/cm^2 failed between cycles 60 and 69. The failure mode was a high-impedance short, similar to the cell failures in the AE-B spacecraft. Cells were capable of slight recharge after a short developed. The cell failure profile is given in Figure 5.

A severe capacity unbalance between cells developed during the cycle regime. Although the depth-of-discharge was 70 percent, several cells had little or no residual capacity after the 23rd and 43rd cycles. During the normal cycling regime, these cells evidenced the lowest voltages at the end of charge and discharge.

In order to determine the amount of capacity unbalance between cells, capacity tests were performed during the cycling program. All cells were individually discharged to 1.28 volts, and then individually charged to 2.03 volts. The results of the capacity test, given in Figure 5, are based on the average capacities of the three cells used for each parameter. The loss of residual capacity was predominant in the unradiated cells and in cells irradiated at the zero-percent depth-of-discharge. For example, the results of the 24th cycle charge indicated that the cells discharged to a 70-percent depth before irradiation at 10^{14} e/cm^2, averaged approximately 3 ampere-hours more residual capacity than the fully charged cells irradiated at 10^{14} e/cm^2.

Recharge capability and charge efficiency were determined by discharging each cell to a 100-percent depth (1.28 volts) and recharging to 2.03 volts. For example, the results of the 25th cycle charge showed the recharge capability between all cell groups varied only 0.4 ampere-hours, which indicates that the loss of residual capacity previously evidenced was not caused by a decrease in active material in either the Ag or Zn electrodes. Placing the cells on open

Radiation Level	—	10^{13} e/cm^2		10^{14} e/cm^2		10^{15} e/cm^2	
Number of Cells Cycled	3	3	3	3	3	3	3
Depth of Discharge Prior Irradiation	—	0	70%	0	70%	0	70%

CELL FAILURES	CYCLE PERFORMANCE	—	10^{13} 0	10^{13} 70%	10^{14} 0	10^{14} 70%	10^{15} 0	10^{15} 70%
2	2						2	
1	3							1
2	5						1	1
1	34							1*
1	59				1			
1	60				1			
1	68					1		

CAPACITY TESTS	—	10^{13} 0	10^{13} 70%	10^{14} 0	10^{14} 70%
Average a-h Input (24-cycle charge)	5.1	7.2	4.4	4.7	4.6
Average a-h Input (25-cycle charge)	7.6	7.8	8.0	8.0	7.8
Average a-h Output (44-cycle discharge)	5.0	5.0	6.9	5.2	6.9
Average a-h Input (cycles 45-46)	6.32	6.93	7.12	6.70	7.10
Average Output (cycles 45-46)	6.08	6.59	6.87	6.44	6.95
Final Average a-h Output (72-cycle discharge)	3.67	4.29	4.12	4.1 (1 cell)	4.78 (2 cells)

*Cell 7C-Visual examination indicated cell irradiation < 10^{15} e/cm^2

Figure 5. Cycle Test Profile

circuit for 17 days showed that self-discharge was negligible, attributing little effect to the capacity unbalance that had developed between cell groups.

The test was discontinued after 72 cycles, because losses of Zn material in the negative electrodes caused severe capacity degradation within all cells.

CONCLUSIONS

Irradiation at 10^{15} e/cm^2 caused severe deterioration of the cellophane separator material, resulting in early catastrophic cell failures and an extremely high increase in cell temperature. By the end of the 68th charge-discharge cycle, half of the cells irradiated at 10^{14} e/cm^2 developed high-impedance shorts, similar to the AE-B failures. Irradiation at $>10^{14}$ e/cm^2 and $<10^{15}$ e/cm^2 may cause premature failures without producing severe increases in cell temperature.

The ampere-hour capacity of cells discharged to a 70-percent depth before irradiation was slightly higher than the capacity of unradiated and fully charged irradiated cells. Irradiation of the discharged Ag electrodes may have retarded the loss of active material normally encountered during cycling. Similar results have been observed (Reference 3) in a study of gamma radiation effects on Ag electrodes.

The capacity unbalance that developed between cells appears to have a direct correlation to the state of charge during cell irradiation, which may possibly be attributed to one of the following reasons:

1. Enhancement of charge efficiency in the discharged irradiated cells,
2. Passivation of the active electrode materials in the unradiated and fully charged irradiated cells caused by cycling these cells in series with the discharged irradiated cells.

Further infrared studies of the cellophane separator material and examination of the Ag electrodes from the cycled cells may add to the knowledge acquired from this test.

REFERENCES

1. Donnelly, P. C., and Palandati, C. F.: Silver Zinc Batteries Power Supply for Atmosphere Explorer-B Spacecraft (AE-B). NASA Goddard Space Flight Center Document X-525-64-395, December 1964.

2. Briden, Frank E.: Infra-Red Studies of Separator Materials. R&D Quarterly Report No. 4, April-June 1967.

3. Nicholson, M. M., Recht, H. L., and Argue, G. R.: Radiation Effects on Silver and Zinc Electrodes. Final Report A1-67-7, Prime Contract NAS 7-100, 1967.