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Effect of Storage and LEO Cycling on Manufacturing Technology IPV Nickel-Hydrogen Cells

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EFFECT OF STORAGE AND LEO CYCLING ON MANUFACTURING TECHNOLOGY IPV NICKEL-HYDROGEN CELLS

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ABSTRACT

Yardney Manufacturing Technology (MANTECH) 50 A-hr space weight individual pressure vessel nickel-hydrogen cells were evaluated. This consisted of investigating: (1) the effect of storage and (2) charge/discharge cycling on cell performance. For the storage test the cells were precharged with hydrogen, by the manufacturer, to a pressure of 14.5 psia. After undergoing activation and acceptance tests, the cells were discharged at C/10 rate (5 A) to 0.1 V or less. The terminals were then shorted. The cells were shipped to the NASA Lewis Research Center where they were stored at room temperature in the shorted condition for 1 yr. After storage, the acceptance tests were repeated at NASA Lewis. A comparison of test results indicate no significant degradation in electrical performance due to 1 yr storage. For the cycle life test the regime was a 90 min low earth orbit at deep depths of discharge (80 and 60 percent). At the 80 percent DOD the three cells failed on the average at cycle 741. Failure for this test was defined to occur when the cell voltage degraded to 1 V prior to completion of the 35 min discharge. The DOD was reduced to 60 percent. The cycle life test was continued.

INTRODUCTION

As part of an overall effort to advance the technology of nickel-hydrogen (N_1/H_2) batteries for possible use in an energy storage system, in low earth orbit (LEO), Yardney Manufacturing Technology (MANTECH) 50 A-hr space weight individual pressure vessel (IPV) nickel-hydrogen cells were evaluated. This consisted of investigating the effect of storage and charge/discharge cycling on cell performance. The effect of storage on cell performance is important because nickel-hydrogen batteries could be subjected to storage for extended periods of time prior to launch. It has been reported that some nickel-hydrogen batteries degrade in capacity on storage while others do not degrade on storage.[1] Battery cycle life is important to assess their suitability for specific flight programs. The data base for MANTECH cells is very limited.

In this communication the results of storage and cycle life test on Yardney MANTECH 50 A-hr space weight IPV nickel-hydrogen cells is reported.

EXPERIMENTAL

Test Facility

The test facility used to cycle life test the nickel-hydrogen cells is illustrated in Fig. 1. The facility design incorporates two main features: safety and versatility. Since the nickel-hydrogen cells are precharged with hydrogen and also generates hydrogen during charge, special attention was given to personnel safety. The cells were located on top of the instrumentation cabinets. There were two cells for each cabinet. Each cell was located within a cylindrical shrapnel shield in case of the improbable event of an explosion or rupture of the cell pressure vessel. During a test, the cylindrical shield was purged with nitrogen to create an inert atmosphere. The nitrogen gas, and hydrogen gas if any, would be exhausted from the test laboratory through a hood located above the cells. If the exhaust fan would fail or the nitrogen purge would become interrupted the test would be automatically terminated. A test can also be terminated on a preset upper and/or lower limit of cell voltage, current, pressure, and temperature.

The facility's versatility allows for testing over a wide range of cycle regimes. A geosynchronous earth orbit (GEO) cycle regime can be run in real time using a programmable timer. Various accelerated GEO and low earth orbit cycle regimes can be run using a Texas Instrument timer. The cell discharge current is controlled by an electronic load, which can be varied from 0 to 100 A. The charge current can also be varied in the same range. Test data is printed out locally using a Fluke data collector. Strip chart recorders are used to record cell voltage, current, and pressure as a continuous function of charge and discharge time for selected cycles. A maximum of twelve cells can be tested at the same time.

TEST CELL DESCRIPTION

The three cells were 50 A-hr capacity space weight IPV nickel-hydrogen cells. They were manufactured by Yardney Electric Corporation (Battery Division) according to specifications directed under the Air Force (WPAB) manufacturing technology contract with Yardney.[2] The cell is illustrated in Fig. 2. It consists of a stack of nickel electrodes, separators, hydrogen electrodes, and gas screens assembled in a non back-to-back electrode configuration. In this configuration electrodes of different types directly face each other. The stack is packaged in a cylindrical pressure vessel, with hemispherical end caps. This is made of inconel 718 and lined with zirconium dioxide which serves as a wall wick. The components are shaped in a "pineapple" slice pattern. The electrodes are connected electrically in parallel. A dual separator, consisting of one layer of asbestos and one layer of zircar, is used. Hence, since a high bubble pressure asbestos separator is used, the oxygen generated at the nickel electrode on charge is directed to the hydrogen electrode on the next unit cell, where it combines chemically to form water. The zircar separators are extended beyond the electrodes to contact the wall wick. Hence electrolyte which leaves the stack during cycling will be wicked back into the stack. The gas screens are polypropylene. The electrolyte is a 31 percent aqueous solution of potassium hydroxide. The nickel electrode consisted of a nickel slurry plaque containing a nickel screen substrate, which was electrochemically impregnated by the aqueous Siger/Puglisi process.[3] The cells were precharged with hydrogen to a pressure of 14.5 psia.

Measurements and Procedures

For this experiment the quantities measured for each cell at the end of charge and discharge, and their accuracies were: Current (±0.3 percent), voltage (±0.5 percent) pressure (+1 percent), and temperature (+1 °C limit of error). Additional measurements were charged and discharged ampere-hours (+0.5 percent) and charge to discharge ampere-hour ratio. Cell current, voltage pressure, and temperature were recorded continuously as a function of time, for selected cycles, on a strip chart recorder.

Cell charge and discharge currents were measured across a shunt, using an integrating digital voltmeter. Cell voltage was also measured using an integrating digital voltmeter. Cell pressure was measured using a strain gauge located on the cell dome. The temperature was measured using an iron-constantan thermocouple located on the center of the pressure vessel dome. The thermocouple was mounted using a heat sink compound to insure good thermal contact. Charge and discharge capacity was measured using an ampere-hour meter. Charge to discharge ratio (ampere-hour into cell on charge to ampere-hours out on discharge) was calculated from the ampere-hour measurements.

For the storage test the cells were discharged at the C/10 rate (5 A) to about 0.1 V or less. Then the cell precharge hydrogen pressure was set by the manufacturer to 0 psig (14.5 psia). After undergoing activation and acceptance test, the cells were once again discharged at the C/10 rate (5 A) to 0.1 V or less. The terminals were shorted. The cells were shipped to NASA Lewis where they were stored at room temperature in the shorted condition for 1 yr. After storage the acceptance test was repeated at NASA Lewis. The tests consisted of measuring the discharge ampere-hour capacity, and ampere-hour capacity retention.

The discharge capacity was measured after charging the cell at the C/10 rate (5 A) for 16 hr, followed by a 1 hr open circuit voltage stand. The discharge capacity was measured at the C/2 rate (25 A) to 1 V.

The cell charge retention was calculated from measured capacities. The cell was charged for 16 hr at the C/10 rate, followed by a 72 hr open circuit stand. After the 72 hr the capacity was measured by discharging the cell at the C/2 rate to 1 V, followed by a C/10 rate discharge to about 0 V. The total ampere-hour capacity was compared to a similar capacity measurement prior to open circuit stand. The cell charge retention was calculated as the ratio of the total capacity after the open circuit stand to the total capacity prior to the open circuit stand. The cell temperature was controlled during this experiment to 20±3 °C.

For the cycle life test the cells were charge/discharge cycled to failure under a 90 min LEO cycle regime to deep depths of discharge (80 and 60 percent). Initially the DOD was set at 80 percent of rated ampere-hour capacity. The cells performed poorly at this DOD. They failed on the average at cycle 741. After failure the cells were reconditioned which consisted of: (1) deep discharge - cells were discharged at C/2 rate to 1.0 V then the discharge was continued at C/10 rate to 0.1 V or less; and (2) a combination of open circuit stand and deep discharge reconditioning. The cells were left on open circuit stand for 28 days. Then the cells were deep discharged reconditioned as stated above. After reconditioning the cells were placed back on cycling at 80 percent DOD. When the cells failed after the second attempt to recondition the DOD was reduced to 60 percent and the cycle test continued. For this test failure was defined to occur, when the discharge voltage degraded to 1.0 V during the course of a constant current 35 min discharge. For the first test cycle, the cells were charged for 16 hr at the C/10 rate followed by discharge at the 1.37 C rate (68.5 A) for 35 min. Then the normal 80 percent DOD LEO charge/discharge cycling was initiated which consisted of charging the cells at a constant 0.96 C rate (48 A) for 55 min immediately followed by discharge at a constant 1.37 C rate for 35 min. For the 60 percent DOD test the cells were charged at the 0.72 C rate (36 A) and discharged at a constant 1.03 C rate (51.4 A). The charge to discharge ratio was initially set at 1.05 and increased as the cycling progressed to a final value of 1.10 in an attempt to improve cell performance. The charge and discharge rates stated above are for a charge to discharge ratio of 1.10. During the cycle life test the temperature was controlled to 20±3 °C.

RESULTS AND DISCUSSION

Storage test. The effect of storage (1 yr, terminals shorted) on the capacity of three, 50 A-hr space weight IPV nickel-hydrogen cells is summarized in Fig. 3. The spread in the data indicate there is no significant capacity loss due to the 1 yr storage. This information is relevant to applications where the battery is in planned or unplanned storage (launch delay) for up to 1 yr. It is also advantageous to store cells in the shorted condition, since this eliminates the potential hazard associated with high voltage.

The effect of storage on capacity retention of the nickel-hydrogen cells, after a 72 hr open circuit stand is summarized in Fig. 4. The spread in the data indicate no significant difference in capacity due to the 1 yr storage.

The capacity of each cell after the storage was measured at the intended use rate (1.37 C = 68.5 A) to a 1 V cut off. The results are shown in Table 1. The average capacity of the three cells was 53 A-hr.

Cycle test. The cells were cycled at two different deep depths of discharge (80 and 60 percent). Initially the cells were cycled at 80 percent DOD. At this DOD the performance was poor. The results of the 80 percent DOD test are summarized in Table 2. On the average the cells failed at cycle 741. The failure was characterized by a degradation of end of discharge voltage to 1 V prior to the end of the 35 min discharge. For these cells the 80 percent DOD was apparently too stressful. In an attempt to improve cell performance, the cells were deep discharged and open circuit stand reconditioned. They were placed back on cycling at 80 percent DOD; and once again failed due to low end of discharge voltage. The reconditioning had a very limited beneficial effect. The DOD was reduced to 60 percent and the cycle test continued. At this DOD the performance improved. The cumulative cycle life results (80 + 60 percent DOD) for this continuing test are summarized in Table 3. For cell 1 the V_{EOD} = 1.11 at cycle 2331, for cell 2 the V_{EOD} = 1.11 at cycle 2470, and for cell 3 the V_{EOD} = 1.11 at cycle 2468.

The effect of cycling on the end of discharge voltage for a representative cell is shown in Fig. 5. The cell failed at cycle 750 (80 percent DOD). The cycling was continued until the end of discharge voltage reached 0.94 V. The cell was deep discharge reconditioned and the cycling continued at the 80 percent DOD. This reconditioning had only a short term beneficial effect. It was placed on open circuit stand for 28 days followed by a deep discharge recondition, and placed back on cycling at the 80 percent DOD. This also had only a short term beneficial effect. The DOD was reduced to 60 percent at cycle 1360. This substantially improved the cell performance. At cycle 2220 the recharge ratio was increased from 1.07 to 1.10 in an attempt to improve cell performance. This had a limited beneficial effect. At cycle 2470 the end of discharge voltage was 1.11 V. The cycle life test (60 percent DOD) will be continued until failure. Then the DOD will be reduced to 40 percent and the cycling continued to failure. The cells will undergo teardown and failure analysis.

CONCLUDING REMARKS

The effect of storage and LEO cycling on the performance of Yardney manufacturing technology 50 A-hr space weight IPV nickel-hydrogen cells was investigated. No performance degradation was observed due to 1 yr storage (hydrogen precharge 14.5 psia, terminals shorted). On the average the cycle life was 741 cycles at 80 percent DOD. This cycle life is inadequate for most LEO applications requiring a long cycle life at deep depths of discharge. The DOD was reduced to 60 percent and the test continued. At this DOD the cell performance was improved. The cells have accumulated 2423 cycles (80 + 60 percent DOD) on the average and are performing satisfactorily in the continuing test.

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2. "Manufacturing Technology for Nickel Hydrogen Cells," Yardney Battery Division, Yardney Electric Corp., AFWAL-F-33615-80-C-5036, 1982.
3. Gross, S., "Review of Electrochemical Impregnation for Nickel Cadmium Cells," JPL-953984, 1977. (Also, NASA CR-155155).

TABLE 1. - CAPACITY OF YARDNEY MANUFACTURING TECHNOLOGY SPACE WEIGHT IPV NICKEL-HYDROGEN CELLS AFTER 1 YEAR STORAGE

Cell	Capacity, A-hr[a]	V_{EOD} V[b]	Discharge current, A	Temperature, °C
1	52.5	1.0	68.5	23
2	53.7	1.0	68.5	23
3	53.0	1.0	68.5	23

[a] After charge 16 hr at C/10 (5 A)
[b] V_{EOD} ≡ End of discharge voltage (V)

TABLE 2. - SUMMARY OF CYCLE LIFE TEST RESULTS YARDNEY MANUFACTURING TECHNOLOGY 50 A-hr SPACE WEIGHT IPV NICKEL-HYDROGEN CELLS - 80 PERCENT DOD LEO CYCLES

Cell	Cycle at failure	Failure mode	Status
1	737	Degradation of V_{EOD} to 1.0 V	DOD reduced to 60 percent, cycling continuing
2	750	Degradation of V_{EOD} to 1.0 V	DOD reduced to 60 percent, cycling continuing
3	735	Degradation of V_{EOD} to 1.0 V	DOD reduced to 60 percent, cycling continuing

TABLE 3. - SUMMARY OF CYCLE LIFE TEST RESULTS YARDNEY MANUFACTURING TECHNOLOGY 50 A-hr SPACE WEIGHT IPV NiH_2 CELLS - 80 PLUS 60 PERCENT DOD LEO CYCLES

Cell	Cycle	V_{EOD}, V[a]	Status
1	2331	1.11	Test continuing
2	2470	1.11	Test continuing
3	2423	1.11	Test continuing

[a]V_{EOD} ≡ End of 35 min discharge voltage, V

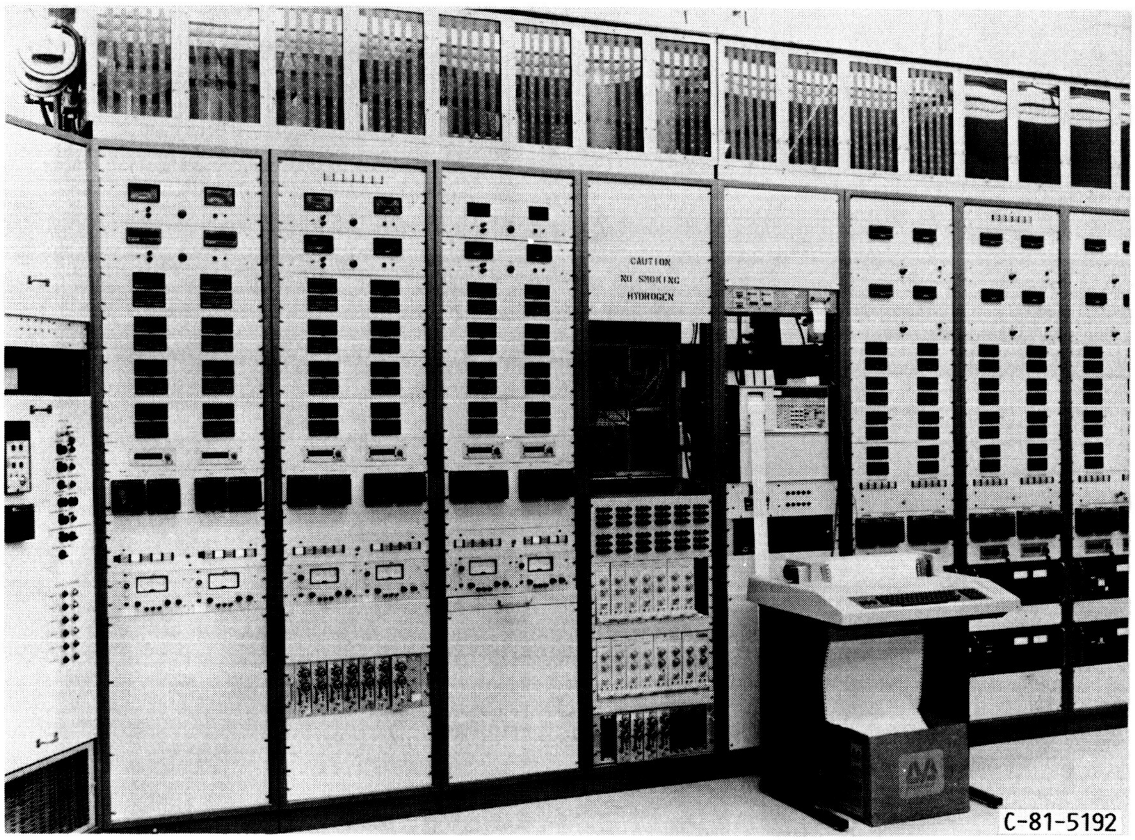

FIGURE 1. - NICKEL-HYDROGEN CELL TEST FACILITY.

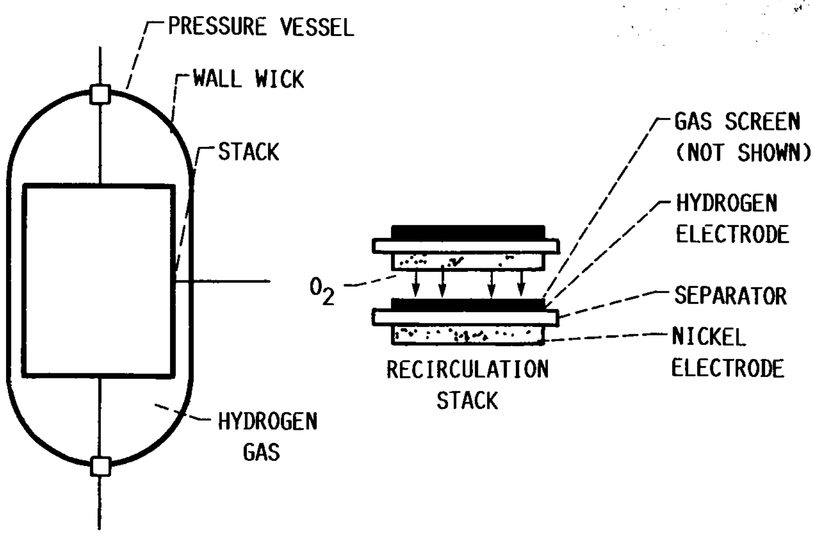

FIGURE 2. - ILLUSTRATION OF YARDNEY MANUFACTURING TECHNOLOGY INDIVIDUAL PRESSURE VESSEL NICKEL-HYDROGEN CELL.

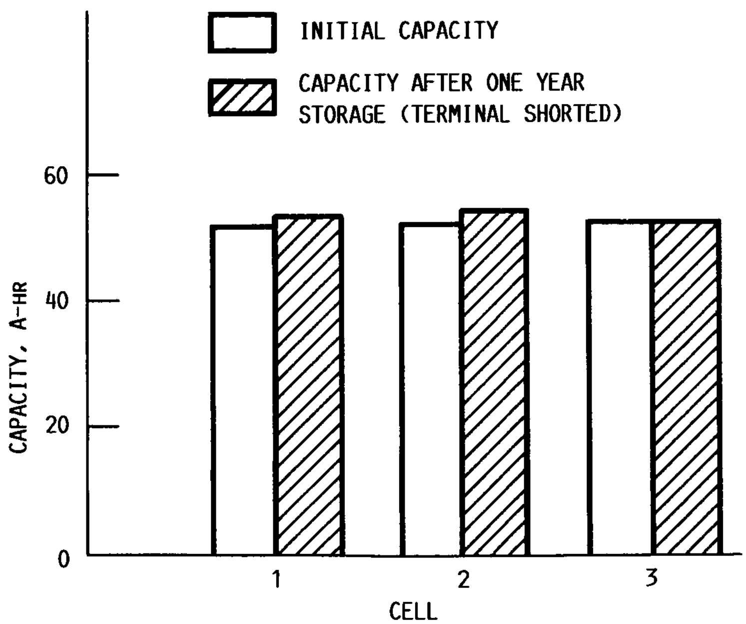

FIGURE 3. - EFFECT OF STORAGE ON CAPACITY OF 50AH YARDNEY SPACE WEIGHT IPV Ni/H_2 CELLS.

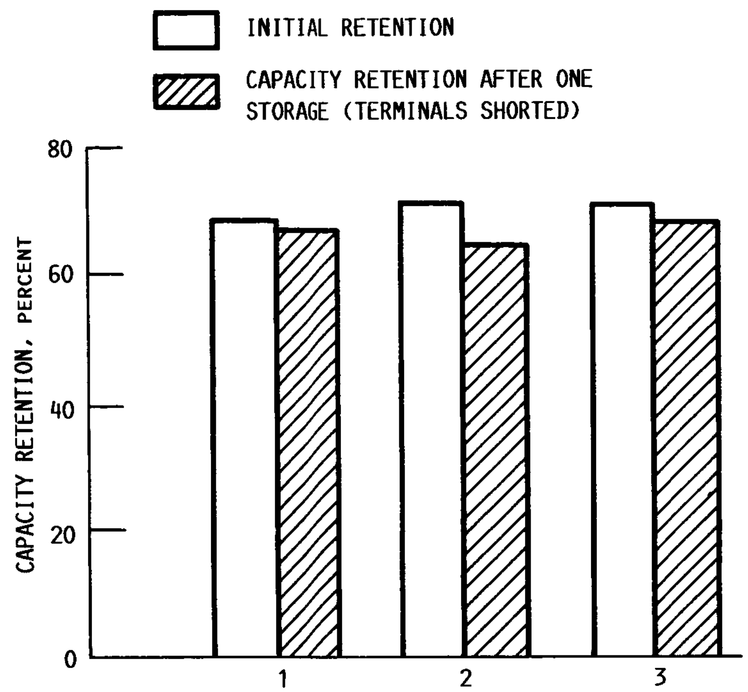

FIGURE 4. - EFFECT OF STORAGE ON CAPACITY RETENTION OF 50 AH YARDNEY SPACE WEIGHT IPV Ni/H_2 CELLS AFTER 72 HR OPEN CIRCUIT STAND.

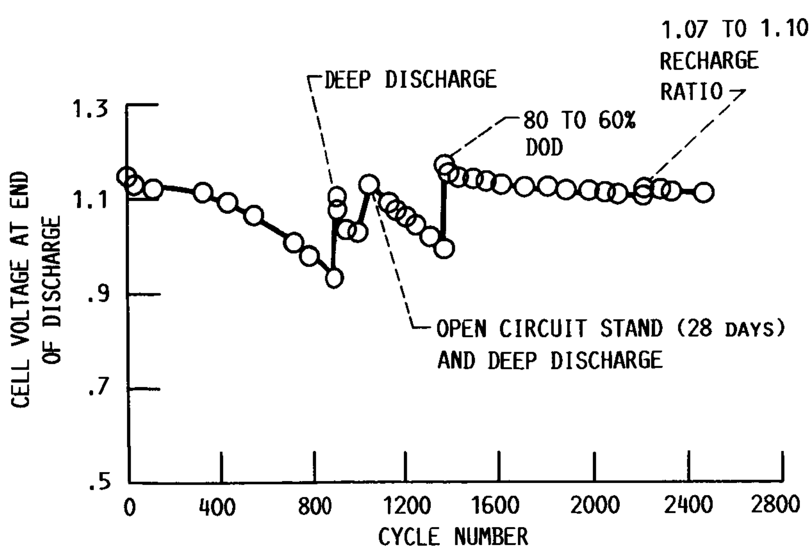

FIGURE 5. - EFFECT OF CHARGE/DISCHARGE CYCLING AND RECONDITIONING ON END OF DISCHARGE VOLTAGE OF A REPRESENTATIVE 50 AH YARDNEY MANTECH IPV Ni/H_2 CELL.

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16. Abstract

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