AN INDUSTRY AND GOVERNMENT SURVEY: A NICKEL-HYDROGEN TESTING DATA BASE

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ABSTRACT

The government and industry were surveyed to determine the level of testing of nickel hydrogen (NiH_2) battery cells and to evaluate the demonstrable capabilities of the couple. Only flight-type cells undergoing ground test were incorporated in the data base, no boilerplate cells or flight batteries were included. Both USAF design and COMSAT design cells as well as a few cells produced by SAFT were listed. The USAF design is in test in both high and low earth orbit simulations, whereas the COMSAT design, intended specifically for high orbit applications, is being tested predominantly in high orbits. The data from over 400 cells show that the reliability and capability of both designs for high orbit applications are reasonably established out to ten years in geosynchronous orbit and to approximately 3000 cycles in other high orbit applications. However, the data base is weak and incomplete for applications of the USAF cell in low earth orbit. This probably arises because of the harsh testing environment to which these cells have been subjected as well as various minor design questions that were not resolved when these cells began testing. It must also be pointed out that most of the testing data base is constructed from cells that were developmental in design or manufacture (all cells purchased for a test are used, even if performance is questionable) as contrasted to a flight program where it can be assumed that many of the failures listed would have been rejected prior to either life test or to use in a flight battery.

INTRODUCTION

A survey of the testing data base for nickel-hydrogen (NiH_2) battery cells has been performed. The objective of this survey was to evaluate the status of testing of cells in general and of the Air Force design nickel-hydrogen cell in particular. Sufficient detail was sought so that a critical evaluation of the test results and of cell performance could be made. Realizing that subtle differences in test conditions can result in large differences in cell performance, an effort was made to define the actual test environment as closely as possible. These data were obtained in the time period February to May 1984, and reflect the status of tests at that time. Periodic updates of the information are planned.

THE DATA BASE

Potential sources of test data in the United States and Canada were asked to provide results of testing of any and all NiH_2 cells. These sources were provided with a questionnaire that was either completed by the respondent or by the interviewer from data received by telephone. These inputs were supplemented by reviewing IR&D reports and reports in Proceedings of the IECEC and the GSFC Battery Workshop. COMSAT Laboratories testing is not included in this report. This omission results in the loss of a significant portion of the COMSAT design NiH_2 cell data base.

In this survey the term USAF design applies to cells with annular electrodes, leads placed on the inner perimeter of the electrodes, and generally, a recirculating stack. Electrolyte has a net flow within the recirculating stack, wherein the negative and positive plates alternate in the plate pack so that the gas screen separates the rear of the positive and negative plates. The front faces of the plates are separated by asbestos or zirconia fabric (Zircar) separators. The gas screen provides for delivery of hydrogen gas and for transport of oxygen gas during overcharge, directly across the screen from the adjoining positive to the catalytic negative. The COMSAT design indicates cells with circular electrodes with chords removed for leads on the outer perimeter and a back-to-back plate pack design. In this design two positives are placed back-to back, separated by asbestos from negatives that are also back-to-back wih a gas screen separating them; during overcharge oxygen escapes from the positives along the plate pack edge to the backs and sides of the negative. This design does not produce a net electrolyte flow. Th COMSAT cell was designed for high orbit use and is not a high rate, high cycle frequency cell. The USAF cell was originally designed for high rate, high cycle frequency, low earth orbit (LEO) use however, it can be used in any less stressful orbit.

The data obtained relate to some 412 cells from several generations of both COMSAT and AF designs. Thus, some of the longest tests and most impressive data are from cells of earlier designs. Differences in designs are, for the most part, evolutionary in nature: changes in seals, improvements in positive electrodes, and minor changes in construction are typical. From a performance standpoint the most significant change in cell design in this data base was the introduction of the wall wick for electrolyte management in the USAF design. The earliest test data are for cells without this feature. All cells manufactured in the U.S. included in this survey utilize electrochemically impregnated positive plates. Ten Saft cells manufactured in France and included in the COMSAT grouping may utilize chemically impregnated positives and a different separator system than the asbestos used universally in the COMSAT design.

The distribution of cells in test by design shows that at least 192 cells of the COMSAT design are either in test, in preparation for testing, or have been tested. All but four of these have been tested in some type of high orbit simulation. Of the 271 USAF cells tested, in-test, or in preparation for testing, well over half have been subjected to, or are planned to be tested in simulated low earth orbit regimes. No "boiler plate" test data were included in the data base because of the questionable relevance of such data to flight type cell performance. Generally "boiler plate" data are applicable but instances of rework during test and variation in electrolyte quantity, pressure and plate-to-volume ratios compared to flight-type cells are sufficiently common that these data cannot readily be evaluated.

DISTRIBUTION OF FAILURES AND TESTING

Figures 1 through 4 present summaries of the data on the distribution of test durations and failures in bar graph form. The definition of failure is taken from the data reviewed. Most failures are defined as the inability of the cell to maintain a minimum of 1.0 V during discharge. Less than one-half of the failed cells shorted. The rest were low voltage failures without confirmed shorts. No cells were reported to have failed open circuit. If a test was terminated without cell failure, it is reported as a discontinued test.

Figure 1 summarizes all low earth orbit test experience for the USAF design cell. These data are skewed somewhat by 20 of 21 cells that have experienced over 8000 cycles and the 20 of 21 cells that exceed 10,000 cycles from the two ground test batteries of the Air Force Flight Experiment. These cells are of an older design (ca. 1975) and do not represent current state-of-the-art; they used back-to-back electrodes and had no wall wick. Only one cell in each group of 21 failed early. The remaining 20 cells are either continuing in test or were discontinued without additional failures. Removal of these Flight Experiment test batteries from the distribution results in the distribution shown in figure 2. The data for the USAF design in low earth orbit suggest that a significant difference in performance exists between cells tested predominantly at 80% depth of discharge (DOD) and those tested at less than that depth. There are insufficient data to make a finer distinction. The cross-hatched bars indicate cells tested at 80% depth of discharge in figures 1 and 2.

Figure 3 summarizes the experience for both USAF cell design in high orbit simulations. Figure 4 shows similar data for the COMSAT cell design except that the testing is all for simulated geostationary orbit conditions. Both accelerated and real time testing are combined in both of these figures. There is no apparent difference between 80% and lower depths of discharge in the performance under these conditions. Most failures, ten for the COMSAT design and one for the USAF design, can probably be attributed to workmanship or design defects that have since been corrected or would not have been included in a flight cell selection process.

DISCUSSION

The data available at this time suggest that both the USAF and COMSAT cell designs can be used in high orbit with high reliability. This assumes that the observed failures were for the most part manufacturing defects and activation problems that have been solved or would be screened out in a flight program. Certainly the number of cells that have survived at least 1000 cycles (ten year geostationary orbit) at up to 80% DOD is impressive at so early a point in the technology development cycle. Taking total numbers and including both high and low orbit testing for the USAF design, some 148 cells have been tested to 1000 or more cycles at DOD's greater than 50%; there have been seven failures prior to reaching 1000 cycles. A similar comparison for the COMSAT design shows that at least 65 cells have provided 1000 cycles or more with seven failures. The failures that have occurred must be considered to be from development lots of cells; the failures would be reduced or eliminated in an actual flight program. It must be pointed out that these data do not support use at 80% DOD because no contingency for acceptable degradation or system failures has been included. The ultimate capability of the cells from which power system designs can be derived is, however, demonstrated.

Low earth testing has not demonstrated the long life at the great depths of discharge that the USAF-design cell promises. Examining the data and coupling it with other information suggests that several elements may well serve to cause premature failure of cells. The streses in low earth orbit can be much greater, particularly at greater depths of discharge. First, recognizing that the nickel electrode is inherently the weakest component of the cell, steps must be taken to minimize the possible stresses. Second, designs and procedures that might prove satisfactory for high orbit use, but that may not permit cell performance to be maintained over the more than 25,000 cycles required for LEO must be scrutinized. Finally, the charge procedures (the discharge is largely dictated by mission considerations) and thermal environment must be adjusted to assure that these do not limit cell life. It is important to note that the capability of NiCd batteries to perform for more than 3 years at 20 to 25% DOD has been developed over the years by a better understanding of how the cells work, by improvements in cell components, and by fine tuning of cell designs. Similar attention to NiH_2 batteries could result in very significant improvements.

The positive electrode is subject to stresses due to charge-discharge cycling and especially to overcharge. These are caused by molecular volume changes between the various phases of charged and discharged material, by relaxation of these phases, by oxygen gas evolution, and by a host of design variables involved in the plate manufacturing process. Research and development can certainly lead to more stress-resistant and efficient nickel electrodes. Similarly the stresses can be mitigated by minimizing overcharge, by limiting charging and discharging that cause high strain rates, and by keeping temperatures low so that electrode efficiency is maximized.

The design and production of NiH_2 cells is still evolving. Improvements in design such as those shown by MANTECH will continue to make the cells that are under test less than the state-of-the-art. Recent problems with asbestos separators in both cell designs and the historic problems with pinholing of the negative electrode in Zircar separated cells suggests that a better separator material is needed. The test data show that neither separator is superior in terms of life or performance. However, it may be that both separators are satisfactory and that activation or other handling procedures are deficient. The performance of some recently manufactured cells may be related to testing or specific manufacturing problems because other cells produced near the same time with similar materials have not shown similar anomalies. Careful review of past procedures and of any proposed changes must be made and acceptability demontrated by test.

The electrical environment must also be adjusted to minimize stress. Overcharge, particularly at high rate, must be avoided. Constant voltage charging does not appear to be an acceptable charge control procedure because the slope of the voltage vs capacity-returned curve is shallow in NiH_2 cells and the abrupt voltage rise near the end of charge characteristic of NiCd cells may not be reliable in NiH_2 cells. Tests have given good results using constant voltage charge; however, the variations in the charge return indicate that the better control of overcharge may be useful. The easiest way to minimize the quantity of overcharge required is to maintain the cells in a cool environment. By minimizing the thermal gradients in the cell and keeping the temperature low, the charge efficiency is maximized and the necessity for large charge return ratios is eliminated. Although it is enticing to treat NiH_2 batteries as "super" NiCd batteries, the cell is a different couple with unique charge control and environmental requirements.

CONCLUSIONS

The testing data collected from most North American sources indicates that the basis for use of NiH_2 cells in high orbits is firm. Results from over 227 cells have produced only 14 failures up to 1000 cycles. The failures are of the type that have either been corrected or would be screened out in a flight program. Recent flight experience appears to support this position.

The data base is very weak and insufficient for low orbit applications. Few cells have more than 8000 cycles (1.4 years in low orbit) before failure or test discontinuance. However, tests have generally been run under unrealistically harsh conditions of high depth of discharge, large charge return ratios, and temperatures near ambient. A particular problem is that the charge return ratios that have been used appear small until it is realized that even 105% charge return results in a large quantity of extra charge at high DOD's. In comparison, a typical NiCd run with 107% charge return at shallow DOD receives much smaller quantity of extra charge. It is such problems as these, coupled with minor design and procedural changes that may not have been beneficial, that lead to the lack of sufficient, demonstrable capability for NiH_2 cells in low earth orbit. A carefully controlled low earth orbit test using reasonable conditions with properly specified and quality-controlled cells would appear to be mandatory in order to demonstrate life.

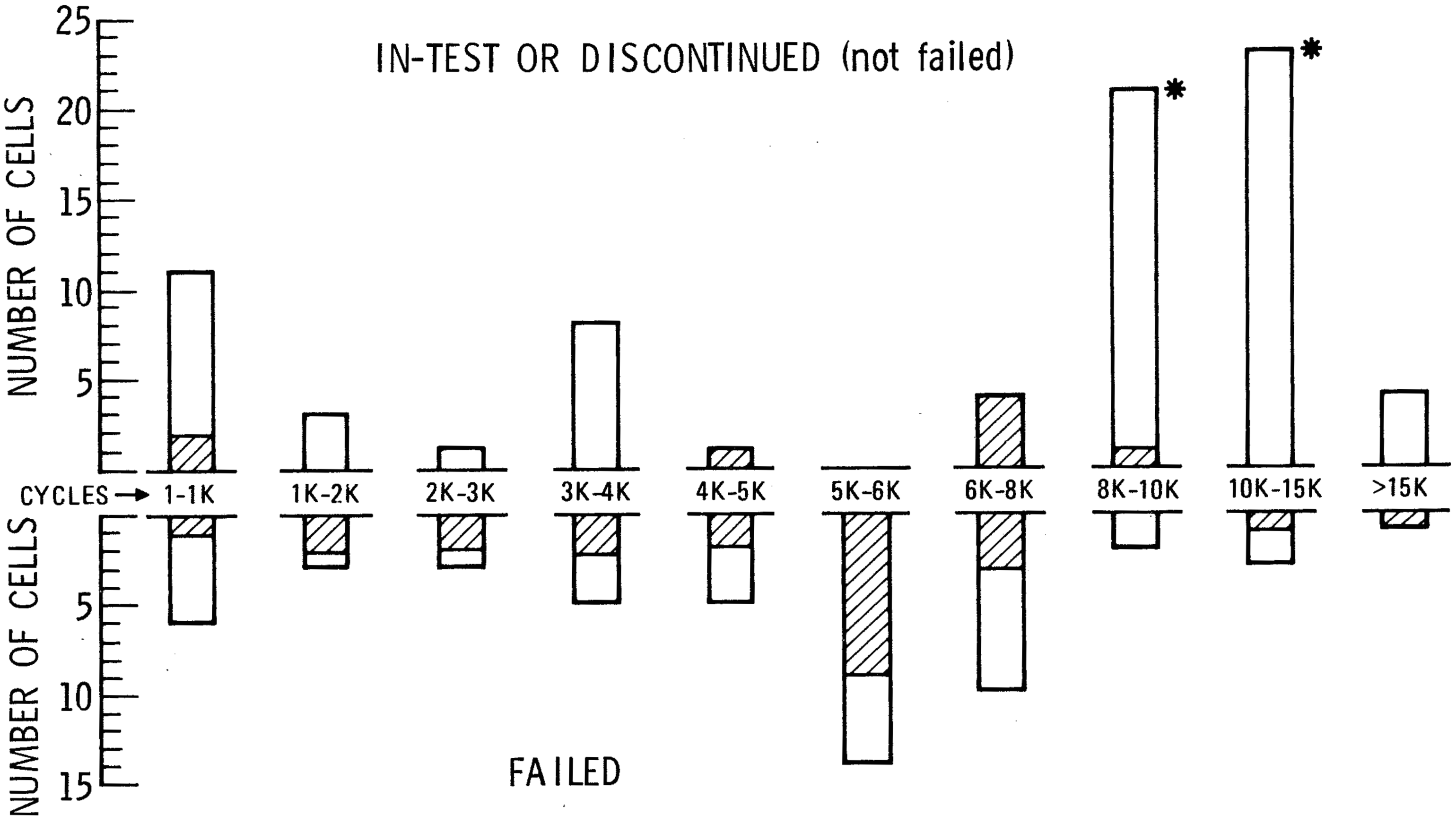
FIGURE CAPTIONS

Figure 1. Distribution of testing and failures for all USAF design cells (128 cells) in low earth orbit (LEO) simulations is shown. Cross-hatched bars are numbers of cells tested at 80% depth of discharge. Asterisks indicate the major contribution from cells in the two USAF Flight experiment batteries.

Figure 2. Distribution of testing and failures for USAF design cells in LEO simulations excluding those 42 cells in the two Air Force Flight Experiment test batteries. Cross-hatched bars are numbers of cells tested at 80% depth of discharge.

Figure 3. Distribution of testing and failures for USAF design cells in high earth orbit simulations are shown for 66 cells. The cross-hatched bars are numbers of cells in elliptical orbit simulations.

Figure 4. Distribution of testing and failures for COMSAT design cells in geostationary orbit simulations are shown for 132 cells.



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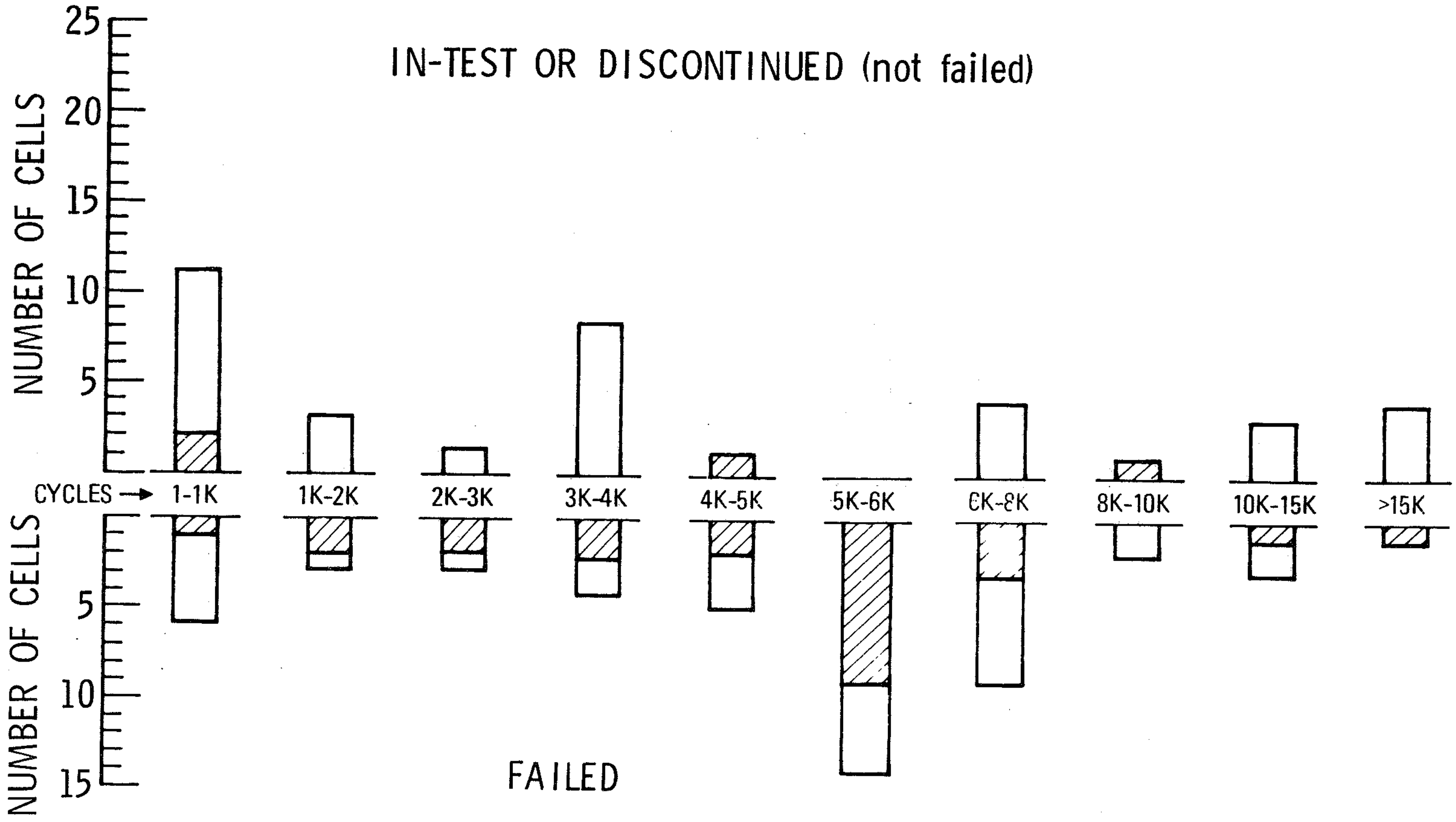

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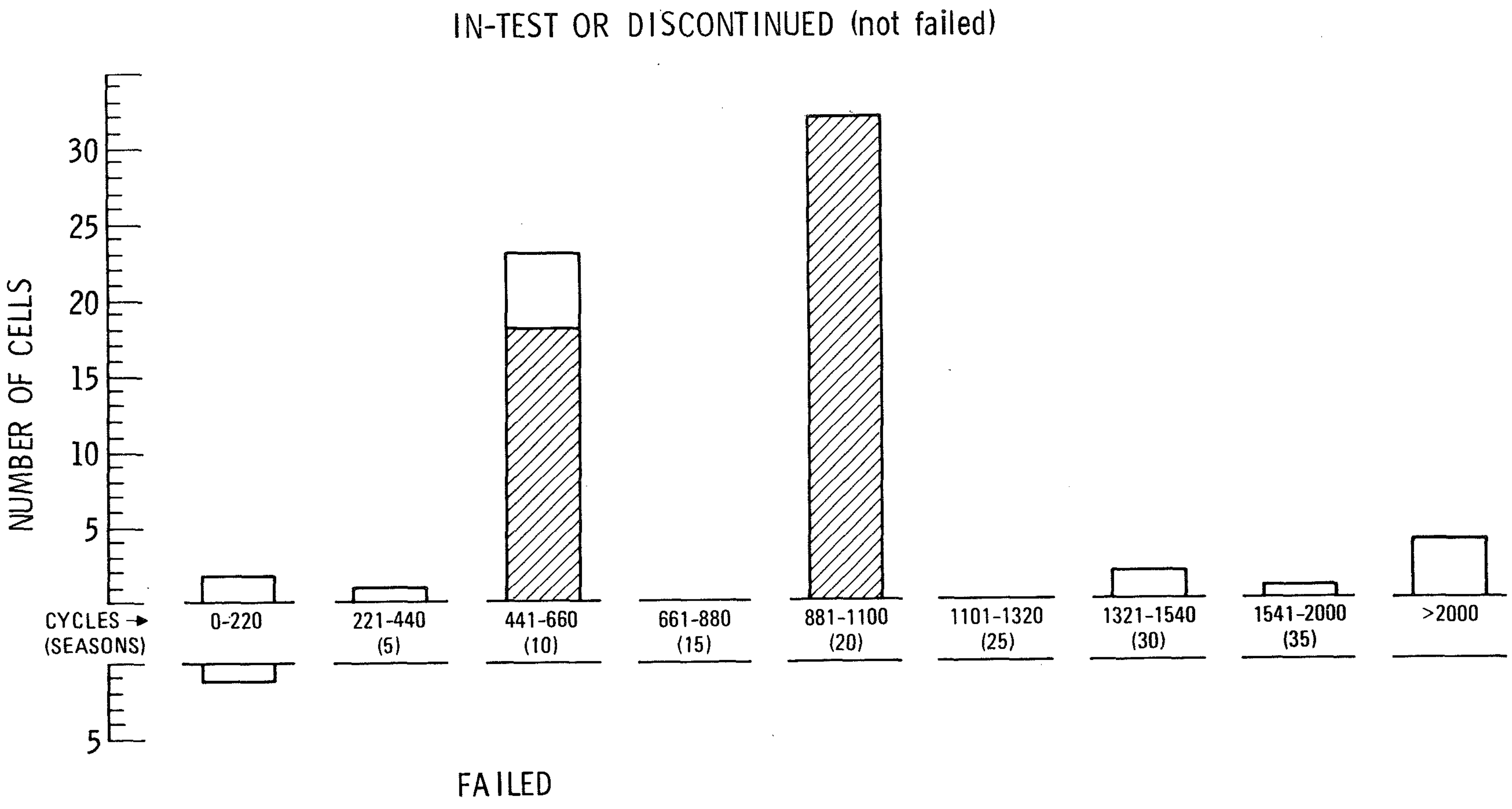

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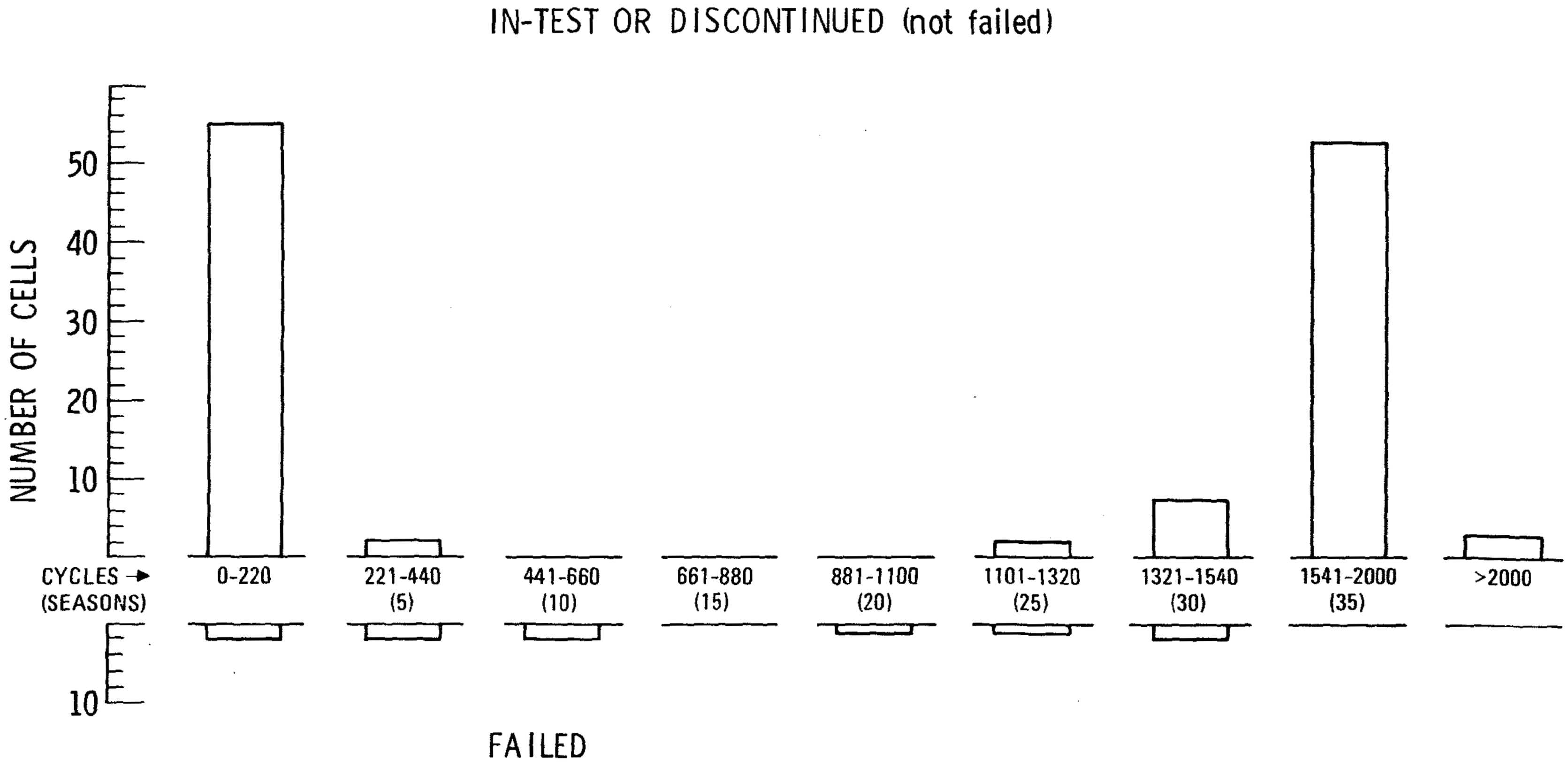

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