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Environmental Technology Verification Report

Rechargeable Alkaline Household Battery System Rayovac Corporation, Renewal®

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Rechargeable Alkaline Household Battery System
Rayovac Corporation, Renewal®

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U.S. ENVIRONMENTAL PROTECTION AGENCY
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Notice

The information in this document has been funded in part by the U.S. Environmental Protection Agency (EPA) under a Cooperative Agreement (CR 824433-01-0) with the California Environmental Protection Agency (Cal/EPA), Department of Toxic Substances Control (DTSC). This verification effort was supported by the Hazardous Waste Treatment and Pollution Prevention Pilot Project under the EPA Environmental Technology Verification (ETV) Program. This verification effort has been subjected to EPA's and Cal/EPA's peer and administrative review, and has been approved for publication as an EPA document.

This verification of the performance of the Rayovac Renewal® Rechargeable Alkaline Household Battery System (Renewal® System) is the first time EPA based a verification of a hazardous waste treatment or pollution prevention technology on a certification by DTSC, and is limited to the use of Rayovac's Renewal® System. The Renewal® System was certified by DTSC under the California Hazardous Waste Environmental Technology Certification Program as a pollution prevention technology on April 6, 1998. EPA and DTSC make no express or implied warranties as to the performance of the Renewal® System. Nor do EPA and DTSC warrant that the Renewal® System is free from any defects in workmanship or materials caused by negligence, misuse, accident or other causes. Mention of corporation names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products.

Foreword

The Environmental Technology Verification (ETV) Program has been established by the U.S. Environmental Protection Agency (EPA) to evaluate the performance characteristics of innovative environmental technologies across all media and to report this objective information to the permitters, buyers, and users of environmental technology. EPA's Office of Research and Development (ORD) has established a five year pilot program to evaluate alternative operating parameters and determine the overall feasibility of a technology verification program. ETV began in October 1995 and will be evaluated through October 2000, at which time EPA will prepare a report to Congress containing the results of the pilot program and recommendations for its future operation.

EPA's ETV Program, through the National Risk Management Research Laboratory (NRMRL), has partnered with the California Department of Toxic Substances Control (DTSC) under an ETV Pilot Project to verify hazardous waste pollution prevention, recycling, or treatment technologies. This Pilot Project focuses on, but is not limited to, hazardous waste management technologies used in several EPA "Common Sense Initiative" industry sectors: printing, electronics, petroleum refining, metal finishing, auto manufacturing, and iron and steel manufacturing.

The following report describes the verification of the performance of the Rayovac Renewal® Rechargeable Alkaline Household Battery System.

Acknowledgment

DTSC acknowledges the support of all those who helped plan and conduct the verification activities. In particular, we would like to thank Ms. Norma Lewis, EPA ETV Project Manager, and Mr. Sam Hayes, EPA ETV Project Quality Assurance Manager, of EPA's National Risk Management Research Laboratory in Cincinnati, Ohio. We would also like to thank Dr. C. Richard Walk, Director, Tracor Applied Sciences Battery Testing Facility, Rockville, Maryland, for his assistance in developing and interpreting energy capacity tests. Toxicity Characteristic Leaching Procedure sampling and analysis was performed by MVTL Laboratories of Oak Creek, Wisconsin. Finally, we would like to acknowledge the assistance and participation of Mr. Ray Balfour and Mr. Rod Donaldson of Rayovac Corporation.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington DC 20460

ENVIRONMENTAL TECHNOLOGY VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**RECHARGEABLE ALKALINE HOUSEHOLD BATTERY SYSTEM**
APPLICATION:	**1.5 VOLT BATTERIES IN STANDARD SIZES AAA, AA, C, AND D**
TECHNOLOGY NAME:	**RENEWAL®**
COMPANY:	**RAYOVAC CORPORATION**
ADDRESS:	**601 RAYOVAC DRIVE MADISON, WISCONSIN 53711-2497 P.0 BOX 44960**
PHONE:	**(608) 275-4584**
FAX:	**(608) 278-6666**

The U.S. Environmental Protection Agency (EPA) has created a program to facilitate the deployment of innovative environmental technologies through performance verification and information dissemination. The goal of the Environmental Technology Verification (ETV) Program is to enhance environmental protection by substantially accelerating the acceptance and use of innovative, improved, and more cost-effective technologies. The ETV Program is intended to assist and inform those individuals in need of credible data for the design, distribution, permitting, and purchase of environmental technologies. This Verification Statement provides a summary of the performance results for the Rayovac Corporation's Rechargeable Alkaline Household Battery System, trade name Renewal®.

PROGRAM OPERATION

The EPA's ETV Program, in partnership with recognized testing organizations, objectively and systematically documents the performance of commercial ready technologies. Together, with the full participation of the technology developer, they develop plans, conduct tests, collect and analyze data, and report findings. Verifications are conducted according to a rigorous workplan and established protocols for quality assurance. Where existing data are used, the data must have been collected by independent sources using similar quality assurance protocols. The EPA's ETV Program, through the National Risk Management Research Laboratory (NRMRL), has partnered with the California Department of Toxic Substances Control (DTSC), under an ETV Pilot Project, to verify the performance of pollution prevention, recycling, and waste treatment technologies.

TECHNOLOGY DESCRIPTION

Rayovac redesigned their alkaline household batteries so that they could be recharged. The additional charge cycles extend battery life by increasing the energy capacity, which benefits the environment by generating less waste. The design changes included increased void space, and addition of lead and silver. The Rayovac Renewal® Rechargeable Alkaline Household Battery System consists of rechargeable alkaline zinc-manganese dioxide 1.5 volt batteries, in sizes AAA, AA, C, and D, and a recharging device for the batteries. Typical consumer applications of household batteries include toys and games, portable audio equipment, cameras, sporting goods equipment, test equipment, personal care products, hearing aids, portable data terminals, sub-notebook computers and personal digital assistants, watches, flashlights, lanterns, and cellular phones. Such applications typically require continuous currents of up to 400 milliamperes (mA), which is within the range of the Renewal® batteries, sizes AA, C, and D. Size AAA can supply up to 150 mA continuous current, which is sufficient for applications such as clocks.

EVALUATION DESCRIPTION

The approach of this evaluation was to verify the independent data for energy capacity performance previously collected as part of the DTSC certification, and to collect additional data for toxicity and cost. The specific objectives were to:

1) determine the initial and cumulative capacity of the Renewal® System's batteries under controlled laboratory conditions using, to the extent possible, industry-accepted standard tests that model typical consumer applications, and to compare the Renewal® batteries' performance to that of Rayovac's non-rechargable alkaline batteries;

2) determine what levels of federally regulated toxic metals might leach from the Renewal® System's batteries, using the federal Toxicity Characteristic Leaching Procedure (TCLP) test method; and

3) estimate consumer costs, using conservative calculations and independently verified cost and performance data.

Availability of independent data limited performance verification to initial, five, and twenty-five cycle energy capacity tests. Initial energy capacity indicates how much energy a battery contains when first used, while cumulative energy capacity indicates the total energy the battery yielded after a series of discharge/charge cycles. TCLP data are used to determine if a waste is regulated as hazardous by EPA, and to estimate land disposal impacts of the waste.

In 1995, Tracor, Inc., a contractor with an independent battery testing facility, conducted several series of American National Standards Institute (ANSI) energy capacity tests. Tracor conducted a total of 12 tests on four sizes of Renewal® batteries. The tests measure how long a battery provides energy under conditions that simulate the electrical load and cutoff voltage of typical consumer devices such as toys, tape players, portable lighting, or transistor radios. (The cutoff voltage is the lowest voltage on which a device will operate.) The batteries were drained, charged to their initial voltage, and drained again to their cutoff voltage for a total of five cycles. Each test was conducted on four batteries of the same size so performance variability could be analyzed. In 1996, four Size AAA batteries were further tested for 25 cycles. For ETV, in 1998, TCLP tests were performed for all four sizes of the Renewal® batteries. For TCLP results, the batteries were purchased, prepared, and analyzed by an independent analytical laboratory.

Details of the evaluation, including data summaries and discussion of results, may be found in the report entitled, "U.S. EPA Environmental Technology Evaluation Report: Rayovac Renewal® Rechargeable Alkaline Household Battery System" (EPA/600/R-99/005)."

VERIFICATION OF PERFORMANCE

The observed performance characteristics of the Renewal® System include the following:

- **Energy Capacity:**

  The initial energy capacity of the Renewal® batteries, as compared to non-rechargeable alkaline batteries of the same size, was as follows: Size AAA: 4.0 hours (51.9% of that of a nonrechargeable alkaline), size AA: 4.0 hours (76.0%), size C: 14.4 hours (81.4 %), and size D: 14.7 hours (89.6%).

  After five cycles, for sizes AAA and AA, the Renewal® batteries produced cumulative hours of service that ranged between that produced by two and three non-rechargeable alkaline batteries of the same size. For sizes C and D, the Renewal batteries produced cumulative hours of service that ranged between that produced by two and four non-rechargeable alkaline batteries of the same size.

  After 25 cycles, for size AAA, the Renewal® batteries produced cumulative hours of service that ranged between seven and eight non-rechargeable alkaline batteries.

- **Toxicity Tests:**

  TCLP results for all metals were below their respective EPA regulatory limits. Only barium and silver were found above the detection limits; barium was found at two orders of magnitude below its regulatory limit, while silver was found at one order of magnitude below its regulatory limit. The maximum results are listed below (in milligrams per liter); results below detection limits are listed as <(detection limit):

METAL	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
REGULATORY LIMIT	5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0
MAXIMUM DETECTED	<0.036	0.32	<0.0068	<.065	<.029	<.0083	<.39	0.19

* Regulatory Limit values are EPA TCLP regulatory thresholds, 40CFR261.24, 1997.

- **Cost Estimates:**

  Consumer capital and operating costs were estimated and compared to non-rechargeable alkaline batteries by purchasing batteries in packs of four at 1998 prices. Capital costs include the cost of batteries and charger; the only operating cost is the cost of electricity for charging. Renewal® batteries cost slightly more than twice that of Rayovac non-rechargeables, and the cost of chargers ranges from $10 to $20 before rebates. The average cost to charge four batteries was conservatively estimated to be three fourths of a cent. A savings of $2 to $12 per pack of four is estimated as compared to non-rechargeables. This savings is based on a useful life of at least 25 charges, and varies depending on the size of batteries and type and number of chargers purchased.

Results of the verification show that the Renewal® System is capable of reducing waste volume by extending battery life through recharging. The amount reduced depends on the battery size, application type, and user practices such as frequency of charging. In addition, no TCLP results were above EPA levels for regulating metals as hazardous waste, and were below detection limits for most metals. Finally, the costs of the Renewal® System were compared to the costs of non-rechargeable alkaline batteries for Size AAA. For this case, based on 25 useful charging cycles, total costs were estimated to be lower for the Renewal® System. Actual savings depends on current prices, the type and number of batteries and chargers purchased, and user applications and practices.

Original Signed By
E. Timothy Oppelt
3/26/99

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E. Timothy Oppelt Date
Director, National Risk Management Research Laboratory
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Original Signed By
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James T. Allen, Ph.D. Date
Chief, Office of Pollution Prevention And Technology Development
Department of Toxic Substances Control
California Environmental Protection Agency

Notice: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and Cal/EPA make no expressed or implied warranties as to the performance of the technology. The user is solely responsible for complying with any and all applicable federal, state, and local requirements.

Availability of Verification Statement and Report

Copies of the public Verification Statement (EPA/600/R-99/005VS) and Verification Report (EPA/600/R-99/005) are available from the following:

(Note: Appendices are not included in the Verification Report. Appendices are available from DTSC upon request.)

1. **US EPA / NSCEP**
   P.O. Box 42419
   Cincinnati, Ohio 45242-2419

   Web site: http://www.epa.gov/etv/library.htm *(electronic copy)*
   http://www.epa.gov/ncepihom/ *(hard copy)*

2. **Department of Toxic Substances Control**
   Office of Pollution Prevention and
   Technology Development
   P.O. Box 806
   Sacramento, California 95812-0806

   Web site: http://www.dtsc.ca.gov/sppt/opptd/etv/txppetvp.htm
   or http://www.epa.gov/etv (*click on partners)*

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LIST OF ACRONYMS

AB	Assembly Bill
Ah	Ampere-hours
ANSI	American National Standards Institute
Cal/EPA	California Environmental Protection Agency
CIWMB	California Integrated Waste Management Board
DTSC	California Department of Toxic Substances Control
EP	Extraction Procedure
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification Program
HML	Hazardous Materials Laboratory (State of California)
IRIS	Integrated Risk Information System
kg	kilograms
l	liter
mA	milliamperes
mg	milligrams
NiCd	nickel-cadmium
NiMh	nickel-metal hydride
NEMA	National Electrical Manufacturers Association
NRMRL	National Risk Management Research Laboratory
OEHHA	Office of Environmental Health Hazards Assessment
OPPTD	Office of Pollution Prevention and Technology Development
ORD	Office of Research and Development (EPA)
OEM	Original Equipment Manufacturers
ppm	parts per million
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
Renewal	Registered Trade Name for Rayovac's Rechargeable Alkaline Battery
SB	Senate Bill
TCLP	Toxicity Characteristic Leaching Procedure
V	Volts

Executive Summary

Background

The U.S. Environmental Protection Agency (EPA) created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative technologies through performance verification and information dissemination. EPA, through its National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio, has partnered with the California Department of Toxic Substances Control (DTSC), to verify pollution prevention, recycling, and waste treatment technologies under one of twelve ETV Pilot Projects. This Pilot Project is based on California's existing Hazardous Waste Environmental Technology Certification Program (Certification Program). DTSC, under authority of Section 25200.1.5., California Health and Safety Code, established the Hazardous Waste Environmental Technology Certification Program in 1994. This Pilot Project focuses on, but is not limited to, several EPA "Common Sense Initiative" industry sectors: printing, electronics, petroleum refining, metal finishing, auto manufacturing, and iron and steel manufacturing. The Renewal® System was certified by DTSC as a pollution prevention technology on April 6, 1998.

Technology Description

The Rayovac Renewal® Rechargeable Alkaline Household Battery System consists of rechargeable alkaline zinc-manganese dioxide 1.5 volt batteries, in sizes AAA, AA, C, and D, and a recharging device/method for the batteries. Typical consumer applications of household batteries include toys and games, portable audio equipment, cameras, sporting goods equipment, test equipment, personal care products, hearing aids, portable data terminals, sub-notebook computers and personal digital assistants, flashlights, lanterns, and cellular phones.

Verification Approach

Rayovac redesigned alkaline household batteries so that they could be recharged. The additional charge cycles increase the battery energy capacity, extending battery life, which benefits the environment by reducing waste. The objectives of the verification project were to determine the performance using the existing verified independent data for energy capacity collected as part of the California Certification Program project, and to collect additional data on toxicity and cost. Availability of independent data limited performance verification to initial, five, and twenty-five cycle cumulative energy capacity tests. Initial energy capacity indicates how much energy a battery contains when first used, while cumulative energy capacity indicates the total energy the battery yielded after a series of charge/discharge cycles.

In 1995, as part of the California Certification Program, Tracor Inc., an independent battery testing facility, conducted several series of American National Standards Institute (ANSI) energy capacity tests on Renewal® batteries. The tests measure how long a battery provides energy under conditions that simulate the electrical load and cutoff voltage of typical consumer devices such as toys, tape players, portable lighting, or transistor radios. (The cutoff voltage is the lowest voltage on which a device will operate.) The batteries were drained to the test-specified cutoff voltage, charged to their initial voltage, and drained again to their cutoff voltage for a total of five cycles. Each test was conducted on four batteries so performance variability could be analyzed. In 1996, Size AAA batteries were tested for 25 cycles. For ETV, in 1998, federal Toxicity Characteristic Leaching Procedure (TCLP) tests were performed for all four sizes of the Renewal® batteries. The batteries were purchased, prepared, and analyzed by an independent analytical laboratory. Cost data were gathered in 1998 by DTSC staff surveying retail outlets and electricity utilities.

Verification Results

The observed performance characteristics of the Renewal® System include the following:

Objective #1 - Energy Capacity Determination

The initial energy capacity of the Renewal® batteries, as compared to non-rechargeable alkaline batteries of the same size, was as follows: Size AAA: 4.0 hours (51.9% of that of a nonrechargeable alkaline), size AA: 4.0 hours (76.0%), size C: 14.4 hours (81.4 %), and size D: 14.7 hours (89.6%). After five cycles, for sizes AAA and AA, the Renewal® batteries produced cumulative hours of service that ranged between that produced by two and three non-rechargeable alkaline batteries of the same size. For sizes C and D, the Renewal batteries produced cumulative hours of service that ranged between that produced by two and four non-rechargeable alkaline batteries of the same size. After 25 cycles, for size AAA, the Renewal® batteries produced cumulative hours of service that ranged between seven and eight non-rechargeable alkaline batteries of the same size. (Rayovac reported similar results for Sizes AA, C, and D, but those tests were not independently verified.)

Objective #2 - Toxicity Determination:

The federal Toxicity Characterization Leaching Procedure (TCLP) test was performed to determine what levels of toxic metals might leach from the batteries. TCLP results for all metals were below their respective EPA regulatory limits. Only barium and silver were found above the detection limits; barium was found at two orders of magnitude below its regulatory limit, while silver was found at one order of magnitude below its regulatory limit. The maximum results are listed below (in milligrams per liter); results below detection limits are listed as <(detection limit):

METAL	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
REGULATORY LIMIT	5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0
MAXIMUM DETECTED	<0.036	0.32	<0.0068	<.065	<.029	<.0083	<.39	0.19

* Limits are US EPA TCLP regulatory thresholds, 40CFR261.24, 1997

Objective #3 - Cost Estimates:

Consumer capital and operating costs were estimated and compared to non-rechargeable alkaline batteries by purchasing batteries in packs of four at 1998 prices. Capital costs include the cost of batteries and charger; the only operating cost is the cost of electricity for charging. Rayovac estimates the life expectancy of the chargers to be five years. Renewal® batteries cost slightly more than twice that of Rayovac non-rechargeables, and the cost of chargers ranges from $10 to $20 before rebates. The average cost to charge four batteries was conservatively estimated to be three fourths of a cent. A savings of $2 to $12 is estimated as compared to non-rechargeables. This savings is based on a useful life of at least 25 charges, and varies depending on the type of batteries and charger purchased.

Section 1
Introduction

This section provides background on the U.S. Environmental Protection Agency's (EPA) Environmental Technology Verification (ETV) Program, especially its partnership with California, introduces the Rayovac Renewal® System verification project, including the project's unique focus on existing independent objective data, and describes the project's verification objectives.

1.1. ETV Program Background

EPA created the ETV Program in 1995 to facilitate the deployment of innovative commercial-ready technologies through performance verification and information dissemination. EPA, through its National Risk Management Research Laboratory (NRMRL), has partnered with the California Department of Toxic Substances Control (DTSC) under an ETV Pilot Project to verify hazardous waste pollution prevention, recycling, and waste treatment technologies. The Pilot Project is based on California's existing Hazardous Waste Environmental Technology Certification Program (Certification Program). The DTSC Office of Pollution Prevention and Technology Development (OPPTD), under authority of Section 25200.1.5., California Health and Safety Code, established the Certification Program in 1994. The Pilot Project focuses on, but is not limited to, hazardous waste management technologies used in several EPA "Common Sense Initiative" industry sectors: printing, electronics, petroleum refining, metal finishing, auto manufacturing, and iron and steel manufacturing.

The performance verification contained in this report is based on independent data collected and documented as part of the California certification of Rayovac Corporation's Renewal® System. Moreover, this verification report presents additional hazardous metals leach test data by an independent source using EPA's Toxicity Characteristic Leaching Procedure. The Renewal® System was certified as a pollution prevention technology on April 6, 1998. DTSC's certification report describes performance, recommended applications, regulatory implications, specific conditions, and limitations, as well as providing the certification statement (2). From these, and vendor-supplied data, DTSC concluded that the Renewal® System can reduce the generation of hazardous waste.

1.2. Problem Description

The waste management of household batteries, also referred to as consumer or dry cell batteries, is regulated by states and the federal government under special reclamation strategies. The term "household battery" is used to define the general type of battery, not specific use; many household batteries are used in industrial, commercial, or institutional settings.

The disposal of household batteries is a concern because of their wide-spread use, and the levels of toxic metals such as mercury, cadmium, lead, nickel, and silver. In a 1992 report to the California Integrated Waste Management Board, Ernst and Young analyzed national sales data that indicate that about 5.5 billion household batteries will be sold in the year 2000; the largest portion of which (about four billion) are projected to be alkaline (3).

1.3. Problem Solution

Rayovac redesigned their alkaline household batteries so that they could be recharged. The additional charge cycles extend battery life, and reduce waste. The redesign resulted in a change of materials and a loss of initial energy capacity.

1.4. Verification Objectives

This project focused on verifying the independent performance data previously collected as part of the DTSC certification that meet desired data quality objectives, including national versus state-only applicability and quality assurance/quality control standards, and to collect additional data for toxicity and cost. Existing performance data meeting these criteria are: initial energy capacity, five-cycle and 25-cycle cumulative energy capacity, and 25-cycle energy capacity (for size AAA only). Moreover, toxicity and cost data were collected during the verification project. The toxicity data are results of the Toxicity Characteristic Leaching Procedure (TCLP) test, the EPA test for hazardous waste toxicity characteristic and disposal acceptance.

Specifically, the objectives of this verification were to:

1) determine the initial and cumulative capacity of the Renewal® System's batteries under controlled laboratory conditions, using to the extent possible industry-accepted standard tests that model typical consumer applications, and to compare the Renewal® batteries' performance to that of Rayovac's non-rechargable alkaline batteries;

2) determine levels of federally regulated toxic metals that might leach from the Renewal ® System's batteries, using the federal Toxicity Characteristic Leaching Procedure (TCLP) test method; and

3) estimate consumer costs, using conservative calculations and independently verified cost and performance data.

Section 2
Technology Description

2.1. Batteries

Batteries consist of two electrodes with different electrical potentials immersed in an electrically conducting medium (electrolyte). The positive electrode is termed the cathode; the negative electrode, anode. A battery transforms chemical energy into electrical energy. As ions flow through the electrolyte to the electrodes, electric current is produced in an external circuit. Battery types differ in materials used for the electrodes or electrolyte; this leads to varying characteristics such as storage life, power, operating time, and cost.

2.1.1. Household Batteries

Generally, household batteries are of nominal 1.5 volts (V), and come in standard cylindrical sizes (AAA, AA, C, or D), as well as button shapes. Button cells are generally used for hearing aids or watches. Household batteries use a “dry” electrolyte which is actually a moist or solid paste or gel.

Household batteries are of two major types: “Primary” batteries are those constructed so that only one continuous or intermittent discharge can be obtained, whereas “secondary” batteries can be recharged for multiple uses by applying an electrical current to the battery to reestablish the electrical potential. Lead-acid automobile batteries are explicitly defined and regulated separately from household batteries.

Primary household batteries include: carbon-zinc, alkaline, silver oxide, and lithium. Secondary household batteries include: nickel-cadmium (NiCd), lithium-ion, and rechargeable alkaline manganese (RAM). Rayovac’s Renewal® batteries are RAM batteries.

The following is a brief description of the major types of household batteries (3):

<u>PRIMARY (non-rechargeable):</u>

- *carbon-zinc* - contain a zinc anode and carbon cathode with ammonium chloride (general purpose) or zinc chloride (heavy-duty) electrolyte.

- *alkaline* - contain a zinc anode and manganese dioxide cathode with a strongly alkali electrolyte, typically potassium hydroxide. Alkaline batteries historically have been non-rechargeable (primary) batteries with five to eight times the service life of carbon-zinc batteries.

- *silver oxide* - are often used in place of mercuric oxide for longer life button cells.

- *zinc-air* - Atmospheric oxygen acts as the cathode and the space normally containing the cathode is filled with the zinc anode, thus doubling service life. They must be exposed to air to function; therefore, they cannot be used in applications such as watches that have a relatively tight seal.

- *lithium* - are also a relatively recent innovation. Primary lithium batteries are used in applications such as cameras, calculators, watches, and pacemakers. They also have the longest shelf life, losing only one percent of power per year.

<u>SECONDARY (rechargeable):</u>

- *nickel-cadmium (NiCd)* - NiCds are the most common type of secondary household battery. NiCds typically only last about one-third as long as alkaline, but can be recharged several hundred times. NiCds can provide higher currents than most household batteries due to their cell structure, allowing their use in applications such as portable power tools.

- *Nickel-metal hydride (NiMH)* - are similar to NiCds, and were developed in response to concerns about NiCds' toxicity.

- *lithium-ion* - a secondary version of lithium batteries, they are typically used in laptop computers.

- *rechargeable alkaline manganese (RAM)* - trade name Renewal®. Combines the long life of alkaline with the rechargeability of NiCds. Applications of these relatively new batteries include high temperature uses and intermittent use requiring minimal discharge.

Table 2-1 lists the major constituents found in the most common household batteries' electrodes and electrolytes, and the typical consumer application for those batteries.

Table 2-1. Household Batteries (Source: adapted from "Household Battery Waste Management Study: Final Report," Ernst & Young, 1992.)

Battery Type	Battery Sizes	Cathode	Anode	Electrolyte	Typical Applications
Primary Batteries					
Alkaline	D, C, AA, AAA, 9V	Manganese Dioxide	Zinc	Potassium Hydroxide	Toys, games, clocks, electronic flashes, tape recorders, calculators, flashlights, radios, smoke alarms, cameras
Carbon-Zinc[a/]	D, C, AA, 9V	Carbon	Zinc	Ammonium Chloride or Zinc Chloride	Toys, games, flashlights, radios, tape recorders
Silver Oxide	Button	Silver Oxide	Zinc	Potassium Hydroxide	Watches, calculators, hearing aides, cameras
Zinc Air	Button	Atmospheric Oxygen	Zinc	Potassium Hydroxide	Hearing aids, pagers
Lithium	Button[b/]	Manganese Oxide	Lithium	Organic Solvent	Cameras, calculators, pacemakers, watches
Secondary Batteries					
Nickel-Cadmium	D, C, AA, AAA, 9V	Nickel Oxide	Cadmium	Potassium Hydroxide	Power hand tools, portable vacuums, computers, fire and burglar alarms, electric razors, cordless and cellular telephones, toys, games, video cameras, electric toothbrushes
Nickel-Metal Hydride	Same as Nickel-Cadmium	Nickel Oxyhydoxide	alloys or rare earth metals[c/]	Potassium Hydroxide	Same as Nickel-Cadmium
Rechargeable Alkaline Manganese	D, C, AA, AAA	Manganese Dioxide	Zinc, Lead	Potassium Hydroxide	Same as alkaline

a/ Includes "General Purpose" and "Heavy Duty" batteries.
b/ Lithium batteries are also available in C, AA, and 9V sizes; however, these sizes currently represent a negligible part of the market.
c/ NiMH anodes are of two general types: AB_2 Type: alloys containing vanadium, zirconium, titanium, chromium, nickel, cobalt, manganese and/or others. AB_5 Type: rare earth metals with nickel.

2.1.2. Renewal® Batteries

The Renewal® System consists of rechargeable alkaline zinc-manganese dioxide batteries, a recharging device for the batteries, and pertinent technical and consumer literature. Figure 2-1 is an illustration of the Renewal® batteries. The design of the primary alkaline battery was changed to allow recharging. More internal void space was introduced to allow for hydrogen gas created when the battery is charged. In addition, silver oxide replaced part of the manganese dioxide cathode, to act as a catalyst in recombining the hydrogen gas. Also, lead was added to the zinc anode. These changes were necessary to prevent excessive water loss and internal pressure, which could lead to leaking at dry seals or rupturing. However, the same changes reduced the amount of zinc and manganese dioxide available and increased the internal void space, thus reducing the initial energy capacity of the cell.

The batteries have zinc anodes, manganese dioxide cathodes, and a "dry", i.e. solid or moist paste, alkaline (approximately 40% potassium hydroxide) electrolyte. Consumer applications typically require continuous currents of up to 400 milliamperes. Typical consumer applications of household batteries include toys and games, portable audio equipment, cameras, sporting goods equipment, test equipment, personal care products, hearing aids, portable data terminals, sub-notebook computers and personal digital assistants, watches, flashlights, lanterns, cellular phones, etc.

Rechargeable batteries are susceptible to "capacity fade". Capacity fade refers to the loss of energy capacity each time the battery is charged. Each time the battery is discharged and subsequently recharged, the cell does not regain all of its previous capacity. Eventually the battery's capacity fades to the point that there is not enough capacity remaining for the cell to be useful, and it must be discarded. The amount of capacity needed for the cell to be useful depends on the application of the battery and the user's preferences. For Renewal® batteries, capacity fade is sensitive to depth of discharge, which is related to discharge rate and cut-off voltage. "Depth of discharge" refers to the amount of energy withdrawn from the cell by converting the manganese dioxide to manganese trioxide. Limiting the depth of discharge will reduce the loss in available capacity, i.e., capacity fade, for each successive discharge cycle.

Depth of discharge can be controlled by setting a cut-off voltage. For a specific cut-off voltage, more fade occurs at lower discharge rates because the cut-off voltage is reached later due to less pronounced internal resistance losses, and thus more capacity is removed. Therefore, setting a cut-off voltage higher for low discharge rates will reduce capacity fade. For a specific discharge rate, more capacity fade will occur when the batteries are discharged to a lower cut-off voltage because more capacity is removed from the cell. At higher discharge rates, the internal resistance losses will cause the voltage to drop before all of the available capacity is withdrawn. Internal resistance losses are higher at higher discharge rates because the cells are of the "bobbin," or cylinder type, as opposed to spiral-wound. This bobbin design allows high capacity, but causes higher internal resistance. In either case, not all the capacity can be regained because the chemical reactions are not completely reversible, therefore, after a certain number of cycles the batteries will no longer gain useful capacity.

FIGURE 2-1. Rayovac Renewal® Batteries

2.2. Renewal Charging Devices

The Rayovac Renewal® charging device is known as a Power Station™. The Power Station™ recharger comes in two sizes: PS1 for a combination of AA and AAA batteries, and PS3 for a combination of one to eight AA, AAA, C, and D batteries. The PS3 will accept RAM, NiCd, and NiMH batteries. Figure 2-2 is an illustration of the PS3 charging device.

The PS1 and Renewal® batteries are designed so that only Renewal® batteries can be charged by the PS1 (4) without compromising the ability of the Renewal® batteries to be used in electronic devices. This is accomplished by two methods, one for battery sizes C and D, and another for sizes AAA and AA (5). For example, Renewal® Sizes AAA and AA have an exposed metal layer on the top of the cell case whereas conventional alkaline cells have an insulating layer covering this surface. When any AA or AAA size battery other than a Renewal® is placed in the charging unit, the charge contact is blocked by the plastic label overwrap of the cell and no charge current can be applied.

According to Rayovac, Renewal® batteries should be charged only by Rayovac's charging device and method because, "Methods of charging which have been used in NiCd systems such as continuous trickle-charging or constant-current fast charge are not suitable for use with rechargeable alkaline batteries. The alkaline cells are not tolerant of high continuous charge currents, and may be damaged if high current is forced into them after they have reached a partially recharged state."(6) Products which have Rayovac's charging technology built in can operate on other types of batteries, but will only recharge Renewal® batteries.

The charging method consists of a "... pulse charge method. Fixed amplitude, variable duty cycle pulses are applied to the battery during charge. The pulses are limited in amplitude by current-limiting resistors. The duty cycle is modulated by a control chip (Application Specific Integrated Circuit, or ASIC) specifically designed for use in the Renewal® Power Stations. The average value of the charging current applied to the batteries is gradually reduced as the open-circuit voltage of the battery increases during the charge... A Light Emitting Diode (LED) is activated when the battery is properly placed into the charger; it is deactivated when three consecutive charge pulses are disabled (the battery has stayed above the 1.65 [volt] reference value for this period of time)."(6)

FIGURE 2-2. Rayovac Charging Unit (PS3)

Section 3
Performance Verification Tests

3.1. Introduction

In the following sections, performance measures, test methods, data, observations, and conclusions regarding performance are presented. The verification performance testing was conducted by the Tracor Battery Technology Center, an independent testing facility.

3.2. Performance Measures

There are many ways of measuring a battery's performance, including initial capacity (Ampere-hours of service), usable cycles, nominal voltage range, energy density, output current under continuous or pulse loads, self-discharge rate (i.e., charge retention or shelf life), charge time, weight, sensitivity to temperature, susceptibility to leakage, cost, and ease of disposal. No one battery performs best in all categories. Similarly, for battery chargers, there are a number of ways of measuring a battery charger's performance, including time of recharge, ability to sense when a battery is fully charged, ability to prevent overheating, and number and types of batteries which can simultaneously be charged.

The main measure of the pollution prevention performance of the Renewal® batteries is the number of primary alkaline batteries that the Renewal® batteries can replace. For example, if a primary alkaline battery provides 10 hours of service, i.e., capacity, and a Renewal® battery of the same size provides 100 hours of useful cumulative capacity, then the Renewal® replaces 10 primary batteries. Therefore, the cumulative capacity of the Renewal® battery must be known in order to compare its performance to that of the primary alkaline battery.

Capacity is defined as the electrical output, expressed in ampere-hours (Ah), obtained from discharging a cell at a specific current and temperature, to a specified end-of-discharge voltage (7). Cumulative capacity is the hours of service after repeated discharge and charge cycles as measured by continuous tests, under specified loads to specified voltage-cutoffs, which correspond to certain typical consumer applications.

3.2.1. ANSI Energy Capacity Tests

Capacity is expressed in terms of service life using a given load (electrical resistance), schedule (for intermittent tests), and discharge to a specified endpoint voltage. Changes in test procedures are determined by market studies and electronic characterization of popular classes of appliances. Prior to 1992, ANSI capacity test methods specified that the tests be continuous in nature -- the batteries were continuously drained from the nominal voltage to the specified cutoff voltage. However, the battery manufacturers recognized that in actual practice devices are typically used for a certain time period, then rested. Thus, in 1992, intermittent test schedules were developed (8). In contrast to continuous tests, intermittent schedules require that the test be suspended after a specified length of time prior to reaching the cutoff voltage, the batteries allowed to rest and recover, and the test continued until the cutoff voltage or next rest period is reached. For large size batteries operated under low drain conditions, intermittent tests substantially increase the amount of time required to complete the test.

The size and type of batteries and conditions of use determine the test specification to be applied. The test specification that best represents any particular use is that which most nearly duplicates the load, schedule, and end-point voltage when in actual use. Tables 3-1, 3-2, 3-3, and 3-4 are the ANSI C18.1M-1992 battery testing specification sheets, including capacity tests, for 1.5V alkaline zinc-manganese batteries, sizes AAA, AA, C, and D, respectively. From Table 3-1, for example, the four variations of testing of size AAA alkaline zinc manganese batteries are based on typical uses, e.g., photography, portable lighting, personal tape recorders/cassette players, and transistor radios. To approximate the requirements of a cassette player, the test conditions are at a resistance of 10 ohms, test schedule of one hour per day, and an end-point of 0.9V.

Table 3-1. ANSI C18. 1M-1992 Specifications, Alkaline Manganese Dioxide, Size AAA

LOAD (Ohms)	TEST SCHEDULE	END POINT(Volts)	TYPICAL PERFORMANCE		TYPICAL USE
			INITIAL	12 MONTHS	
3.6	15 SEC/MIN, 24 HRS	0.9	450 PULSES	405 PULSES	PULSE TEST (PHOTO)
5.1	4 MIN / HR, 8 HRS / DAY	0.9	125 MIN	112 MIN	PORTABLE LIGHTING
10	1 HR/ DAY	0.9	5.5 HRS	5 HRS	PERSONAL TAPE RECORDER & CASSETTE PLAYER
75	4 HRS/DAY	0.9	48 HRS	43 HRS	TRANSISTOR RADIO

Table 3-2. ANSI C18. 1M-1992 Specifications, Alkaline Manganese Dioxide, Size AA

LOAD (Ohms)	TEST SCHEDULE	END POINT (Volts)	TYPICAL PERFORMANCE		TYPICAL USE
			INITIAL	12 MONTHS	
1.8	15 SEC/MIN, 24 HRS	0.9	360 PULSES	324 PULSES	**PULSE TEST (PHOTO)**
3.9	1 HR/DAY	0.8	5 HRS	4.5 HRS	**MOTOR & TOYS**
10	1 HR/ DAY	0.9	13.5 HRS	12 HRS	**PERSONAL TAPE RECORDER & CASSETTE PLAYER**
75	4 HRS/DAY	0.9	115 HRS	104 HRS	**TRANSISTOR RADIO**

Table 3-3. ANSI C18. 1M-1992 Specifications, Alkaline Manganese Dioxide, Size C

LOAD (Ohms)	TEST SCHEDULE	END POINT (Volts)	TYPICAL PERFORMANCE		TYPICAL USE
			INITIAL	12 MONTHS	
3.9	4 MIN/HR, 8HRS/DAY	0.9	830 MIN	737 MIN	**PORTABLE LIGHTING**
3.9	1 HR / DAY	0.8	14.5 HRS	13 HRS	**TOYS**
6.8	1 HR/ DAY	0.9	24 HRS	22 HRS	**TAPE RECORDER**
39	4 HRS/DAY	0.9	160 HRS	144 HRS	**TRANSISTOR RADIO**

Table 3-4. ANSI C18. 1M-1992 Specifications, Alkaline Manganese Dioxide, Size D

LOAD (Ohms)	TEST SCHEDULE	END POINT (Volts)	TYPICAL PERFORMANCE		TYPICAL USE
			INITIAL	12 MONTHS	
2.2	4 MIN/HR, 8 HRS/DAY	0.9	800 MIN	720 MIN	**PORTABLE LIGHTING**
2.2	1 HR/ DAY	0.8	15.5 MIN	13.9 MIN	**TOYS**
3.9	1 HR/ DAY	0.9	26 HRS	23.5 HRS	**TAPE RECORDER**
39	4 HRS/DAY	0.9	375 HRS	338 HRS	**TRANSISTOR RADIO**

3.2.2. Modified ANSI Energy Capacity Tests

ANSI standard C18.1M-1992, *Dry Cells and Batteries - Specifications*, was sponsored by the National Electrical Manufacturers Association (NEMA), and includes test procedures for measuring the capacity of primary cells.

In order to quantitatively and conservatively measure capacity, Rayovac and DTSC agreed to use modified ANSI capacity tests and cumulative performance for 25 charging cycles. Twenty-five cycles were chosen based on two factors. First, Rayovac had already performed tests to 25 cycles, so data which were comparable were desired. Second, limiting the number of charging cycles to 25 was considered a reasonably conservative comparison to a primary alkaline battery. This is because the capacity of the Renewal® battery, as that of other rechargeables, decreases each time it is charged. At some number of charging cycles the performance has decreased to the point where the battery no longer has a useful capacity. Some Rayovac customers reported as many as several hundred charge cycles with useful capacity (9). However, for other applications useful capacity may not be achievable after fewer cycles.

The tests were modified to make them continuous discharge tests instead of interrupted discharge tests; this was done so that the results could be obtained as quickly as possible, but also had the effect of making the tests a more conservative measure of performance. The continuous tests give more conservative results because the batteries do not have an opportunity to recover.

Recovery occurs after discharge when zinc ions from the anode diffuse towards the cathode and combine with ammonia produced by the cathode reaction to produce complex ions. This removes the ammonia that had decreased the available current by forming an insulating layer around the cathode, thus allowing the batteries to recover (10).

The ANSI tests were designed for measuring the capacity of single use primary batteries, therefore, the tests were modified such that the batteries were charged for 16 hours, rested one hour, then tested again per the ANSI procedures for non-rechargeable batteries.

In summary, modified energy tests were used for the following reasons:

1. No ANSI standard capacity tests for rechargeable alkaline batteries exist;

2. The standard tests upon which the modified tests are based were developed by consensus of a variety of industry experts and stakeholders, thus the methods are widely accepted;

3. Tests are designed to replicate actual conditions of use for a variety of consumer applications;

4. The methods are quantitative and the results reproducible; and

5. The modified tests for capacity are conservative due to continuous discharge, infrequent charging, and high depth-of-discharge conditions.

3.3. Independent Tests

This section describes the performance tests and resulting data generated by an independent testing facility. When Rayovac applied to the Cal/EPA Certification Program, DTSC did not have the internal capability to test the performance of the batteries. Therefore, DTSC requested that an independent firm, knowledgeable in battery performance testing, be retained to verify the batteries' performance. Tracor, Inc., a defense contractor located in Rockville, Maryland, with an in-house battery testing center, was retained to do the testing. For a description of Tracor's battery testing qualifications, refer to Appendix A.

In September 1995, Tracor completed its initial performance comparison testing of primary, nickel-cadmium, and Renewal® batteries. Rayovac submitted the data to DTSC in October 1995. DTSC also obtained the results directly from Tracor to verify their accuracy and completeness. Comparing the results of the Tracor and Rayovac tests was complicated by the fact that the tests which Tracor performed were not identical to the ones which Rayovac themselves conducted. In some respects the Rayovac tests were more comprehensive, and in other respects more limited.

The Tracor tests were more comprehensive in that Tracor used four batteries per test to analyze performance variability, Tracor conducted tests for all of the ANSI recommended load and end-point voltage specifications except for photoflashes, and Tracor used the Rayovac Power Station™ Charger. Rayovac only tested one battery per size, using only the high drain test conditions, and had a charging mechanism built directly into its test board. However, Tracor only tested the first five cycles, whereas Rayovac performed 25 cycle testing.

In five of the 12 five-cycle tests conducted by Tracor, one of the four batteries being tested exhibited performance which was less than 50 percent of the mean performance of the remaining three cells, and was disqualified. This equates to five of 48 batteries or about 10 percent. Tracor stated this is not unusual during battery testing (11). DTSC requested further testing for full 25 cycles because of concerns over the limited amount of data, discrepancies, and the specific nature of the performance claims. Therefore, Tracor performed full 25-cycle testing on four size AAA Renewal® batteries, considered the conservative size battery for capacity tests due to higher ratios of void space and inert ingredients than the other sizes. Tracor completed those tests in October 1996.

3.4. Results

Table 3-5, presents the results, as averages, of the testing performed by Tracor to verify the in-house testing conducted by Rayovac. Refer to Appendix B for the Tracor Data Sheets, which include statistical variation information.

Table 3-5 presents Tracor's results as hours of service and as a percentage of the capacity of non-rechargeable alkaline batteries. The capacity of the Renewal® batteries is presented as initial capacity (hours of service at the first cycle), hours of service at the fifth cycle, cumulative hours of service at the fifth cycle, hours of service at the 25th cycle, and cumulative hours of service after 25 cycles.

An explanation of the testing conditions listed in Table 3-5 is in order: "Load' refers to the electrical resistance, measured in ohms, applied to the testing circuit. The smaller the load, the greater the current that can be drawn from the battery, and thus the faster the battery energy capacity is depleted. Small loads correspond to applications such as portable lighting, medium loads to toys or motors, and high loads to low-current devices such as transistor radios. "Endpoint voltage" simrefers to the cutoff voltage, measured in volts, below which the device is designed not to operate. Typically, electronic devices are designed for cutoff voltages of 0.8 or 0.9 volts. Thus, for a given load, a cutoff voltage of 0.8 volts will lead to a greater depth-of-discharge than an cutoff voltage of 0.9 volts.

The initial capacity ranged from approximately 47 percent to 70 percent of that of non-rechargeable alkaline battery of the same size, depending on the load and cutoff voltage. As the battery size increased, so did the Renewal® batteries' initial capacity relative to that of non-rechargeable alkaline batteries of the same size. For size AA, the Renewal®'s initial capacity ranged from approximately 73 percent to 76 percent. For size C, the initial capacity ranged from about 72 percent to 81 percent. For size D, the initial capacity ranged from about 69 percent to 90 percent.

The five cycle tests provide useful information about the capacity fade over the first five cycles. From Table 3-5 and Figure 3-1, one can see that the energy capacity present after the fifth cycle ranged from about 35 to 40 percent of the capacity of a size AAA non-rechargeable alkaline battery. For size AA, the range was about 37 to 42 percent, for size C, it was about 45 to 57 percent and for size D, it was about 45 to 59 percent. However, in one low-drain (39 ohm) test for size D, at the 5th cycle, the Renewal® batteries only had 16 percent of the capacity of a non-rechargeable size D alkaline battery. This is so far outside the other ranges that the possibility of an outlier should be considered. In summary, after five cycles, the Renewal® batteries still provide energy capacity from about 35 to 60 percent of that of non-rechargeable alkaline batteries of the same size. The available relative energy capacity increases with the size of the battery. Users can determine if that energy capacity is sufficient on an application-specific basis.

The five-cycle cumulative capacity data in Table 3-5 follows a similar pattern as the initial capacity data. The cumulative capacity of size AAA Renewal® batteries ranged from about 200 to 260 percent of the energy capacity of non-rechargeable size AAA alkaline batteries, for size AA the range was 250 to 275 percent of size AA non-rechargeable alkaline batteries, for size C the range was about 260 to 325 percent, and for size D the range was about 170 to 325 percent. In other words, after five cycles the Renewal® batteries provided the energy of about two non-rechargeable alkaline batteries for sizes AAA and AA, and about three non-rechargeable alkaline batteries for sizes C and D.

Data from the size AAA 25-cycle capacity tests conducted by Tracor are summarized in the last four columns of Table 3-5. Also presented for the convenience of the reader are 25-cycle data for sizes AA, C, and D generated by tests conducted by Rayovac. However, those results were not independently verified.

The size AAA 25-cycle data indicate that for a load of 10 ohms and an endpoint voltage of 0.9 volts, simulating toys and electrical motors, the Renewal® batteries provided 1.6 hours of service at the 25th cycle, or 20.8 percent of the energy capacity of a size AAA non-rechargeable alkaline battery. Furthermore, the cumulative energy capacity after 25 cycles was 57.0 hours of service, or 740 percent of the energy capacity of a size AAA non-rechargeable alkaline battery. In other words, after 25 cycles, the size AAA Renewal® batteries provided the energy of about 7.5 non-rechargeable alkaline batteries, with about 21 percent of the energy available on the first cycle still available on the 25th cycle.

Table 3-5. Renewal® vs. Primary Alkaline Performance (Hours of Service)

Size	Load (ohm)	EndPt. (Volt)	Tracor - 5 Cycle Continuous Tests: Primary Alkaline Hours	%	Renewal® Initial Hours	%	Renewal ® 5th Cycle Hours	%	5 Cycle Cumulative Hours	%	Std. Dev. (%)[+]	25 Cycle Continuous Tests: 25th Cycle Hours	%	25 Cycle Cumulative Hours	%
D	2.2	0.8	16.4	100	14.7	89.6	9.7	59.1	53.4	325	66	6.6*****	40.2*	233.2*****	1380*****
D	3.9	0.9	34.5	100	27.8	80.1	15.4	44.6	104.1	302	30	-----	-------	---------	-----------
D	39	0.9	534.5	100	370.4	69.3	86.3	16.1	916.9	172	35	-----	-------	---------	-----------
C	3.9	0.8	17.7	100	14.4	81.4	10.1	57.1	57.6	325	21	5.5*****	29.4*	202.4*****	1190*****
C	6.8	0.9	33.5	100	25.2	75.0	17.6	52.5	106.0	316	7	-----	-------	---------	-----------
C	39	0.9	241.4	100	173.0	71.7	108.3	44.9	636.0	263	36	-----	-------	---------	-----------
AA	3.9	0.8	5.3	100	4.0	75.5	2.2	41.5	14.6	275	8	1.3*****	24.5*****	52.0*****	980*****
AA	10	0.9	16.7	100	12.7	76.0	6.9	41.3	45.4	272	19	-----	-------	---------	-----------
AA	75	0.9	155.6	100	113.3	72.8	57.6	37.0	389.7	250	7	-----	-------	---------	-----------
AAA	5.1	0.9	3.12	100	1.46	46.8	1.08	34.6	6.28	201	8	-----	-------	---------	-----------
AAA	10	0.9	7.7	100	4.0	51.9	2.9	37.7	16.3	212	49	1.6[#]	20.8[#]	57.0[#]	740[#]
AAA	75	0.9	67.2	100	47.0	69.9	26.7	39.7	172.9	257	6	------	-------	---------	---------

Note: Results reported as average of four measurements. "Percent" refers to percentage of primary alkaline capacity.
+ largest standard deviation of five individual cycles, expressed as percent of mean.
* Rayovac-generated data, not independently verified by Tracor.
# Tracor-generated 25-cycle test data.

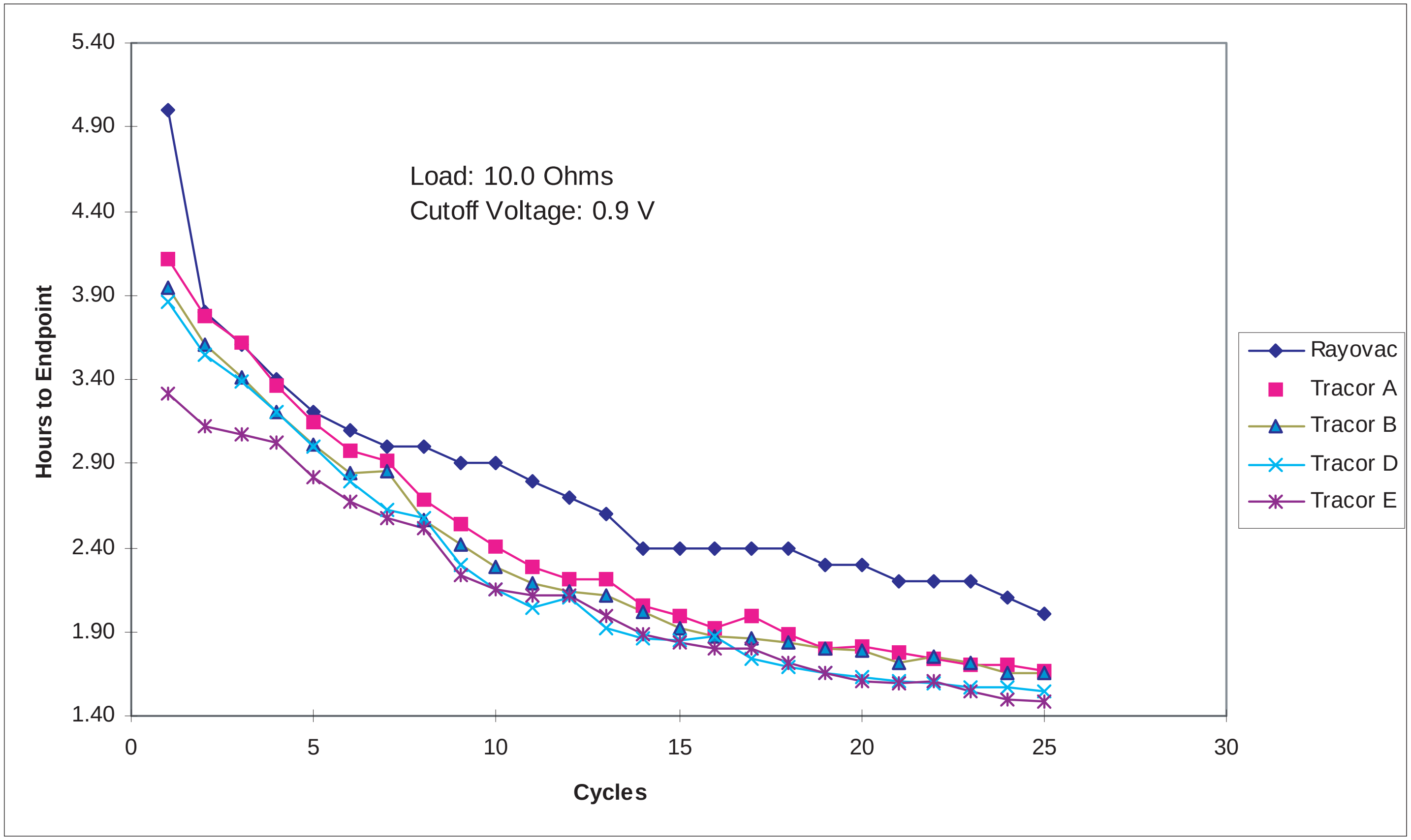

Figure 3-1. Size AAA Renewal® Capacity Fade Trends

3.5. Summary

This project focused on verifying the independent performance data previously collected as part of the DTSC certification that met desired data quality objectives, including national versus state-only applicability and quality assurance/quality control standards. Independently generated data provided both five-cycle and 25-cycle performance data, as expressed by initial and cumulative energy capacity in hours of service and as percent of non-rechargeable alkaline batteries. The five-cycle data were for sizes AAA, AA, C, and D batteries, whereas the 25 cycle-data were independently generated for size AAA only. Five cycle tests were conducted for 12 of the 16 ANSI tests modeling consumer applications such as toys, portable lighting, transistor radios, and portable audio equipment. The following performance characteristics were verified:

The initial capacity of the Renewal® batteries, as compared to non-rechargeable alkaline batteries of the same size, in high-drain tests, was as follows: Size AAA: 4.0 hours (51.9%), size AA: 4.0 hours (76.0%), size C: 14.4 hours (81.4 %), and size D: 14.7 hours (89.6%).

After five cycles, for sizes AAA and AA, the Renewal® batteries produced cumulative hours of service that ranged between that produced by two and three non-rechargeable alkaline batteries of the same size. For sizes C and D, the Renewal batteries produced cumulative hours of service that ranged between that produced by two and four non-rechargeable alkaline batteries of the same size.

After 25 cycles, for size AAA, the Renewal® batteries produced cumulative hours of service that ranged between seven and eight non-rechargeable alkaline batteries of the same size: 57.0 hours versus 7.7 hours. (Sizes AA, C, and D produced similar results in 25-cycle tests reported by Rayovac, but those tests were not independently verified.)

3.6. Conclusions

The Renewal® System batteries, under controlled laboratory conditions, using ANSI tests modeling consumer applications, after five cycles, provided energy (measured as cumulative hours of service) equivalent to that produced by two to three non-rechargeable alkaline batteries of the same size for sizes AAA and AA, and produced energy equivalent to that between two and four non-rechargeable alkaline batteries of the same size for sizes C and D. Similarly, for 25 cycles of size AAA, energy equivalent to that between seven and eight non-rechargeable alkaline batteries, was produced. Therefore, the Renewal® System can reduce the number of batteries used, and the number of batteries disposed.

Section 4
Toxicity Characteristic Leaching Procedure (TCLP) Tests

4.1. Introduction

Pollution can be prevented by either reducing the amount of waste generated or reducing its risk or hazard to humans or the environment before it is generated. The previous section provided performance data related to the life expectancy of the batteries, and thus the amount of waste generated. This section provides data related to the toxicity of the batteries.

4.2. Sampling and Analyses

This section discusses the sampling and chemical analyses performed as part of the verification effort. Renewal® batteries were subjected to U.S. tests for soluble metals content. The purpose of the tests was to determine if the Renewal® batteries posed any potentially significant risk to human health or the environment.

4.2.1. Background

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The TCLP is a modified form of EPA's previous hazardous waste extraction procedure, the Extraction Procedure (EP) test. The TCLP is required for federal Resource and Conservation Recovery Act (RCRA) hazardous wastes in two instances: Determination of compliance with EPA Land Disposal Restriction regulations, and for waste classification of RCRA hazardous wastes (12). The TCLP is intended to simulate the leaching of constituents from wastes disposed in a municipal or sanitary waste landfill. This test has been shown to be more reproducible, and, for certain waste constituents, more aggressive than the EP toxicity test (that is, higher concentrations are extracted with the TCLP). The TCLP is Method 1311 in "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," EPA Publication SW-846 (13).

For RCRA hazardous waste toxicity characterization, the TCLP must be used; total metals concentrations are not used by the U.S. government for characterization purposes. The TCLP is used in conjunction with applicable analytical methods to determine if the eight metals and six pesticides previously regulated as "EP Characteristic" wastes, as well as more than 25 organic compounds, are present at or above hazardous levels. These contaminants and their maximum concentrations are listed in Section 261.24 of Title 40, Code of Federal Regulations.

4.2.2. Sample Preparation

Sample preparation is a critical step in analyzing batteries for metals content. Obtaining a representative sample can be very difficult due to metal volatilization, loss through adherence to sampling equipment, and the nonhomogeneous structure of the batteries. Also, standard sample preparation techniques can be hazardous to personnel and labor intensive, due to the need to separate the electrolyte from the case and grind the materials. Moreover, there is no national standard for preparing batteries for analyses. Rayovac submitted its internal sample preparation procedures for batteries for review and comment. The procedure was reviewed by NRMRL, OPPTD and HML. The procedure is summarized below (14):

> The entire battery or cell is weighed. Rayovac recommends always using one or more entire cells or batteries because metals are not uniformly distributed throughout the cells. Then the batteries are frozen using liquid nitrogen so that the internal components become brittle for easier processing and to minimize volatilization. The batteries are then crushed to pass a 9 mm sieve, sized as necessary, and placed in sample jars for analyses. Sample pieces are removed from tools and combined with the rest of the sample. Tools are cleaned with isopropyl alcohol between analyses.

4.2.3. TCLP Analyses

Renewal® Batteries were purchased, prepared, and analyzed by Minnesota Valley Testing Laboratories (MVTL) of Oak Creek, Wisconsin, in June, 1998. Four samples were obtained. The samples were prepared using Rayovac's "*Cell Preparation for Testing Primary Whole Cells and Batteries*." TCLP extraction was performed using SW-846 Method 1311, acid digestion using SW-846 Method 3010A, mercury digestion and analysis using SW-846 Method 7470, and analyses for metals using SW-846 Method 6010A. Chain-of-Custody requirements were followed, as were standard Quality Assurance/Quality Control requirements from SW-846.

4.3. Results

The results are reported in Table 4-1. All non-detect results are reported as <[detection limit]. Only barium and silver had results over the detection limit. Refer to Appendix C for the Laboratory Final Report, the QA/QC Analysis Report, and Chain of Custody Forms.

Table 4-1. Toxicity Characteristic Leaching Procedure Results

		As	Ba	Cd	Cr	Pb	Hg	Se	Ag
	mg/l limit	5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0
SAMPLE	DESCRIPTION	D004	D005	D006	D007	D008	D009	D010	D011
98C126	AAA-SIZE	<0.036	0.35	<0.0068	<0.065	<0.029	<0.0083	<0.39	<0.14
98C125	AA- SIZE	<0.036	0.35	<0.0068	<0.065	<0.029	<0.0083	<0.39	0.24
98C121	C-SIZE	<0.036	<0.29	<0.0068	<0.065	<0.029	<0.0083	<0.39	<0.14
98C124	D-SIZE	<0.036	<0.29	<0.0068	<0.065	<0.029	<0.0083	<0.39	0.23
	SAMPLES[1]	4	4	4	4	4	4	4	4
	DETECTION	0.036	0.29	0.0068	0.065	0.029	0.0083	0.39	0.14
	MAXIMUM[2]	<0.036	0.35	<0.0068	<0.065	<0.029	<0.0083	<0.39	0.24
	MAX % OF	0.7%	0.3%	0.7%	1.3%	0.6%	4.2%	39.0%	4.5%
Renewal® sample preparation and testing by MVTL Laboratories, Inc. Oak Creek, Wisconsin									

Notes:
1. One sample per battery size
2. Results are reported as maximums without statistical analyses because nearly all analyses resulted in non-detects
3. Regulatory Limits Reference - U.S. Code of Federal Regulations, Title 40, Section 261.24, 1997.

4.4. Summary

Four samples of batteries were independently collected and analyzed. TCLP results for all metals were below their respective EPA regulatory limits. Only barium and silver were found above the detection limits; barium was found at two orders of magnitude below its regulatory limit, while silver was found at one order of magnitude below its regulatory limit. Statistical analyses are not relevant or presented because only four of 32, or 12.5 percent, of the analyses yielded results above the detection limit. These results are consistent with results reported by Rayovac; however, those results were not independently verified.

4.5. Conclusions

No potentially significant impacts due to leaching of federally regulated toxic metals were identified. All metals were at least one order of magnitude below their respective regulatory threshold.

Section 5
Cost Estimates

This section presents current typical retail costs for Rayovac primary alkaline and Renewal® batteries, and for charging units. Then, as an example, the costs of the Renewal ® System, using the independently verified battery life data for 25 cycles of size AAA batteries, are compared to the cost of the equivalent number of primary alkaline batteries.

Table 5-1 presents typical 1998 retail prices for Rayovac alkaline and Renewal® batteries, and power station charging units. Table 5-2 presents costs for various amounts of Rayovac batteries and charging units. Prices were verified by telephoning and visiting two retailers in the Sacramento, California, area: Target and Wal-Mart. Both retailers were selling Rayovac products within the ranges specified in Rayovac-supplied literature.

As an example, the cost for a PS1 charger and a package of four size AAA Renewal® batteries is approximately $16, while the cost for a four-pack of size AAA alkaline batteries is $4. From the verified data over 25 cycles, the cumulative energy capacity of the Renewal® batteries is approximately equivalent to seven alkaline batteries. Therefore, using the Renewal® batteries saves purchasing seven packages of alkaline batteries for a savings of $28. Subtracting the cost of the Renewal® charger and batteries nets a savings of $12, minus the cost of electricity for recharging. If the PS3 charger was purchased instead of the PS1 charger, the cost would be about $26 instead of $16, and there would be a net savings of $2. (While the PS3 charger is more expensive, it will charge more types and quantities than the PS1, thus providing more flexibility.) Rayovac estimates the life expectancy of the chargers to be five years, but this was not verified. As will be shown below, the cost to charge the batteries is negligible.

The cost of electricity to charge the batteries can be estimated as follows: On average, three to five hours of charging are required. The PS3 charging unit is rated at 12 watts, with an average current of 570 milliamperes supplied to four parallel charging circuits. As a conservative estimate, five hours at 12 watts is 60 watt-hours, or 0.060 kilowatt-hours. A survey of residential rate schedules for Southern California Edison, Pacific Gas & Electric, and the Sacramento Municipal Utilities District indicates that the highest price for residential electricity in California is about $0.12 per kilowatt-hour, so five hours is $0.0072, or roughly a penny. For 25 charges, the cost is about $0.18, or about three percent of the cost of the four-pack of Renewal® batteries.

Actual performance and cost savings depends on the types of batteries, chargers, applications, user practices affecting the number of cycles and depth of discharge, and local cost of electricity.

Table 5-1. Typical Rayovac Retail Prices (Source: Rayovac, November 1998)

BATTERY SIZE	BATTERIES PER PACKAGE	TYPICAL RETAIL PRICES/PACKAGE	
		PRIMARY ALKALINE	RENEWAL
D	2	\$2.19 - \$2.79	\$4.99 - \$5.99
C	2	\$2.19 - \$2.79	\$4.99 - \$5.99
AA	4	\$2.57 - \$2.99	\$5.99 - \$6.99
AAA	4	\$2.57 - \$2.99	\$5.99 - \$6.99

TYPICAL RETAIL PRICES FOR RAYOVAC POWER STATIONS (CHARGERS):

PS1 (AA AND AAA SIZE RENEWAL BATTERIES): \$ 9.99
PS3 (D, C, AA, AND AAA SIZE RENEWAL BATTERIES): \$19.99

Table 5-2. Costs for Various Amounts of Rayovac Batteries (Source: Rayovac, November 1998)

BATTERY SIZE	RAYOVAC RENEWAL BATTERIES, POWER STATION				PRIMARY ALKALINE BATTERIES		
	NO. OF PACKAGES OF BATTERIES	PRICE OF POWER STATION	PRICE PER PACKAGE, BATTERIES	TOTAL PRICE, BATTERIES PLUS POWER STATION	NO. OF PACKAGES OF BATTERIES	PRICE PER PACKAGE, BATTERIES	TOTAL PRICE, BATTERIES
D, C	1	$19.99	$4.99 $5.99	$24.98 $25.98	7	$2.19 $2.79	$15.33 $19.53
	2	$19.99	$4.99 $5.99	$29.97 $31.97	14	$2.19 $2.79	$30.66 $39.06
	3	$19.99	$4.99 $5.99	$34.96 $37.96	21	$2.19 $2.79	$45.99 $58.59
	4	$19.99	$4.99 $5.99	$39.95 $43.95	28	$2.19 $2.79	$61.32 $78.12
	5	$19.99	$4.99 $5.99	$44.94 $49.94	35	$2.19 $2.79	$76.65 $97.65
AA, AAA	1	$ 9.99	$5.99 $6.99	$15.98 $16.98	7	$2.57 $2.99	$17.99 $20.93
	2	$ 9.99	$5.99 $6.99	$21.97 $23.97	14	$2.57 $2.99	$35.98 $41.86
	3	$ 9.99	$5.99 $6.99	$27.96 $30.96	21	$2.57 $2.99	$53.97 $62.73
	4	$ 9.99	$5.99 $6.99	$33.95 $37.95	28	$2.57 $2.99	$71.96 $83.72
	5	$ 9.99	$5.99 $6.99	$39.94 $44.94	35	$2.57 $2.99	$89.95 $104.65

Section 6
Application Assessments

Typical consumer applications of household batteries include toys and games, portable audio equipment, cameras, sporting goods equipment, test equipment, personal care products, hearing aids, portable data terminals, sub-notebook computers and personal digital assistants, watches, flashlights, lanterns, and cordless or cellular phones. Sometimes the battery is a built-in part of a consumer product; in those cases the battery may or may not be rechargeable. A portable electric razor is one example of such a product where the built-in battery may be rechargeable.

The most common 1.5V batteries that come in standard sizes AAA, AA, C, or D are carbon zinc, primary alkaline, and nickel cadmium (NiCd). Rechargeable Alkaline Manganese (RAM, trade name Renewal®) batteries are now also available. The major criteria for battery selection are the application, storage life (ability to hold charge during storage), capacity, rate capability (maximum current), frequency of use, ease of disposal, and cost. The driving criterion is application, or what device the battery will power. No one battery is the optimum choice for every application. Household battery users should consult consumer product specifications and battery selection criteria when evaluating what type of battery to choose.

In general, non-rechargeable alkaline batteries are good for applications which are single use (e.g., disposable devices), require or desire high energy capacity (e.g., toys, portable stereos), or long storage life (e.g., emergency lighting and communications). Renewal® batteries are appropriate for applications that need high capacity, low self-discharge characteristics, and rechargeability. Rechargeable alkalines are candidates for applications where non-rechargeable alkalines are now used. However, rechargeable alkaline batteries such as the Renewal® System batteries are a better choice if the devices are used frequently, use low to medium currents (150 - 400 mA for size AA), and have cutoff voltages of 0.9V or greater. Cutoff voltages lower than 0.9V may allow deep depth of discharge leading to undesirable fade capacity under conditions of very low current and long time of use (e.g., clocks).

The Renewal® System is especially well suited for intermittent-discharge applications which may not fully drain the batteries prior to each recharge because they do not experience significant capacity fade under those conditions. When fully drained, Renewal® batteries experience capacity fade -- the capacity of the cell will be lower in comparison to the previous cycle. Thus, for example, they are appropriate for applications such as emergency lighting, which may require long storage life; palm-held computers, cordless or cellular phones, and electric razors, which may require intermittent use; and portable music devices and toys, which require low to moderate discharge rates and high capacity.

The Rayovac Renewal® System is not appropriate for applications that require high current such as portable electric power tools such as electric drills. Nickel-cadmium batteries are better suited for such applications. NiCd batteries also are a good choice for applications requiring high continuous currents (for example, currents above 250 mA when using size AAA, and above 400 mA when using size AA batteries), many cycles, frequent use, and deep discharge. Also, devices such as photoflashes and video camera recorders may require more current than Renewal® batteries can deliver. NiCd batteries can be charged and discharged multiple times (theoretically several hundred) and have a higher rate capability (maximum current) than both primary alkaline and Renewal® batteries due to less internal resistance.

Thus, NiCds are a good choice for high-current products such as power tools and notebook computers. NiCds would not be a good battery choice for applications that require long shelf lives, however, because they self-discharge over time when left in storage (approximately 1% per day). NiCd batteries may also not be the best selection for applications that do not fully discharge the battery. NiCd cells, if not fully discharged with each use, develop a memory effect and may not charge back to the nominal voltage, which can shorten cycle life. NiCd batteries can have a longer cycle life than either primary alkaline or Renewal® batteries if not damaged due to overcharging or overheating. Thus, NiCds may not require replacement as often as alkaline batteries, but require special handling for disposal or recycling because of statutory requirements imposed due to their high toxicity.

An application such as an emergency flashlight that requires batteries to have a long storage life would be best suited to primary alkaline or Renewal® batteries, which have longer storage lives than NiCds, and are sold in a charged state. Primary alkaline and Renewal® batteries, because of their relatively high capacity, are also suitable for equipment such as electronic games and toys and portable cassette players, which do not require high currents to operate, but may be frequently used for long periods of time.

Renewal® batteries are basically appropriate for most of the applications as primary alkaline batteries. However, because Renewal® batteries have a higher internal resistance than primary alkalines, they may not perform as well as primary alkalines in applications that require high continuous or pulse current loads, such as photo flashbulbs. Renewal® batteries also differ from primary alkalines in that they have a slightly shorter storage life, lower energy capacity, and a longer cycle life. Renewal® batteries, because they can be recharged, require disposal less often than primary alkalines.

In summary, primary alkaline batteries are good for applications such as single use (disposable devices), those which require or desire high capacity (toys, portable stereos), or long storage life (emergency lighting, communications). NiCds are a good choice for applications requiring currents above 400 mA when using size AA batteries - other sizes have different maximum continuous current limits. NiCds are also a good choice for applications which require many cycles, frequent use, and deep discharge (portable power tools). Renewal® batteries in general are candidates for most applications where primary alkaline batteries are now used. Renewal® batteries are a better choice if the devices are used frequently, use low to medium current (150 - 400 mA for size AA), and have cutoff voltages of 0.9V or greater.

Section 7
References

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Availability of this Report

Copies of the public Verification Report (EPA/600/R-99/005VS) and Verification Report (EPA/600/R-99/005) are available from the following:

1. **US EPA / NSCEP**
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   Web site: http://www.epa.gov/etv/library.htm *(electronic copy)*
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2. **Department of Toxic Substances Control**
   Office of Pollution Prevention and
   Technology Development
   P.O. Box 806
   Sacramento, California 95812-0806

   Web site: http://www.dtsc.ca.gov/sppt/opptd/etv/txppetvp.htm