

# TECHNICAL REPORT

F-C4812-01  
April 20, 1979

NATIONAL CONTROLLED STUDY OF RELATIVE RISK  
OF OVERHEATING OF ALUMINUM COMPARED  
WITH COPPER WIRED ELECTRICAL RECEPTACLES  
IN HOMES AND LABORATORY

## EXECUTIVE SUMMARY

*prepared for*

U.S. Consumer Product Safety Commission  
Washington, D.C. 20207

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## EXECUTIVE SUMMARY

The Franklin Institute Research Center (FRC) in Philadelphia, Pennsylvania, performed a nationwide home testing survey for the Consumer Product Safety Commission (CPSC) to compare the overheating experienced by aluminum wired and copper wired duplex receptacles on 15 ampere and 20 ampere branch circuits in single family homes. In particular, the comparison made was between "old technology" aluminum wiring, used before 1972, and copper wiring in use at the same time. The study incorporated:

- Random selection of survey sites, homes and receptacles so that statistical comparison could be made between results on aluminum wired and those on copper wired receptacles and homes.
- Systematic procedures for taking thermal measurements on duplex receptacles in the selected homes. Specially designed and selected instrumentation was used so that measurements could be made on the receptacles in the "as installed" condition, i.e., without disturbing the installation in any manner.
- Provisions for removing receptacles reaching specified threshold conditions in home testing and transferring them, with wire leads attached, to the laboratory test facility of the Franklin Research Center in Philadelphia for further testing under controlled conditions.
- Procedures for monitoring laboratory testing so that fires and fire hazardous conditions could be documented by computerized instruments and film.

Surveys were conducted in four randomly selected locations--in Phoenix, Arizona; Pinellas County (Unincorporated Area), Florida; Baltimore County, Maryland; and King County (Unincorporated Area), Washington. A representative sample of single family dwellings for which building permits were issued in 1969-1970 -- over 1,000 homes in all four locations -- was inspected to determine the type of wiring. In each site, approximately 40 homes per major type of wiring found were selected to provide comparable samples of homes [Aluminum-Wire Binding Screw, Copper-Wire Binding Screw, Copper Backwiring]. Over 400 homes were thermally tested.

The comparisons made were based on indicators of heating reached by wall receptacles in two consecutive tests:

- The first test was the application of an electrical load of 75 percent of rated branch circuit current for thirty minutes to four selected circuits in samples of homes with aluminum wiring and with copper wiring. The criterion of overheating in this test was the attainment of 75°C (167°F) or higher at

any one of the four blade terminals of a receptacle. This threshold was based on a conservative adaptation of Underwriters Laboratories' (U.L.) test for residential receptacles. [Laboratory Report - Appendix A, page A-3].

- The second test, under laboratory controls, was the application of an electrical load of rated branch circuit current cycled for 60 minutes on and 30 minutes off. The primary statistical criterion of heating attained in the laboratory was "Fire Hazard Condition." Fire Hazard Condition (FHC) was reached when the temperature at the receptacle coverplate mounting screw reached 149°C (300°F), or sparks were emitted from the receptacles, or materials around the receptacle box were observed to be charred.

The risk of reaching an overthreshold condition was higher for aluminum wired than for copper wired receptacles and homes in all four surveys. Based on the composite results:

- The risk of an aluminum wired home having at least one receptacle reaching 75°C (167°F) in home testing was 9 times that for a copper wired home.
- The risk of an aluminum wired home having at least one receptacle reaching Fire Hazard Condition was 55 times that for a copper wired home.
- The risk that a home would have at least one receptacle reach Fire Hazard Condition was 42 percent for an aluminum wired home and less than one percent for a copper wired home.

Other comparisons yielded statistics showing similar higher risks for aluminum wired receptacles than copper wired receptacles. These are included in the results.

The statistical results of the survey were highly significant. Aluminum wired homes showed a higher risk than copper wired homes of having at least one receptacle reach 75°C (167°F) or higher under the study protocol in every one of the four areas tested. The probability that risk differences as large as those found in each site could be attributed to chance is less than one in a billion. The gross error possible from sampling error and systematic errors is insignificant in terms of the risk levels, risk differences, and relative risks found and reported herein.

Receptacles reaching Fire Hazard Conditions [107 Al WBS and 2 Cu WBS] were further tested until a fire or fault occurred in the laboratory in an environment which might be encountered in the home. Fires were ignited by 25 receptacles, 24 aluminum wired and 1 copper wired. Short circuits or open circuits occurred after Fire Hazard Condition was reached in 34 aluminum wired receptacles and 1 copper wired receptacle. Laboratory results were documented on film and by detailed records.

## STUDY FINDINGS

The study findings are based on results from all four surveys of branch circuit wiring in homes with permits issued in 1969 and 1970 and measured at an average age of about 8 years. In homes tested, all accessible receptacles on two 15 ampere and two 20 ampere circuits were measured for temperatures reached after carrying 75 percent of rated branch circuit current for 30 minutes. If a receptacle reached 100°C, testing was discontinued as a safeguard against reaching temperatures associated with melting of wire insulation. Receptacles reaching 75°C or higher were removed with wire leads, transported to the laboratory and tested by cycling 60 minutes on and 30 minutes off at rated branch circuit current until Fire Hazard Condition was reached (149°C (300°F), sparking or charring) or testing was discontinued.

### Statistical Results:

#### Homes

- For an aluminum wired home, the risk of having at least one receptacle reach Fire Hazard Condition was 55 times as great as for a copper wired home (aluminum 42% / copper 0.8%).
- For an aluminum wired home, the risk of having at least one receptacle reach 100°C (212°F) in home testing was 30 times as great as for a copper wired home (aluminum 22% / copper 0.8%).
- For an aluminum wired home, the risk of having at least one receptacle reach 75°C (167°F) or higher in home testing was 9 times as great as for a copper-wired home (aluminum 51% / copper 5.4%).
- In the homes with four circuits tested, only 30% to 50% of the total receptacles present in the home were tested. If all receptacles could be tested, the proportion of homes with at least one overthreshold receptacle would probably be higher but could not be lower.
- In each of the four sites, the risk of overthreshold temperatures or Fire Hazard Condition was higher for aluminum wired homes than for copper wired homes. The probability that risk differences as large as those found in each site could occur by chance is less than one in a billion.

#### Receptacles

A total of 1,590 aluminum wired receptacles and 2,025 copper wired receptacles (1485 copper backwired and 540 copper wire binding screws) were tested in the four sites.

### 20 Ampere Circuits

- In a branch circuit rated 20 amperes, the risk of an aluminum wire binding screw (Al WBS) receptacle reaching Fire Hazard Condition was 50 times as great as for a copper wired receptacle (aluminum 10%/copper 0.2%).
- In a branch circuit rated 20 amperes, the risk of an Al WBS receptacle reaching 75°C (160°F) or higher in home testing (aluminum 13%/copper 1.1%).

### 15 Ampere Circuits

- In a branch circuit rated 15 amperes, the risk of an Al WBS receptacle reaching Fire Hazard Condition was estimated conservatively at more than 40 times as great as for a copper wired receptacle (aluminum 3.9%/copper 0%).

(Note: Relative risk with zero denominator was underestimated using method described in Appendix A, page 1-16).

- In a branch circuit rated 15 amperes, the risk of an Al WBS receptacle reaching 75°C (167°F) or higher in home testing was 65 times as great as for a copper wired receptacle (aluminum 6.1%/copper 0.09%).

### Installation Observations

Electricians were instructed to carefully remove faceplates and examine receptacles for deviations from recommended installation practices as set forth in the 1973 statement by an Ad Hoc Committee sponsored by Underwriters Laboratories, Inc., ("The Use of Aluminum Conductors with Wiring Devices in Electrical Wiring Systems," March 1973).

- Copper wire binding screw (Cu WBS) receptacles were observed to have installation deviations of the same general categories as aluminum wire binding screw receptacles.
- For Cu WBS receptacle terminals, occurrence of deviations with the exception of "loose termination" seemed to have no influence on the occurrence of terminal overheating.
- For Al WBS receptacle terminals, rates of overheating were somewhat greater if certain terminal connection installation deviations were observed than if not. These conditions, namely, "loose connection," "wire wrapped in wrong direction," and "other problems," were observed relatively infrequently in the study.

## Laboratory Results:

### Rack and Wall Testing to Fire Hazard Condition {149°C (300°F), sparking or charring.}

Mounted receptacles were placed on an open rack, and rated branch circuit current was cycled one hour on and one-half hour off through the receptacles. Each receptacle was tested for 2000 hours or until a power dissipation of 20 watts was reached.

Receptacles which reached 20 watts power dissipation were removed from the rack and placed in a wall built to represent construction found in single family homes. A single sheet of cotton material was draped in front of the receptacle. Rated branch circuit current was cycled one hour on and one-half hour off through each receptacle until Fire Hazard Condition was reached or testing was terminated at 2000 hours [except for 9 receptacles discontinued because of project time limitations].

#### Aluminum WBS Receptacles

- Seventy-five percent (107 of 143) of aluminum wired receptacles sent to the laboratory reached Fire Hazard Condition.
- In a 20 ampere branch circuit, the majority of Al WBS receptacles which reached Fire Hazard Condition did so in less than 100 cycle hours of total testing (4 days).
- In a 15 ampere branch circuit, the majority of Al WBS receptacles which reached Fire Hazard Condition did so in less than 250 cycle hours of total testing (10 days).
- Over 90 percent of receptacles reaching 20 watts power dissipation on the rack reached Fire Hazard Condition on the wall.

#### Copper Wired Receptacles

- Only two wire binding screw receptacles terminated with copper wire reached 20 watts power dissipation; they also reached Fire Hazard Condition.

#### Wall Testing Under Hazardous Conditions

Once a specimen reached Fire Hazard Condition in the wall, the standard cotton material was replaced with common household materials, and the receptacle testing in either cyclic or continuous mode until a fire or fault occurred. Photographs are included in laboratory report.

### Fires

- Twenty-four aluminum wired receptacles ignited fires.
- One copper wired receptacle ignited a fire.
- The copper wired receptacle which ignited a fire had a very loose screw which was the probable cause of the fire. Of 24 aluminum wired receptacles which ignited fires, 2 were noted to have a loose termination.
- Fires and Fire Hazard Conditions occurred in receptacles from all four sites surveyed.
- Fires occurred with plasterboard or wooden panelling, with or without thermal insulation, and either cyclic or continuous mode.
- Fires occurred in receptacles in both 20 ampere and 15 ampere branch circuits.
- The 24 aluminum specimens operated under conditions which might be encountered in U.S. homes demonstrate the ease with which a fire hazard can quickly develop into a fire. Almost 90 percent of these specimens ignited a fire in less than 6 hours of testing under hazardous conditions.

### Faults

- In addition to the 24 fires, 34 aluminum wired receptacles developed short circuits or open circuits. It is noteworthy that at least one of the fires was the direct result of sparks emitted by the receptacle during such a fault.

### Copper WBS Control Specimens

- Sixteen copper wire binding screw specimens that did not overheat in the field were sent to the laboratory for testing as control specimens. These specimens came from the four different survey areas and were tested a minimum of 2000 hours. None of the specimens showed any indication of overheating.

### Inferences from the Study as a Whole:

- While the study measured risks and relative risks in homes permitted in 1969 and 1970, the homes were built in 1969, 1970 and 1971. Similar wiring systems were used in homes built between 1960 and 1969. The risks in these older homes are not likely to be lower than in the ones sampled.
- In the four sites selected by chance, aluminum wiring was found in over 60% of the homes in two sites (Phoenix, Arizona and Baltimore County, Maryland) and in about 10% of the homes

in two sites (King County, Washington and Pinellas County, Florida). Regardless of the amount of aluminum wiring used in an area, the risk of overthreshold temperatures was higher with aluminum wiring than with copper wiring.

- The threshold temperature in home testing, of 75°C-99°C as well as that of 100°C or higher identified receptacles which had a high risk of reaching Fire Hazard Condition.

Half of receptacles which reached 75°C to 99°C in home testing and reached Fire Hazard Condition did so within 500 hours of cycling (21 days). As might be expected, receptacles reaching 100°C or higher in home testing reached Fire Hazard Condition faster than those with lower temperatures - 50% within 100 hours of cycling (4 days).

Almost half of the fires were ignited by receptacles which had reached 75°C to 99°C in home testing.



## SURVEY BACKGROUND

The branch wiring survey was initiated by the Consumer Product Safety Commission as the result of a considerable body of information which indicated that over 1.5 million homes wired with aluminum branch circuits between 1960 and 1972 might represent a fire hazard to the occupants.

- The Consumer Product Safety Commission undertook to ascertain whether and to what extent a safety hazard exists in residences which were constructed using "old technology" aluminum wiring in 15 and 20 ampere branch circuits. Aluminum wiring and wiring devices produced prior to revised U.L. specifications issued in June and September of 1972 are referred to as "old technology."
- A pilot survey of single family homes was conducted by CPSC<sup>(1)</sup> in Montgomery County, Maryland, in order to obtain a statistically valid measure of the extent to which duplex receptacles wired with aluminum and copper in that area exhibited above-threshold temperatures. Laboratory testing for the pilot study was performed by the Wright-Malta Corp., Ballston Spa, New York.
- The results from the pilot survey showed that aluminum wired receptacles had a significantly greater risk of reaching above-threshold temperatures than copper wired receptacles in the area surveyed. The magnitude of risk estimated for aluminum wired homes indicated that the small sample controlled study design was a feasible approach to obtaining statistical data needed by the Commission.
- Since results from the pilot survey could only be projected to the area sampled, plans were developed to enlarge the study to a national level by replication of the survey in four additional areas located throughout the United States.
- The Franklin Institute Research Center (FRC) contracted to review and revise the survey plans, to select four sites, to conduct the surveys in four sites, to test field specimens (receptacles) in the laboratory test facility of FRC, to analyze the study results, and to prepare reports of both statistical and laboratory findings.

(1) Newman, Rae and King, William H; Pilot Survey of Branch Wiring Systems on Montgomery County, Md; U.S. Consumer Product Safety Commission; September 1977.

## MAJOR STUDY OBJECTIVES

The major objectives of the study were:

- To ascertain whether there is a significant risk of over-heating associated with "old technology" aluminum branch wiring or with copper branch wiring in single family homes built during the same period.
- To quantify the relative risks for major types of wiring in different situations.
  - (a) Testing receptacles for threshold temperatures in home environment.
  - (b) Testing receptacles for Fire Hazard Condition in a laboratory environment resembling a home.
- To quantify relative risks nationwide by assessing the risks in four sites selected by chance from four broad regions of the United States.
- To provide estimates of sampling variability, i.e., the probable differences between sample results and those that would have been achieved by testing the entire sampling frame.
- To determine whether receptacles which had reached 75°C or higher in the home would, under continuing operation, become a potential hazard and possibly cause a fire in a short period of time if operated at rated branch circuit current in an environment which might be encountered in the home.
- To ensure that throughout the tests the receptacles were handled carefully and their environment controlled to the extent that any results which occurred in the laboratory could be considered results which might have occurred if the receptacles had remained in their original home environment.
- To ensure that measurements taken and procedures employed throughout the laboratory tests were of sufficient accuracy and quality to meet recognized technical standards.

## SURVEY METHODOLOGY

### Site Selection

- The inferential universe extends to duplex receptacles wired with "old technology" aluminum wire and wired with copper wire in the entire United States over the time period during which "old technology" wiring was used (1960-1972).
- Bureau of the Census reports of building permits for new single family residential construction during 1969-1970 were used to construct the survey frame. The frame, defined to include those jurisdictions which issued as many as 2,000 single-family residential building permits in the two years, was stratified into four regions.
- The four locations: Phoenix, Arizona; King County, Washington; Pinellas County, Florida; and Baltimore County, Maryland; were each randomly selected from one of four broad regions of the country.

### Site Surveys

#### Sample Selection

- Within each site a list of single family residences authorized for construction in the two-year period comprised the detailed frame.
- The survey design employed a two-phased sampling procedure to identify aluminum wired and copper wired homes (Phase I), for a controlled study (Phase II).

#### Phase I

- Probability procedures were employed for selection of 400 homes in each site for Phase I
- An initial inspection by an electrician identified the type of wiring system and circuit information in homes examined.

#### Phase II

- Probability procedures were employed for selection of a controlled sample of 30 to 60 homes for each major type wiring used in that location (aluminum wired homes and copper wired homes) for thermal testing.
- Selected homes were visited and all accessible receptacles on four branch circuits were measured for temperatures reached after 30 minutes under 75% of rated branch circuit current.

- The four circuits tested included two 20 ampere and two 15 ampere circuits: one preselected (refrigerator or television) and one randomly chosen for each current rating.
- Testing was interrupted for receptacles which reached 100°C to avoid reaching temperatures which might cause damage to the home.
- Receptacles reaching 75°C or more were replaced, and were shipped to the FRC laboratory for further testing.
- A small number of Cu WBS receptacles that did not exhibit high temperatures in the house were also removed and brought to the laboratory as control samples.

### Laboratory Testing

The procedure for removal of the duplex receptacles from the sample homes, their transportation to the FRC laboratory, and their handling in the laboratory were all carefully designed to minimize disturbance to the receptacle samples and thus to ensure sample integrity. Laboratory results were documented by detailed records and films.

### Rack Testing

The mounted receptacles were placed on an open rack and rated branch circuit current was passed through them. The current was cycled one hour on and one-half hour off. The rack testing was continued for up to 2000 hours or until a power dissipation level of 20 watts was reached. A receptacle that reached 20 watts was removed from the rack and placed in a wall test facility.

### Wall Testing to Fire Hazard Condition

This facility was constructed so that it represented typical wood frame wall construction found in single family homes. The specimens were installed in test wall cavities faced with either plasterboard or wooden panelling, with or without fiberglass insulation. A single sheet of cotton material was draped in front of the receptacle. The wall cavities effectively isolated each specimen so that unusual activity in one cavity, e.g., a fire, would not affect any other specimens in the test wall. A receptacle remained in the wall for testing with rated branch circuit current cycled one hour on and one-half hour off until a Fire Hazard Condition occurred or testing was terminated at 2000 hours (except for 9 receptacles discontinued at 720 to 1500 hours because of project time limitations.)

### Wall Testing Under Hazardous Conditions

Once a specimen reached a Fire Hazard Condition in the wall, the standard cotton material was replaced with a variety of common

household materials and the specimen placed in either the cyclic or continuous mode. Each specimen was given at least 40 hours of wall testing at hazardous conditions unless a fire or fault occurred. The following materials were used: newspaper, cotton polyester, cotton cheesecloth, nylon/polyurethane cheesecloth, dacron, synthetic acetate.

#### STUDY REPORTS

The methodology and results of the surveys and of the laboratory testing are presented in two separate reports; a statistical report and a laboratory report. The statistical report includes detailed information for each of the four sites and the laboratory report presents results of testing, related technical data and includes photographs of many of the specimens tested.