J. ARONSTEIN

CONSULTING ENGINEER

MECHANICAL AND MATERIALS ENGINEERING
BME, MSME, Ph.D., N.Y.S. P.E. LIC. NO. 39860
50 PASTURE LANE POUGHKEEPSIE, N.Y. 12603
(845) 462-6452
EMail protune@aol.com

REDUCING THE FIRE HAZARD

IN ALUMINUM-WIRED HOMES

Jesse Aronstein, PH.D., P.E.
Vice President, Special Engineering Projects,
Wright-Malta Corp., Ballston Spa, NY
(When this report was originally written)

Latest update: May 21, 2007

Original: January 25, 1982
Major Revison May 10, 1996

This report was originally prepared for:
Electrical Safety Conference - Electrical Fires
University of Wisconsin-Extension
Madison, Wisconsin 4/14/82

CONTENTS

Preface ii

Introduction 1

Electrical Safety Warning 3

Disclaimer...3

1. Reducing the Possibility of Connection Overheating 4
A. Use of Anti-Oxidant Compound and Abrasion 4
(When making new connections to aluminum wire)
B. Pigtailing using AMP "COPALUM" Connectors 5
C. Pigtailing using "AlumiConn" Connector 6
D. Pigtailing using Ideal #65 "Twister" Twist-on Connections 7
E. Field Experience With "Pigtailing" of Aluminum Wire 9
F. Box Fill 10
G. Alternative Corrective Actions 10
1) Service Panel Connections 10
2) Receptacles and Switches 10
3) Other Connections 12
H. New Circuits and Circuit Additions 12
I. Homes Wired With Alloy ("New Technology") Aluminum Wire 12
J. Homes Wired With Plated Aluminum Wire 13
K. Homes Wired With Copper-Clad Aluminum Wire 13
L. Misidentification - Plated Copper Wire 13
M. Circuit Usage 13
N. Do Nothing? 14

2. Detection of Overheating Connections 15
A. Detection of overheating at Receptacles and Switches 15
B. Detection of Overheating at Other Connections 15

3. Reducing the Possibility of Fire if Overheating Occurs 16
A. Inside the Electrical Enclosures 16
B. Cover Plates on Receptacles and Switches 16
C. Adjacent to the Receptacles and Switches 16

4. If Fire Occurs 16

5. References 17

6. Bibliography 18
(Technical Reports on Connector Performance With Aluminum Wire

PREFACE

New to this April, 2007 revision is the inclusion of information on a new connector for the "pigtailing" repair method (see Section 1-C). With the availability of this new connector, the previously-included alternate to CPSC's recommended "COPALUM" repair has been deleted.

This report is based on more than twenty five years of investigation and testing of aluminum wire branch circuit connections. Included are in-home inspections and testing, investigation of burnouts and fires, laboratory testing, and extensive review of industry and public agency test results and documents. The laboratory testing and investigations performed by the author were done for the U.S. Consumer Product Safety Commission (CPSC), for litigants and insurance interests with respect to fires which may be aluminum wire related, and for Canadian consumer groups, among others.

This report was first issued by Wright-Malta Corporation, which at the time had one of the largest aluminum branch circuit connection testing operations in the world. In 1982, there were approximately 7,500 aluminum and aluminum-copper connections on long-term test, plus (for comparison purposes) a substantial number of copper-wired connections. The results of many of the tests performed at Wright-Malta Corp. have been documented in reports written for CPSC and in published articles and technical papers. Some of these reports and papers are listed in this report as references (Sec. 6) and in the Bibliography (Sec. 7).

In initiating this report, Wright-Malta Corporation did not represent any commercial interests. The company did not (and still does not) manufacture or market any of the products or services involved or any competitive products or services. Wright-Malta Corporation's aluminum wire testing activity was completed in the late 1980's, and the company has not been involved in this matter (including the revisions of this report) since then. From that time to the present, J. Aronstein, the original author of this report and project engineer for the aluminum-wire testing performed at Wright-Malta Corporation, has continued evaluation and testing of aluminum wiring and its connections.

This report is made available by the original author for homeowner, inspector, and trade information. The report reflects best information and test results available through the revision date.

INTRODUCTION

A fundamental principle of electrical safety for wiring in buildings is that high temperatures are hazardous. While some protection is provided by electrical enclosures, the high temperature that can develop at failing branch circuit connections can lead to fire in many ways.[1]

Aluminum-wired connections in homes have been found to have a very high probability of overheating compared with copper-wired connections.[2][3][4] The aluminum-wired connections that fail tend to progressively deteriorate at a slow rate, and after many years can reach very high temperature when carrying current while still remaining electrically functional in the circuits. A large number of connection burnouts have occurred in aluminum-wired homes. Many fires have resulted, some involving injury and death. Examples of overheating of two common types of aluminum wire connections are shown in Figures 1 and 2 (following page).

The probability of aluminum-wired connection overheating in a home varies considerably according to the types of connections, the installation methods used, and the circuit usage, along with many other factors. Without detailed knowledge of the installation in a particular home, it is not possible to provide specific advice on corrective measures.

The most certain corrective action for all cases would be to rewire the home with copper wire. This is expensive and impractical in most cases. A practical approximation to rewiring can be achieved by a method known as "pigtailing", using a specially-selected connector and installation method to splice a short length of solid copper wire to each aluminum wire end. The copper wire "pigtail" is then connected to the circuit breaker, light fixture, receptacle, dishwasher, or other termination. This method is only effective if the connections between the aluminum wires and the copper pigtails are extremely reliable. Pigtailing with some types of connectors, even though they might be presently listed by UL or certified by CSA for the application, can lead to increasing the hazard.[5][6] (See Figure 1.)

Other actions and partial repairs are less certain in effectiveness, but they still can substantially reduce the risk of fire due to aluminum wire connection overheating. Among the possibilities are replacing certain failure-prone types of devices and connections with others more compatible with the aluminum wire, and removing the ignitable materials from the vicinity of the connections. These actions can be accomplished at lower cost than rewiring or complete pigtailing, but with less reduction of the hazard. The homeowner has choices to make. The objective of this report is to present the choices with a relative ranking of fire risk reduction.

The corrective methods and fire preventative actions described in this report are based on the best information available at this time. The installation and repair information in this report is provided only for guidance in establishing specifications for contracted work, which must be done in accordance with applicable codes and regulations by qualified electricians.

FIGURE 1 - ALUMINUM WIRE SPLICES MADE WITH TWIST-ON CONNECTORS CAN BE DANGEROUS. The use of most types of twist-on connectors with aluminum wire can lead to hazardous results. This twist-on pigtailing connection (two #10 aluminum wires with one #12 copper wire, in a 20-amp circuit), made with a twist-on connector that was UL listed for use with aluminum wire at the time, remains electrically functional in the circuit, but it becomes extremely hot whenever a significant amount of current flows. The heat has deteriorated the insulation on both the connector and the wires. In this photo, a portion of the connector's spring is red hot, at current well below the circuit rating.

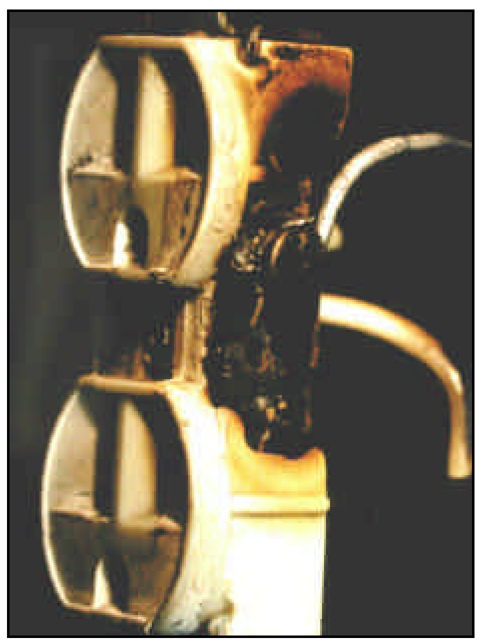

FIGURE 2 - EXAMPLE OF OVERHEATING OF ALUMINUM-WIRED TERMINALS ON A RECEPTACLE. Enough heat was generated by current flowing through the aluminum wire connections to cause charring of the receptacle body and disintegration of the insulation that was on the wire. Note that the face of the receptacle, as the homeowner or an inspector would have seen it, with the cover plate on, would look normal.

ELECTRICAL SAFETY WARNING

There is risk of property damage, injury, and death associated with working on the electrical system of a home. Shock, electrocution, and fire hazards are present. All work involving electrical components in the home wiring system should be done by persons trained and qualified for the job, with the power turned off at the main disconnect (main breaker, switch, or fuse block). Refer to appropriate industry and trade publications for safety precautions that should be taken.

DISCLAIMER

The information contained in this report is based on a large body of documented test data and sound engineering analysis. It is considered to be accurate and up to date. However, since the practical application of the information contained in this report is totally in the contractor's and/or homeowner's control, and application of the information in the report can only reduce but not totally eliminate the hazards associated with aluminum wiring, the author and/or provider of this report disclaim any responsibility or liability of any sort related to the application of the information that it contains.

1. REDUCING THE POSSIBILITY OF CONNECTION OVERHEATING

A. USE OF ANTI-OXIDANT AND ABRASION

To make the safest lowest resistance and most permanent connections to aluminum wire, the following procedure must be followed:

1) After stripping the insulation off the wire for the proper distance, using a stripping tool that does not nick the wire, coat the bare aluminum with a noncombustible corrosion inhibitor compound.*

2) Abrade the surface of the aluminum wire, with the compound* on it, with #240 grit "wet-or-dry" abrasive paper. Maintain the coating of compound while abrading.

3) Coat mating parts of the connector (if not factory prefilled) with corrosion inhibitor compound*.

4) After completing the connection, thoroughly clean off excess compound that is outside the connector.

*** Note: If the connector is pre-filled with inhibitor compound, use the same compound for protecting the abraded wire. It is preferable to use a corrosion inhibitor compound that does not burn freely. Burndy Penetrox "A" was the only one originally found by the author to be noncombustible, but recent information indicates that the formulation may have been changed. Corrosion inhibitors for aluminum wire and cable connections are known by different names, such as "oxide inhibitor", "connector aid", and "joint compound." They are generally a greasy substance. Some are simply petroleum jelly (Vaseline), some have various added ingredients. Among the electrical inhibitor compounds available, try to find one that does not flame readily. This can be tested by placing a small "glob" of the compound on the end of a piece of wire and trying to ignite it with a match. If possible (depends on availability), avoid the use of any compound that ignites readily and flames vigorously (like a match).**

B. PIGTAILING USING AMP* (TYCO) "COPALUM" CONNECTORS

The AMP* “COPALUM” connector is applied using a special set of dies in a power-driven tool. After application of the connector, a heat-shrink insulator is applied. Solid copper wire "pigtails" spliced to the aluminum wire this way may be connected to receptacles, switches, circuit breakers, lamps, appliances, and all other terminations in the normal manner. (Note: all aluminum branch circuit wire terminations in the home must be treated this way for a complete and permanent repair, as the overheating problem involves all types of aluminum-wired connections.)

Repair by pigtailing, using COPALUM connectors installed by a qualified electrician, is the only method considered by the U.S. consumer Product Safety Commission ("CPSC") to be a permanent repair. Their recommendation is based on extensive testing. The method is described in more detail, and sources for more information are provided in an article in Consumer Reports, January 1981.[7] While the application of COPALUM connectors is considered to be satisfactory without special preparation of the aluminum conductor, it is suggested that antioxidant compound and abrasion as per Section 1A (above) be used to provide an additional safety factor.

WARNING - **Use of other types of crimp-on connections with aluminum branch circuit wire can be hazardous. Do not use commonly-available crimp connectors applied with a plier-like hand tool, even though they are often sold as applicable for "all wiring repairs", and in fact may be made by AMP (the same manufacturer that makes the "COPALUM" connector). If the AMP* COPALUM connector (with its special tooling and qualified installer) is not locally available, see Section 1C, below.**

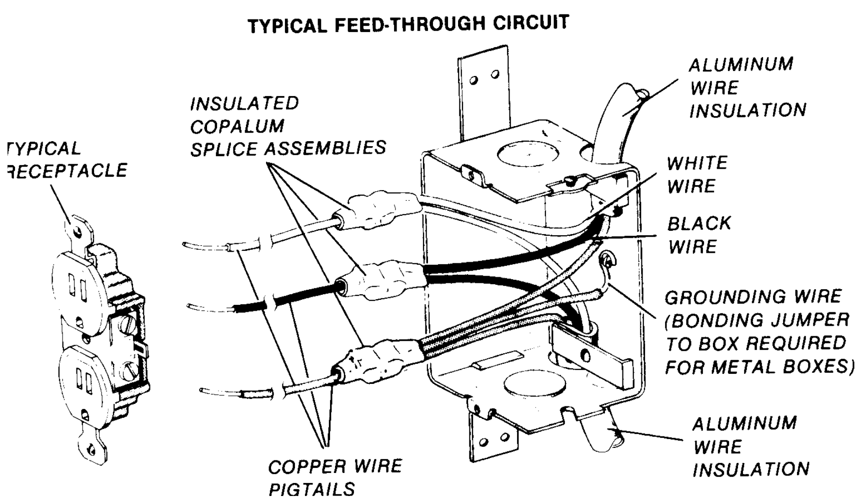

FIGURE 3 - llustration of copper wire pigtails spliced to aluminum circuit wires using AMP* (Tyco) COPALUM connectors (Source: U.S. Consumer Product Safety Commission)

*** Note: AMP is now a subsidiary of TYCO**

****** CAUTION - THESE REPAIRS MUST BE DONE BY A QUALIFIED ELECTRICIAN ******

C.PIGTAILING USING KING INNOVATION "ALUMICONN" CONNECTORS

In mid-2006 a new connector became widely available for the aluminum wire pigtailing application. This connector is shown in Figure 4. An initial set of tests on this connector has been completed. (These test results will be presented, published, and made publicly available in September, 2007.[13]

FIGURE 4 - King Innovation "AlumiConn" Connector

On the basis of the test results, the AlumiConn connector is predicted to have a high probability of failure-free long-term safe performance, *PROVIDED THAT THE SETSCREWS ARE CAREFULLY TIGHTENED TO THE MANUFACTURER'S RECOMMENDATION* (see notes below). If not tightened to the manufacturer's recommendation, there is a possibility that the connections will degrade due to wire stresses and/or motion when the completed connection is manipulated into the outlet (or junction) box.

SPECIAL NOTES:

1. The manufacturer's instructions provide two alternative methods for tightening. Either (instruction card, item #3 or 3A) may be used.

2. It is difficult to properly tighten the setscrews if the connector is hand-held. The connector needs to be held in a tool wile tightening. The manufacturer has indicated that some electricians are using "channel-lock" type pliers for this purpose. A special holding tool may be developed and made available by the connector manufacturer.

Prior to the April 25, 2007 revision of this report, a different connector had been identified as having the best probability of long-term safe performance if the Copalum repair was not available. Provided that special installation methods were used, 3M Scotchlock connectors were considered to be the best available alternative to the COPALUM crimp connector for pigtailing. The field performance of the Scotchlock connector, installed as had been noted, has been good, reflecting the favorable test results that had been obtained. A major drawback of that repair method, however, is that these connectors are not presently "listed" for use with aluminum wire. The AlumiConn connector, with favorable test results and with UL listing for use with aluminum wire, now replaces the Scotchlock in this report as the best alternative if the COPALUM repair is not available.

****** CAUTION - THESE REPAIRS MUST BE DONE BY A QUALIFIED ELECTRICIAN ******

D. PIGTAILING USING IDEAL #65 "TWISTER" CONNECTOR

After about 1987, when UL adopted a revised standard (UL486C) applicable to twist-on connectors for aluminum wire, twist-on connectors were no longer being marked (in the USA) as UL listed for aluminum wire applications. In 1995, UL accepted a twist-on connector - the Ideal #65 "Twister" - for aluminum-to-copper wire combinations, including those commonly used in the "pigtailing" retrofit. The Ideal #65 has been heavily promoted for that application. The connector is essentially the same as twist-on connectors that had performed poorly in previous testing, the major difference being that it is pre-filled with inhibitor compound. Based on its construction, there is good reason to question the long-term performance of the Ideal #65. Because of its UL listing, however, most electrical inspectors would accept this connector for pigtailing of aluminum wiring.

As soon as it appeared on the market, the Consumer Product Safety Commission (CPSC) questioned UL's listing of this connector for the aluminum wire pigtailing wire combinations. Although the manufacturer claims that the connector has been thoroughly tested for the application, neither the manufacturer or UL have released any detailed test data. The manufacturer states that the connector has received CSA certification for the same wire combinations. Information developed so far indicates the following:

- The manufacturer did not initially claim that the connector is intended for use in the pigtailing retrofit application. Instead, the manufacturer stated (to CPSC) that the Ideal #65 is intended for such applications as connecting lighting fixtures and ceiling fans. Ideal's engineering manager at that time committed to CPSC to change their its advertising and instructional information accordingly, but Ideal has not followed through on that commitment.

- UL did not independently perform the "heat-cycle" life tests required by their standard. These tests were performed by the manufacturer, with UL accepting the manufacturer's results.

- The connector was not "heat-cycle" tested for the common pigtailing wire combinations with current passing through the aluminum-aluminum wire path (in an aluminum-aluminum-copper splice).

- The "heat-cycle" tests that were performed by the manufacturer on the Ideal #65 "Twister" connector were not done using aluminum wire of the type actually installed in homes built in the 1960's and early 1970's.

- The CSA certification was based on UL's acceptance for listing. CSA did not independently evaluate the Ideal #65 connector. In fact, the use of a zinc-plated steel spring in the connector violates a CSA general requirement for connectors for aluminum wiring.

- The inhibitor compound/plastic shell of the connection in combination can ignite readily and burn freely. This increases the chance of fire ignition if connection failure occurs.

****** CAUTION - THESE REPAIRS MUST BE DONE BY A QUALIFIED ELECTRICIAN ******

Independent testing of the Ideal #65 "Twister" has demonstrated the following:[11]

- **Installed according to the manufacturer's instructions (without abrasion or pretwisting), the connector does not reliably establish low-resistance connections. (This finding contradicts the manufacturer's claim that particles in the inhibitor inside the connector serve to abrade the wire and eliminate the need for separate abrasion of the wires.)**

- **The Ideal #65 connector does not consistently pass the UL "heat-cycle" test requirement when tested with aluminum wire of the type actually installed in homes with current passing through the aluminum-aluminum path in a pigtailing (aluminum-aluminum-copper) splice.**

- **The performance of the Ideal #65 Twister is essentially the same as that of poorly-performing twist-on connectors previously evaluated for the aluminum wire pigtailing application.**

Additionally, field burnouts have now been reported with the Ideal #65 connectors in their rated applications. With CPSC skeptical (and requesting that UL withdraw its listing), the manufacturer initially agreeing that the connector is not for the pigtailing retrofit application, independent tests clearly demonstrating poor performance, and field failures reported, the use of the Ideal #65 "Twister" connector for the pigtailing application is definitely not recommended. If the COPALUM repair is not available, use the AlumiConn connector (See Section 1C).

A. THESE TWO FAILED SPLICES ARE ADHERED TOGETHER BY THE MELTED PLASTIC SHELLS

B. SEVERE FAILURE, PLASTIC SHELL MELTED AND CHARRED. THE CHARRING INDICATES THAT IT HAD PROBABLY IGNITED.

<u>FIGURE 5</u> - FIELD FAILURES OF ALUMINUM TO COPPER SPLICES MADE WITH IDEAL #65 CONNECTORS [12]

<u> CAUTION - THESE REPAIRS MUST BE DONE BY A QUALIFIED ELECTRICIAN ***</u>***

E. FIELD EXPERIENCE WITH "PIGTAILING" OF ALUMINUM WIRE

The previous sections have discussed "pigtailing" using different connectors, in terms of relative assurance of long-term safety in actual use, based on lab test results and field experience. For those connectors that have been in use for some years, the reported field experience for each connector is consistent with the lab test results -- good for the AMP COPALUM and the 3M Scotchlock, and poor for the Ideal #65. It is too soon after its introduction to have any significant field experience to report for the AlumiConn connector.

Feedback regarding field experience with the various connectors is summarized as follows:

1. AMP COPALUM Connector: has been used in this application since the early 1970's, and is present in a significant number of aluminum-wired homes. To date, to my knowledge, there have been no reports (to CPSC or other) of burnouts or other in-home failures of aluminum-wired pigtailing splices employing the AMP Copalum connectors.

2. 3M Scotchlock twist-on connector (using special installation method): was originally proposed for use as a more readily available alternative to the AMP COPALUM in about 1980, based on superior laboratory test results relative to other twist-on connectors that had been evaluated (for CPSC) for the pigtailing repair.[5] The number of homes in which this connector has been used for aluminum wire pigtailing is unknown, but no doubt is far less than for the COPALUM or the IDEAL #65. There have been no reports of burnouts or other in-home failures of these connectors used for aluminum-wire pigtailing.

3. IDEAL #65: came on the market in the mid-1990's. Within three years of its introduction, the first report of field failure surfaced. There have been additional failures reported since then.

4. AlumiConn: This connector has been on the market for less than a year, so is no field experience to report. (Similar setscrew connectors have been in use for many years, but the application is different. In particular, other applications do not involve severe distortion and stressing of the wires that ocurs in the pigtailing application when the connections are forced into the outlet (or junction) box.)

F. BOX FILL

Most aluminum wire splices and terminations that are to be pigtailed are in metal or plastic electrical enclosures ("boxes"). Some boxes are too small to accept the pigtailing connectors in addition to the items originally in the box. When this happens, the available volume can be increased by changing the box, extending it, or adding an adjacent box. Some cutting and subsequent touchup of finished surfaces may have to be done when boxes are changed or added.

G. ALTERNATIVE CORRECTIVE ACTIONS

With less certainty of safe, permanent, and complete correction relative to pigtailing of all connections, the following actions can reduce the probability of aluminum-wired connection overheating, thereby reducing the hazard. Note that ground connections should be addressed as well as the neutral and line connections.

1) Service Panel Connections: ****** CAUTION - SUBSTANTIAL HAZARD: THE SERVICE ENTRANCE CONDUCTORS AND CONNECTORS ARE LIVE (ELECTRICALLY ENERGIZED) EVEN WHEN THE MAIN BREAKER OR SWITCH IS "OFF" OR THE MAIN FUSES PULLED. SOME PANELS MAY NOT HAVE MAIN BREAKERS/FUSES, BUT, INSTEAD, THEY HAVE UP TO SIX DOUBLE POLE BREAKERS THAT MUST ALL BE TURNED OFF TO DISCONNECT ALL OF THE BRANCH CIRCUITS. SERVICING OF THE SERVICE ENTRANCE CONNECTIONS CAN ONLY BE DONE SAFELY WITH POWER COMPLETELY DISCONNECTED AT THE UTILITY POLE OR METER. USE A METER OR TEST LIGHT TO ASSURE THAT THERE IS NO VOLTAGE (TO GROUND) ON THE WIRING BEING SERVICED.***

Remake all branch circuit aluminum wire connections (including to the neutral buss) using corrosion inhibitor compound and abrasion of the aluminum wire, as described above in Section 1A. Make sure all connections are tight. Recheck tightness after one year, and thereafter at intervals determined by the amount of loosening detected, if any.

Visually inspect the service entrance cable connections. If there is any abnormality or signs of corrosion or overheating then servicing is required.

2. Receptacles and Switches ("wiring devices"): ****** CAUTION - SUBSTANTIAL HAZARD - USE A METER OR TEST LIGHT TO ASSURE THAT THERE IS NO VOLTAGE (TO GROUND) ON THE WIRING BEING SERVICED.***

Replace with CO/ALR devices installed per industry recommendations.[9] NOTE: Some CO/ALR wiring devices that are available are old stock and should not be used. The indium plating used on the screw terminals of some brands degrades with time, so the devices have a limited shelf life. Inspect the screw terminals and the terminal plate. If the terminals have a fresh metal look, they are probably OK. If the screws and/or terminal plate look tarnished or off-color, do not use them with aluminum wire, as the long-term performance and safety would be questionable.

****** CAUTION - THESE REPAIRS MUST BE DONE BY A QUALIFIED ELECTRICIAN ******

If full replacement cannot be done due to economic factors or limited availability of fresh CO/ALR rated devices, then the following actions are suggested:

- Replace all devices which have "push-in" wire terminations where there is no provision for reconnection to a binding-head screw terminal.

- Replace all devices which have 6-32 size terminal screws. (Outside diameter is 0.138", the same as the screws which hold the device to the box: 8-32 screw threads are 0.164".)

- Replace all devices which have steel terminal screws. (Check with magnet *after turning the MAIN POWER OFF*!)

- Priority should be given to the replacement of unsuitable devices in the more heavily loaded circuits, in which portable heaters, cooking appliances, air conditioners, and similar loads are used. All unsuitable receptacles and switches on these circuits should be replaced, not just those into which the loads are plugged. (Since the wiring devices are most often "daisy-chained" in the circuit, full current flows through the wiring terminals on all of the devices "upstream" of the device into which a load is plugged.)

Receptacles and switches which are not being considered for replacement should be inspected for heat damage. (Replace all damaged receptacles.) Reconnect the aluminum wire at the screw terminals by preparing the aluminum wire per Section 1A, above, and connect to the screw terminal per the industry recommendations.[9]

Re-tightening existing screw terminal connections, without remaking them, is simpler but less effective.

If CO/ALR devices are not available for replacement, the next best alternative, besides pigtailing, would be the use of devices with brass (nonmagnetic) 8-32 terminal screws. Connect per the industry recommendations after preparing the wire as described above in Section 1A.

NOTE: In all cases, when installing the connected device into the box in the wall, push it into place while folding the wires behind it. then pull the device out slightly and check the tightness of the terminal screws prior to screwing the device to the box.

3) Other Connections: Pigtailing to solid copper wire, as described in previous sections, should be used for connections between branch circuit aluminum wire and screw terminals or stranded leads of built-in appliances, heaters, furnaces, fixtures, and controls. Do not connect aluminum wire directly to stranded copper wire leads. Use an intermediate solid copper pigtail. The solid copper is then spliced to the stranded copper lead in the conventional manner. In some instances, such as connections to motors, there is often not enough space in the junction box for the pigtailing connectors, and an external junction box must be added.

Splices involving only the branch circuit aluminum wire (ie: aluminum-to-aluminum wire connections) should be made using the AlumiConn connector.

H. NEW CIRCUITS AND CIRCUIT ADDITIONS

Use copper or copper-clad wire for all circuit additions and for the installation of new circuits.

I. HOMES WIRED WITH ALLOY ("NEW TECHNOLOGY") ALUMINUM WIRE

The Corrective actions described in the sections above are required for homes wired with "new technology" wire just as they are for the "old technology" wire.

Homes wired with sme types of "alloy" aluminum wire may have lower probability of overheating at the binding head screw connections. There is little improvement in the probability of overheating in other types of terminations, however. In particular, the alloy aluminum conductors show high failure rates in tests with twist-on connectors.[6][8] Most of the alloy wires have improved mechanical properties but may have essentially the same electrically-insulating oxide surface film. As with the "old technology" ("EC" grade) aluminum wire, the oxide must be removed to reliably make a low resistance connection.

J. HOMES WIRED WITH PLATED ALUMINUM WIRE

Aluminum wire plated with tin or nickel was listed by UL in the early 1970's. The actual amount that was ever installed in homes in that time frame, if any, is very small. The only known brand name (on the cable jacket) that is known to indicate plated aluminum wire is "SINIPAL". In general, it can be assumed that the aluminum wire in a home is not plated.

Tests of plated aluminum wires with twist-on connectors showed that the plating did not solve the connection deterioration and overheating problem.[10] If it is known with certainty that the aluminum wire is plated, omit the abrasion step in the connection procedures described above. The corrosion inhibitor compound is still required, however. (Note: abrasion of the plated aluminum wire is not harmful provided that the inhibitor compound is used.)

K. HOMES WITH COPPER-CLAD ALUMINUM WIRE

Copper-clad aluminum wire has a thin copper outer skin and a core of aluminum. Therefore it looks like copper, except on close examination of a cut end. Markings on the cable jacket would include "Al" or "Aluminum". There is no known history of connection overheating problems associated with copper-clad aluminum wire. No corrective actions are required for copper-clad aluminum wire.

L. MISIDENTIFICATION - PLATED COPPER WIRE

Plated copper wire is relatively common in older homes, and it looks like aluminum wire. It was commonly used with rubber-based insulation. Identification can be made by careful inspection of a cut end of the wire. In general, plated copper wire would not be present in nonmetallic sheathed cable ("Romex"), it is most generally found in metallic sheathed cable ("BX"). Cable of the "BX" type is not likely to contain aluminum wire.

M. CIRCUIT USAGE

Keeping the circuit current low will minimize the possibility of fire hazard due to overheating aluminum wire connections. Heat generation at a connection is related to current flow. The lower the current, the less heat produced at a given failing connection. Where no corrective actions have been taken, occupants of aluminum-wired homes should minimize the use of plug-in appliances that draw current approaching the circuit rating, such as portable heaters, cooking appliances, and air conditioners. Additionally, the total of all loads active at any time on a given circuit, due to TV's, computers, lighting, etc., should be minimized.

N. DO NOTHING?

The electrician, handyman, inspector, or realtor who suggests that you could "leave well enough alone" with respect to aluminum wiring is most often badly mistaken. Even if it is correct that "nothing happened" in previous years (or while a previous owner resided there), changes in occupancy patterns and electrical circuit usage can heavily load some wiring connections that had never before been subjected to any significant current.

For example, in my own home, a circuit feeding the receptacles in two of the bedrooms has never carried more than the current to a few lamps and an alarm clock, perhaps 5 amps maximum with all the lights on at once. If the next owner plugs a portable heater into a receptacle in the corner bedroom (which tends to be chilly), and perhaps a TV and a computer are added, the maximum current in this circuit can be as high as its circuit breaker will allow without tripping. (A 15-amp breaker typically will trip at somewhere between 16 and 20 amps.) The current is passing through a daisy chain of wiring terminals on the receptacles (behind the coverplate, in the box), as many as 22 of them in this particular circuit in my home. It would only take one deteriorated wiring connection in that daisy chain circuit to cause a problem (in the worst case, a fire) even though it had previously appeared to be OK at very low electrical loading.

Does the electrician or inspector - or anyone else - know anything about the aluminum-wire terminations in this particular home? With respect to receptacles, are the aluminum wires terminated at screw terminals or push-in "backwire" terminals? If screw terminals, are they clamp type or is the wire wrapped around under the screw head ("binding-head" screw terminal)? If binding-head screw terminal, are the wires all properly wrapped under the screw head (2/3 wrap, no overlap, clockwise direction)? Are the screws steel (worst) or brass (not as bad)? Are the screws zinc plated (worst), indium plated (questionable), or tin or nickel plated (better than zinc)? Were the screws originally tightened adequately? Are they all still tight? Are all the receptacles marked "CO/ALR"? Are they marked "AL/CU" or do they have no markings at all as to suitability for aluminum? Were the aluminum wire terminations made using a corrosion inhibitor? Were the bare wire ends abraded before making the terminations? And that's only the receptacle wiring terminals! One also has to consider the wiring splices (twist-on connectors, "wire nuts"), and aluminum wire terminations at various built-in appliances (heating, air conditioning, hot water heater, dishwasher, etc.) and at the circuit breaker panel. Has anyone inspected all of the aluminum wire terminations in the home to certify that none of them show signs of overheating (yet)?

A further point to consider is that the aluminum wiring terminations tend to degrade with time. Some may actually be "as good as new", some may be deteriorated (relatively high electrical resistance) but show no visible signs yet (perhaps for lack of any significant current flow -- yet), and some may show signs of mild or severe overheating. As the house ages, so do the aluminum wire terminations. None of them will improve with age and further usage.

This is an "occupant beware" (or "buyer beware") situation. You are living in the home and raising your family there. Not the electrician, not the sales agent, not the previous owner (seller), not the inspector. If you are considering the purchase of an aluminum-wired home, the aluminum wiring need not be a "show stopper". It becomes a question of cost of the home, cost of improvements, your budget, and your own set of value judgments and sense of the relative risks that you are willing to take.

2. DETECTION OF OVERHEATING CONNECTIONS

Detecting an overheating Connection in the early stages, and taking corrective action, can be an effective fire-prevention procedure. This is an inexpensive way of reducing the fire hazard where complete corrective actions have not yet been taken. The effectiveness is limited, however, and strongly depends on the thoroughness and frequency of inspection.

A. DETECTION OF OVERHEATING AT RECEPTACLES AND SWITCHES

With main power off, remove the cover plates of the receptacles and switches ("wiring devices"). Using a bright flashlight, carefully inspect the area of each wire terminal. The wires should be connected at the screw terminals (not inserted into "push-in" wiring holes in the back of the device). Look for the following signs of overheating: 1) charring or discoloration of the plastic wiring device body around the screw terminals, 2) abnormal tarnishing or corrosion of wire and screw terminal, and 3) melting, bubbling, burnback, or discoloration of the wire insulation. If any of these signs of overheating exist, or if the device is push-in backwired, replace or reconnect the device as previously described. Each and every wiring device should be inspected (not just a random sample). Replace all cover plates before restoring main power.

WARNING: The often-quoted advice to "feel the outlet faces" to detect overheating is ineffective and, potentially, dangerously misleading. The homeowner cannot be expected to know how much current, if any, a receptacle's connections have been carrying, and for how long, prior to being checked in that manner.

B. DETECTION OF OVERHEATING AT OTHER CONNECTIONS

Periodic visual inspection, looking for signs of discoloration, insulation deterioration, or other abnormalities, is the only readily available method for detecting overheating of the various wire splices and terminations in the home. Inspection of electrical boxes and panels other than at wiring devices should be done by a qualified electrician or inspector, and must include all connections, not just a random sample.

WARNING: So-called "warning signs", such as flickering lights, inoperative circuits, strange odors, smoke, sparks, and arcing, sometimes occur at advanced - and hazardous- stages of connection failure, but they cannot be counted on as warning signs in all instanaces.

WARNING: Inspections can reveal what has happened in the past, but cannot assure future safe performance. A high resistance connection may not have overheated simply because no significant current was ever flowing in its part of the circuit. It will look "like new". The same connection may then overheat to hazardous levels when a new load (TV, portable heater, cooking appliance, or other) is plugged into the circuit.

3. REDUCING THE POSSIBILITY OF FIRE IF CONNECTION OVERHEATING OCCURS

Overheating connections can get hot enough to ignite fire, if there is an ignitable material nearby. Whether one has a "burned out connection" or a serious fire loss is determined to a great extent by the materials that are near the overheating connection. Removing the easily ignited materials from the vicinity of the aluminum wire connections can substantially reduce the possibility of fire ignition if a connection overheats. This activity is most efficiently done as part of a general inspection for overheating connections (Section 2, above), and should be done with the main power off.

A. INSIDE THE ELECTRICAL ENCLOSURES

Wallpaper and wood paneling material are often installed so that they intrude into the wiring device boxes, sometimes in actual contact with the wire terminals. These materials should be cut back beyond the border of the box. Remove all dust, wood chips and splinters, paper material, and other extraneous combustible materials from the receptacle and switch boxes and all other electrical enclosures.

B. COVER PLATES ON RECEPTACLES AND SWITCHES

Use metal coverplates on receptacles and switches. Most "decorator" type plastic and wood coverplates ignite relatively easily. Metal coverplates provide better protection and also serve to dissipate the abnormal amount of heat that may be generated inside the box by a failing aluminum wire termination on the wiring device.

C. ADJACENT TO THE RECEPTACLES AND SWITCHES

Bedding, furniture, drapes, books, newspapers, and other potential fuels are often found in direct contact with the wiring devices. Remove all combustible materials that are in contact at the face of receptacles and switches, so that there is at least 2" of clearance.

4. IF FIRE OCCURS (from any cause)

KNOW WHAT TO DO IF FIRE OCCURS. HAVE A PLAN. DISCUSS IT WITH THE WHOLE FAMILY. SEE YOUR LOCAL FIRE DEPARTMENT FOR GUIDANCE.

INSTALL DETECTORS. EARLY WARNING IS IMPORTANT.

5. REFERENCES

1. J. Aronstein, "Fire Due to Overheating Aluminum Wired Branch Circuit Connections", Electrical Safety Conference: Electrical Fires; Cause, Prevention, Investigation. University of Wisconsin, Extension, Madison WI, April 7, 1981.

2. "National Controlled Study of Relative Risk of Overheating of Aluminum Compared With Copper Wired Electrical Receptacles in Home and Laboratory", Executive Summary. Prepared for U.S. Consumer Product Safety Commission. Report #F-C4812-01, Franklin Research Center, Philadelphia, PA, April 20, 1979.

3. R. Newman and W.H. King, Jr., "Pilot Study of Branch Wiring Systems in Montgomery County, Maryland", U.S. Consumer Product Safety Commission, Sept., 1977.

4. J. Aronstein, "Summary Report, Study of Overheating of Aluminum-Wired Electrical Receptacles in Scarborough, Toronto, Homes", Wright-Malta Corp., Ballston Spa, NY, January 11, 1982.

5. J. Aronstein, "Test of 'Old Technology' Aluminum Wire With Twist-On Connectors", Project Report CPSC-C-79-0079, Task II, For U.S. Consumer Product Safety Commission, Wright-Malta Corp., Ballston Spa, NY, Feb. 24, 1981.

6. J. Aronstein, "Overheating Failures of Presently-Listed Aluminum-Wired Connection Combinations Within Rated Service Conditions", Wright-Malta Corp., Ballston Spa, NY, November 23, 1981.

7. "The Trouble With Aluminum Wiring", Consumer Reports, January, 1981, p.42.

8. R.L. Hicks, "Pigtail Splicing Connections for Baseboard Heaters and Similar Cyclic Loads", Ontario Hydro Research Division, Report #78-235-K, May 17, 1978, p. 3, (Table 1).

9. "Aluminum Building Wire Installation Manual and Design Guide", The Aluminum Association, Inc., Washington, DC. (p. 12 in 1978 Edition).

10. J. Aronstein and T.K. Hare, "Evaluation and Analytical Electron Microscopy Investigation of a Plated Aluminum Wire for Branch Circuit Applications", IEEE Transactions: Components, Hybrids, and Mfg. Tech., V. CHMT-11 No. 2, June 1988.

11. J. Aronstein, "Evaluation of a Twist-On Connector for Aluminum Wire", Transactions, 43rd IEEE Holm Conference on Electrical Contacts, Philadelphia, 1997

12. J. Aronstein, "Analysis of Field Failures of Aluminum-Copper Pigtail Splices Made With Twist-on Connectors", Transactions, 45th IEEE Holm Conference on Electrical Contacts, Pittsburgh, PA, 1999

13. J. Aronstein, "Evaluation of a Setscrew Connector for Aluminum Wire", Transactions, 53rd IEEE Holm Conference on Electrical Contacts, Pittsburgh, PA, 2007

6. BIBLIOGRAPHY: TECHNICAL REPORTS, CONNECTOR PERFORMANCE WITH ALUMINUM WIRE

R. Newman, "Hazard Analysis of Aluminum Wiring", April, 1975, U.S. CPSC, NIIC-0600-75-H006

M. Leger, "Metallurgical Analysis of Failed CO/ALR Devices", Ontario Hydro, #78-54-K, Ontario, Canada, February, 1978

J. Aronstein and W.E. Campbell, "Failure and Overheating of Aluminum-Wired Twist-on Connections", IEEE Trans. Components, Hybrids, and Mfg. Tech., V. CHMT-5 No.1, March 1982

J. Aronstein, "Tests of 'Old Technology' Aluminum Wire at Special Crimp Type Compression Connectors" (Amp COPALUM), Wright-Malta Corp. Project Report CPSC-C-79-0079 Task III, U.S. Consumer Product Safety Commission, Washington, DC, Feb. 5, 1983

J. Aronstein, "Tests of 'Old Technology' Aluminum Wire", Wright-Malta Corp. Project Report CPSC-C-81-1418, U.S. Consumer Product Safety Commission, Washington, DC, Feb. 10, 1983

J. Aronstein and W.E. Campbell, "Overheating Failures of Aluminum-Wired Special Service Connectors", IEEE Trans. Components, Hybrids, and Mfg. Tech., V. CHMT-6 No. 1, Mar. 1983

J. Aronstein and W.E. Campbell, "The Influence of Corrosion Inhibitor and Surface Abrasion on the Failure of Aluminum-Wired Twist-On Connections", IEEE Trans. Components, Hybrids, and Mfg. Tech., V. CHMT-7 No. 1, Mar. 1984

J. Aronstein and W.E. Campbell, "Evaluation of an Aluminum Conductor Material for Branch Circuit Applications", IEEE Trans. Components, Hybrids, and Mfg. Tech., V. CHMT-8 No. 1, Mar. 1985

R. Schubert, "Erratic Behavior of Al/Al Wire Junctions", Electrical Contacts - 1986, Proceedings of the 32nd IEEE Holm Conference on Electrical Contacts, Boston, 1986.