UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

This document has been electronically approved and signed.

Memorandum

Date: August 17, 2012

TO : The Commission
Todd A. Stevenson, Secretary

THROUGH : Cheryl A. Falvey, General Counsel
Kenneth R. Hinson, Executive Director
Robert J. Howell, Deputy Executive Director for Safety Operations

FROM : J. DeWane Ray, Assistant Executive Director,
Office of Hazard Identification and Reduction
Andrew M. Trotta, Director, Division of Electrical Engineering
Directorate for Engineering Sciences

SUBJECT : Contractor Report on Development and Testing of a Temperature-Sensing Control System for Preventing Cooking Fires on Ranges and Status of Staff Cooking Fire Reduction Efforts

Attached is a contractor report from Primaira, LLC, on development and testing of temperature-sensing-based control systems for electric coil element, gas, and glass ceramic cooktops. This contract work[1] was conducted in support of U.S. Consumer Product Safety Commission (CPSC) technical staff efforts to implement strategies to reduce the likelihood of the occurrence of cooking fires.

According to CPSC Directorate for Epidemiology staff estimates, cooking equipment, primarily ranges and ovens, continues to account for the largest percentage of fires attributed to products under the CPSC's jurisdiction.[2] The National Fire Protection Association (NFPA) reports that between 2005 and 2009, cooking materials, including food, were the first item ignited on ranges or cooktops in 18,800 nonconfined fires that were attended by fire departments, with 150 associated civilian deaths, 1970 civilian injuries, and $314 million in associated direct property damage.[3] Another important factor is that for many fires the user is away from the cooktop when a fire occurs; these incidents include those where food was the item first ignited as well as those where other materials were the item first ignited. NFPA's estimates, based on the data from between 2005 and 2009, indicate that an average of 13,300 nonconfined range fires

---

[1] The contract (Contract #: GS11T10BJM6060) was administrated by the General Services Administration Federal Acquisition Service Assisted Acquisition Services Office with funds provided by CPSC.
[2] Miller, David E and Chowdhury, Risana; *2006-2008 Residential Fire Loss Estimates*; U.S. Consumer Product Safety Commission Directorate for Epidemiology; July 2011; www.cpsc.gov/LIBRARY/fire08.pdf.
[3] Ahrens, Marty; *Home Fires Involving Cooking Equipment;* National Fire Protection Association; Table 2.9, pg. 65; November 2011; www.nfpa.org/assets/files/pdf/os.cooking.pdf.

THIS DOCUMENT HAS NOT BEEN REVIEWED
OR ACCEPTED BY THE COMMISSION.

CLEARED FOR PUBLIC RELEASE
UNDER CPSA 6(b)(1)

occurred each year, resulting in 180 deaths, 1490 injuries, and $253 million in property losses each year.[4] At a minimum, implementation of automated temperature-limiting controls, such as those that were developed as part of the Primaira contract, would target unattended overheating of food to ignition.

Highlights of the Primaira work include development and testing of heating element/burner control systems that limit pan temperature to a 700°F threshold while still allowing normal high heat input cooking to occur without noticeable degradation of food quality or increases in cooking time. The systems were developed for an electric coil element, gas burner, and electric element under a glass ceramic cooktop. The system developed for the gas range did not require the flame to be extinguished, addressing a potential concern with re-ignition of the burner. The sensors that were designed and fabricated are more robust than those that were developed previously. Control algorithms were designed to determine when a pan is getting hot and when a pan is cooling down so that the heating element can operate more effectively in the range of temperatures where cooking is taking place. This was evidenced by comparable cooking times for boiling between control and noncontrol tests, which has been an issue with previous control systems. In addition, the proposed sensor designs are significantly improved in terms of potential for durability and reduced cost.

Primaira's test and development contract is part of a long succession of studies conducted in pursuit of a technical approach to reducing the number of cooking fires and the associated deaths and injuries. In fiscal year 1995, CPSC staff initiated the project to reduce deaths, injuries, and property loss from surface cooking fires by exploring the possibility of developing a sensor that could be adapted to a range and integrated into a control system that could act to prevent cooking fires. From 1995 through 1997, three phases of cooking characterization testing were conducted, two by the National Institute of Standards and Technology (NIST),[5,6] and one by CPSC staff.[7] The U.S. Fire Administration (USFA) provided funding for the tests at NIST. One of the conclusions from the tests was that temperature measured on the bottom of a cooking vessel was a reliable indicator of pending ignition.

In 1997, as a means of demonstration of concept, CPSC staff developed an experimental range control system for an electric coil-element range, based on temperatures measured on the bottom of the pan with a thermocouple-based contact sensor.[8] The system prevented ignition, but some

[4] ibid; Table 2.6, pg. 59.
[5] Johnsson, E. L.; *Study of Technology for Detecting Pre-Ignition Conditions of Cooking Related Fires Associated with Electric and Gas Ranges and Cooktops, Phase I report*; NISTIR 5729: United States Department of Commerce; 1995.
[6] Johnsson, E. L.; *Study of Technology for Detecting Pre-Ignition Conditions of Cooking Related Fires Associated with Electric and Gas Ranges and Cooktops, Phase II report;* NISTIR 5950: United States Department of Commerce, 1997; www.cpsc.gov/LIBRARY/FOIA/FOIA98/os/352178C.pdf.
[7] Lim, H. et al.; *Study of Technology for Detecting Pre-Ignition Conditions of Cooking Related Fires Associated with Electric and Gas Ranges: Phase III;* U.S. Consumer Product Safety Commission; 1998; www.cpsc.gov/LIBRARY/FOIA/FOIA98/os/Rangerpt.pdf and www.cpsc.gov/LIBRARY/FOIA/FOIA98/os/rangerpt2.pdf.
[8] Lim, H. *Study of Technology for Detecting Pre-Ignition Conditions of Cooking Related Fires Associated with Electric and Gas Ranges: Phase IV -- Experimental Control System Feasibility Demonstration;* U.S. Consumer Product Safety Commission; 2000.

cooking operations took longer. With USFA funds in 1999, CPSC contracted with Energy International, Inc., to develop and test an experimental burner control system for gas-fueled ranges. The system prevented ignition, and cooking operations were largely unaffected.[9]

On the basis of these successful demonstrations, in August 1999, CPSC staff requested that standards developers for gas and electric ranges (CSA-International and Underwriters Laboratories, respectively) form working groups to develop requirements for ranges to address the ignition of cooking materials on cooktops. Working groups were established, and in spring 2000, meetings were held. In the course of discussions within the working groups, CPSC staff and the Association of Home Appliance Manufacturers (AHAM) agreed to fund an independent assessment of the technical, practical, and manufacturing feasibility of technologies to address surface cooking fires. A contract was awarded to Arthur D. Little, Inc. (ADL), and their study identified several technologies that showed promise.[10] In their conclusions, ADL indicated that a pan-contact temperature sensor, like the two that CPSC staff had developed, would require two to three years of extensive development to address reliability and durability issues but would not work on glass ceramic cooktops. Three successive contracts on glass ceramic cooktop control system development were awarded to ADL[11] and to Advanced Mechanical Technology Inc. (AMTI).[12,13] Success was achieved in preventing ignition, but there were some increases in time needed for water to come to a boil.

Subsequent to the release of the ADL study, in 2001 CPSC staff requested that Underwriters Laboratories (UL) form a task group specifically to draft proposals for test requirements for preventing cooktop food ignitions. While CPSC staff efforts, including this most recent study conducted by Primaira, have focused on pan contact technology as a means to reduce the likelihood of igniting pan contents to ignition, this approach was only intended to serve as a basis for rationale to convince the standards developing committees for gas and electric range standards (ANSI Z21.1 - *Household Gas Cooking Appliances* and ANSI/UL 858–*Household Electric Ranges*) that a technical solution is available for further refinement into an acceptable system. Staff's intent has not been to prescribe that this pan-sensing technology be adopted, but rather, that the standards would incorporate ignition-reduction performance requirements that would give manufacturers the flexibility to integrate whichever type of sensing and control technology they preferred.

---

[9] Corliss, J.; *Development of a Control System for Preventing Food Ignition on Gas Ranges*; Energy International; 2000; www.cpsc.gov/LIBRARY/FOIA/Foia00/brief/range1.pdf and www.cpsc.gov/LIBRARY/FOIA/Foia00/brief/range2.pdf.

[10] Carbone, P. and Benedek, K.; *Technical, Practical and Manufacturing Feasibility of Technologies to Address Surface Cooking Fires*; Arthur D. Little, Inc., 2001; www.cpsc.gov/LIBRARY/FOIA/Foia01/brief/Ranges.pt1.pdf and www.cpsc.gov/LIBRARY/FOIA/Foia01/brief/Ranges.pt2.pdf.

[11] Brekken, M.; *An Evaluation of Sensor and Control Technologies to Address Cooking Fires on Glass Ceramic Cooktops*; Arthur D. Little, Inc.; 2002; www.cpsc.gov/LIBRARY/FOIA/FOIA03/os/Ceramic.pdf.

[12] Krass, B. and Corliss, J.; *Identification and Evaluation of Temperature Sensors for Preventing Fires on Electric Smooth-top Ranges*; Advanced Mechanical Technologies Incorporated; 2003; www.cpsc.gov/LIBRARY/FOIA/FOIA04/brief/Cooking.pdf.

[13] Krass, B. and Corliss, J.; *Development and Manufacturing Assessment of the Concentric-Ring Smooth-Top Range Sensor*; Advanced Mechanical Technology, Inc.; 2004.

In accordance with CPSC staff's request, UL formed a task group under the UL 858 Standards Technical Panel (STP), which is the committee that acts on proposals for revision of the standard. The task group included CPSC staff, UL staff, industry members and the Association of Home Appliance Manufacturers (AHAM) staff. However, the task group members disagreed about what the task group charter was and elected to survey the full STP membership to determine whether they supported changes to UL 858 before ranges with temperature-limiting controlled heating elements were commercially available. Balloting indicated by a margin of 16 to 6, that the STP did not think it was time to revise the standard. Subsequently, the task group proceeded to refine guidelines to which prospective systems could be assessed to be considered feasible for implementation. These guidelines are called the Technical Feasibility Performance Goals (TFPGs), an extensive set of rigorous performance tests that was based on a list of criteria that range manufactures provided in 1998, to reflect what they considered defined feasibility. CPSC staff participated in the task group discussions on the TFPGs and acknowledges that they are a useful set of guidelines for the development of range control technologies. However, they are not part of UL 858, and CPSC staff does not view strict adherence to the TFPGs as a condition of acceptability of candidate control systems. After the issuance of the TFPGs, and with the survey vote indicating that the STP would not consider changes to UL 858 without an off-the-shelf system, the task group work was discontinued.

In the ensuing years, CPSC staff executed the contracts for the two AMTI smooth cooktop studies but did not resume any major studies until August 2010, when the Primaira contract was awarded. The Primaira study coincided with national and international efforts to address ways to reduce incidents of cooking fires. In February 2010, CPSC staff participated in Vision 20/20's Kitchen Fire Prevention Technologies Workshop, which was sponsored by State Farm Insurance (Vision 20/20 provides a collaborative process for achieving actions that are targeted toward bridging gaps in our nation's fire prevention efforts). After a day of discussion, workshop participants recommended that an additional study be undertaken to identify the barriers to the use of these technologies and to develop an action plan toward improving cooking fire safety.

Also, CPSC staff served on the Fire Protection Research Foundation (FPRF) steering committee for Stove Top Technologies for Cooking Fire Safety (May 2010–November 2011). FPRF is an independent nonprofit whose mission is to plan, manage, and communicate research in support of the National Fire Protection Association mission. With NIST funding, FPRF sponsored a study by Hughes Associates, which resulted in a report, *Home Cooking Fire Mitigation: Technology Assessment*, released in October 2011. Concurrently with the study, FPRF sponsored a workshop, Technology Assessment: Home Cooking Fire Mitigation Development of an Action Plan, in July 2011. The workshop concluded with a commitment from participants to continue to participate in activities to achieve the goal of reducing cooking fire loss through technology solutions.

In 2009, the Ontario, Canada Office of the Fire Marshal released a study on addressing cooking fires, *Reducing Residential Stovetop Fires in Ontario*, which included a recommendation to "Request standards development organizations to incorporate performance requirements into their range construction standards to address the prevention of stovetop fires."

The European Committee for Electrotechnical Standardization (CENELEC) established a working group, Committee on Cooking Safety Standards in Europe, CLC/TC61/WG4, that sponsored a range industry research project, which was conducted by a consortium of manufacturers in Europe in 2008–2009. The cooking tests were conducted to validate proposed requirements that WG4 had drafted to prevent cooking fires and to assess the effects of meeting these requirements on cooking performance. The cooking tests were performed on a glass ceramic cooktop with a temperature threshold of 698°F and on an induction cooktop. An induction cooktop is a type of glass ceramic cooktop that heats cookware directly by transmitting a magnetic field that induces current in the pan; only cookware that is made from ferromagnetic metals such as stainless steel and cast iron will work. A summary of the test results was presented by AHAM at the Vision 20/20 workshop in February 2010, indicating unacceptability due to poor cooking performance and inadequate fire prevention response with warped cookware. AHAM reported that as a result of the tests, WG4 concluded that the standard could not be changed to address cooking fires, but that they would continue to monitor if new solutions appear, and they would promote fire safety education.

However, Nordic authorities reportedly are developing draft proposals to stop the many types of cooktop fires that were discussed in the CENELEC working group. The Norwegian Electrotechnical Commission issued NEK 400:2010, *Electrical Low Voltage Installations*, which is a collection of 41 adapted standards. Viewed in total, the standard series provides minimum safety requirements for electrical low-voltage installations. Each part (except for the standards in NEK 400-8 being purely national) is based on corresponding international standards from CENELEC and/or the International Electrotechnical Commission. For ranges, Norway uses the European standard, EN 60335-2-6 *Household and Similar Electrical Appliances -Safety; Part 2-6 Particular Requirements for Cooking Ranges, Hobs, Ovens and Similar Products,* but NEK 400 includes a particular requirement, *Clause 823.421.01,* which states: "*To reduce the risk of fire when using the stove/cook top, there shall be arranged protective measures that ensure disconnection of power supply to the cooker/cook top if there is danger of overheating.*"

Japanese cook stoves already require temperature-limiting controls. A two-burner gas cook stove with a pan-contact sensor temperature-limiting control was evaluated as part of the ADL study in 2000. In addition, Primaira examined two Japanese gas cook stoves with pan-contact temperature-limiting controls as part of their study. The cook stoves are tabletop style units that more closely resemble a table stove than a typical U.S. 30-inch slide-in or counter-mounted range. While Japanese cultural and cooking habits differ from those of U.S. consumers, the presence of pan-temperature sensing controls in these units for more than a decade illustrates that such a technical solution is able to be manufactured and implemented commercially on a mass scale.

The opposition to reducing the incidence of cooking fires through a change to cooktop controls has raised a number of valid concerns, including reliability and durability of sensors, effect on cooking performance, sensor response to harsh/dirty conditions, and incomplete coverage of all fire scenarios. Some have emphasized a need to improve consumer information above technical approaches. CPSC staff agrees that the problem of cooking fires is very broad and requires a multipronged approach that includes consumer information, among other strategies. However, staff does not believe that consumer information alone can supplant the need for a fundamental change to the product standards to effect a technical solution to reducing the likelihood of food ignition. Further, staff believes that, as indicated in the ADL report, many of the issues of reliability, durability, and performance are matters of engineering and design and not technological hurdles. This is evidenced by the performance improvements that have been achieved by Primaira over previous developments. This is also evidenced in the presence of pan-sensor-based temperature-limiting controls that are incorporated into Japanese cook stoves (and have been since at least 1998, when CPSC staff first purchased a Japanese gas cook stove with temperature sensing). Further, although reducing the incidence of food ignitions does not address all cooking fires, it does relate to 68 percent of range fires.

In the intervening years since the 2002 UL STP survey indicated that the time for changes to UL 858 was premature, hundreds of victims have died in cooktop-related fires associated with food ignitions and thousands have been injured. No integrated temperature-limiting controls have been introduced on ranges or cooktops in the U.S. market (although several aftermarket add-on systems exist). CPSC staff believes that it is long past due to commit to changes to the range standards to reduce the likelihood of these food fires. Based on the relative success of the Primaira developments, staff also believes that validation testing of the prototypes developed by Primaira is an important next step. Staff plans to approach UL again about the formation of a task group to develop test requirements to address cooking fires that start with ignition of cooking materials in a pan.

UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Memorandum

ATTACHMENT

Pan Temperature-Limiting Control Technology to Reduce Incidence of Unattended Cooking Fires

Final Report

Period of Performance:

October 1, 2010 – December 31, 2011

Report Prepared for:

U.S Consumer Product Safety Commission

Contract #: GS11T10BJM6060
ACT #: A19613514

Report Prepared by:

Primaira, LLC
30 Commerce Way, Suite 300A
Woburn, MA 01801
tel 781 937 - 0202
fax 781 937 - 0229
www.primaira.com

Table of Contents

List of Figures

List of Tables

Executive Summary

Background, Objectives and Approach

Since 1995, the U.S. Consumer Product Safety Commission (CPSC) has supported work aimed at identifying and mitigating the risks of unattended cooking fires. According to CPSC staff cooking equipment accounted for the largest percentage of residential fires. An estimated annual average of 149,500 cooking equipment-related fires during 2006–2008 accounted for nearly 40 percent of the average annual estimate of total residential fires for the same period. Range/oven fires account for approximately 14,600 non-confined incidents per year (i.e fires that spread beyond their originating item). (D. Miller and R. Chowdhury; 2006-2008 Residential Fire Loss Estimates; U.S. Consumer Product Safety Commission, 2011).

Researchers at several organizations have reviewed a wide variety of potential hazard detection schemes and have tested the efficacy of some of them in practical test environments. This research has demonstrated that food and pan-bottom temperatures are reliable indicators of pending ignition that can be exploited to initiate automatic corrective actions to prevent food ignition.

The objective of the current study was to demonstrate technology that will help to reduce the incidence of unattended cooking fires resulting from ignition of food using a variety of cooking operations, pan types, and cooktop types. The scope of the project was to design, fabricate, and test prototype sensor and control systems capable of detecting pre-ignition conditions and then controlling heat input in for residential gas, electric, glass ceramic, and induction cooktops.

Cooktop Selection, Sensor System Development & Sensor Integration

We purchased four cooktops (glass ceramic, electric coil, gas, and induction) to use as the representative platforms for sensor and controls integration. These cooktops included one glass ceramic (electric), one electric coil, one gas and one induction cooktop. All four cooktops carried the same brand name.

The general approach was to use a relatively inexpensive but effective temperature sensor located in the cooktop to measure or infer temperature at the bottom of the pan. In all cases, we used a resistance temperature detector (RTD) sensor. For gas burner and electric coil cooktops, we developed a rugged pan-bottom-temperature sensor that was positioned to contact the bottom of the pan. For the glass ceramic cooktop, we used an RTD sensor positioned beneath and contacting the underside of the glass ceramic. In this case, the temperature of the pan needs to be inferred, based on a combination of measurements and calculations. The induction cooktop included an embedded RTD sensor in the center of each inductive element.

Algorithm Development.

Previous work by Arthur D. Little, Inc. (2001), showed that limiting pan temperature to 700°F (370°C) or below would avoid food ignition hazards. The challenge in previous work has been to limit the pan temperature at or below 700°F while ensuring that the heating rate remains high enough so that heat-up times, boil times, and high temperature cooking methods are not compromised. The control algorithms we developed to overcome this challenge use a combination of rate of change and threshold monitoring to decide when to interrupt the element's power (or gas input). In the gas cooktop, the heat-input was reduced to 50 percent of the maximum heating rate when the algorithm called for heat reduction. With this approach, it was not necessary to re-ignite the flame as the control was turned on and off. In the electric coil cooktop, power to the element was shut off entirely until conditions for repowering the element were met.

The algorithm used in the glass ceramic cooktop was more sophisticated because the pan temperature was being inferred from the measured glass ceramic temperature and not measured directly. While this algorithm also considered measured temperature and rate of change of the temperature, it also incorporated a calculation of the change in the slope of the temperature/time curve. This added algorithm element was necessary to compensate for the high thermal inertia of the system.

Controls Implementation and Testing

We implemented the control algorithms in a small Programmable Logic Controller (PLC), which allowed for straightforward modification and optimization of the control parameters. A cooktop or range manufacturer would implement the controls with a modification to the chip on an existing electronic control board, or the addition of a simple electronic board in the case of lower end gas or electric coil products that currently do not use electronic controls.

Cooking tests were performed with and without the prototype fire mitigation controls. All tests were conducted with pans of three materials: aluminum, stainless steel, and cast iron. These pans were of sizes and styles appropriate for each cooking or performance test conducted. Cooking tests included: dry cook, pasta boil, sauce simmer, long boil, blackening chicken, steak cook, vegetable stir-fry, and batch shallow frying. Appendix C provides details of these test methods.

Test Results

The pan temperature-limiting sensor and control systems that were implemented in the electric coil, gas, and glass ceramic cooktops all maintained pan temperatures to below the threshold limit of 700°F. This temperature-limiting control was effective on initial heat-up (dry cook tests), as well as for a boil-dry situation, or a condition in which cooking was completed, food was removed, but the hot empty pan was left on the element/burner.

The algorithms for the electric coil, gas, and ceramic glass cooktop controls were refined until all cooking processes for all pan types tested provided results that were equivalent to the cooking performance without the controls activated, while at the same time preventing the pan from exceeding 700^{o}F . All boil times with the controls were within the standard deviation of the boil test. Cooking performance for sear, blacken, simmer, and sauté modes with the controls active were all equivalent to non-control-active tests. All cooking and temperature-limiting tests were conducted with aluminum, cast-iron, and stainless steel pans of various configurations.

The as-manufactured induction cooktop includes RTD temperature sensors and temperature limiting controls, but the manufacturer's control software was inaccessible to be modified. It is likely that software and/or setpoint modification can provide the same fire mitigation utility in the induction cooktop.

In this testing program, we confirmed that proper implementation of the temperature limit would not compromise cooking modes, including boiling, searing, sautéing, frying, blackening, or simmering.

Costs & Further Development Requirements

In all cases, as a cost-estimation worst case, it is assumed that the sensor and control system is required on four hobs on each cooktop. Further testing and analysis may demonstrate that the sensors are not needed on the smaller hobs as their input power is limited and the risk of exceeding the threshold pan bottom temperature is low. This conservative assumption results in estimated incremental manufacturing costs ranging from $30 for the electric coil cooktop, to $46 for the gas cooktop, to $61 for the glass ceramic cooktop.

Manufacturers would have to pursue additional development steps prior to implementing the controls commercially. At a minimum these steps would include: a development of self-check algorithms to ensure that the sensor remains operational and calibrated after years of use; durability testing; and design for manufacturability and cost reduction

Conclusions and Summary Recommendations

The objectives of the current project have been met: a robust fire mitigation control scheme has been integrated successfully into a variety of cooktop types without impacting cooking performance. No fires occurred on any of the cooktops in the course of the testing when the control system was operating; this included cooking on the high setting with fats and oils. However, control system operation should be validated to confirm fire mitigation performance. In addition, costs could be reduced significantly if sensor systems were not needed on the smaller cooktop hobs. The power input guidelines for sensor and control implementation need to be established.

We believe that the technology has significant merits as a performance enhancement; the pan temperature limiter will prevent food from "burning" (*i.e.*, overcooking): most foods are not cooked acceptably on the highest input. This control approach can distinguish between water boil and other cooking functions, so boiling time will not be increased in order to provide the desired fire-mitigation performance. It is possible that commercial introduction of the technology would be faster if it were provided not as a "safety" feature, but rather, as a performance feature. This desirable performance feature would bring with it a mitigation of the likelihood of cooktop fires.

1. Introduction

The U.S. Consumer Product Safety Commission (CPSC) initiated a Range Fire Project in 1995 to identify measurable pre-fire conditions and lessen the risk of unattended cooking fires. Over the course of this project, work has been conducted by researchers at the National Institute of Standards and Technology (NIST), the CPSC, Energy International (EI), Arthur D. Little, Inc. (ADL), and Advanced Mechanical Technology Inc. (AMTI) to review a broad range of potential detection systems and to test the efficacy of a few systems in practical test environments. The research demonstrated that food temperatures and pan-bottom temperatures are reliable indicators of pending ignition and that they can be exploited to initiate automatic corrective actions to prevent food ignition.

Using all of this work as a starting point, the objective of the current study was to demonstrate technology that will help to reduce the incidence of unattended cooking fires resulting from ignition of food in a pan on a cooktop. The scope of the project was to design and fabricate prototype sensor and control systems for residential gas, electric, glass ceramic, and induction cooktops capable of detecting pre-ignition conditions and shutting off or modulating heat input. It was another objective of the project that the prototype cooktop control systems would meet or exceed established Technical Feasibility Performance Goals (see below in Section 1.1) to establish feasibility for the residential market.

1.1 Background – Cooking Fires

According to the U.S. CPSC report on residential fire loss estimates published in July 2011, cooking equipment accounted for the largest percentage of residential fires in the period from 2006 to 2008. In this period, there was an average of 14,600 range/oven fires annually. These fires were associated with an annual average of 120 deaths, 1,390 injuries, and $267 million in property damage. (D. Miller and R. Chowdhury; 2006-2008 Residential Fire Loss Estimates; U.S. Consumer Product Safety Commission, 2011).

To address the cooking fires issue, a Cooktop Fire Working group was formed in August 2001, at the request of CPSC staff after ADL's study results were presented to the Underwriters Laboratories Inc. (UL) 858 Standards Technical Panel (STP). The Cooktop Fire Working Group developed the test protocols and common acceptance criteria, referred to as the Technical Feasibility Performance Goals (TFPG). The TFPG were intended to provide guidance to engineers, inventers, entrepreneurs, or others who may be involved with the design of a device intended to reduce cooktop fires by sensing an over-temperature condition. The Cooktop Fire Working Group has stated that the TFPG are available for guidance but are not meant to be final requirements. The TFPG focus on devices that could be incorporated into a cooktop surface element/burner and that would interface with a cooking utensil (pan) to sense the over temperature condition.

1.2 Project Approach

There were four key elements of our technical approach to this project: cooktop selection, sensor system development and integration, algorithm development, and controls implementation. Each of these elements of our technical approach is summarized below.

1.2.1 Cooktop Selection

We selected a popular brand of each cooktop type (electric coil, gas, glass ceramic, and induction) as the cooktop platforms for sensor and controls integration. The brand was chosen based on its long term range market share. All cooktops include four elements and are 30”-wide class products. Their specifications are listed in Appendix A. A brief description of each cooktop as it relates to the implementation of pan temperature limiting controls is provided below.

Electric Coil

With the electric coil cooktop, the pot is placed directly on top of one of four electric resistance elements. The heat from the elements is transferred into the pot by some combination of conduction, convection, and radiation, depending on how well the pot contacts the element.

There is access for a pan-bottom temperature sensor to contact the pan directly. There is some thermal inertia in the electric element. The implication of the thermal inertia of the coil is that the pan temperature can continue to rise even after the power to the element has been reduced or removed. Therefore, even with a sensor contacting the pan directly, there is a need to know both the temperature of the pan and its rate of change of temperature in order to ensure that the temperature does not exceed a preset value.

When the rate of change of pan temperature is quite low, the measured pan temperature can be allowed to approach the threshold temperature more closely, without risk of temperature overshoot.

Gas

With the gas cooktop, the pot is placed on a grate that is located above the gas burner. The heat from the flame is transferred into the pot primarily by convection. As is the case with the electric coil, there is access for a pan-bottom temperature sensor to contact the pan directly. There is some thermal inertia in the gas, but it is less than that of the electric coil. The rapid responsiveness of the gas burner makes it possible to reduce pan temperature by turning the flame down, rather than turning it off entirely. The turndown approach significantly simplifies the process of returning the heat to the previous input rate.

Gas cooktops sold in Japan have a safety feature that allows complete shutdown of the flame and re-ignition of the flame after safe temperatures are reestablished. This commercially obtainable method of control is available for use in gas cooktops, but it involves a different configuration of gas valve. This trade-off (turndown versus turn-off) is discussed further in a subsequent report section.

Electric Glass Ceramic

With an electric glass ceramic cooktop, the electric resistance heating elements are located under a sealed, ceramic surface. The electric element radiates heat to and through the glass ceramic surface. The element also convects heat to the glass ceramic surface. Heat is subsequently radiated, conducted, and convected from the top of the glass ceramic surface to the bottom of the pan. In all cases, the temperature under the glass ceramic surface is significantly higher than the temperature of the cooking utensil (pot or pan).

There is no access for a sensor to contact a pan directly without disturbing the smooth and sealed cooktop surface. Therefore, the temperature sensor is positioned under the glass ceramic surface. In this configuration, the environment around the temperature sensor is much hotter than the pan itself. There is also significant thermal inertia in the combination of the heating element and the glass ceramic cooktop surface. The pan-temperature limiting control algorithm, therefore, infers pan temperature, rather than measuring it directly.

Induction under Glass Ceramic

An induction cooktop heats a pan by creating a magnetic field which in turns induces a current in the pan directly. There is no heating element under the glass ceramic surface that is becoming hot and then transferring its heat to the ceramic surface and subsequently to the pot above. With the induction cooktop, the pan is the hottest part of the system, and the glass ceramic surface is heated by the pan. A temperature sensor located under the glass ceramic surface is cooler than the pan. But the pan is the only source of heat measured by the sensor.

Therefore, the temperature sensed under the glass ceramic surface with an induction system is inferring heat transferred from the pot to the glass ceramic surface. There is some thermal inertia in the system, but less than in a conventional electric resistance glass ceramic cooktop.

1.2.2 Sensor System Development

The general approach for sensor development was to use a temperature sensor located in the cooktop to measure or infer temperature at the bottom of the pan. In all cases, we used a resistance temperature detector (RTD) sensor for the development work. RTD sensors have a robust output signal, are stable, and are accurate over the measurement range. A generic thin film RTD sensor is shown in Figure 1.

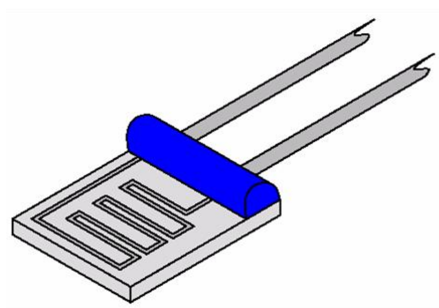


Figure 1: Thin Film RTD Sensor

For gas burner and electric coil cooktops, we developed a rugged pan-bottom-temperature sensor assembly that was positioned to maintain a secure contact the bottom of the pan. This approach provided the closest coupling of the sensor to the pan temperature, while addressing durability, reliability, and manufacturability issues that were not addressed sufficiently in previous studies. The RTD could be replaced with a lower cost thermistor in the commercial implementation of the sensor in gas and electric coil cooktops, with no loss of accuracy, reliability, or stability. We did not use them initially because when we started component selection for the control system, we were not sure we could operate in the more restricted temperature range of the thermistor. Subsequently, we can see from the data that a thermistor could be a good lower-cost choice for the sensors that contact the pans directly. More detailed testing is necessary to confirm this.

For the glass ceramic cooktop, we used an RTD sensor positioned beneath and contacting the underside of the glass ceramic surface. In this case, the temperature on the pan needed to be inferred, based on a combination of measurements and calculations, as will be discussed in more detail in Section 2.3. The indirect nature of the measurement required a more sophisticated algorithm to balance the needs to limit pan temperature and meet technical performance goals.

The induction cooktop that we purchased for this study included an imbedded RTD temperature sensor in the center of each inductive element.

1.2.3 Algorithm Development

The approach to mitigating cooking fires is based on the history of testing and analysis that shows that limiting the pan temperature to 700°F or below will avoid temperatures at which the preponderance of fires from ignition of food in a cooking vessel will occur. Previous work by Arthur D. Little, Inc. (2001), showed that limiting pan temperature to 700°F or below would permit good cooking performance in the cooking modes tested. These results are summarized in the figure below.

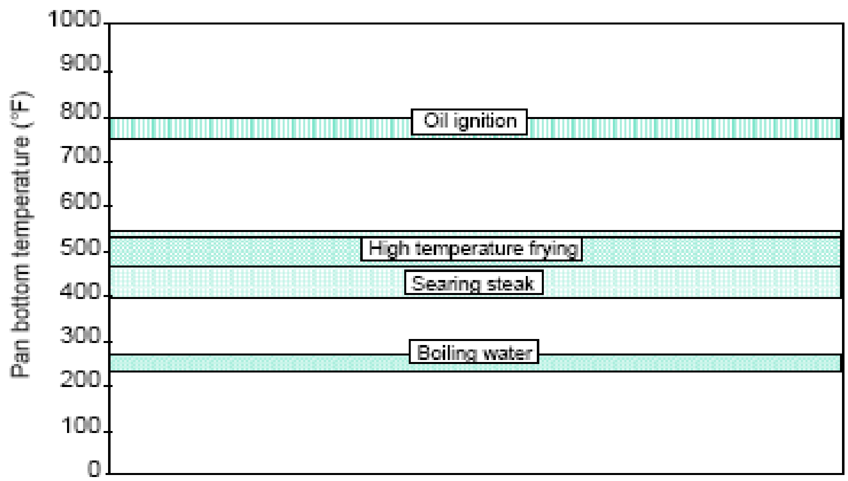


Figure 2: Pan Bottom Temperatures for Functions and Ignition (from ADL Report, 2001)

The challenge has been to limit the pan temperature at or below 700°F while ensuring that the heating rate remains high enough that heat up times, boil times, and high temperature cooking methods are not compromised. In this program, we confirmed that proper implementation of the temperature limit would not compromise cooking modes including: boiling, searing, sautéing, frying, blackening, or simmering.

We implemented a threshold temperature algorithm in three cooktop control systems: electric coil, gas, and glass ceramic. The algorithms used in the gas and electric coil cooktops were similar, as both systems used a pan-bottom-sensor that contacted the pan directly. In both systems, the control algorithm uses a combination of rate of change and threshold monitoring to decide when to interrupt the element's power (or gas input). In the gas cooktop, the heat-input was reduced to 50 percent of the maximum heating rate when the algorithm called for heat reduction. With this approach, it was not necessary to re-ignite the flame as the control was turned on and off. It is a significant benefit to simplification of the control system to be able to keep the flame burning. Otherwise, re-ignition of the flame would become a critical design consideration. In the electric coil cooktop, power to the element was shut off entirely until conditions for repowering the element were met.

The algorithm used in the glass ceramic cooktop was more sophisticated as the pan temperature was being inferred from the glass ceramic temperature (and the air temperature in the rough-in box below the glass ceramic surface). While this algorithm also considered measured temperature and rate of change of the temperature, it also incorporated a calculation of change in the slope of the temperature/time curve. This added algorithm element was necessary to compensate for the high thermal inertia of the system.

As will be described below, we did not implement an algorithm for the induction cooktop due to the complexity of the induction electronics. However, it is clear that temperature limits are already implemented in the existing control algorithms. Small adjustments to the existing set points may be all that is necessary to apply the pan temperature limiter to the induction cooktop. Unfortunately, we could not access the software to make these adjustments.

In all cases, the algorithms limit the apparent pan bottom temperature to a control point that is above the temperature needed for “normal” cooking but below a threshold associated with an ignition condition.

1.2.4 Controls Implementation

We implemented the controls through a Programmable Logic Controller (PLC) and the appropriate mechanical relays or valves depending on the cooktop. This approach provided us flexibility in the development process. A cooktop or range manufacturer would implement the controls with a modification to the chip on an existing electronic control board, or the addition of a simple electronic board in the case of lower end gas or electric coil products that currently do not utilize electronic controls.

1.2.5 Performance Requirements

The controls of all cooktops were required to maintain a pan temperature below 700^{o}F in any situation. Our primary test method for this was to place an empty pan on the element/burner, turn the heat input to high, and monitor a thermocouple on the inside surface of the pan to determine whether it reached or exceeded 700^{o}F. All temperature and cooking tests were conducted with pans of three materials: aluminum, stainless steel, and cast iron. These pans were of sizes and styles appropriate for each cooking or performance test conducted. Because these pans were subjected to an extensive amount of “dry cook” tests, in which they were heated to temperatures of 700-800^{o}F, they became discolored and warped over time. The results presented cover a range of pans from new to considerably worn.

A list of all pans tested in the program is included in Appendix B. Photographs of the pans are also included to reflect the degree of wear and warping of the pans.

1.2.6 Test Methods

A list of the cooking tests conducted in this program is shown as Table 1.

Table 1: Cooking Tests

Test Name	Description	Pan Type	Pan material Aluminum, (Al) Stainless Steel, (SS) Cast Iron (CI)	Criteria for passing
Dry Cook	Empty pan placed on element or burner set to High	10" Skillet	Al, SS, CI	Temperature in pan was maintained below 700°F
Pasta Boil	Pot filled with 4 qt water, element set to High, water brought to boil, 1 lb pasta added and cooked for 4 minutes.	5 – 6 Qt Pot	Al, SS, CI	Time to heat between 80°F and 195°F is within 10% of time in a pot without temperature-limiting control.
Sauce Simmer	One quart of prepared tomato-based pasta sauce was placed in a 2-quart pot and brought to a simmer for 10 minutes.	2 Qt Pot	Al, SS, CI	Sauce would maintain a low simmer without boiling over or losing a low boil.
Long Boil	Pot was filled with 4 quarts of room-temperature tap water (70-80 °F). The burner was switched to High and data collected for 90 minutes.	5 – 6 Qt Pot	Al, SS, CI	Water would come up to boil in time similar to that in a pot without pan temperature-limiting controls and would maintain rolling boil over long period of time.
Blackening chicken	One boneless, skinless chicken breast (1/2 lb), split in half to ½" thickness. 30mL of vegetable oil was heated until smoking in a pan, and chicken was added and cooked until blackened on each side.	10" Skillet	Al, SS, CI	Surface of chicken would blacken similarly to that when heated in a skillet without a pan temperature limiter.
Steak	The pan was heated with 30mL of vegetable oil on the "6" setting until smoking hot. Two steaks, 1 pound each, were placed in the hot pan and cooked for 5 to 7 minutes on each side.	10" Skillet	Al, SS, CI	Steaks would sear similarly to those cooked in a skillet without the pan temperature limiter.
Vegetable Stir fry	½ pound of thinly cut strip steak, half of a red bell pepper, and half of an onion were thinly sliced. 20mL of vegetable oil were heated in the pan with the element power set to "high". The oil was heated on high until it began to smoke, a Half of the steak was added, well stirred and cooked rapidly (with the element still on "high"). More oil was placed in the pan and allowed to heat briefly, and then the vegetables were added to the pan and cooked until tender (still on "high"	10" Skillet	Al, SS, CI	Meat and vegetables would have caramelized surface similar to that produced when cooked in a skillet without a pan temperature limiter.
Batch shallow frying	800 mL of canola oil was poured into a pan and the burner turned to High. Once the oil reached 380 °F, 400g of frozen French fries were added, spread out, and cooked until golden brown and crispy. Once the oil had reached 380 °F again, the process was repeated two times. For the full sequence of tests, the element remained at the "high" setting.	10" Skillet	Al, SS, CI	Cooking times and browning are comparable to those from using a skillet without pan temperature limiting controls.

Details of these test methods are provided in Appendix C.

2. Sensor and Control System Design

Sensor system, control system hardware and algorithm used for each cooktop type are described in each section, below.

2.1 Electric Coil Cooktop

The pan-bottom temperature sensor is a platinum RTD sensor enclosed in a metal housing. The RTD sensor is spring-loaded to ensure direct contact with the cookware. Photographs of the sensor integrated into the coil element are shown in Figure 3 and Figure 4. As can be seen, the element with the sensor is barely distinguishable from a standard element.

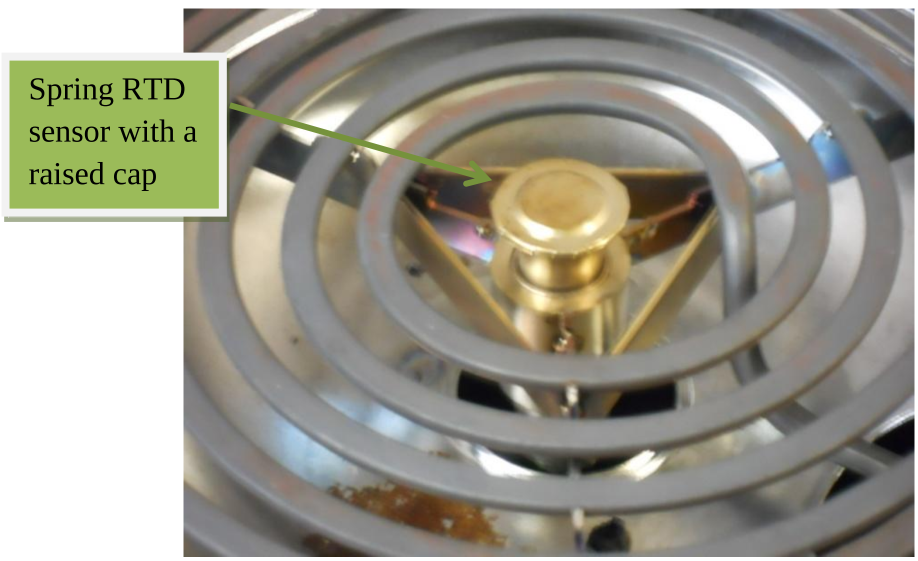


Figure 3: Spring Loaded RTD Sensor with Raised Cap

Figure 4: RTD Sensor with Raised Cap

In our test setup, we controlled a mechanical relay with the sensor output through a Programmable Logic Controller (PLC), as shown in Figure 5. Ultimately, the PLC would be replaced with a small microprocessor chip.

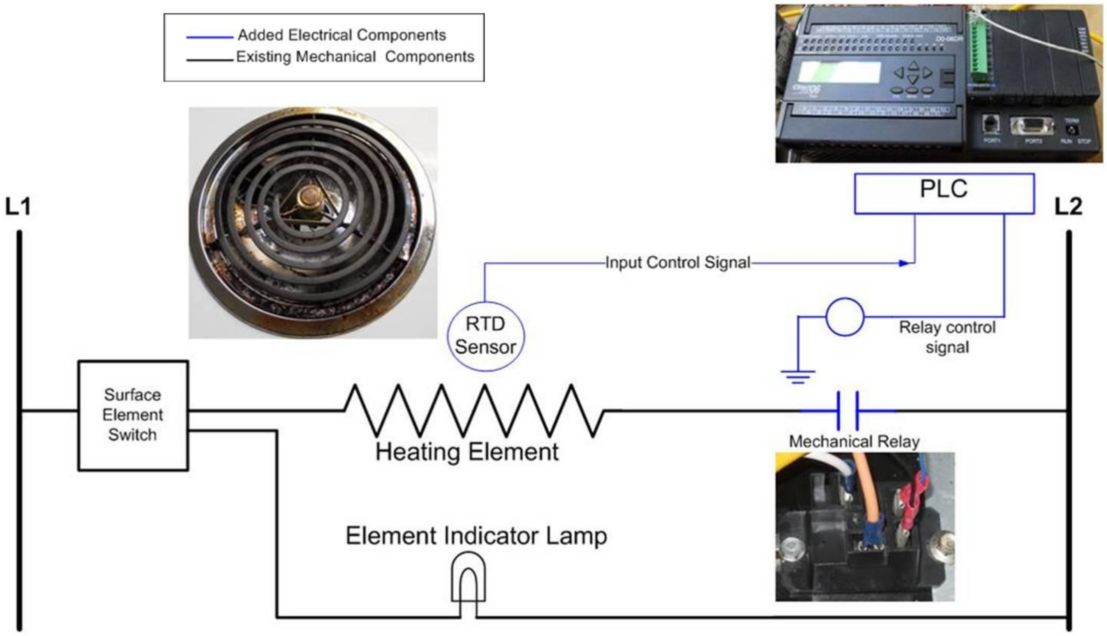


Figure 5: Electric Coil Cooktop Control System Hardware

A control algorithm was developed and implemented to prevent vessel temperatures from rising above 700˚F without interfering with normal cooking. The control algorithm uses a combination of rate of change and threshold monitoring to decide when to interrupt the element's power. This combination of threshold temperature and rate of change allows the controller to avoid overshoot of pan temperature that may occur during an initial heat-up phase of cooking, while maintaining a high enough steady state temperature threshold for excellent cooking performance. The specifics of the algorithm set points and logic are shown in Table 2. The overall control strategy utilizes a state control method which only changes the output parameters once predefined state conditions are met. If input parameters are in transition between two states the output parameter will stay unchanged until the input parameters of next state condition are met.

The controller regulates the element power using the control logic described below:

Table 2: Electric Coil Algorithm Set Points

State Conditions	Output Parameter (Element Power)
Sensor Temp < 515˚F	ON
Sensor Temp ≥ 535˚F AND Sensor Δ ≥ 2.0	OFF
Sensor Temp < 575˚F AND Sensor Δ < 2.0	ON
Sensor Temp ≥ 590˚F	OFF

The sensor system is currently configured to monitor temperature continuously.

A temperature measurement is sampled by the controller from the sensor every second. The controller is also calculating the rate of change of the sensed temperature (Δ) every 10 seconds. The controller only changes the element power when one of the four conditions statements listed in Table 2 is met; otherwise the controller maintains the existing state of the element power. If the sensor output voltage corresponds to a temperature that is less than 515^{o}F, there is no action taken by the controller. When the sensor temperature is 535˚F or above, and the calculated rate of change of temperature is greater than 2^{o}F per second, control algorithm sends a signal to the relay to turn the element off. The element will stay off until the sensor temperature is less than 575^{o}F, and the slope is less than 2.0^{o}F/sec. Once both of these conditions are met, the element power is resumed. After the initial heating of the cookware, the slope tends to level off well below the 2.0^{o}F/sec set point, and the controls will interrupt the element power only if the sensor temperature rises to or above 590^{o}F. The element will be turned on again as the temperature of the sensor drops below 590^{o}F.

This combination of control state balances issues of thermal inertia of the boil (and potential cookware temperature overshoot) during the heat up of the pan with the need to maintain high enough steady-state operating temperatures to perform all the desired cooking functions. Extensive testing was conducted to determine the values of the control parameters. The slope parameter had to be high enough to distinguish a period of pan heat-up from a period of steady-state cooking. If the pan is heating quickly, the temperature threshold for shutoff needs to be low (because thermal inertia makes the pan continue to heat after the element is shut off). If the slope parameter selected is too high, the threshold temperature must be even lower to avoid overshoot. A slope of 2^{o}F/second, combined with a threshold of 535^{o}F, worked well.

One additional note on the temperature set points in the control algorithm and our experimental method: The RTD temperature sensor output was used by the controller to compare to the algorithm set points and turn the elements off or back on. This RTD temperature output was different (and always lower) than the temperature measured by a thermocouple welded to the center of each pan. The set points in the algorithm account for the fact that the sensor temperature is lower than the actual pot temperature. The pan temperatures illustrated in graphs showing the impact of the controls on pan temperature during a dry cook test may appear to be higher than one would anticipate from the set points listed in Table 2.

2.2 Gas Cooktop

The pan-bottom temperature sensor is a platinum RTD sensor enclosed in a metal housing. The RTD sensor is spring-loaded to ensure direct contact with the cookware. It is positioned off to the side of the burner so that the burner requires no modification. The sensor used for test purposes is shown integrated into the gas cooktop in Figure 6 through 8. (A design modification intended to address the durability and reliability requirements of the TFPGs is described in Section 4.

Figure 6: Top View of RTD Sensor Integrated with the Largest Burner of the Gas Cooktop

Figure 7: Side View of RTD Sensor Integrated with the Largest Burner of the Gas Cooktop

Figure 8: RTD Sensor Being Engaged by a Stainless Steel Pan

Gas flow is restricted by energizing a solenoid valve that diverts the gas through a smaller diameter tube, reducing the burner output to half (maximum) power, as shown in Figure 9. The reduced input rate is always the same. It is not dependent upon the input rate at the point that the control reduces the gas flow rate. This approach to burner control ensures that the heat rate is never low enough that there is a risk that it extinguishes or needs to be re-lit.

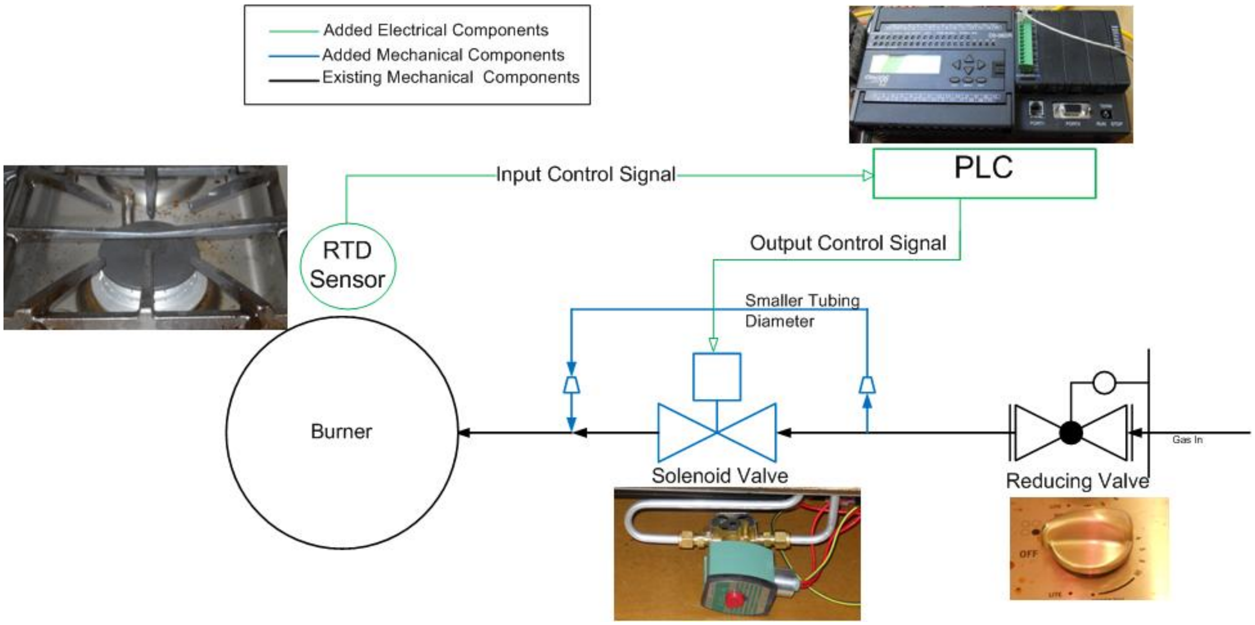


Figure 9: Gas Cooktop Control System Hardware

The control algorithm uses a combination of rate of change and threshold monitoring to decide when to reduce the gas flow to the burner. The controls continuously monitor the temperature of the cookware as soon as the burner is turned on. The rate of change (Δ) of the temperature of the cookware is calculated every 10 seconds. The controller regulates the flow of gas to the burner using the control logic described in Table 3.

Table 3: Gas Cooktop Algorithm Set Points

State Conditions	Output Parameter (Burner Flame)
Sensor Temp < 515˚F	Full
Sensor Temp ≥ 550˚F AND Sensor Δ ≥ 1.0	Reduced
Sensor Temp < 550˚F AND Sensor Δ < 1.0	Full
Sensor Temp ≥ 585˚F	Reduced

The temperature sensor is always activated. The controller is sampling temperature data every second and calculating rate of change of temperature every 10 seconds. The controller only changes the flame of the burner when one of the four condition statements listed in Table 3 is met; otherwise the controller maintains the existing state of the burner flame. If the sensor temperature is less than 515˚F, no control action is needed, and there is no activation of any control valves. When the controller detects that the sensor temperature is 550˚F or above, it compares the calculated slope to the slope set point of 1.0^{o}F/sec; if the slope is greater than 1.0^{o}F/sec, and the sensor measures the temperature to be 550˚F or above, the gas is restricted, and the flame reduces to half (the maximum) input rate. The burner will stay at half-rate until the sensor detects that the cookware temperature is less than 550˚F and the slope is less than 1.0^{o}F/sec. Once both of these conditions are met, the burner's flame returns to the user's set point. After the initial heating of the cookware, the slope tends to level off well below the 1.0^{o}F/sec set point, and the controls will only reduce the burner flame if the cookware temperature rises to, or above, 585˚F. The burner's flame returns to the user's set point again as the temperature of the cookware drops below 585˚F.

2.3 Glass Ceramic Cooktop

The temperature sensor in the Glass ceramic cooktop is positioned below the glass ceramic so that there is nothing visible on the exterior cooktop surface. The platinum RTD sensor is located in the center of the element and is held against the ceramic with a spring force (that is similar to how the element itself is pressed against the glass ceramic). A schematic and photograph of the sensor is shown in Figure 10. A schematic of the control system is shown in Figure 11.

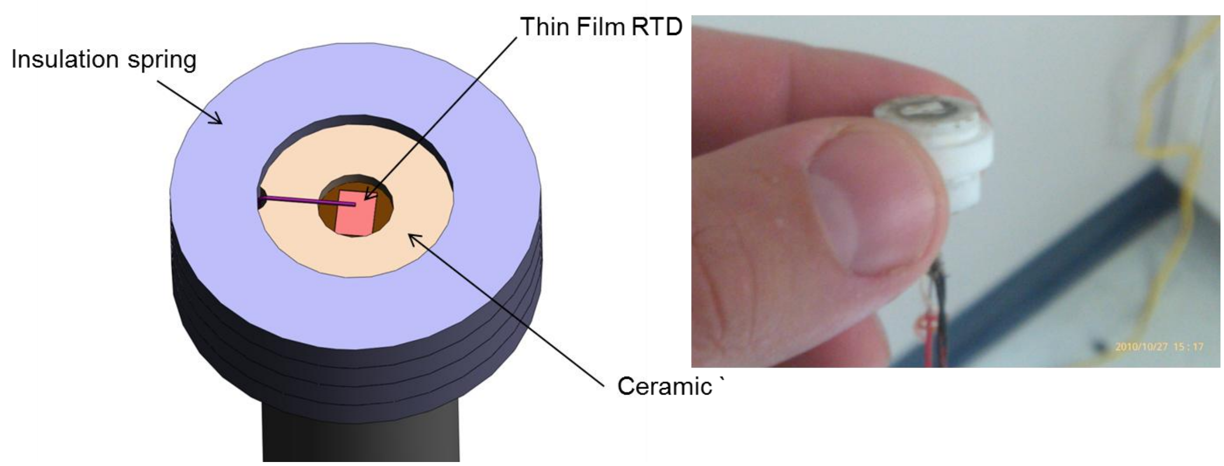


Figure 10: RTD Sensor Used Under Glass Ceramic Cooktop

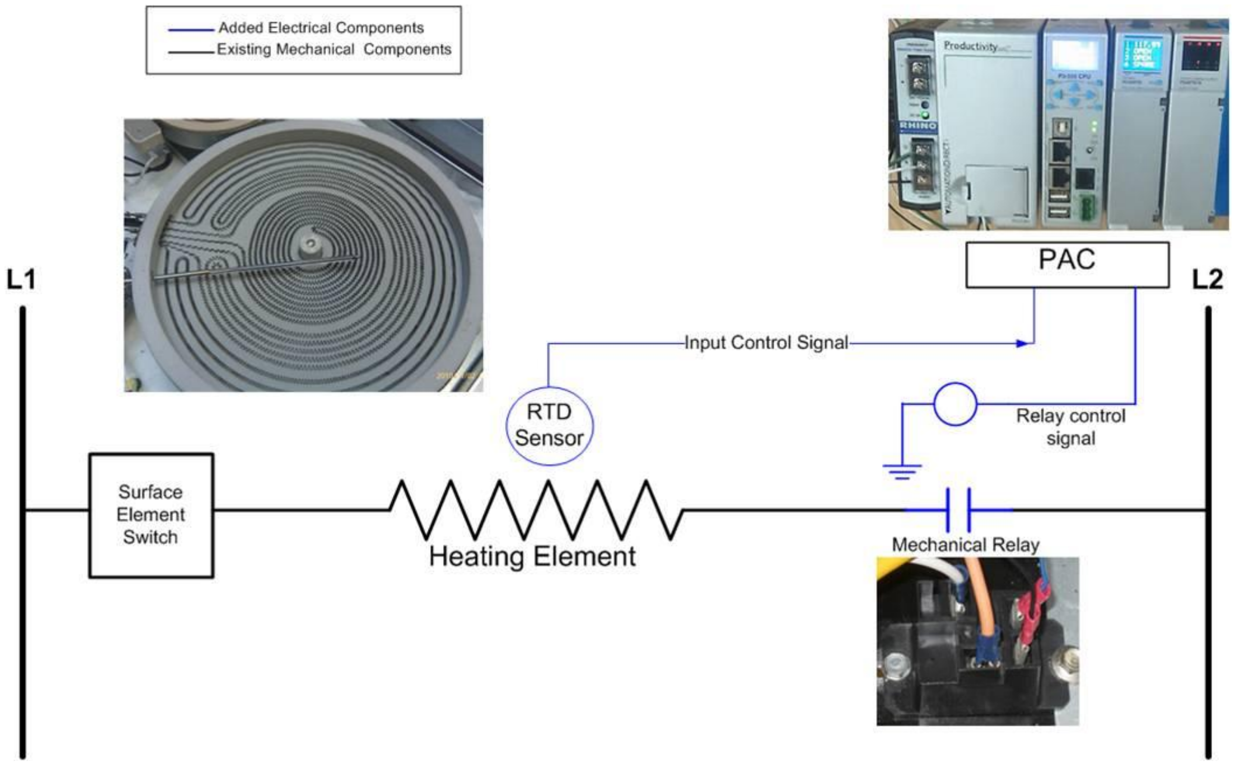


Figure 11: Glass Ceramic Cooktop Control Hardware

The control algorithm uses a combination of rate of change and threshold monitoring to decide when to remove power to the element. The controls continuously monitor the glass ceramic temperature. The rate of change (Δ) of the measured temperature is calculated every ten seconds. The duty cycle of the heating element is established based on specific combinations of measured temperature and change in temperature, as defined in Figure 12.

If the measured temperature exceeds 440°F AND the rate of change of temperature is greater than 1.65°F per second, then the duty cycle of the element is limited to 18 second on, 12 seconds off. This same duty cycle is also imposed if the measured temperature is between 550 and 572°F, but the rate of change of temperature is greater than 0.9°F per second.

The controller maintains the duty cycle at this defined level (called "Duty 1"), unless the temperature remains over 500°F, then the duty cycle is reduced to "Duty 2", which is 12 seconds on, and 18 seconds off.

Finally, if the measured temperature is falling, but the measured temperature is below 730°F, the element is pulsed "on" for 10 seconds to prevent the pan from falling to excessively low temperatures that will not effectively cook the food.

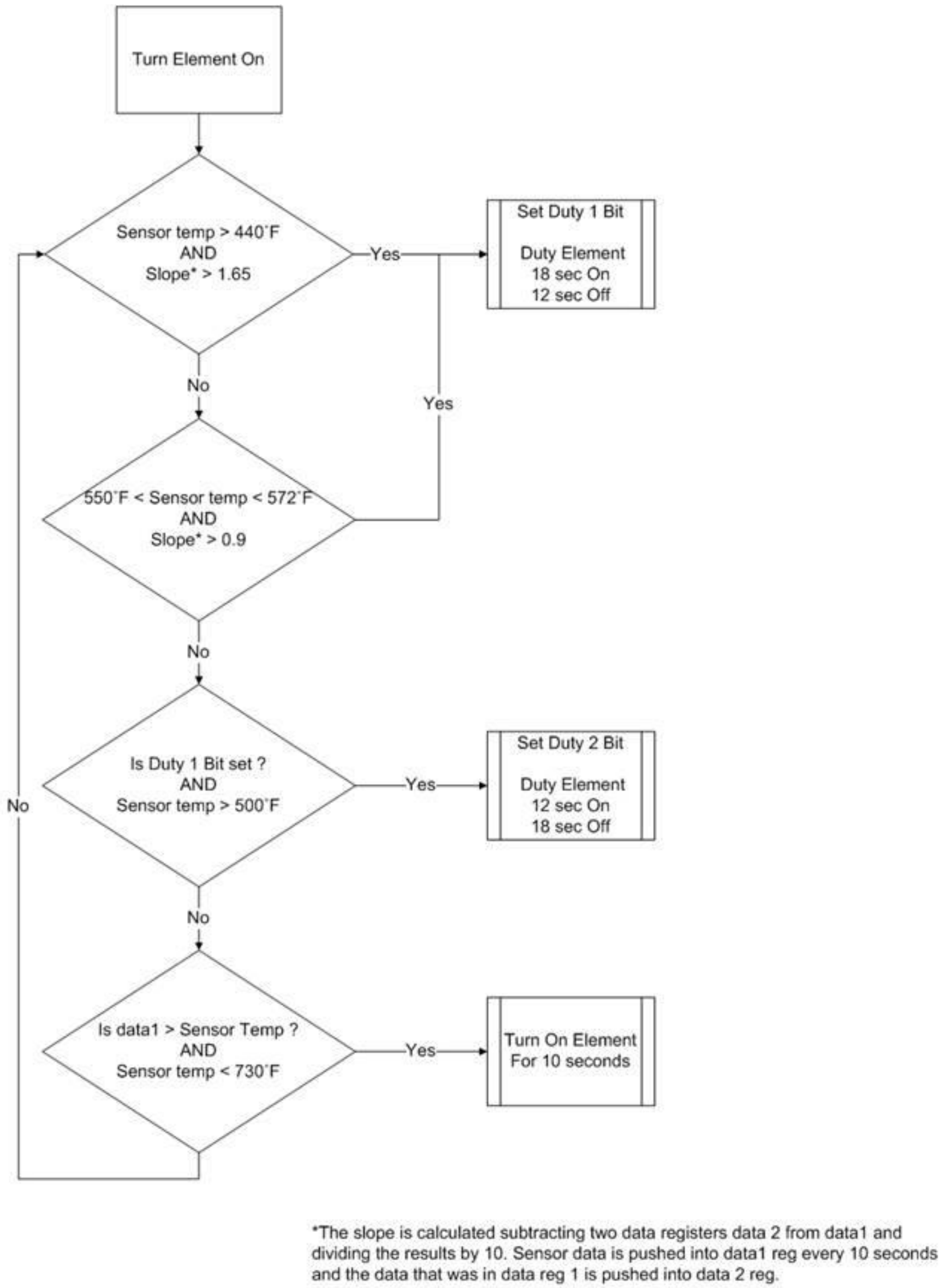


Figure 12: Glass Ceramic Cooktop Algorithm Set Points

2.4 Induction Cooktop

The induction cooktop already incorporates a temperature sensor and extensive electronics for system control, as shown in Figure 13. The region under the cooktop glass ceramic does not get hot (as it does with the standard glass ceramic cooktop). Therefore, the existing RTD is measuring the heat that comes off the pan (indirectly). It is clear that temperature limits are already implemented in the manufacturer's control algorithm, and it may be that modification of set points can provide the necessary fire protection.

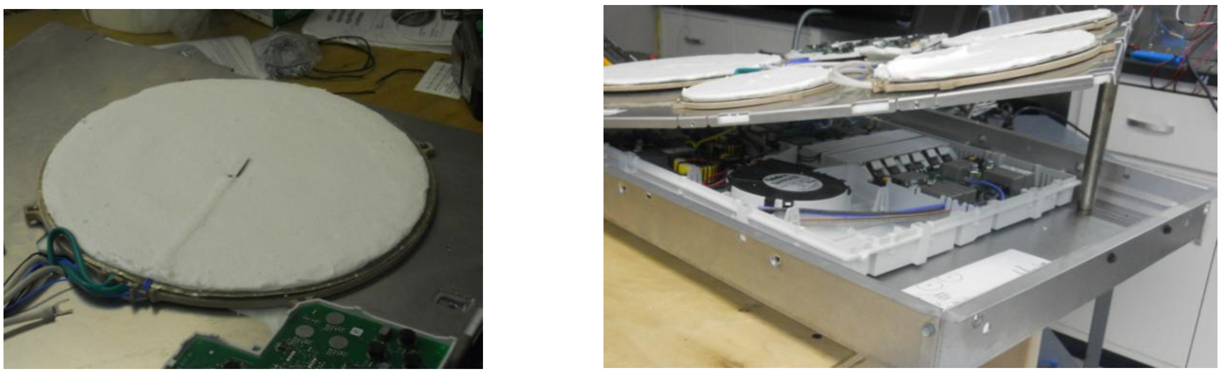


Figure 13: Induction Element with RTD, Induction Cooktop Electronics

3. Test Results

Algorithms were developed that prevented pan-bottom temperatures from exceeding 700˚F, while passing all cooking tests listed in Table 1 for all modified cooktops (gas, electric coil, glass ceramic electric) with all pan materials tested. Summary of results by cooktop type is provided below. Additional detailed results are provided in Appendices A - C.

3.1 Electric Coil Cooktop

The electric coil cooktop was tested at both 208V and 240V. Initial development was done at the facility voltage of 208V, but it was decided to evaluate the system at 204V because, by far, that is the most common nominal voltage for residences. The algorithm developed provides consistent results at both cooktop input voltages. The results are summarized below.

3.1.1 Pan Temperature Limitation

The controls were effective at limiting pan-bottom temperature to below 700˚F, the target temperature for reducing the likelihood of raising food in the pan to its ignition temperature. The ability of the control to limit pan temperatures to the threshold is shown below for three pan materials: aluminum, cast iron, and stainless steel. The data show that pan-bottom temperatures are limited to the set point with the use of the control, while they rise beyond the threshold without the controls. In these tests, the element was set to "high" and an empty skillet of the indicated material was set on the element for the duration of the test. The indicated temperatures were measured in the pan itself, using a thermocouple welded to the center of the pan.

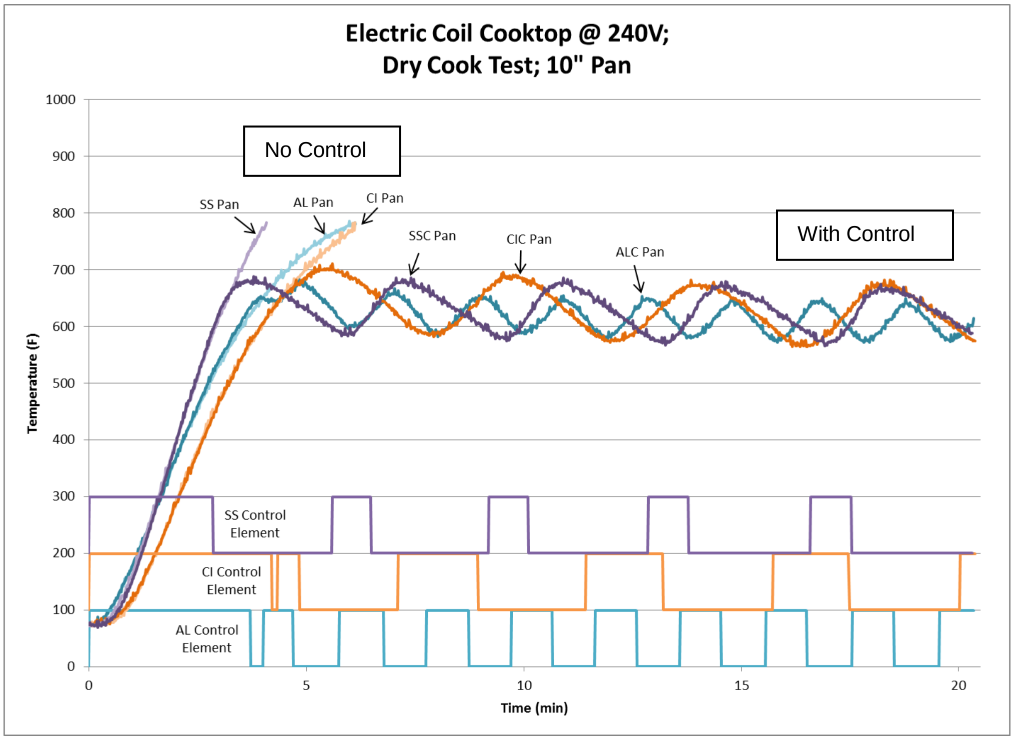


Figure 14: Dry Cook Results using the Electric Coil Cooktop

3.1.2 Cooking Performance

Cooking performance with the controls active was excellent, not exceeding the 15 percent increase in cooking times as set forth in the TFPGs 8.1. Quality of cooked foods was indistinguishable between controlled versus non-controlled cooking operations. Results are summarized here.

Boiling

A comparison of boil times with and without the pan-bottom temperature control is shown in Figure 15. The use of the pan-bottom temperature control did not significantly increase heating times.

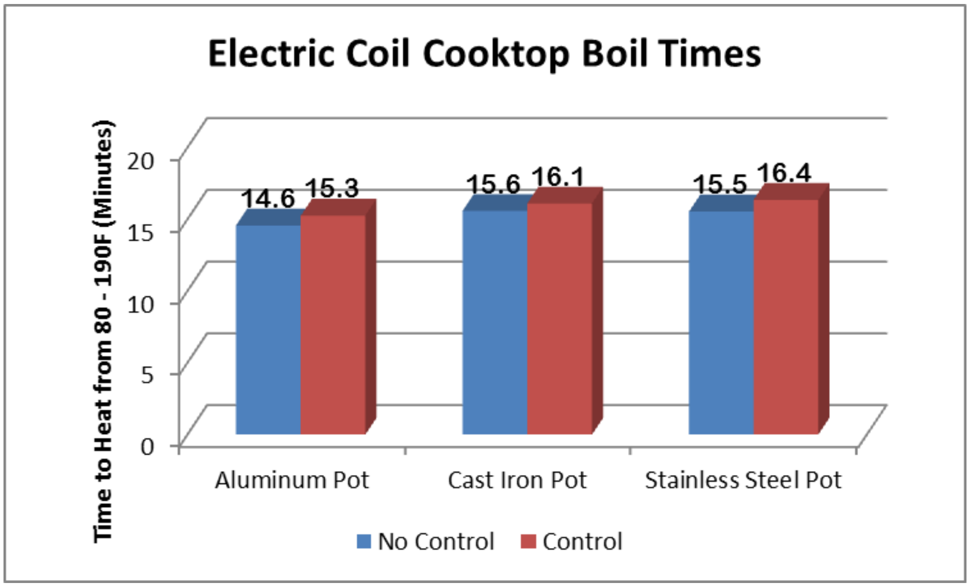


Figure 15: Water Heating Time Comparison, Electric Coil Cooktop

Searing and Blackening

With the cooking controls implemented, the cooktop was able to sear and blacken very effectively. A few sample results are shown below. Details are included in Appendix D.

The steaks were seared deeply on both sides. Even at these hot cooking temperatures, the controls did not restrict heat input at any point during the steak testing. This test is consistent with the expectation that pan temperatures needed for a good sear of the steak are below the temperatures at which we would expect a fire risk.

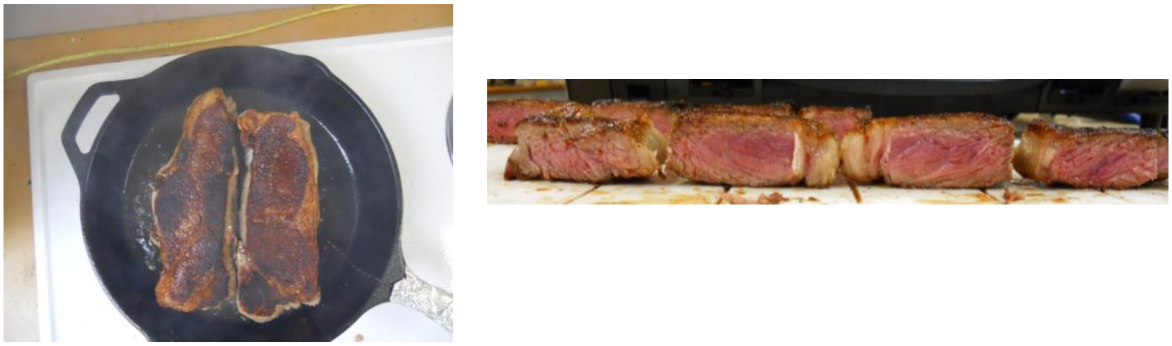


Figure 16: Steaks Cooked in Cast Iron Pan on Electric Coil Cooktop with Controls Activated

Similar results were observed with blackening chicken and cooking vegetables, as photographed in Figure 17 and Figure 18.

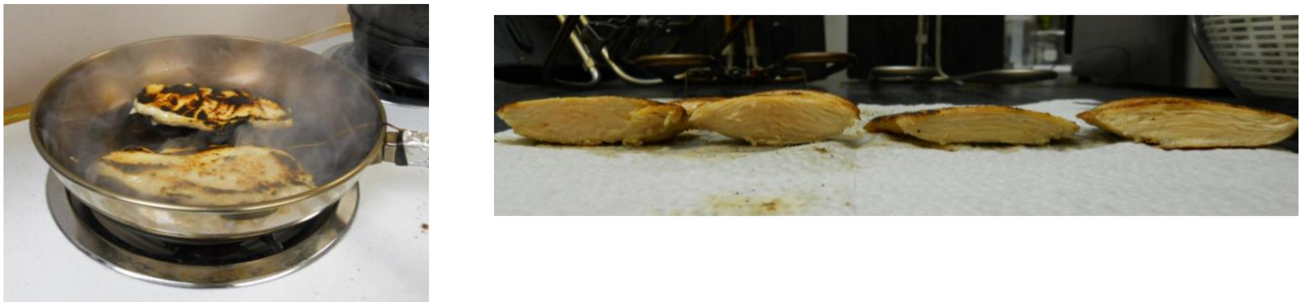


Figure 17: Blackened Chicken Cooked on Electric Coil Cooktop with Controls Activated

Stir fry of beef and vegetables provided good caramelization as desired with the controls activated, as shown in Figure 18, below.

Figure 18: Stir Fry Cooked on Electric Coil Cooktop with Controls Activated

Summary

The electric cooktop controls restricted the pan-bottom temperature to below 700˚F without adversely affecting any cooking function, including boiling, long boiling, cooking pasta, simmering tomato sauce, and searing, blackening or frying various foods.

3.2 Gas Cooktop

The largest burner on the gas cooktop was implemented with the sensor and controls. The dry cook tests illustrate the ability of the controls to prevent the pan temperature from exceeding 700˚F. In all other aspects of testing, the results were the same, with and without the controls activated. These results are summarized below and described in detail in Appendix E.

3.2.1 Pan Temperature Limitation

The controls were effective at limiting pan-bottom temperature to below 700˚F. The ability of the control to limit pan temperatures to the threshold is shown below for three pan materials: aluminum, cast iron, and stainless steel. The data as illustrated in Figure 19, shows that pan-bottom temperatures are limited to the set point with the use of the control, while they rise beyond the threshold without the controls. In these tests, the element was set to "high" and an empty skillet of the indicated material was set on the element for the duration of the test. The indicated temperatures were measured in the pan itself using a thermocouple welded to the center of the pan.

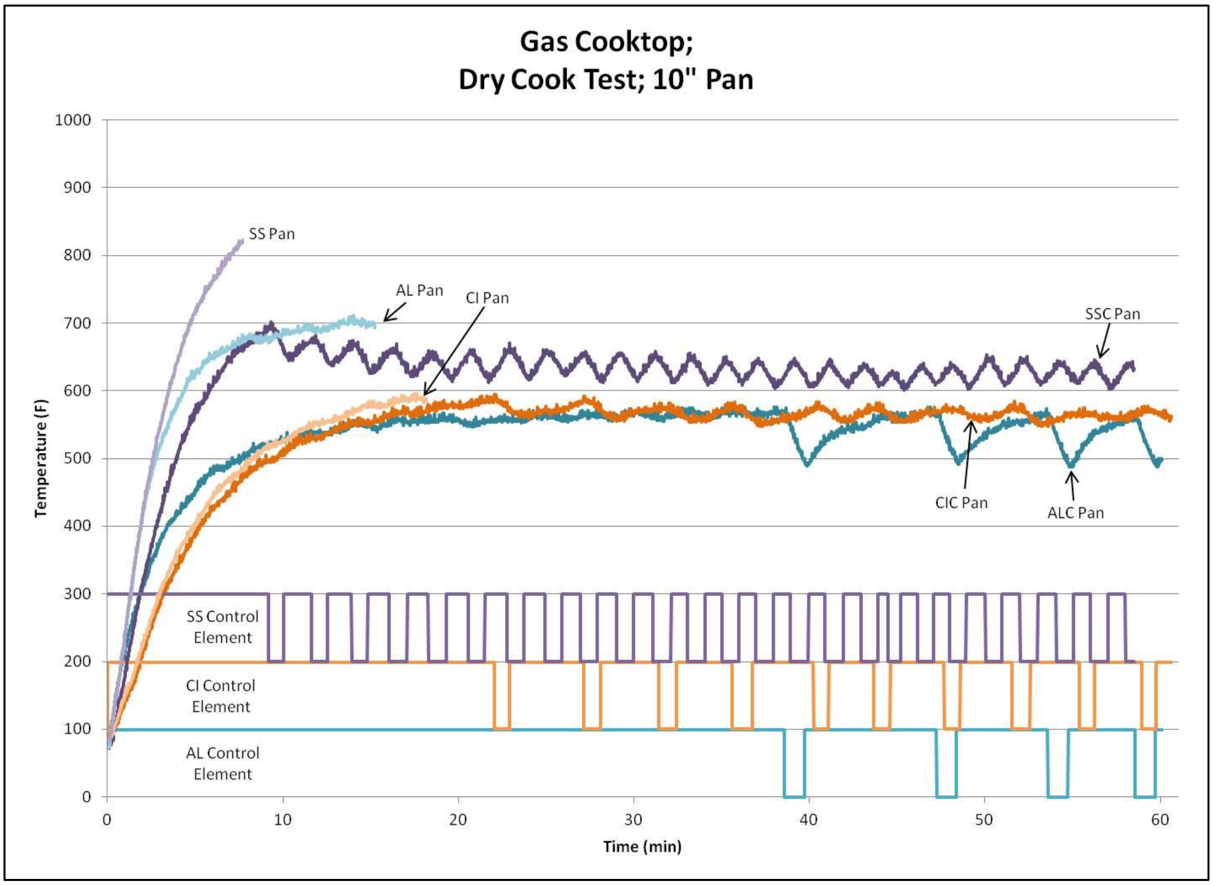


Figure 19: Dry Cook Results Using the Gas Cooktop with Controls Activated

3.2.2 Cooking Performance

Boiling

A comparison of boil times with and without the pan-bottom temperature control is shown in Figure 20. The use of the pan-bottom temperature control did not significantly increase heating times, well within the 15 percent increase prescribed in Section 8.1 of the TFPGs.

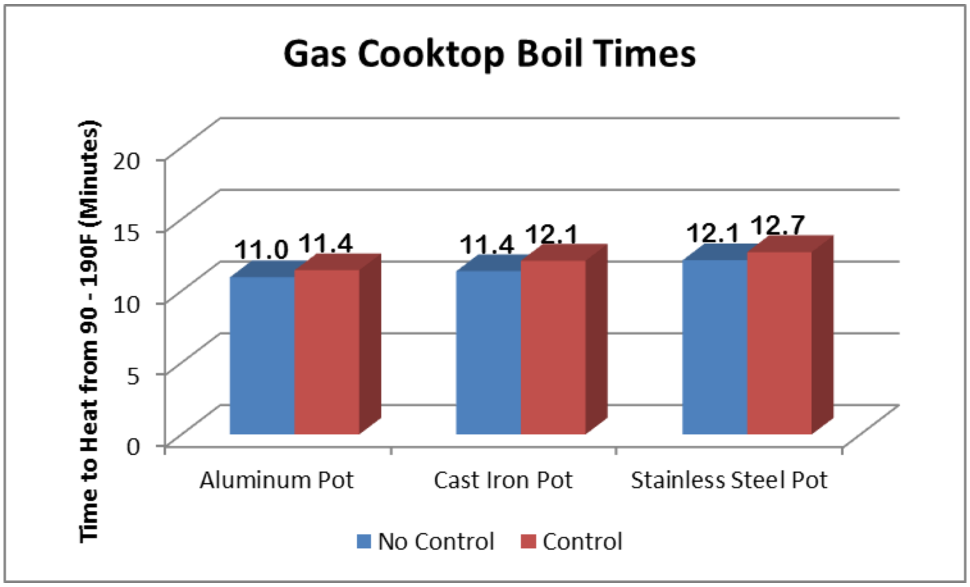


Figure 20: Gas Cooktop – Water Heating Time Comparison

Searing, Blackening, Stir Frying

The gas cooktop controls did not inhibit searing, blackening or stir-frying, as illustrated below and detailed in Appendix E. Each of the figures below compares the measured pan-bottom temperature (using a thermocouple imbedded in the pan) with and without controls activated. The results for various pan types and cooking methods illustrate that the controls do not interfere with standard cooking. Nor do pan temperatures reach levels during standard cooking methods that cause the controls to limit heat input and ultimately disturb pan temperatures.

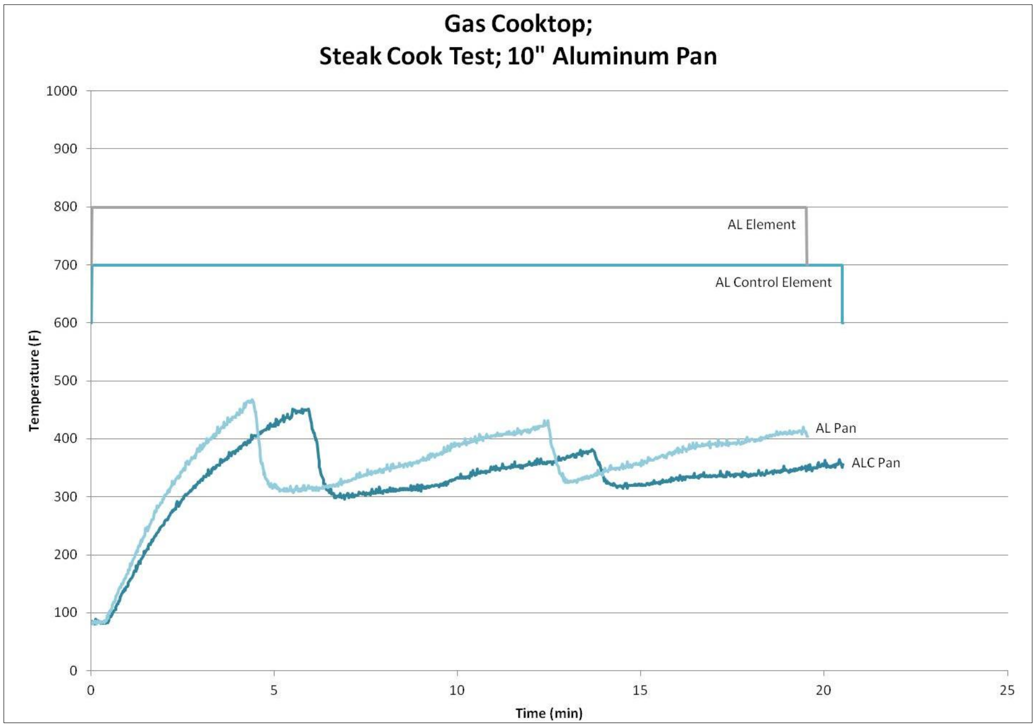


Figure 21: Gas Cooktop – Steak Searing with Aluminum Pan

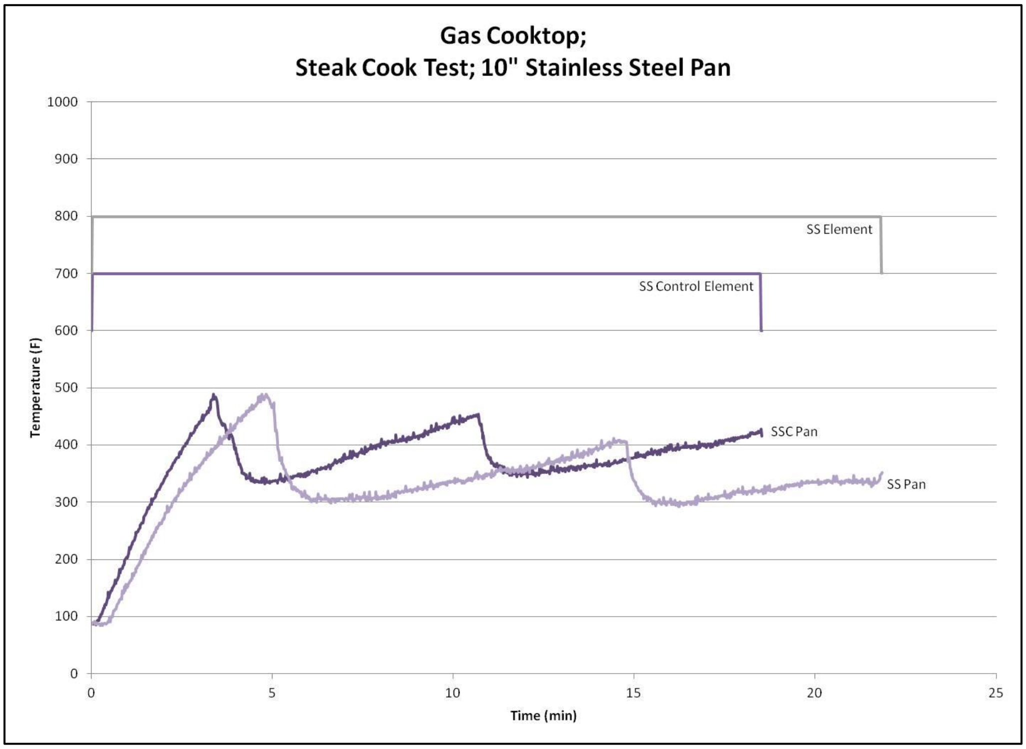


Figure 22: Gas Cooktop – Steak Searing with Stainless Steel Pan

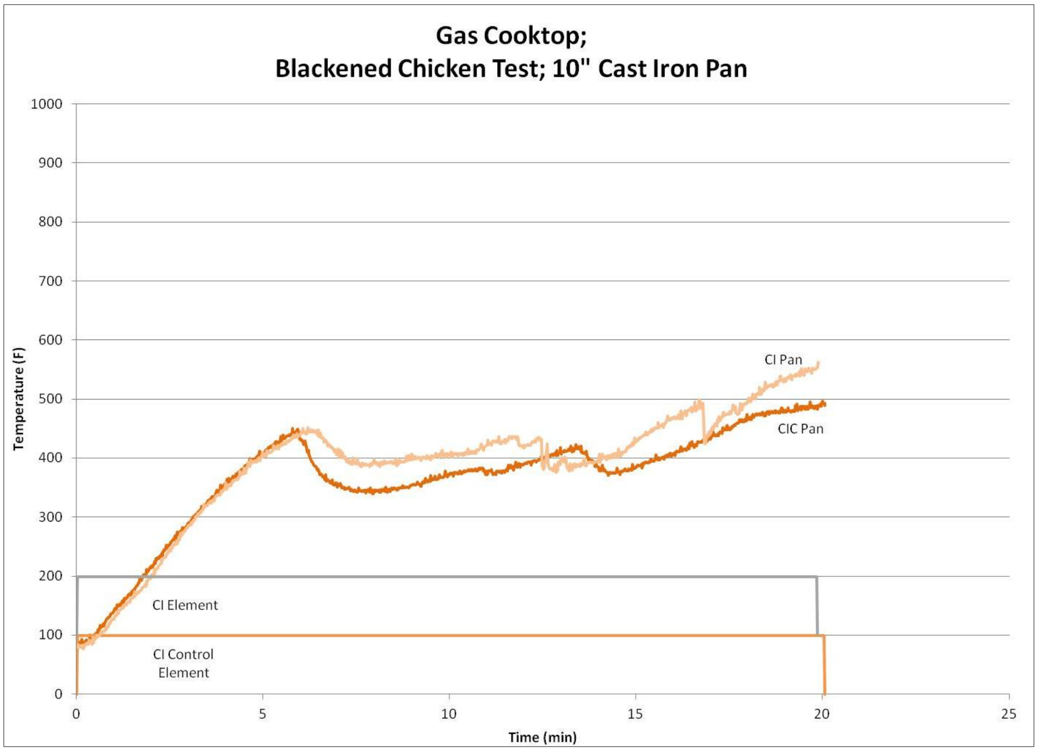


Figure 23: Gas Cooktop – Blackening Chicken in Cast Iron Pan

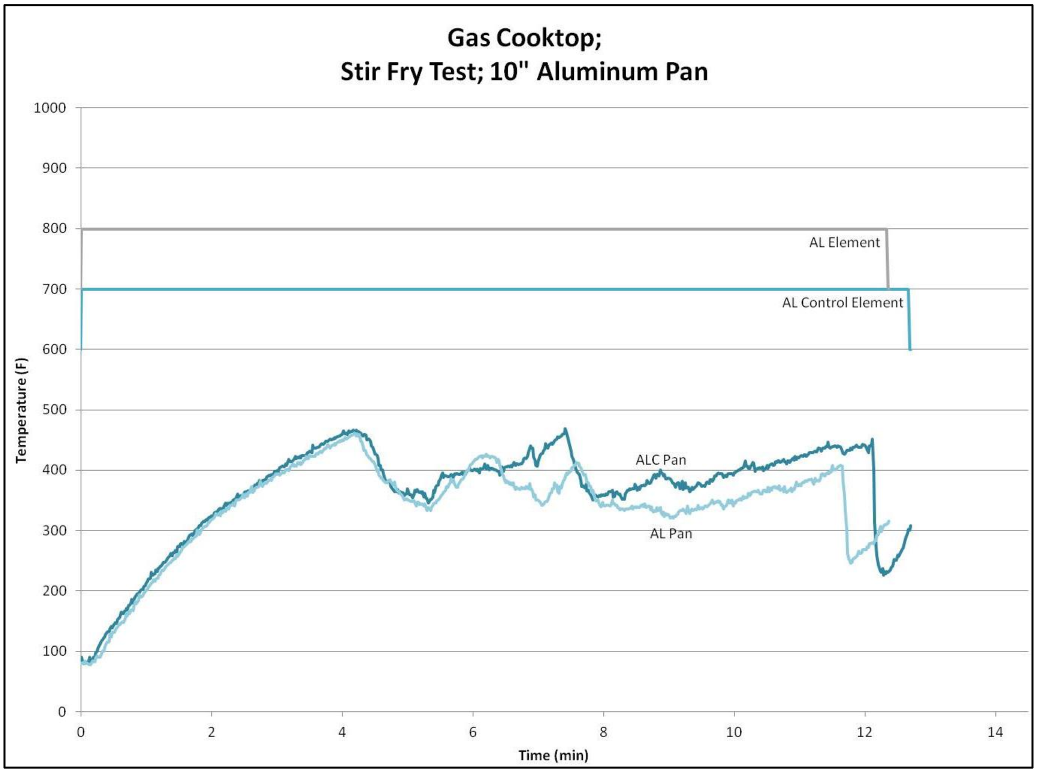


Figure 24: Gas Cooktop – Stir-Frying Vegetables in Aluminum Pan

Summary

The controls implemented in the gas cooktop limited pan temperatures to below 700˚F without impact on cooking function or performance.

3.3 Glass Ceramic Cooktop

The glass ceramic cooktop was tested at both 208V and 240V, as explained in Section 3.1 for the electric coil element cooktop. The algorithm developed provides consistent results at both cooktop input voltages. The results for 240V testing are summarized below.

3.3.1 Pan Temperature Limitation

The controls were effective at limiting pan bottom temperature to below 700˚F. The ability of the control to limit pan temperatures to the threshold is shown below for three pan materials: aluminum, cast iron, and stainless steel. The data show that pan-bottom temperatures are limited to the set point with the use of the control, while they rise beyond the threshold without the controls. In these "dry-cook" tests, the element was set to "high" and an empty skillet of the indicated material was set on the element for the duration of the test. The indicated temperatures were measured in the pan itself, using a thermocouple welded to the center of the pan.

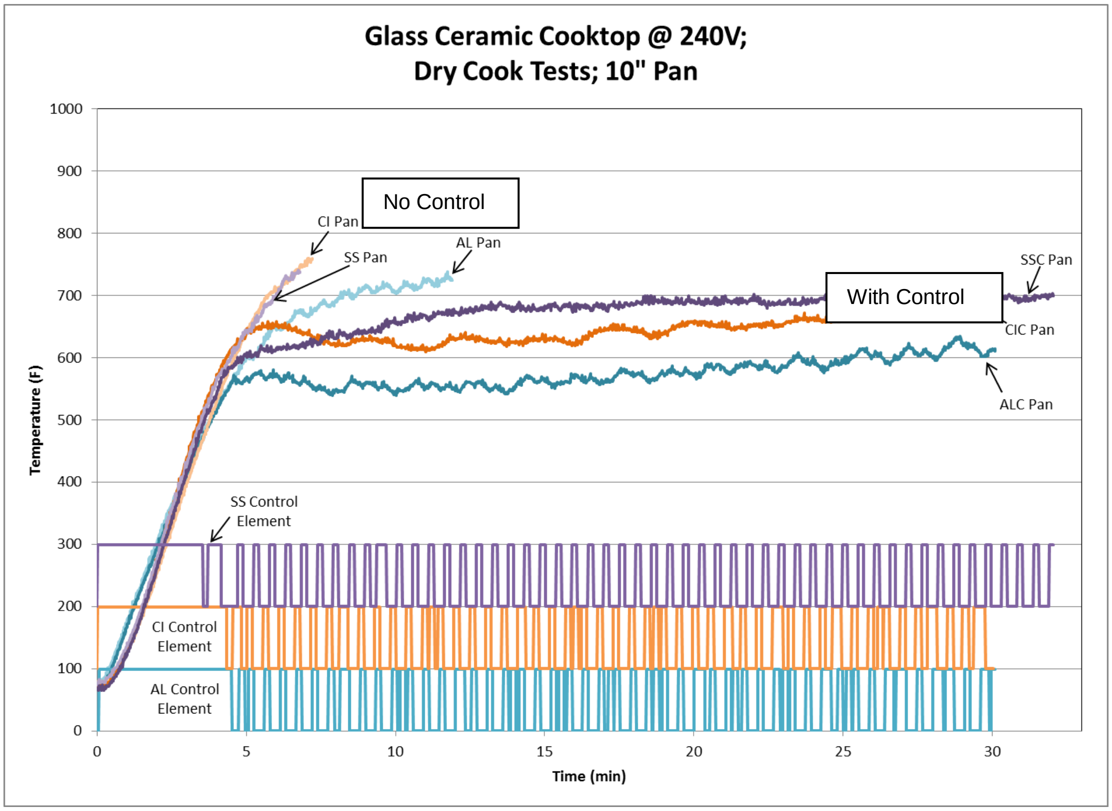


Figure 25: Glass Ceramic Cooktop – "Dry-Cook" Tests for Pan Temperature Limitation

The ability of the temperature controller to limit the pan temperature is not limited to initial heat-up. As shown in Figure 26, the controller limited the pan temperature of a sauté pan after a steak was cooked and the grease-filled pan remained on the cooktop. Pan temperatures were limited to acceptable levels.

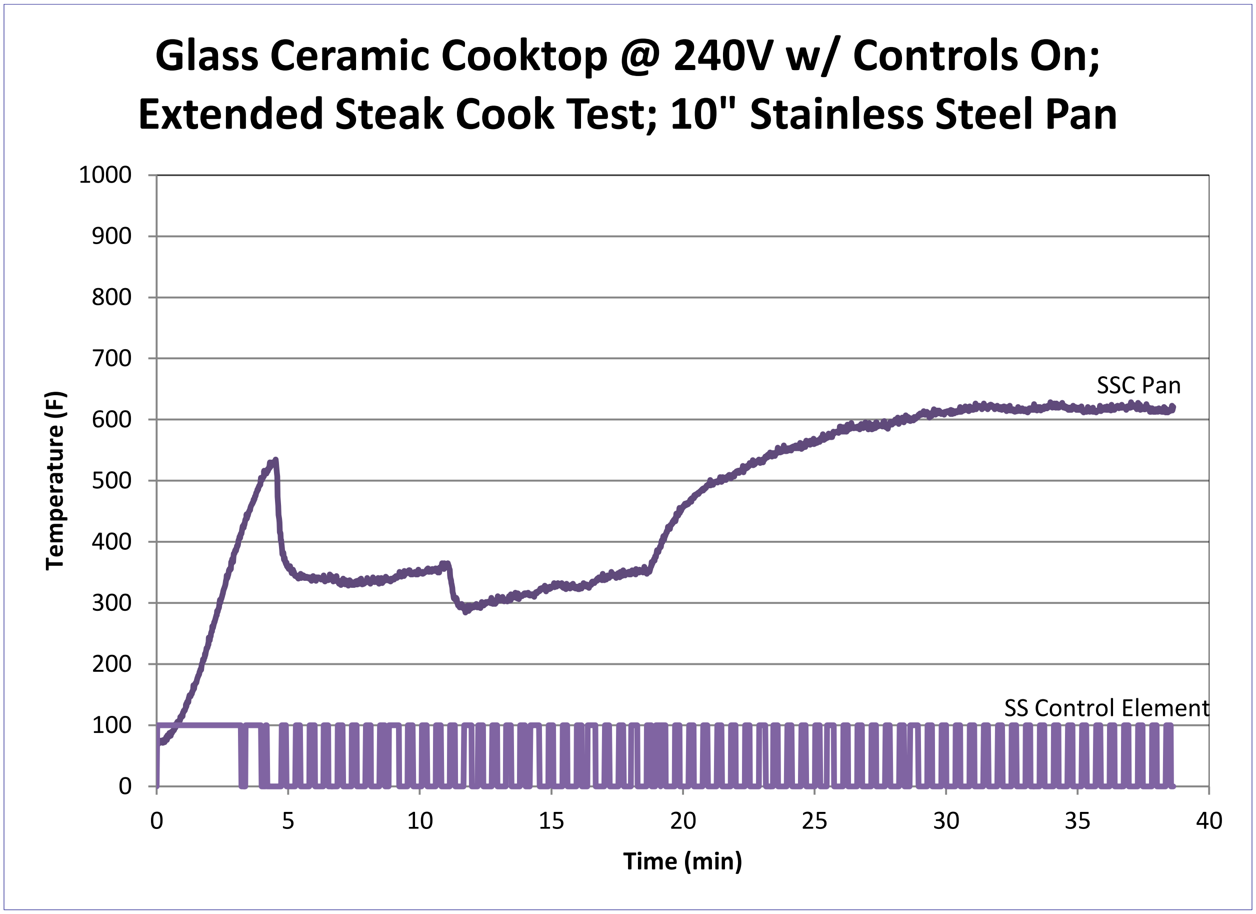


Figure 26: Temperature Limitation on Glass Ceramic Cooktop after Cooking Steak

3.3.2 Cooking Performance

Cooking performance with the controls active was excellent.

Boiling

A comparison of boil times with and without the pan bottom temperature control is shown in Figure 27. The use of the pan bottom temperature control did not increase heating times significantly.

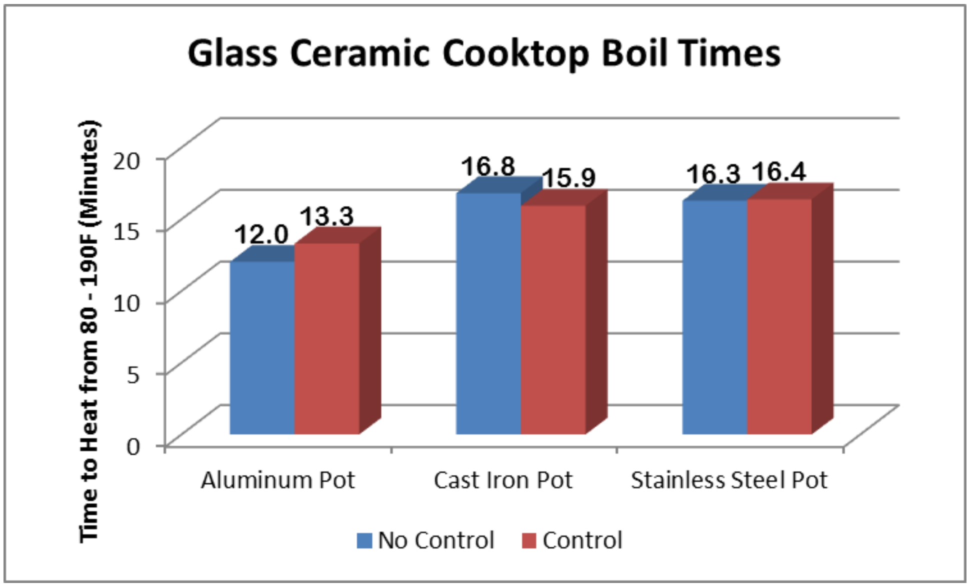
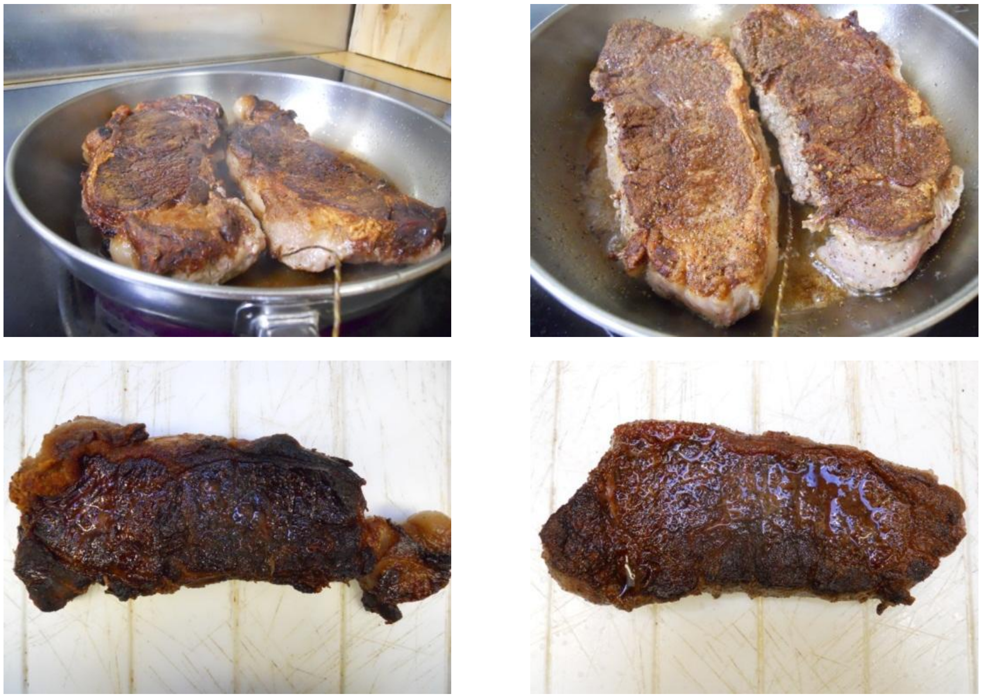


Figure 27: Glass Ceramic Cooktop – Water Heating Time Comparison,

Searing, Blackening, and Stir-Frying

Examples of the steak searing, chicken blackening, and stir-frying results are shown below. Detailed results are shown in Appendix F. The algorithm was able to maintain desired cooking performance in all pans and cooking methods tested.

Stainless Steel, No Controls | Stainless Steel w/ Controls



Aluminum, No Controls | Aluminum w/ Controls

Figure 28: Glass Ceramic Cooktop – Steaks Cooked in Stainless Steel and Aluminum Pans with and without Controls on

Similar results were observed with blackening chicken and cooking vegetables.

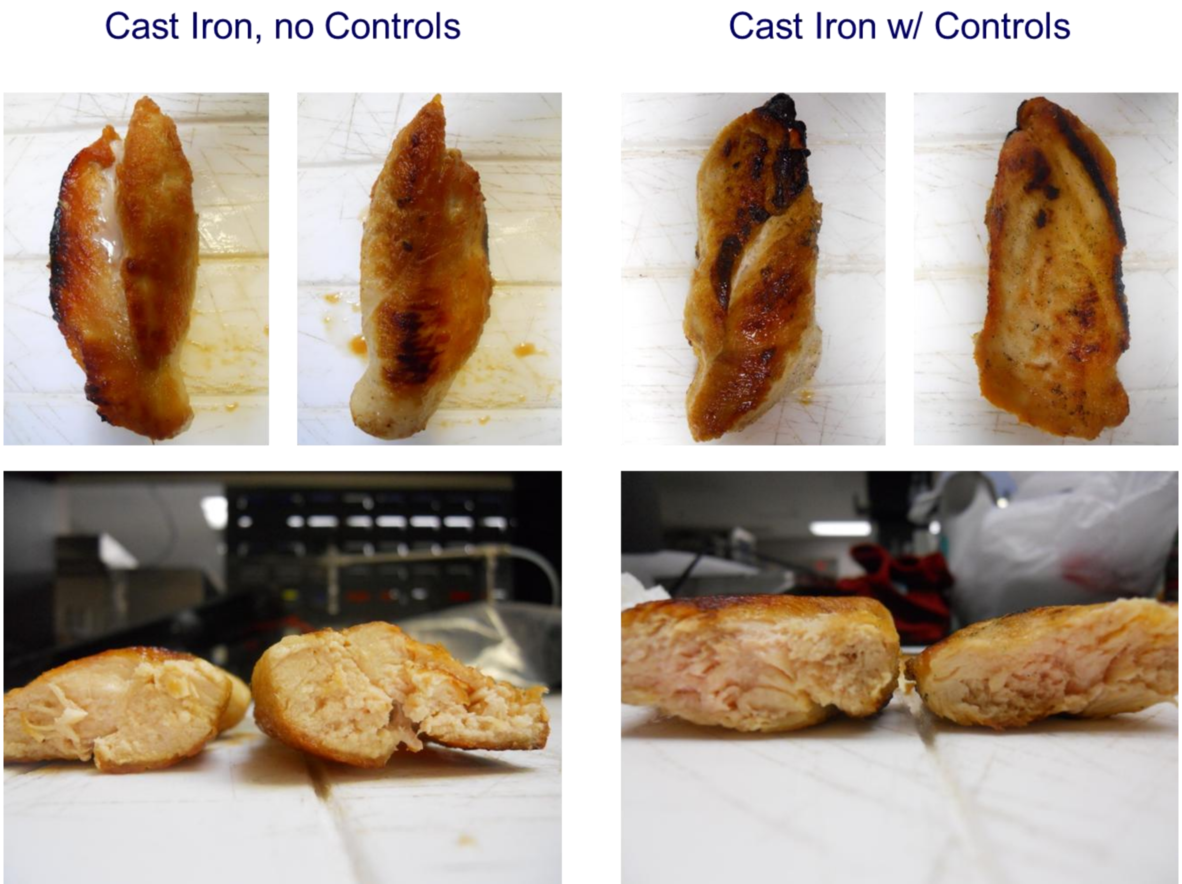


Figure 29: Blackened Chicken Cooked on Glass Ceramic Cooktop with Cast Iron Pan

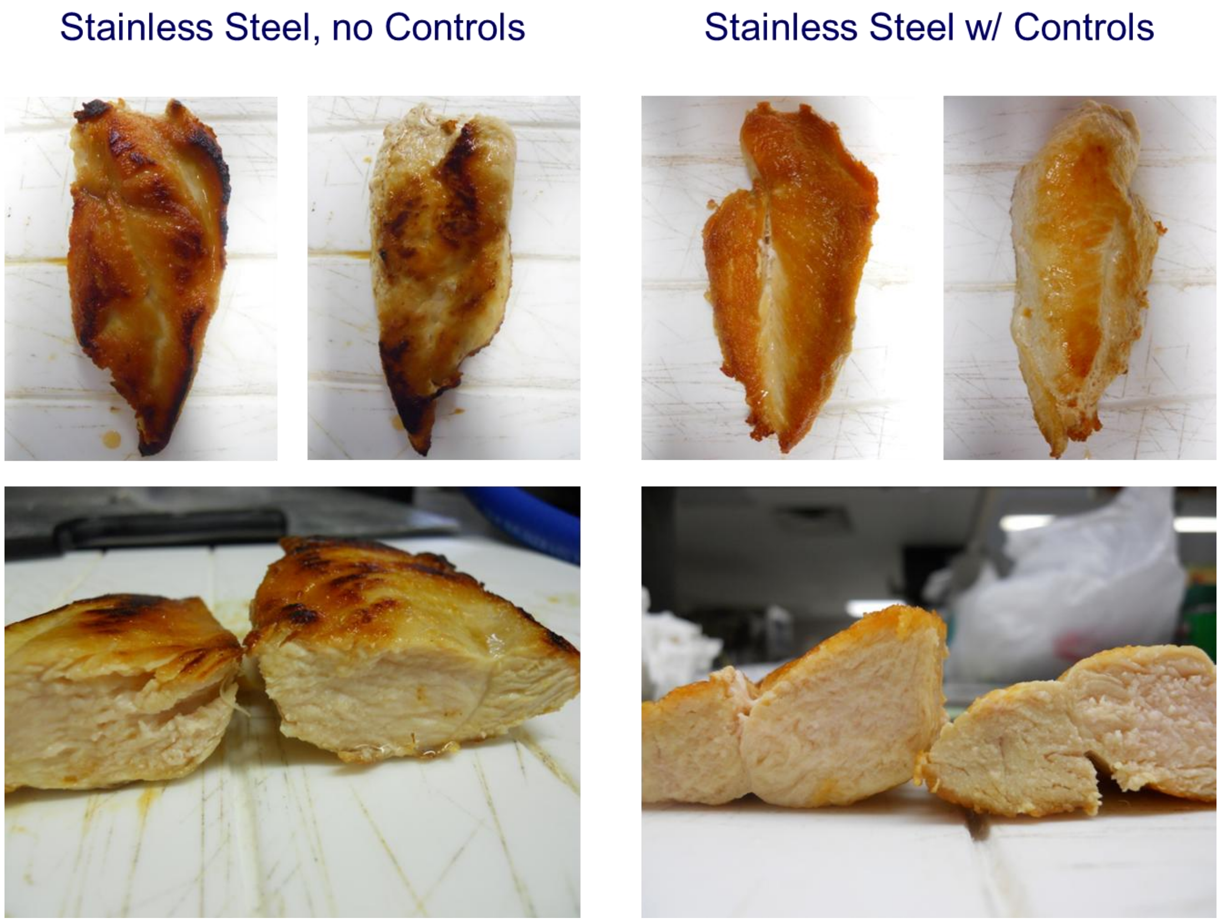


Figure 30: Blackened Chicken Cooked on Glass Ceramic Cooktop with Stainless Steel Pan

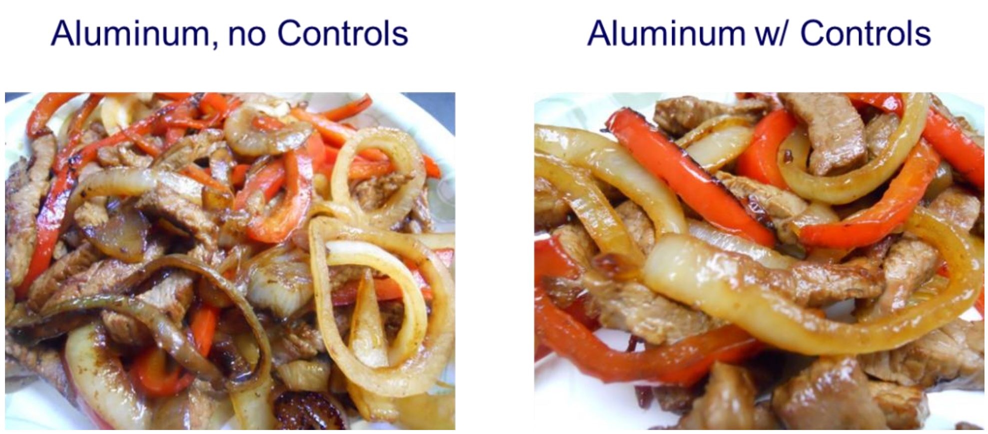


Figure 31: Stir Fry Cooked on Glass Ceramic Cooktop Using an Aluminum Pan

Figure 32: Stir-Fry Cooked on Glass Ceramic Cooktop with Stainless Steel Pan

Summary

The controls implemented in the glass ceramic cooktop limited pan temperatures to below 700˚F without significant impact on cooking function or performance.

3.4 Induction Cooktop

The induction cooktop tested has an RTD sensor embedded in the cooktop. The system includes controls that cycle the induction element in response to this temperature, as shown in Figure 33.

Aluminum cookware is not made of a ferrous metal and will not work with an induction cooktop. The induction system control software and hardware was too complex to modify for this program, but we believe that a modification of the existing temperature control software should allow maximum pan temperature to be controlled.

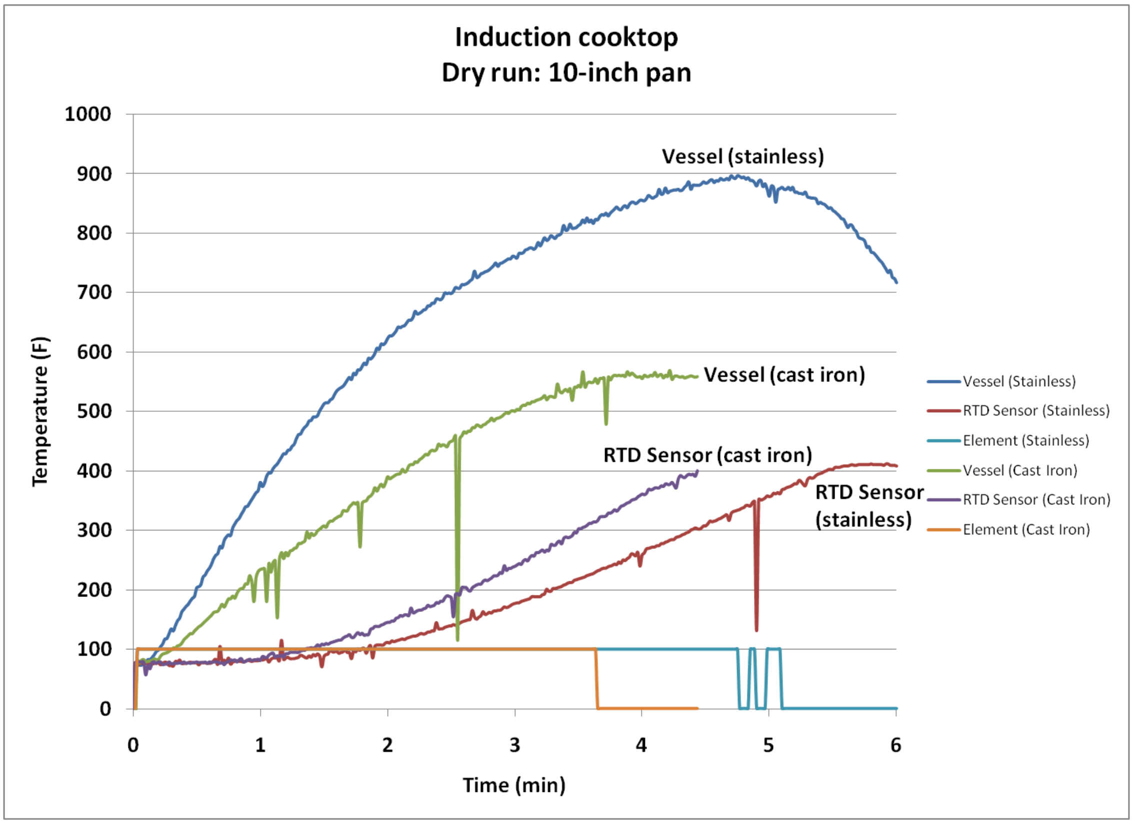


Figure 33: Existing Induction Cooktop Controls React to Pan Temperature

Additional Comments on Testing All Cooktops

No formal durability tests were conducted on any of the sensor systems. However, the cooktops were tested aggressively for 6 months at a range of operating conditions. During this time, none of the sensors were replaced, repaired, or recalibrated. The exposed sensors (in the electric coil and gas cooktops) were cleaned when they appeared to be dirty.

We recognized that there would need to be some modifications to the sensor designs that were used in this testing program in order to address the requirements of the TFPGs and other needs for commercial implementation. The design changes incorporated into the Feasibility Analysis included the following:

- Use a common sensor platform for both the gas and the electric coil cooktop.
- Minimize the throw of the spring in the sensor to meet reliability goals and reduce risk of damage to the sensor.
- Round the top of the sensor to address durability requirement of TFPG 7.3.
- Use a thermistor instead of an RTD sensor for the exposed sensor because the temperature range is compatible with thermistor use.

- Place the sensor as shown in Section 4 so that it is not removed from the cooktop for cleaning and does not interfere in any way with the removal of the grate, the burner, or the electric coil element. In this configuration, the requirements of TFPGs 7.2 and 7.4 are addressed.

4. Feasibility Analysis

The pan temperature-limiting sensor and control systems that were implemented in the electric coil, gas, and glass ceramic cooktops all maintained pan temperatures below the threshold limit of 700°F. This temperature limiting control was effective on initial heat-up (dry cook tests), as well as for a boil-dry situation or a condition in which cooking was completed, food was removed, but the hot, empty pan was left on the element/burner.

The algorithms were refined until all cooking processes tested provided results that were equivalent to the cooking performance without the controls activated. All boil times with the controls were within the standard deviation of the boil test. Cooking performance with the controls in sear, blacken, simmer, and sauté mode was all equivalent to non-control tests. All cooking and temperature-limiting tests were conducted with aluminum, cast-iron, and stainless steel pans of various configurations. This system clearly overcomes the problems from earlier fire mitigation studies that used a pan contact sensor as a temperature-limiting control. The added sophistication of the control algorithms allows the pans to maintain required cooking temperatures without reaching dangerous ignition temperatures.

There are Japanese units [redacted] and Chinese units [redacted] with pa-contact sensors that are already in mass production. Earlier versions of the Japanese cook stoves performed well when evaluated against the TFPGs by UL researches, even though the design was not optimized to pass them (*Underwriters Laboratories Inc.; Report of Research on Cooktop Pan Contact Temperature Sensor Technical Feasibility Performance Goals; August 12, 2004)*.

There are additional development steps required to implement the controls commercially. These steps are listed below:

- Determine need for controls in smaller elements.
  - Power levels on small elements may be below levels that will lead to ignition of foods in pan.
- Develop self-check algorithms to ensure that sensor remains operational and calibrated after years of use.
- Conduct durability tests on spring-loaded sensor in accordance with TFPG 7.3.
- Design for manufacturability and cost reduction.

The cost to implement these controls is estimated Sections 4.1 through 4.4 below. In all cases, as a worst case, it is assumed that the sensor and control system are required on four hobs. Further testing and analysis may demonstrate that the sensors are not needed on the smaller hobs because their input power is limited, and the risk of exceeding the threshold pan-bottom temperature is quite low.

The costs listed are estimated component costs only. These costs do not include labor. They do not include non-recurring engineering costs. They do not include tooling costs or other non-recurring costs associated with modification of assembly lines or training of workers. These cost estimates do not consider broader issues, such as life-cycle costs or the societal benefits of reducing injury, death, and property loss from cooktop fires. These cost estimates include only components, materials, and parts costs in volumes of more than 100,000 units per year.

While the pan-bottom temperature-limiting control is envisioned as a means of reducing cooking fires, it is clearly a method that can enhance coking performance by mitigating the reisk of unintentionally overheating or burning foods. While the technology will have the intended outcome of reducing fires, it does not need to be implemented as a safety control. It can be implemented as a performance feature.

4.1 Electric Coil Implementation Costs

The elements of the sensor system embedded in the electric coil cooktop are illustrated are illustrated in Figure 34. Details of the sensor construction are shown in Figure 35. The components needed for implementation of the pan-temperature-limiting sensor and controls are listed (with cost estimates) in Table 4.

Figure 34: Schematic of Electric Coil Cooktop with Embedded Sensor

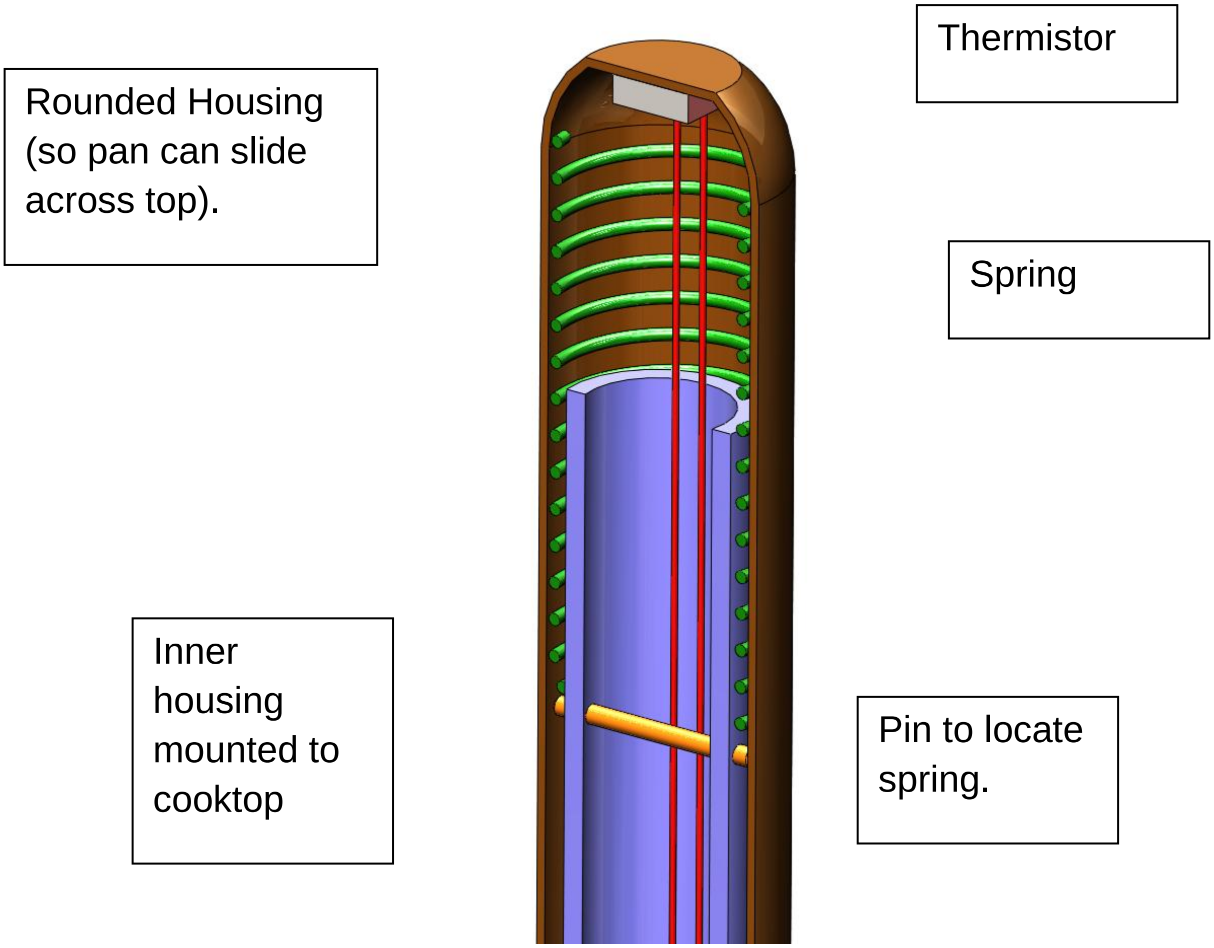


Figure 35: Details of Sensor Construction

Table 4: Electric Coil Cooktop Implementation Cost

Pan Temperature Limiting Component	Estimated Cost at Volumes of >100,000	Number of Components Needed	Total Cost
Thermistor	$0.5	4	$2
Spring-loaded Housing (drawn/stamped cap, inner tube, outer (thick-walled) tube and spring)	$1	4	$4
Sensor Mounting Bracket and Hardware	$0.5	4	$2
Control Board	$4	1	$4
Mechanical Relay	$3	4	$12
Wiring	$1.5	4	$6
Total Cost of All Components			$30

4.2 Gas Cooktop Implementation Costs

The elements of the sensor system embedded in the gas cooktop are illustrated in Figure 36. The sensor construction would be the same as shown in Figure 35. The components needed for implementation of the pan-temperature-limiting sensor and controls are listed (with cost estimates) in Table 5.

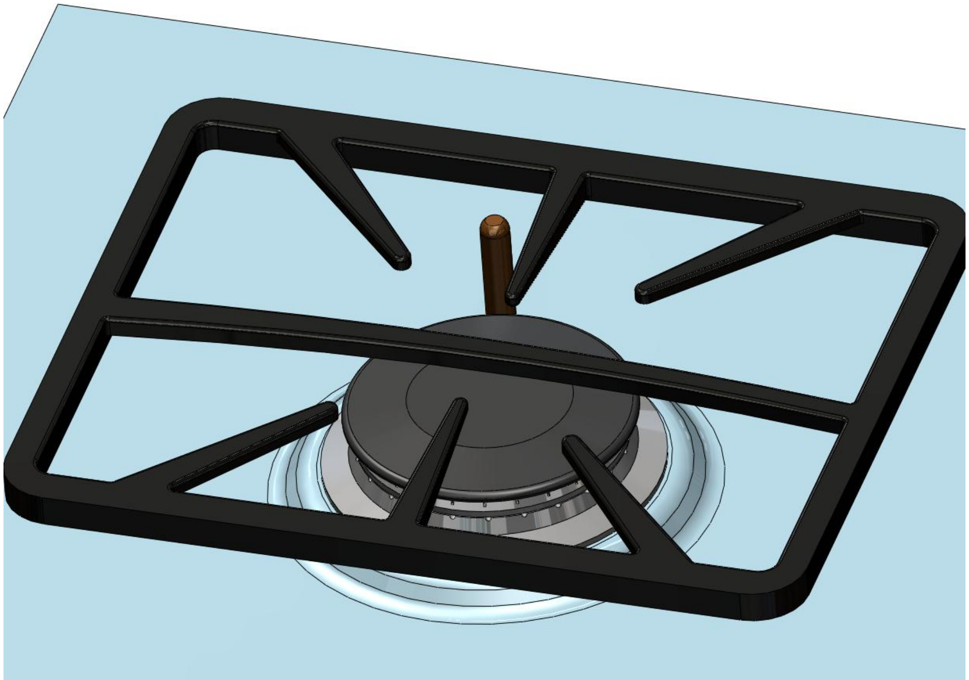


Figure 36: Schematic of Gas Cooktop with Embedded Sensor

Table 5: Gas Cooktop Implementation Costs

Pan-Temperature Limiting Component	Estimated Cost at Volumes of >100,000	Number of Components Needed	Total Cost
Thermistor	$0.5	4	$2
Spring-loaded Housing (same as electric coil) And Mounting Bracket	$1.5	4	$6
Control Board	$4	1	$4
Wiring	$1.5	4	$6
Solonoid Valve	$5	4	$20
Diverter Tube and Fittings	$2	4	$8
Total Cost of All Components			$46

4.3 Glass Ceramic Element

The elements of the sensor system embedded in the glass ceramic cooktop are illustrated in Figure 37. The components needed for implementation of the pan-temperature-limiting sensor and controls are listed (with cost estimates) in Table 6.

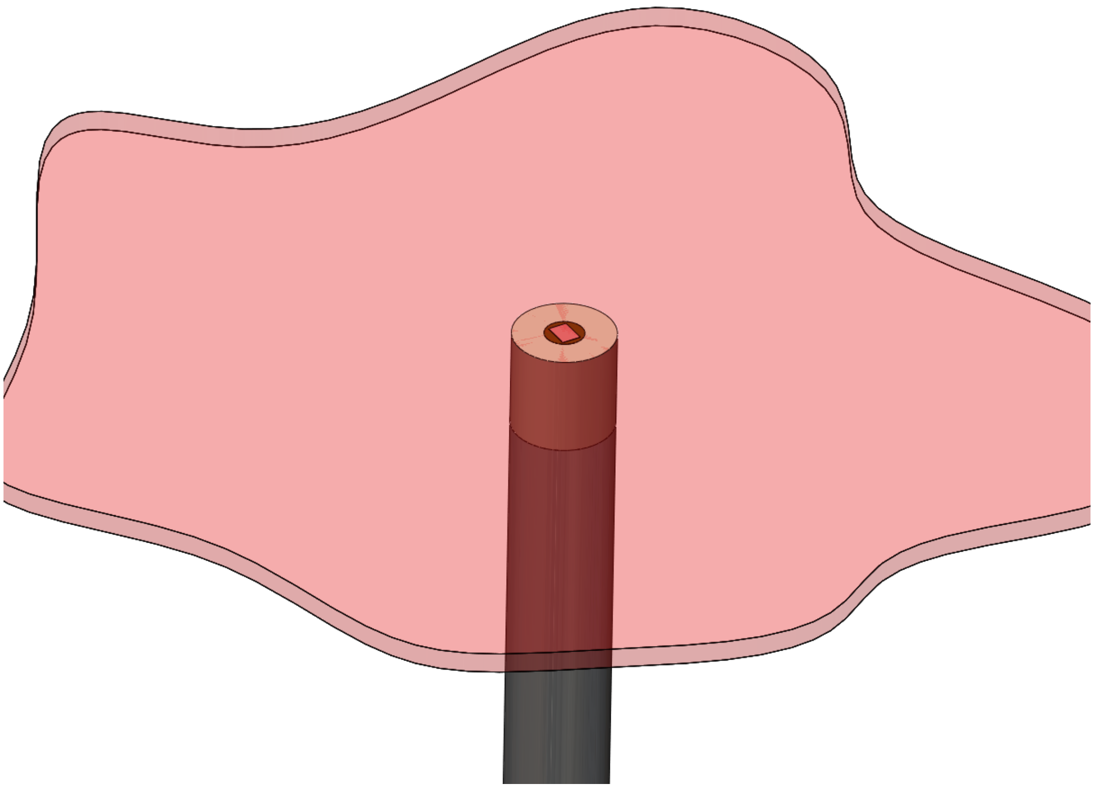


Figure 37: Schematic of Glass Ceramic Cooktop with Embedded Sensor

Table 6: Cost to Implement Control in Glass Ceramic Cooktop

Pan Temperature Limiting Component	Estimated Cost at volumes of >100,000	Number of Components Needed	Total Cost
RTD Sensor with Long Leads	$12	4	$48
Ceramic Housing	$1	4	$4
Control Board Modifications	$3	1	$3
Wiring	$1.5	4	$6
Total Cost of All Components			$61

4.4 Induction

All necessary sensing and control components are in the current cooktops. The control algorithms would need to be modified to provide tighter pan temperature limiting.

5. Conclusions and Summary Recommendations

No fires occurred on any of the cooktops in the course of the testing when the control system was operating; this included cooking on the high setting with fats and oils. The objectives of the project have been met, but the fire-prevention effectiveness of the designed system should be further validated.

Primaira staff believe that the technology also has significant merits as a performance enhancement; the pan temperature limiter will prevent food from “burning”, *i.e.* unintentional blackening. Most foods are not well cooked on the highest element setting. This control can distinguish between water boil and other cooking functions, so boiling time will not be sacrificed. It is possible that commercial introduction of the technology would be faster if it were not provided as a “safety” feature, but rather as a performance feature. This performance feature would bring with it a mitigation in cooktop fires.

Appendix A:

Cooktop Specifications

<u>30" Built-in Glass Ceramic Electric Cooktop:</u>

Dimensions: 29.75″ x 21.375″ x 3.25″

KW Rating:
- 240V: 7.8
- 208V: 5.9

Breaker Size:
- 240V: 40 Amps
- 208V: 30 Amps

6″/9″/12″ Three-Ring Element: 1050W/1950W/3000W
5″/8″ Dual-Heating Element 2200W/2400W
6″ Elements (2): 1200W each

<u>30″ Built-in Gas Cooktop</u>
Dimensions: 30″ x 21″ x 3.1875″
Electrical Rating: 120V, 60Hz, 5A

Dual-Flame Stacked Burner: (1) 18,000 BTU/140F Degree Simmer

<u>30″Built-in Electric Coil-Element Cooktop:</u>

Dimensions: 30.25″ x 21.25″ x 3″
KW Rating:
- 240V: 7.4
- 208V: 5.6

Breaker Size:
- 240V: 40 Amps
- 208V: 30 Amps

8″ Elements (2): 2400W
6″" Elements (2): 1300W

<u>30″ Electric Induction Cooktop:</u>

Dimensions: 29.75″ x 21.375″ x 3.25″
KW Rating:
- 240V: 7.7
- 208V: 5.8

Breaker Size:
- 240V: 40 Amps
- 208V: 40 Amps

11″ Element: 3700W
7″ Elements (2): 2500W
6″ Element (1): 1800W

BOLDED Elements were used for sensor and control implementation

Appendix B:

List of Pans Used in Testing

10″ Skillets:

[redacted] 10″ Skillet
Hard Anodized Aluminum
10.0″ W
2.0″ D

[redacted] 10″ Skillet
Cast Iron
10.75″ W
2.25″ D

[redacted] 10″ Open Skillet:
Stainless Steel
10.0″ W
2.25″ D

Large Pots (5 & 6 Qt):

[redacted] 5 Qt Dutch Oven
Stainless Steel (Brushed)
12.0″ W
5.0″ D

[redacted] 5 Qt Dutch Oven
Hard Anodized Aluminum (Brushed)
10.0″ W
5.0″ D

[redacted] 6 Qt Dutch Oven
Cast Iron
10.75″ W
7.75″ D

2-Quart Pots:

[redacted] 2-Qt Saucepan
Hard Anodized Aluminum (Brushed)
7.5″ W
4.0″ D

[redacted] 2-Qt Saucepan
Stainless Steel
7.75″ W
3.0″ D

Photographs of Skillets Used in Testing

Aluminum Skillet

Stainless Steel Skillet

Cast Iron Skillet

Appendix C:

Details of Test Methods

Test Name	Description	Pan Type	Pan Materials	Criteria for Passing
Dry Cook	Empty pan placed on element or burner set to “high”	10″ Skillet	Al, SS, CI	The temperature in pan was maintained below 700°F.
Pasta Boil	Pot filled with 4 qt water, element set to High, water brought to boil, 1-lb dry angel hair pasta added and cooked for 4 minutes.	5–6 Qt Pot	Al, SS, CI	The time to heat between 80Fand 195F is within 10% of time to heat without control.
Sauce Simmer	One quart prepared tomato-based pasta sauce was placed in a 2-quart pot and brought to a simmer for 10 minutes.	2 Qt Pot	Al, SS, CI	Sauce would maintain a low simmer without overboiling or losing a low boil.
Long Boil	Pot was filled with 4 quarts of room-temperature tap water (70-80° F). The burner was switched to High and data collected for 90 minutes.	5-6 Qt Pot	Al, SS, CI	Water would come up to boil in time similar to that without pan-temperature-limiting controls and maintain rolling boil over long period of time.
Blackening Chicken	One boneless, skinless chicken breast (1/2 lb), split in half to ½” thickness. 30mL of vegetable oil was heated until smoking in a pan, and chicken was added and cooked until blackened on each side.	10” Skillet	Al, SS, CI	Surface of chicken would blacken similarly to without pan temperature limiter.
Steak	The pan was heated with 30mL of vegetable oil on the “6” setting until smoking hot. Two beef loin strip steaks, 1 pound each, were placed in the hot pan and cooked for 5-7 minutes on each side.	10” Skillet	Al, SS, CI	Steaks would sear similarly to those cooked without a pan temperature limiter.
Vegetable Stir Fry	½ pound of thinly cut strip steak, ½ a red bell pepper and ½ an onion were thinly sliced. 20mL of vegetable oil were heated in the pan until smoking, and half of the steak was added and cooked rapidly. More oil was placed in the pan and allowed to heat up briefly, and then the vegetables were added to the pan and cooked until tender.	10” Skillet	Al, SS, CI	Meat and vegetables would have caramelized surface similar to that produced without pan temperature limiter
Batch Shallow Frying	800 mL of canola oil was poured into a pan and the burner turned to High. Once the oil reached 380 F, 400g of frozen french fries were added, spread out, and cooked until golden brown and crispy. Once the oil had reached 380 F again, the process was repeated two times.	10” Skillet	Al, SS, CI	Cooking times and browning are comparable to that without pan temperature limiting controls.

Dry Cook: Empty 10" skillet was placed on burner set to high on 9" setting. Pan was heated to ~750^{0}F (uncontrolled) or for ~20 min (with controls).

Pasta Boil: 4 quarts of water were brought to boil on high in 5-quart aluminum and stainless steel pots and 6-quart cast iron pot. 1 lb of angel hair pasta was added to pot once water had reached a rolling boil. The pasta was cooked for 4 minutes.

Sauce Simmer: 1 quart of prepared, tomato-based pasta sauce was added to a 2-quart pot and heated on high until sauce temperature was at least 200F and boiling. Sauce was stirred continuously during initial heating to prevent splatter and distribute heat. Element setting was then decreased to 3, and sauce was allowed to simmer for 10 minutes. Sauce was stirred occasionally during the simmer phase of test.

Long Boil: 4 quarts of water were brought to boil on high in 5-quart aluminum and stainless steel pots and 6-quart cast iron pot. Pot was heated on high for an additional 90 minutes after reaching initial boil.

Blackening Chicken: Boneless, skinless chicken breasts were dried with paper towels and then cut in half to a width of ½.″ The chicken was then wrapped in paper towels and set aside while a skillet was heated. A 10" skillet, with 30 mL of oil, was heated on high until the oil began to smoke (~550^{0}F). Once the oil was smoking, the chicken breast halves were added to the skillet and cooked until they began to char. The chicken breast halves were then flipped and cooked until they began to char on the second side (although the second side was less blackened as less of the chicken's surface area was in contact with the pan). The chicken cooked without controls was cooked until sufficiently blackened while the chicken cooked with controls was cooked for the same amount of time on each side as the chicken without controls in the same type of pan. This made it possible to compare the relative doneness of the chicken cooked with controls vs. chicken cooked without controls.

Steak: Two beef loin strip steaks were dried with paper towels then seasoned generously with salt and pepper. Steaks were then re-wrapped in paper towels while pan was heated. A 10" skillet with enough oil to coat the bottom of the pan was heated on high until oil began to smoke (~550F). Steaks were added to the pan and cooked on high until just starting to char, then flipped and heated until second side began to char.

Extended Steak Cook: Steak was cooked the same way as in the standard steak cook test. Steak was removed from pan when fully cooked while element remained on. Empty pan with residual oil and char from steak cooking was allowed to continue heating to determine whether the controls would still be activated after cooking with oil.

Vegetable Stir Fry: ½ pound of thin strip steak was cut into thin sections which were then cut to half length. Half of a red pepper was cut lengthwise into thin ~1/4″sections and half of an onion was sliced crosswise. Thirty mL of vegetable oil was heated in a 10″-skillet on high until starting to smoke, and half of steak was then added to pan. Steak was quickly tossed with tongs until browned on all sides and then set aside in a container. The second half of the steak was then cooked and set aside as well. More oil was added to the empty pan and allowed to heat until smoking. Once oil was smoking, vegetables were added to pan and cooked until tender. The steak was then again added to the pan of vegetables and tossed for roughly 20 seconds.

Shallow Batch Frying: Frozen French fries were weighed into three batches of 400g each. A 10" skillet was filled with 800 mL of canola oil and heated on high until oil reached 380F. The first batch of fries was added to the heated oil and cooked until golden brown and crispy. Fries were then removed, and oil was allowed to heat back up to 380F. Once oil had reached 380F again, the process was repeated two more times.

Appendix D:

Detailed Test Results for Electric Coil Cooktop

Primaira, LLC
30 Commerce Way, Suite 300A
Woburn, MA 01801
tel 781 937 - 0202
fax 781 937 - 0229
www.primaira.com

CPSC Cooktop Controls

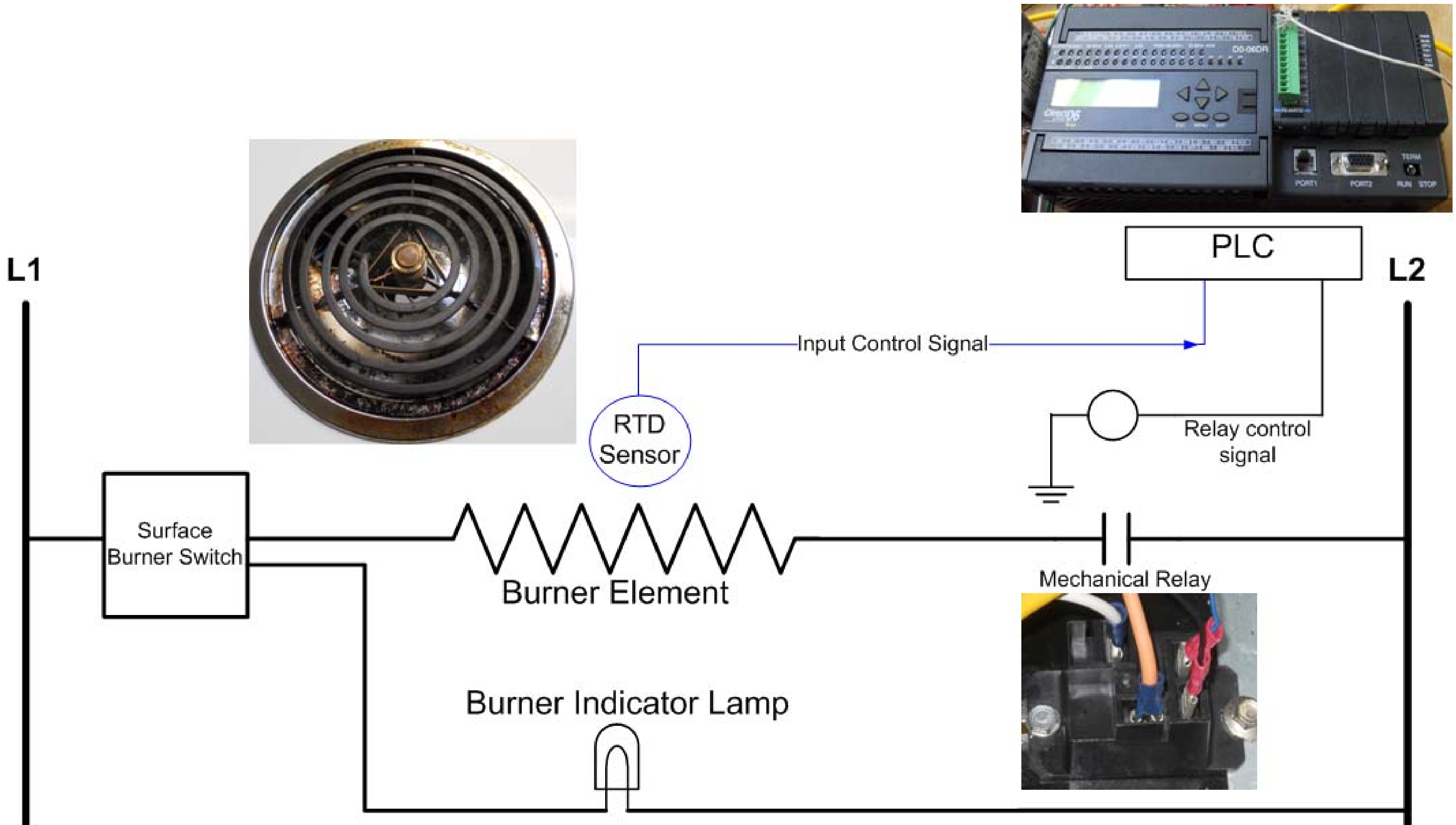
Electric Coil Testing Summary

Electric Coil Cooktop

- A control algorithm has been developed and implemented to prevent vessel temperatures from rising above 700 F without interfering with normal cooking.
- The sensor is a platinum RTD enclosed in a metal housing. The RTD sensor is spring load to ensure direct contact with the cookware.
- The control algorithm uses a combination of rate of change and threshold monitoring to decide when to interrupt the elements power.
- Extensive testing has been carried out with and without the control on and it is clear that the effect of the control on cooking is negligible if any.

PRIMAIRA

Electric Coil Cooktop Control Hardware Diagram



PRIMAIRA

Testing: Electric Coil

- **Eight types of tests were carried out:**
  - Dry cook
  - Pasta boil
  - Sauce simmer
  - Long boil
  - Blackening chicken
  - Steak
  - Stir fry
  - Batch shallow frying

PRIMAIRA

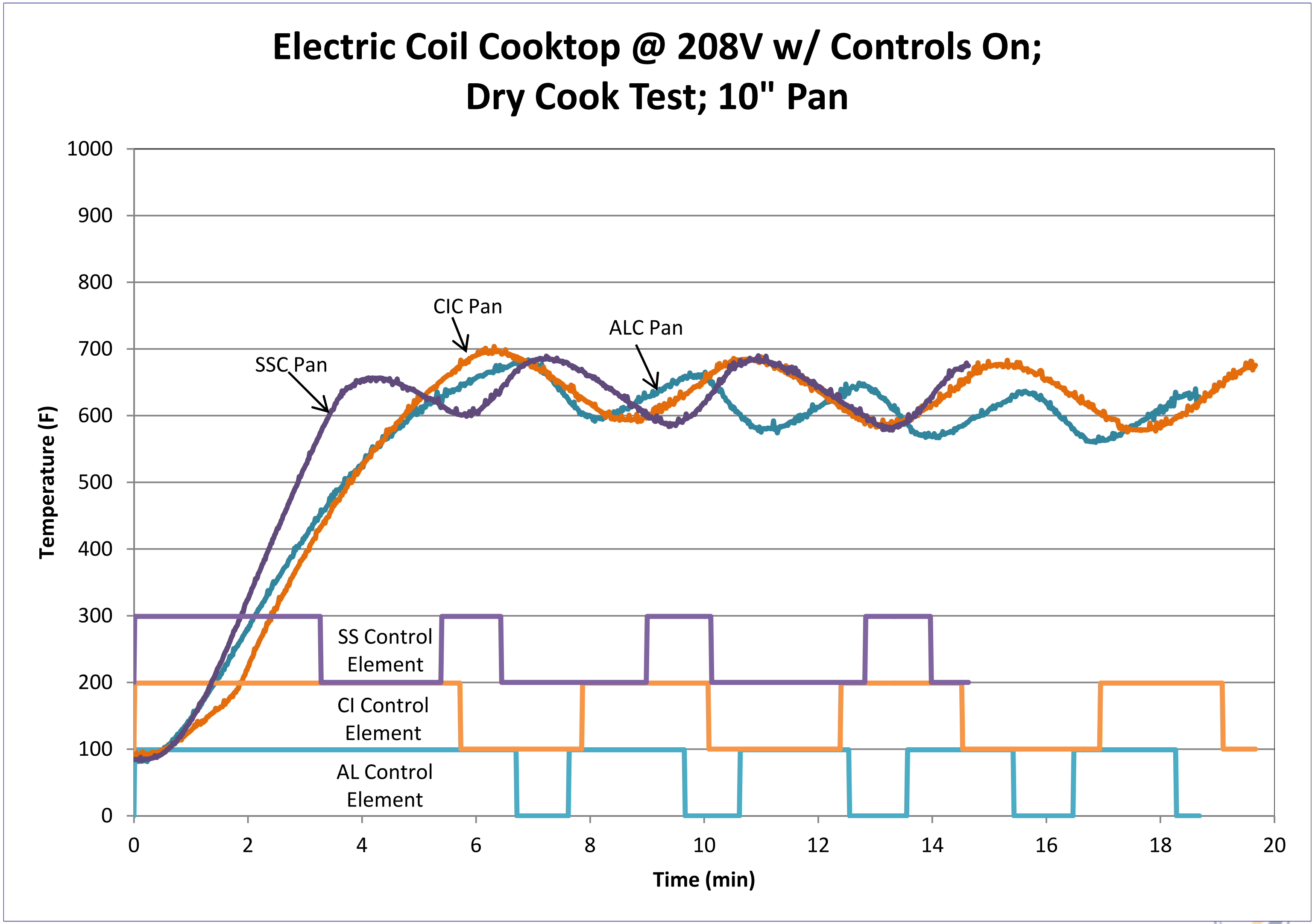
Dry Cook Testing

- An empty 10 inch pan was placed on the cooktop and heated.
- The burner was turned to Hi and remained there for the duration of the test.

- The controls were able to control the pan temperature to the target set point of 700° F.

PRIMAIRA

Dry cook test data below shows that with the controls on the pan temperature did not exceed the target set point of 700˚ F.



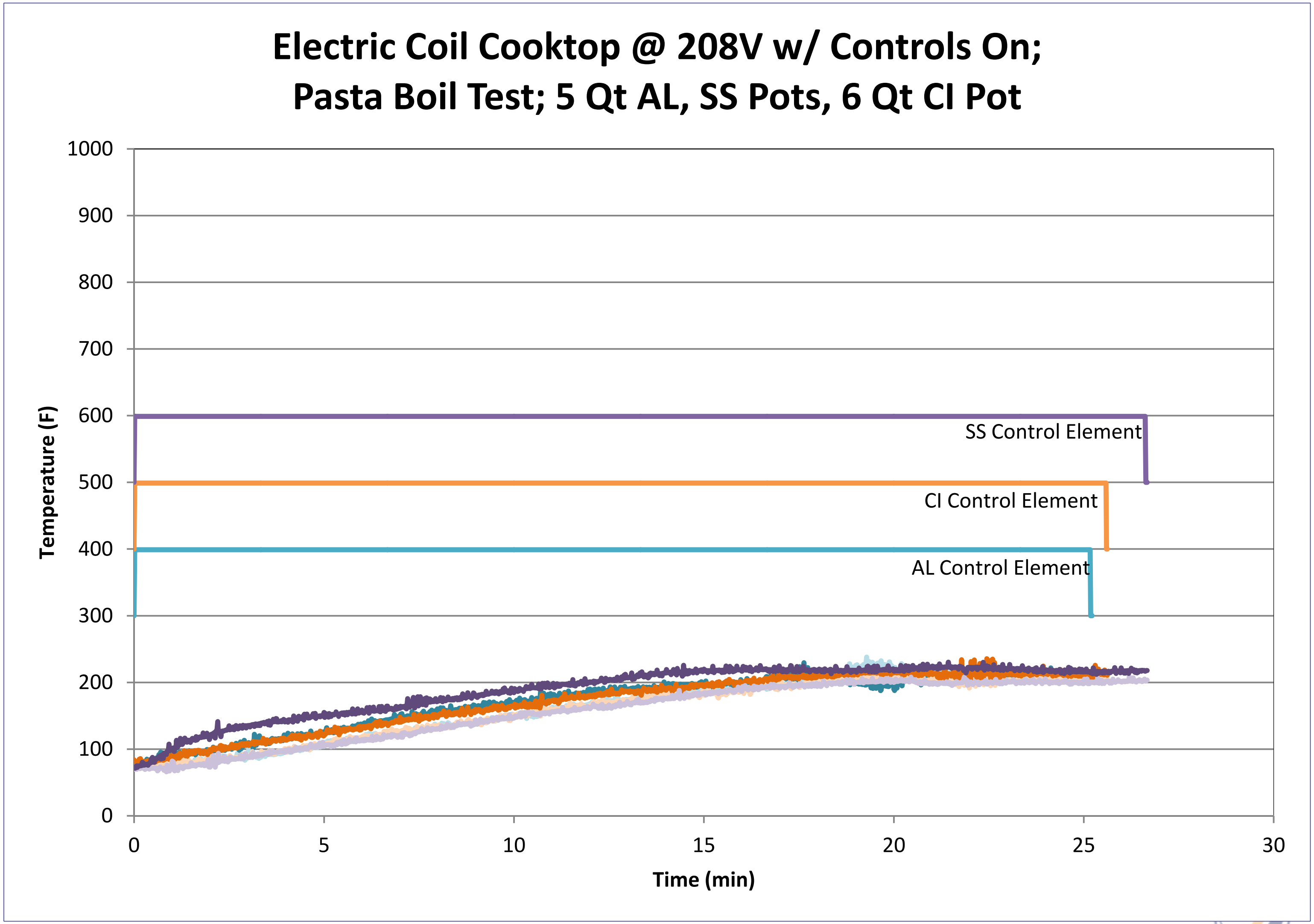
Pasta Boil Test

- Four quarts of water were placed in a 5-quart pot (in the case of cast iron, 6-quart).
- The burner was turned to Hi and remained there for the duration of the test.
- When the water had reached a rolling boil, 1 pound of angel hair was added to the pot and cooked for 4 minutes.

- The controls did not activate at any point during the pasta boil testing.

PRIMAIRA

Pasta boil test data below shows that with the controls did not interrupt the power to the electric cooktop element and did not increase the cooking time.



PRIMAIRA

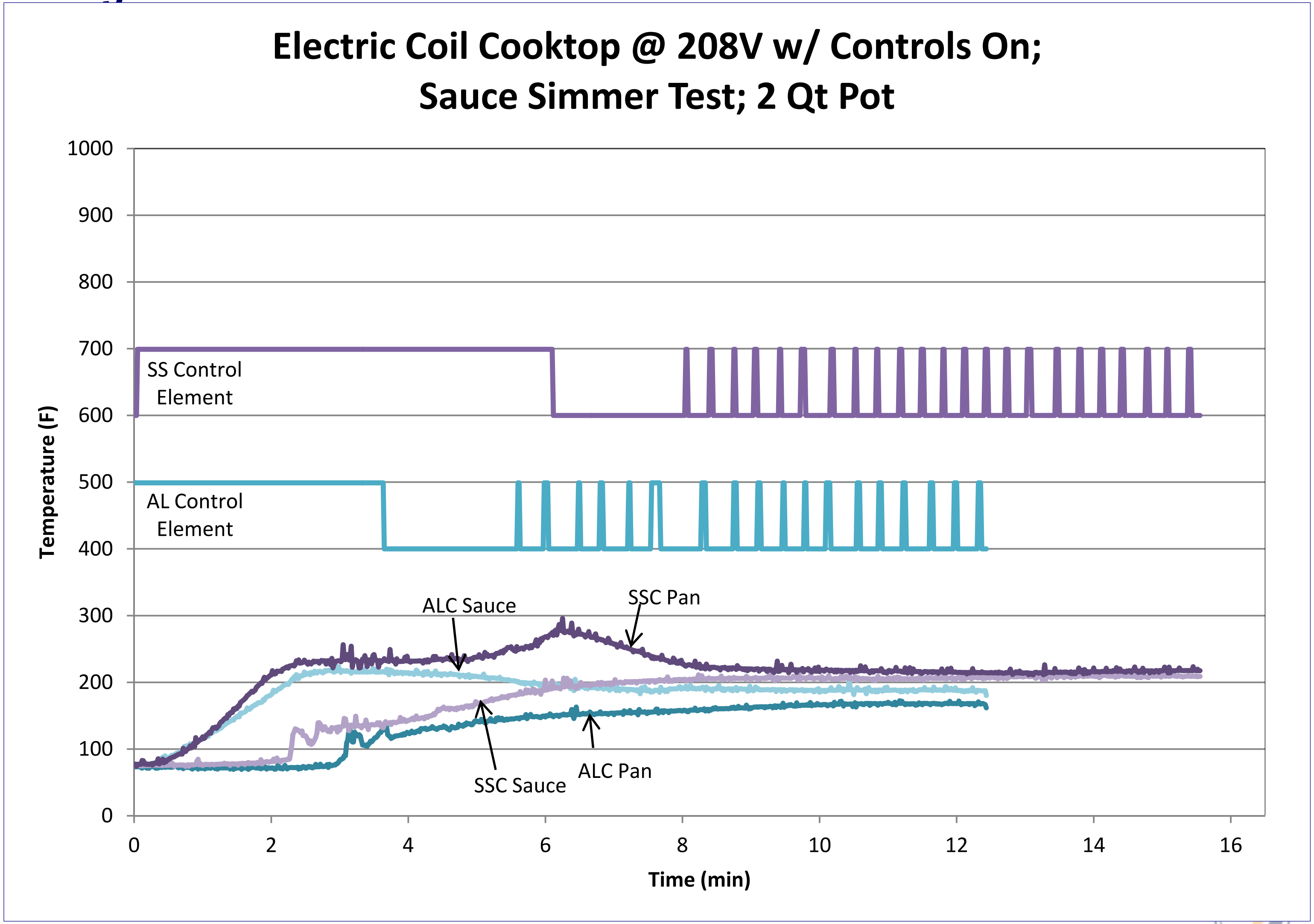
Sauce Simmer

- One quart of jarred tomato sauce was placed in a 2-quart pot and brought to a simmer and allowed to remain there for 10 minutes.
- The burner was turned to Hi at first but then lowered so that sauce was gently bubbling rather than spattering.

- The controls did not activate at any point during the sauce simmer testing.

PRIMAIRA

Sauce simmer test data below shows that with the controls did not interrupt the power to the electric cooktop element and the sauce was able to get to a boil.



PRIMAIRA

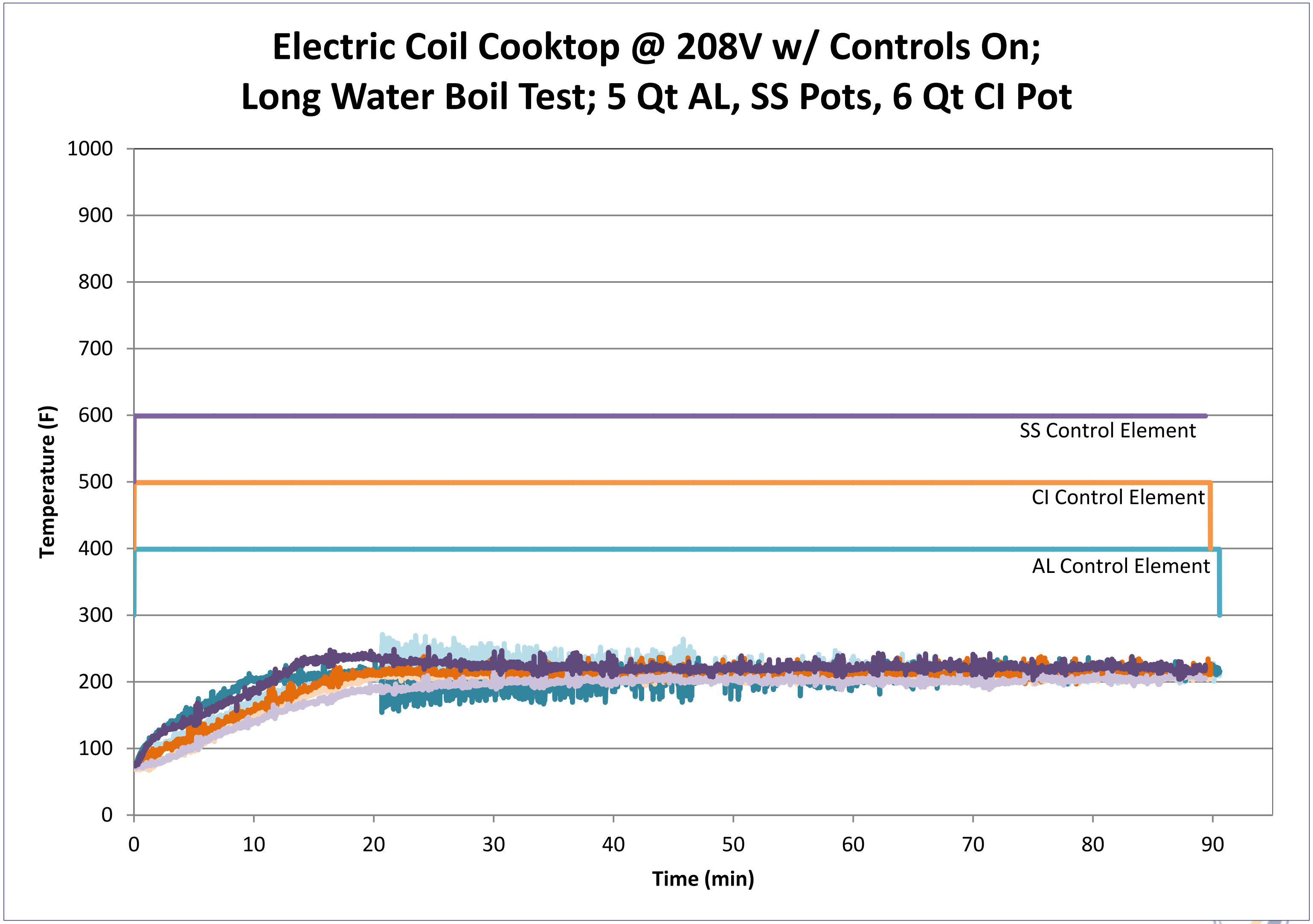
Long Boil

- A 5 or 6 quart pot was filled with 4 quarts of room-temperature tap water (70-80 F).
- The burner was switched to Hi and data collected for 90 minutes.

- The controls did not activate at any point during the long boil testing.

PRIMAIRA

Long water test data below shows that with the controls did not interrupt the power to the electric cooktop element.



PRIMAIRA

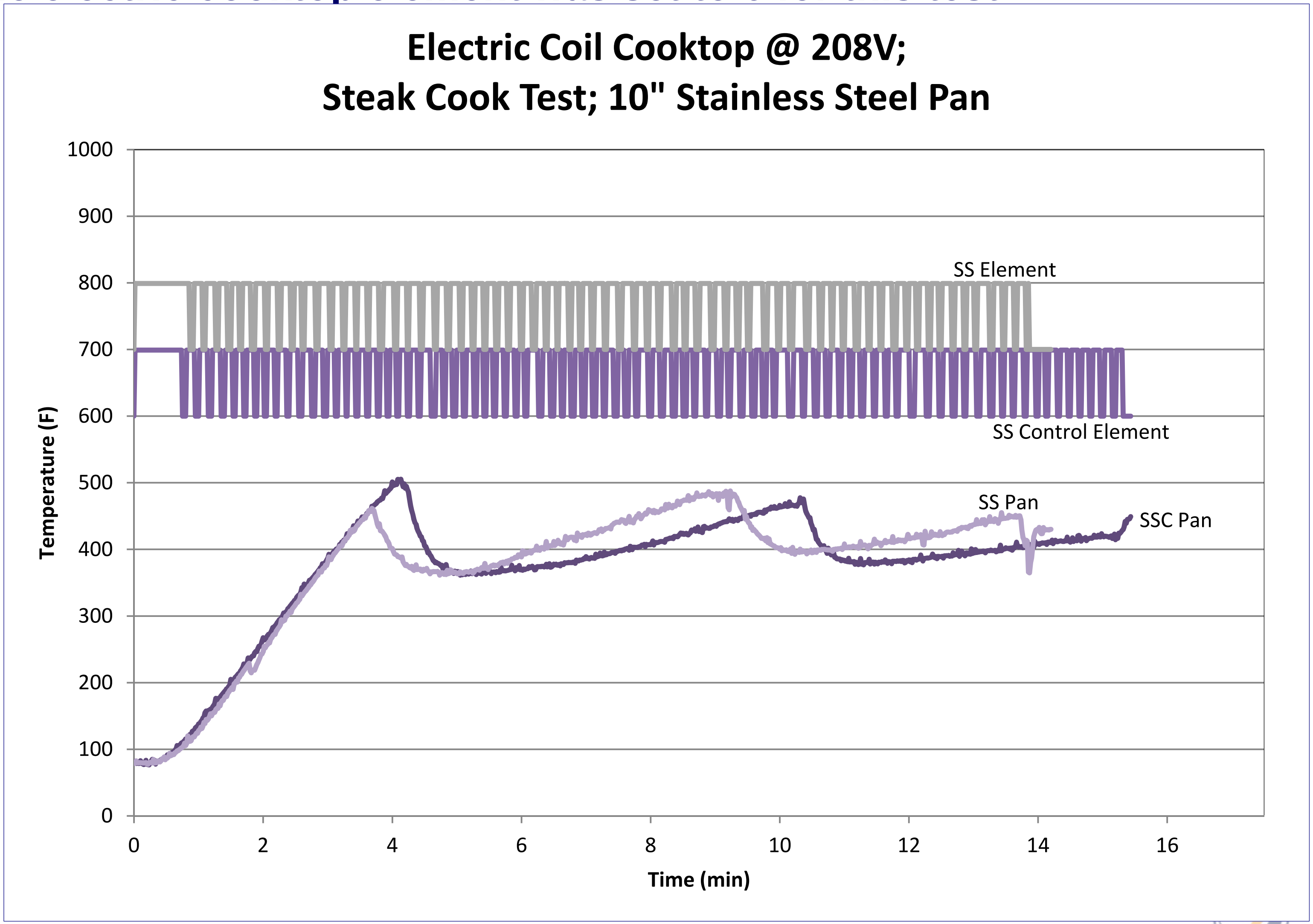
Steak Test

- The pan was heated with 30mL of vegetable oil on the "6" setting until smoking hot.
- Two steaks, dried thoroughly and seasoned, weighing roughly 1 pound each and generally 1 ¼" thick, were placed in the hot pan and cooked for 5-7 minutes on each side, until medium rare.
- Steaks were allowed to rest for five minutes, and then sliced into quarters and doneness determined.

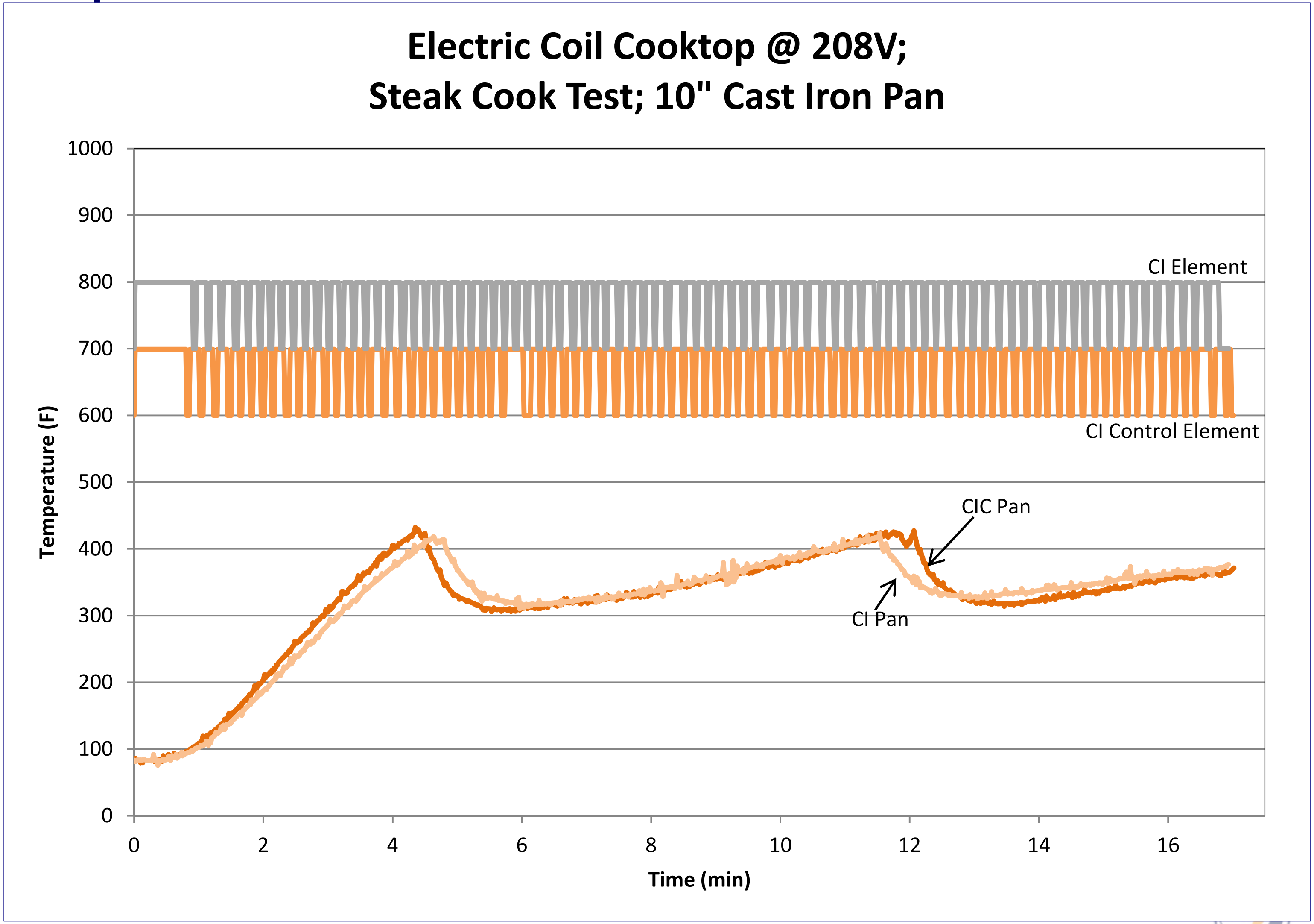
- The controls did not activate at any point during the steak testing.

PRIMAIRA

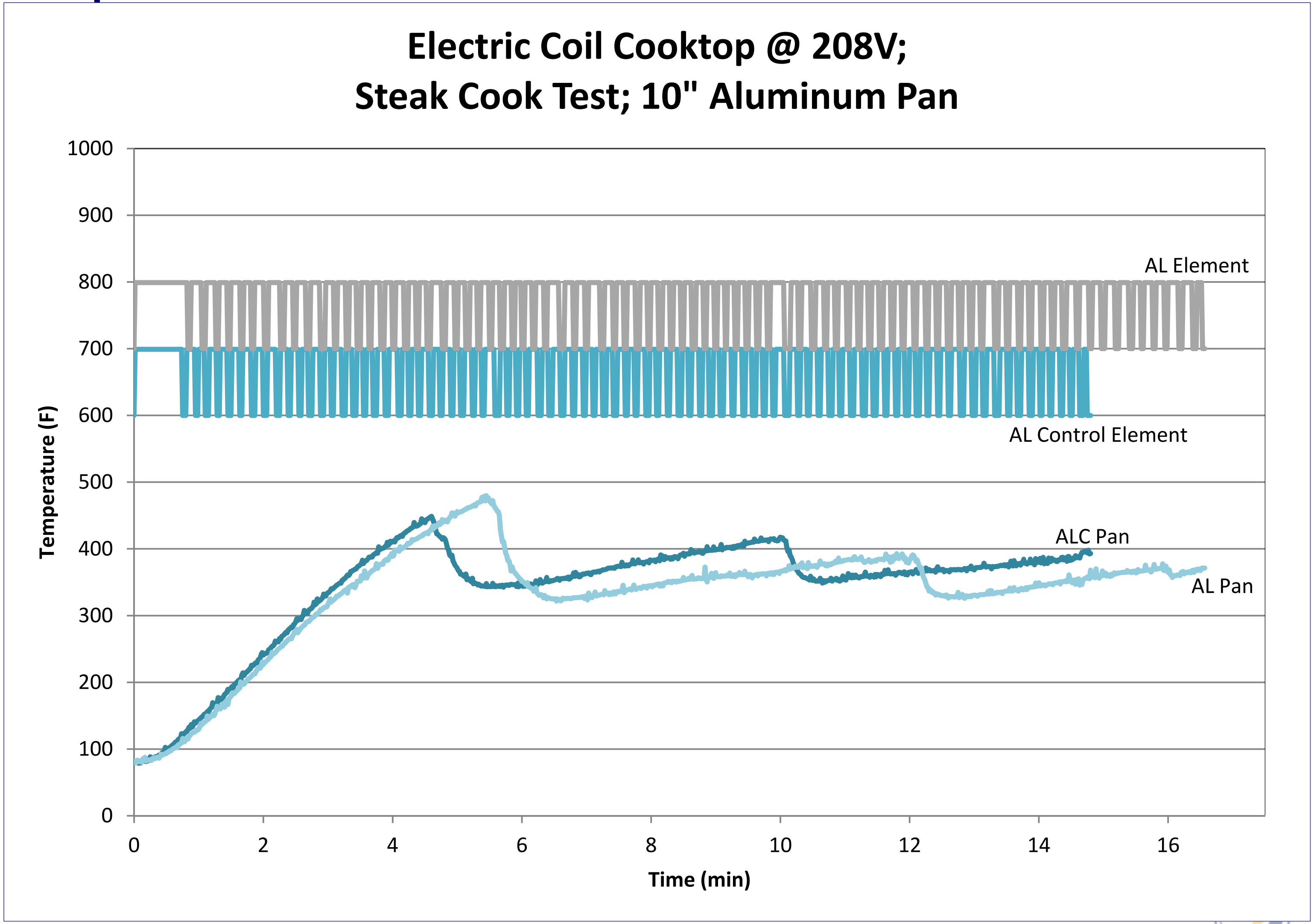
Steak test comparing stainless steel pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to 6 for this test.



Steak test comparing cast iron pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to 6 for this test.



Steak test comparing aluminum pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to 6 for this test.



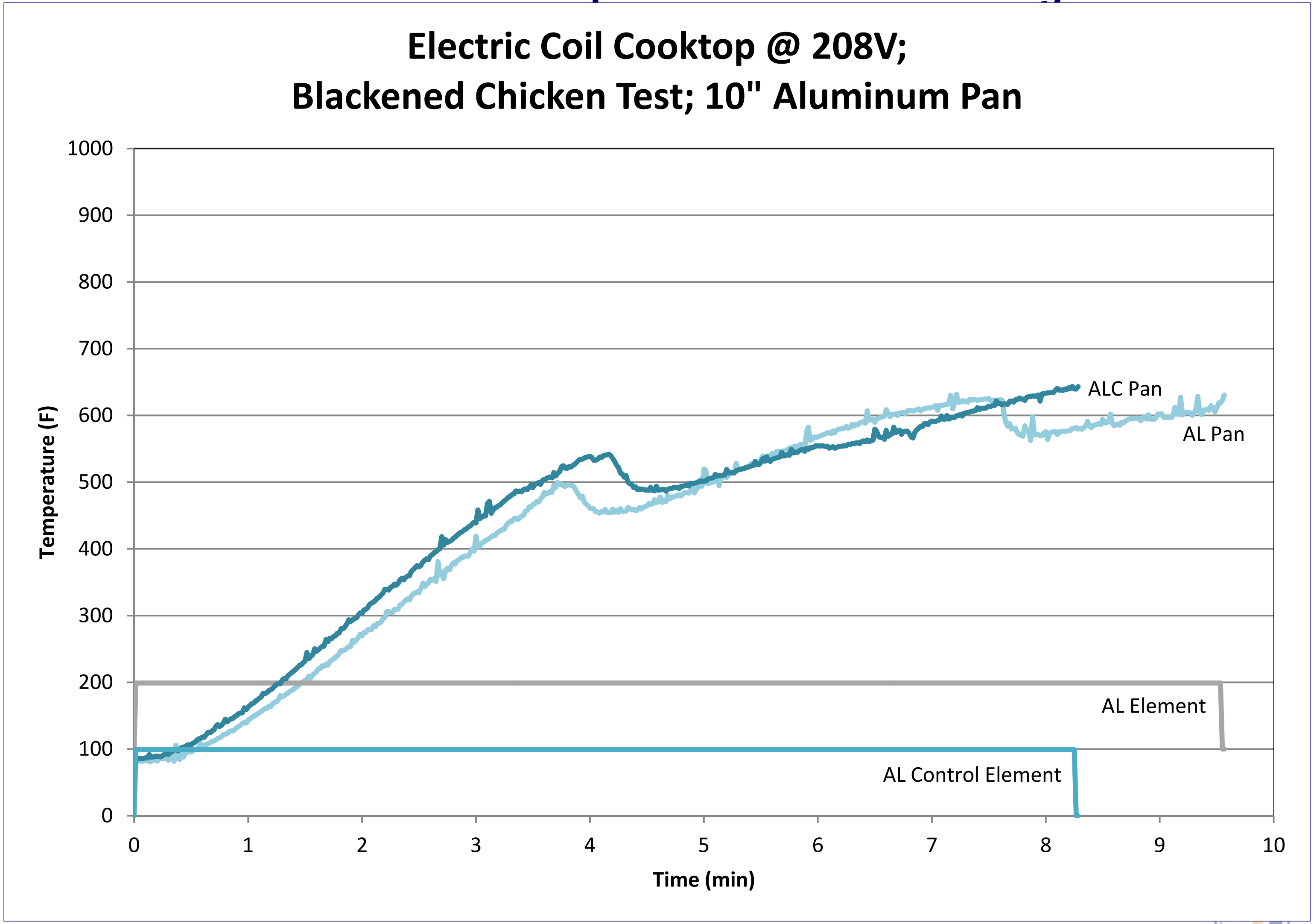
PRIMAIRA

Blackening chicken

- One large chicken breast, roughly half a pound, was split in half to ½” thickness.
- 30mL of oil was heated until smoking in a pan, and chicken was added and cooked until blackened on each side.
- The chicken was sliced to show degree of doneness.
- The controls did not activate at any point during the blacken chicken testing for the aluminum and stainless steel. The controls did activate briefly but had no effect on the cooking.

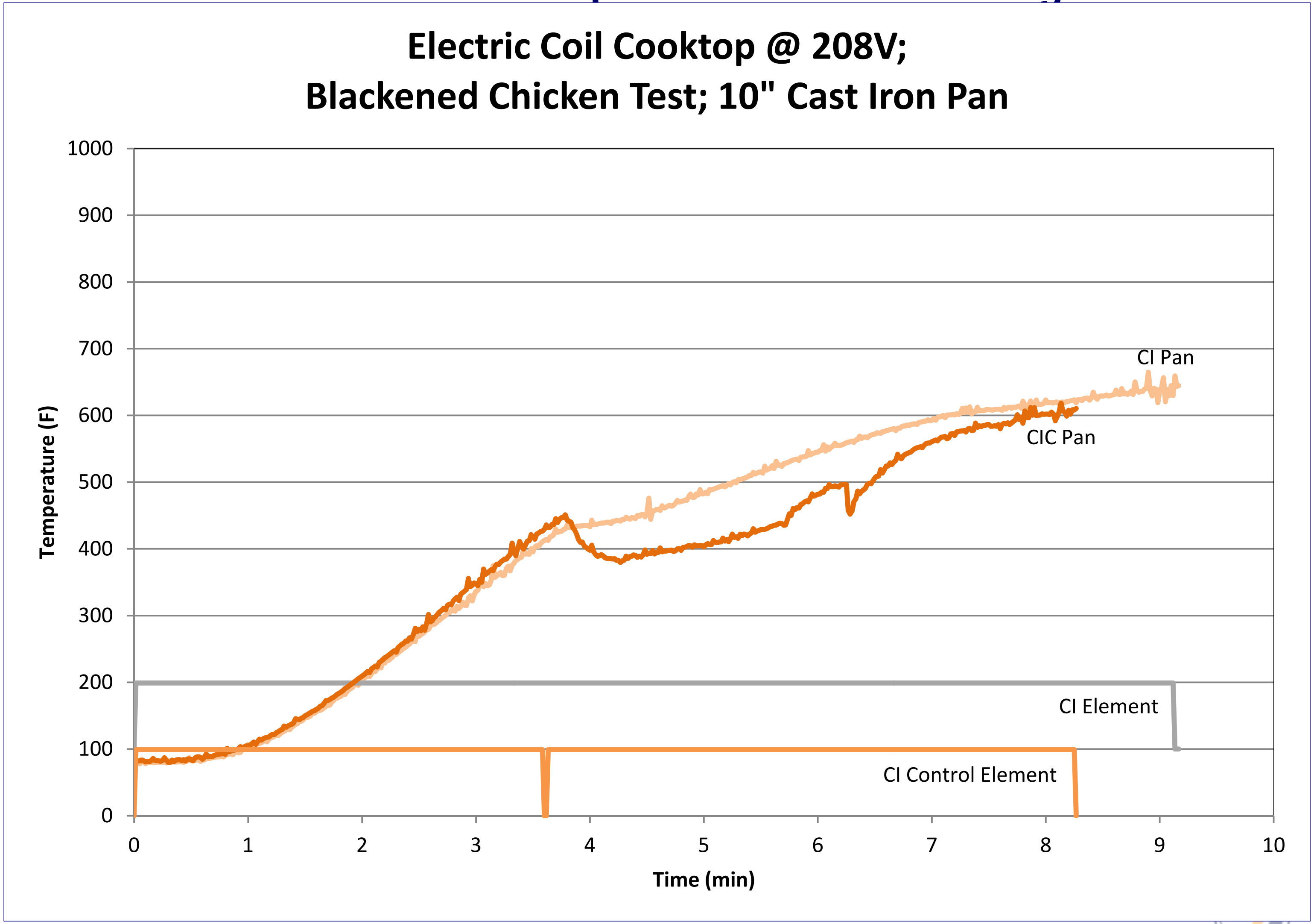
PRIMAIRA

Blackened chicken test comparing aluminum pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to high for this test.



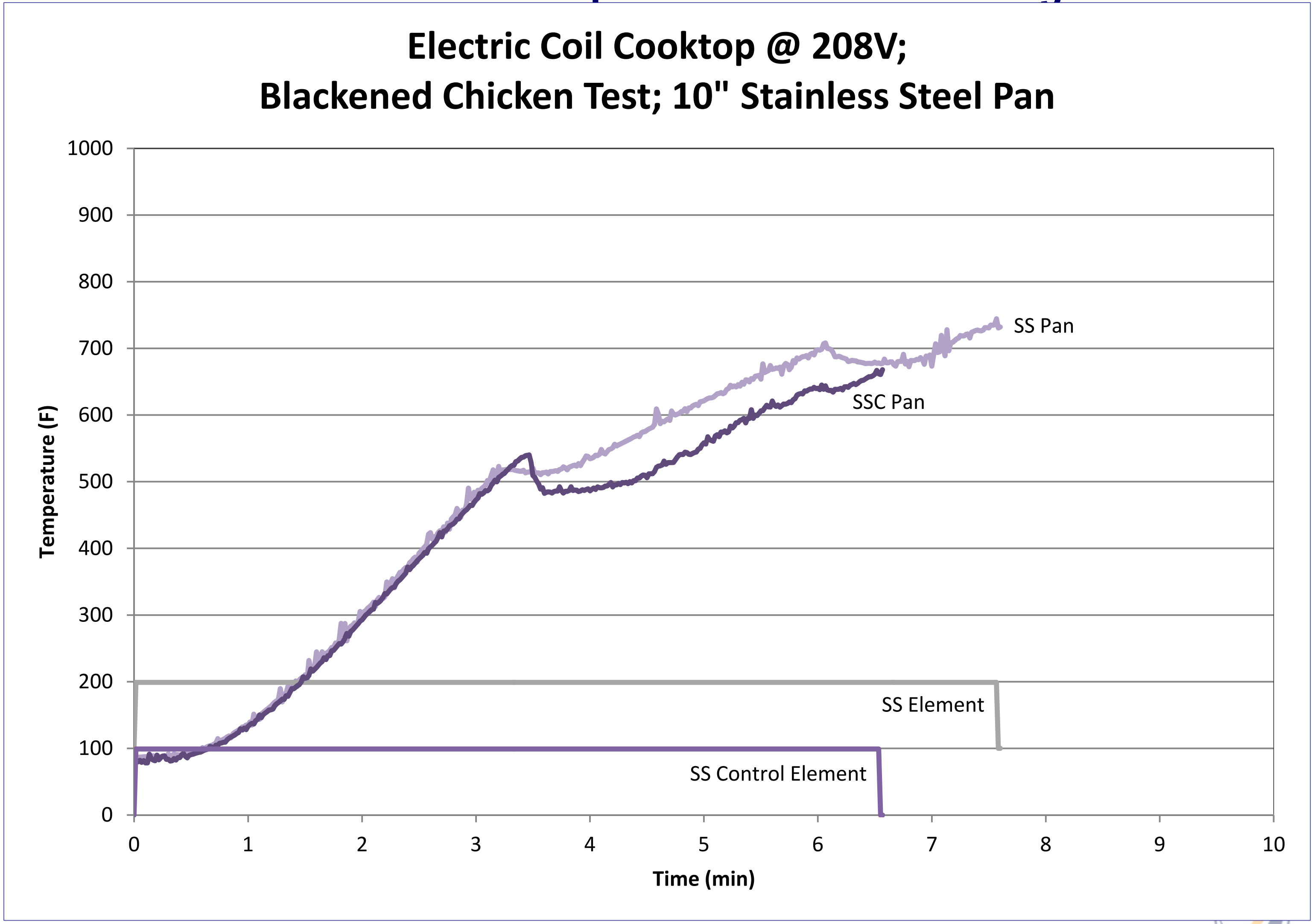
PRIMAIRA

Blackened chicken test comparing stainless steel pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to high for this test.



PRIMAIRA

Blackened chicken test comparing cast iron pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to high for this test.



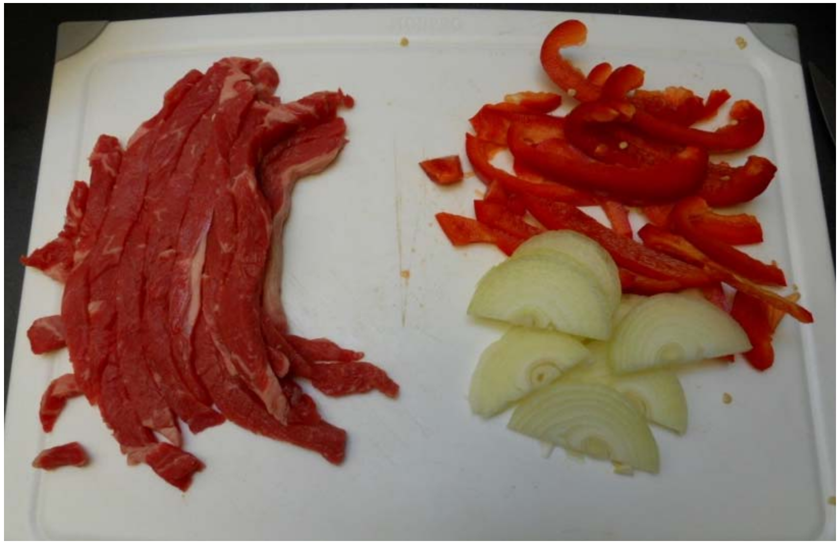
PRIMAIRA

Stir fry

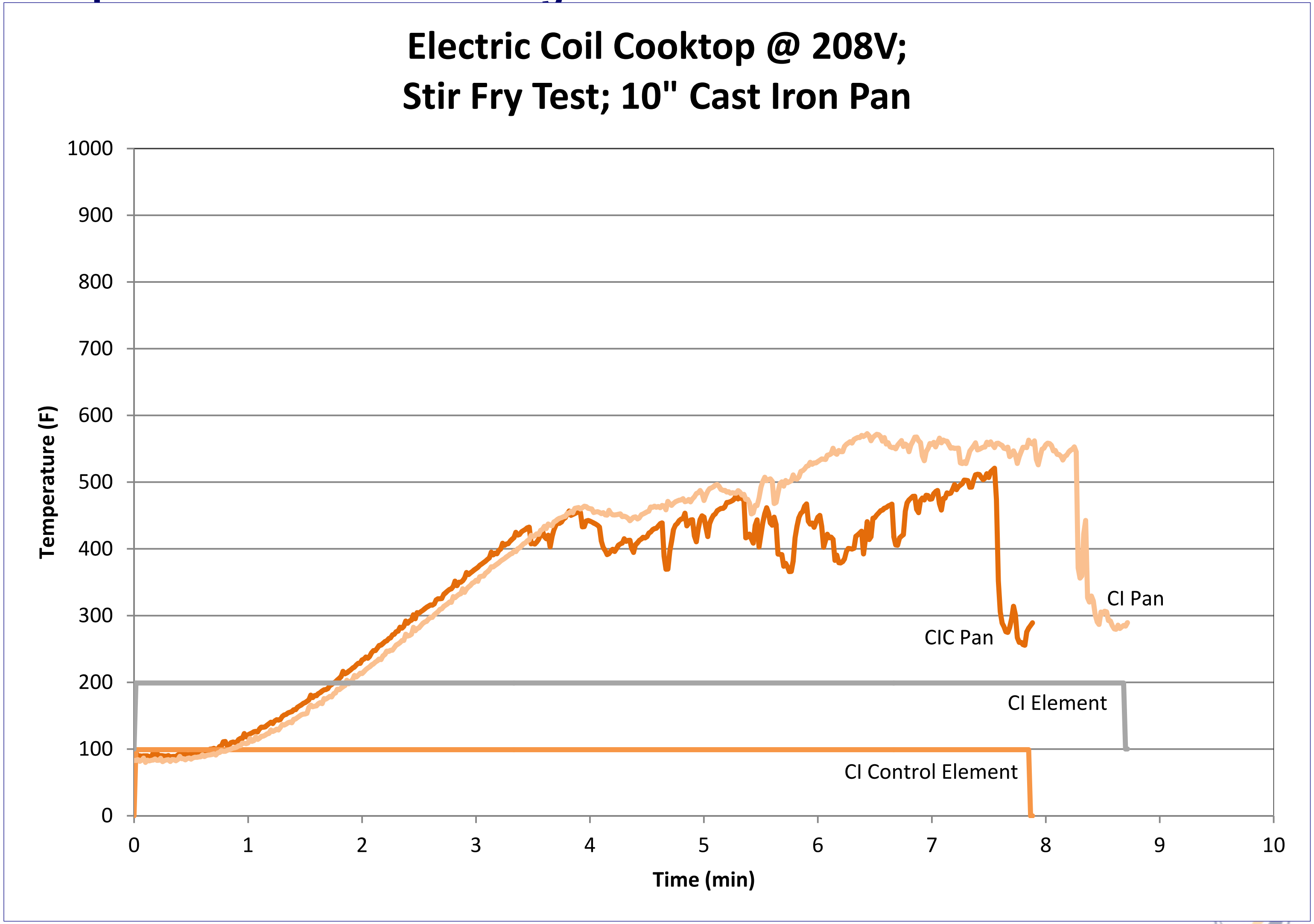
- ½ pound of thinly cut strip steak, ½ a red bell pepper and ½ an onion were thinly sliced.
- 20mL of vegetable oil were heated in the pan until smoking, and half of the steak was added and cooked rapidly, using tongs to toss, until browned on all sides. This steak was removed to a bowl and the rest of the steak added and cooked in the same manner, then removed.
- More oil was placed in the pan and allowed to heat up briefly, then the vegetables were added to the pan and cooked until tender. The steak was added back to the pan with the juices and warmed with the vegetables for about 20 seconds.

Stir fry continued

- The controls activated only with the electric cooktop, and then only briefly. They did not have a noticeable impact on the outcome of the stir-fry.

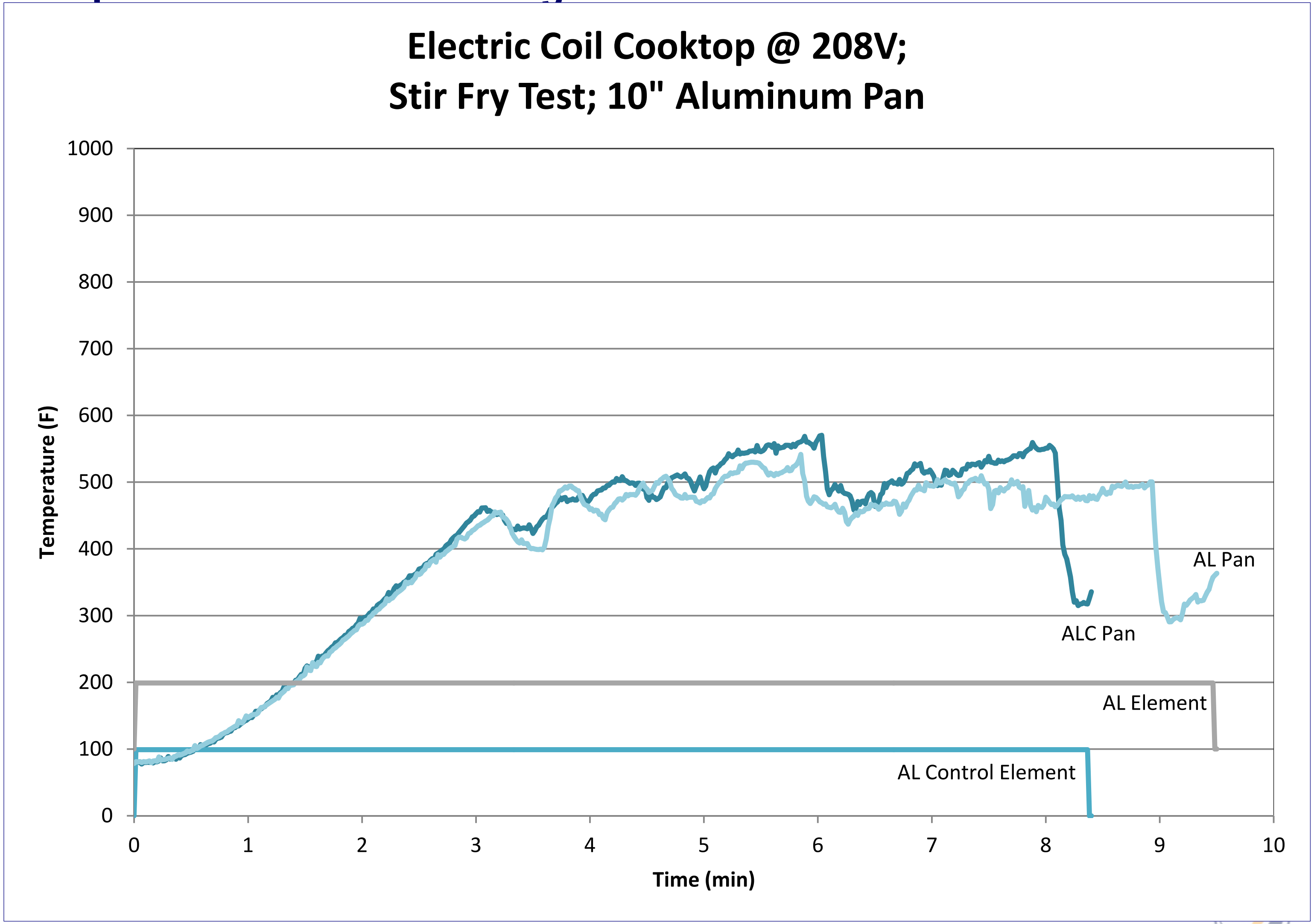


Stir fry test comparing cast iron pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to high for this test.



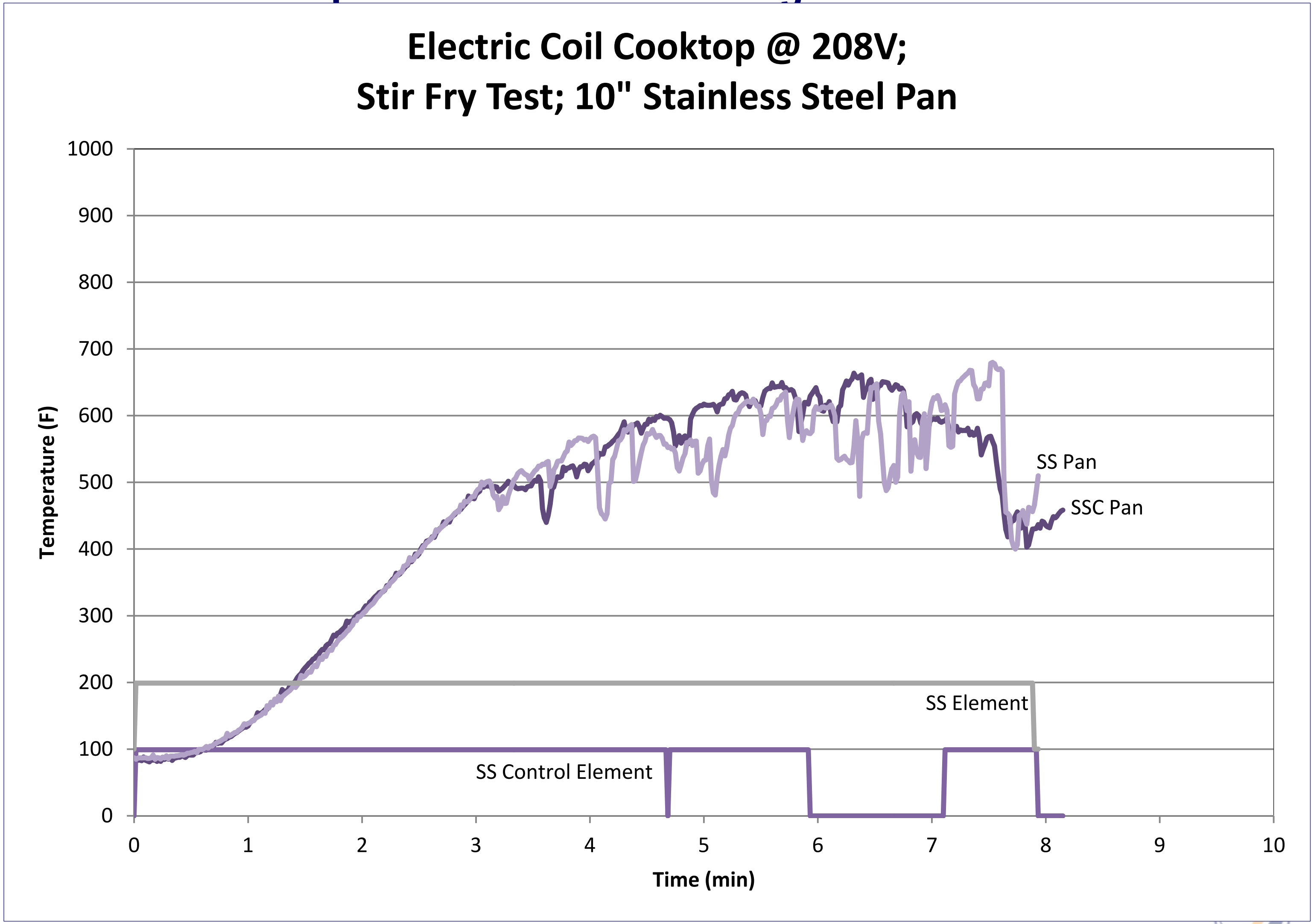
PRIMAIRA

Stir fry test comparing aluminum pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to high for this test.



PRIMAIRA

Stir fry test comparing stainless steel pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The electric cooktop element was set to high for this test.



PRIMAIRA

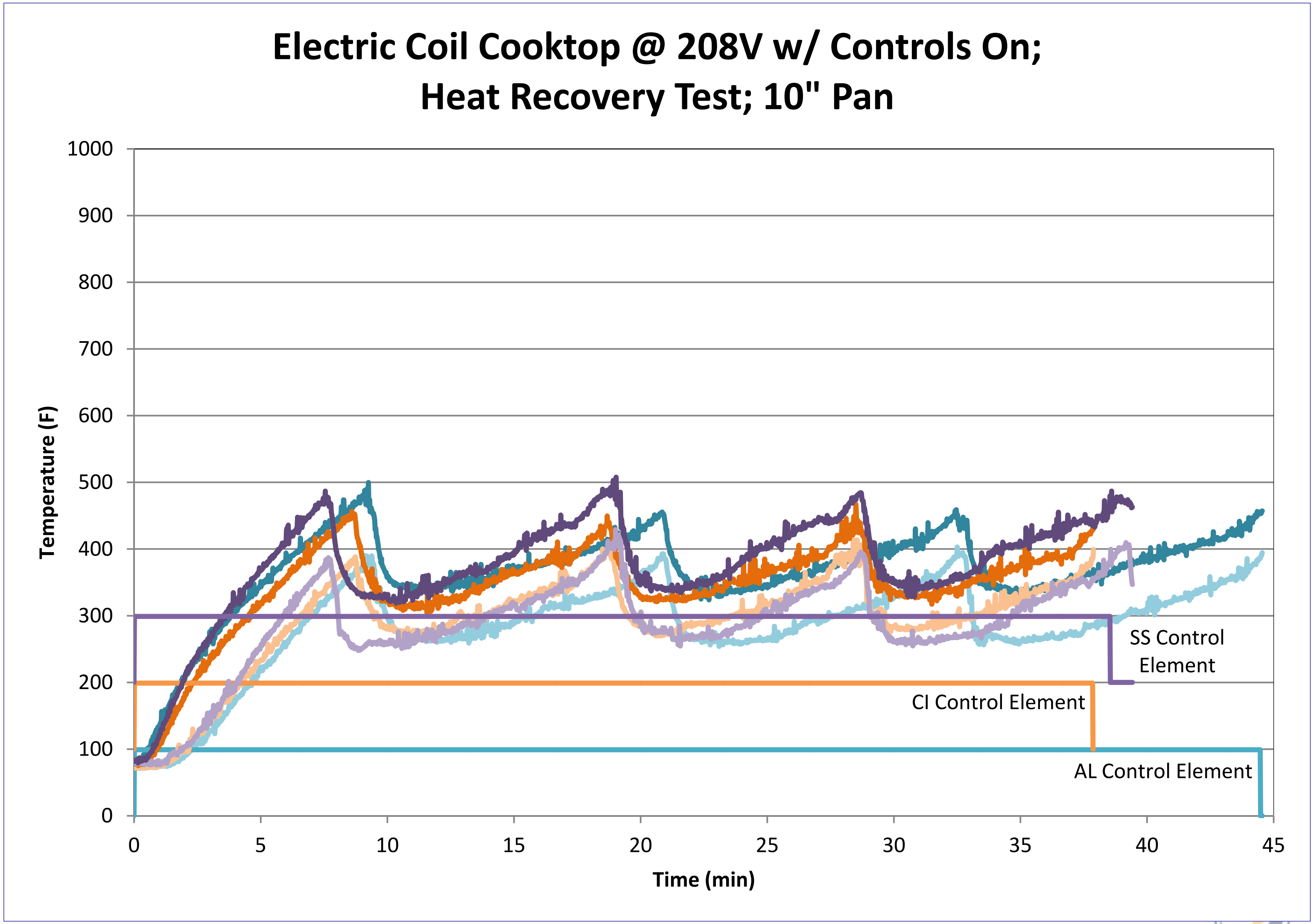
Shallow batch frying

- 800 mL of Canola oil was poured into a pan and the burner turned to Hi.
- Once the oil reached 380 F, 400g of frozen french fries were added, spread out, and cooked until golden brown and crispy and then removed.
- Once the oil had reached 380 F again, the process was repeated two times.

- The controls did not activate at any point during the shallow batch frying tests.

PRIMAIRA

Shallow batch frying test data below shows that with the controls did not interrupt the power to the electric cooktop element.



PRIMAIRA

Appendix E:

Detailed Test Results for Gas Cooktop

Primaira, LLC
30 Commerce Way, Suite 300A
Woburn, MA 01801
tel 781 937 - 0202
fax 781 937 - 0229
www.primaira.com

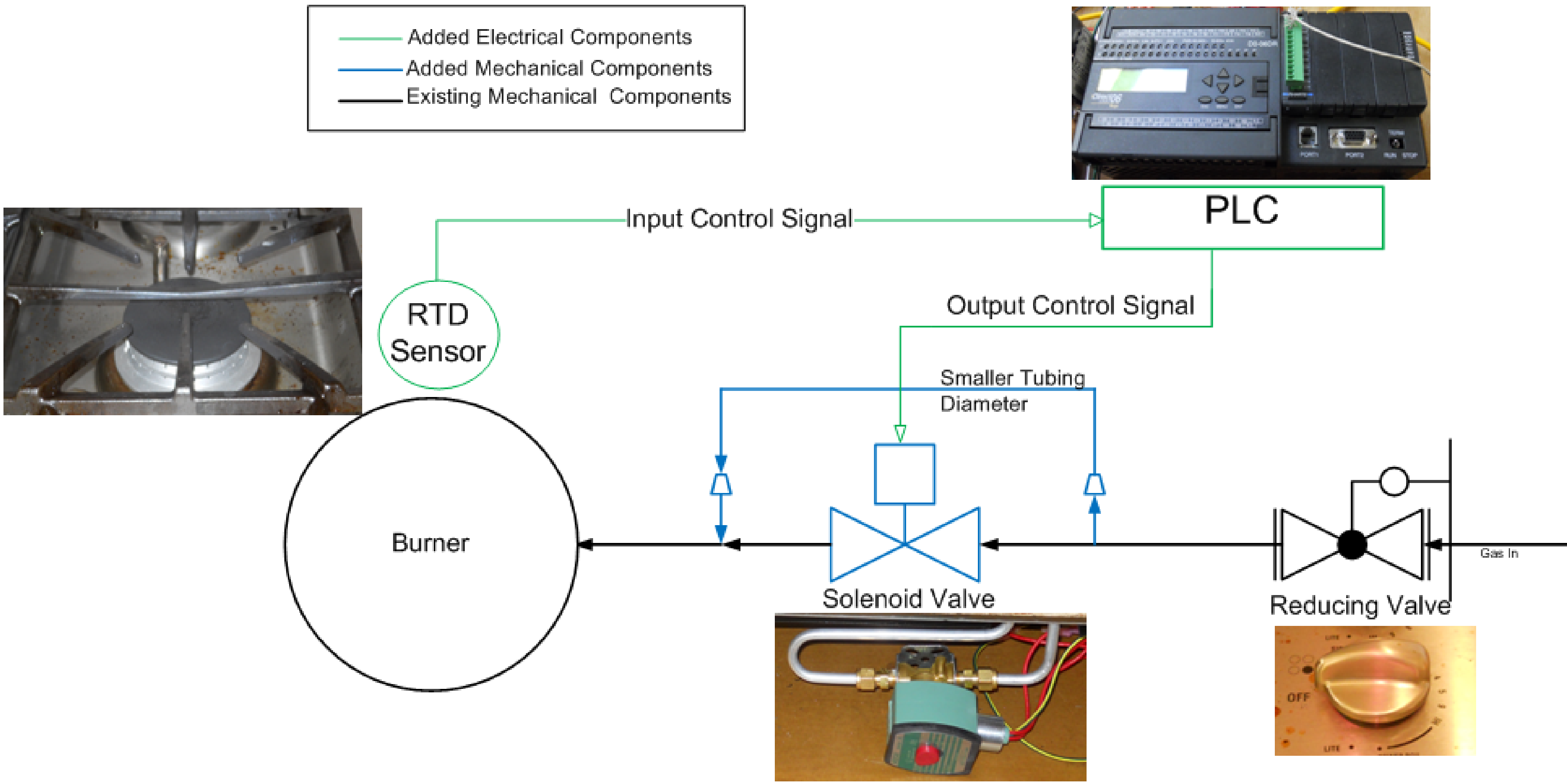
CPSC Cooktop Controls

Gas Burner Testing Summary

Gas Burner Cooktop

- A control algorithm has been developed and implemented to prevent vessel temperatures from rising above 700 F without interfering with normal cooking.
- The sensor is a platinum RTD enclosed in a metal housing. The RTD sensor is spring load to ensure direct contact with the cookware.
- The control algorithm uses a combination of rate of change and threshold monitoring to decide when to reduce the gas flow to the burner.
- Gas flow is restrict by energizing a solenoid valve that diverts the gas through a smaller diameter tube reducing the burner output to half power.
- Extensive testing has been carried out with and without the control on and it is clear that the effect of the control on cooking is negligible if any.

Gas Burner Cooktop Control Hardware Diagram

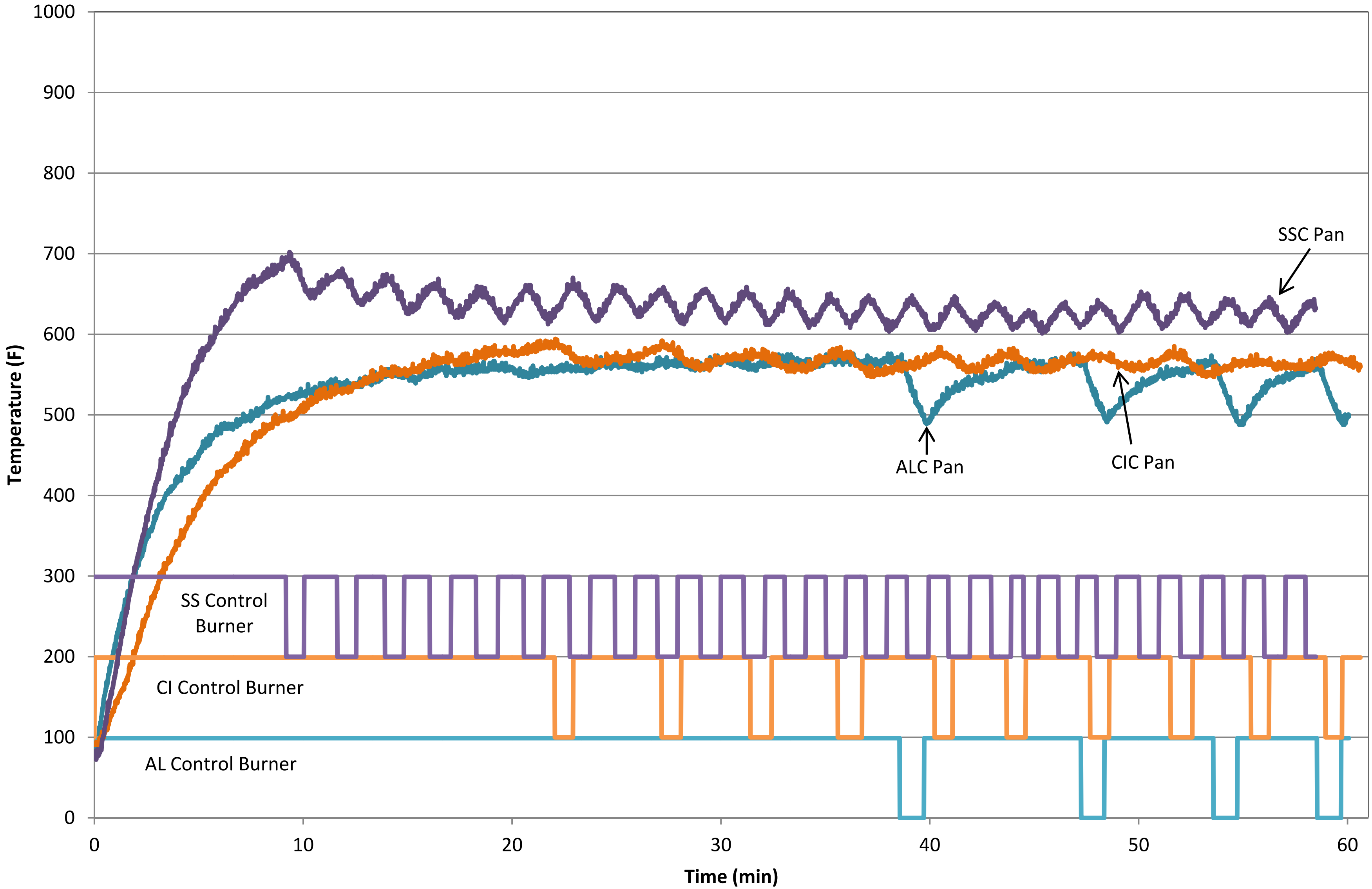


Testing: Gas Burner

- **Eight types of tests were carried out:**
  - Dry cook
  - Pasta boil
  - Sauce simmer
  - Long boil
  - Blackening chicken
  - Steak
  - Stir fry
  - Batch shallow frying

PRIMAIRA

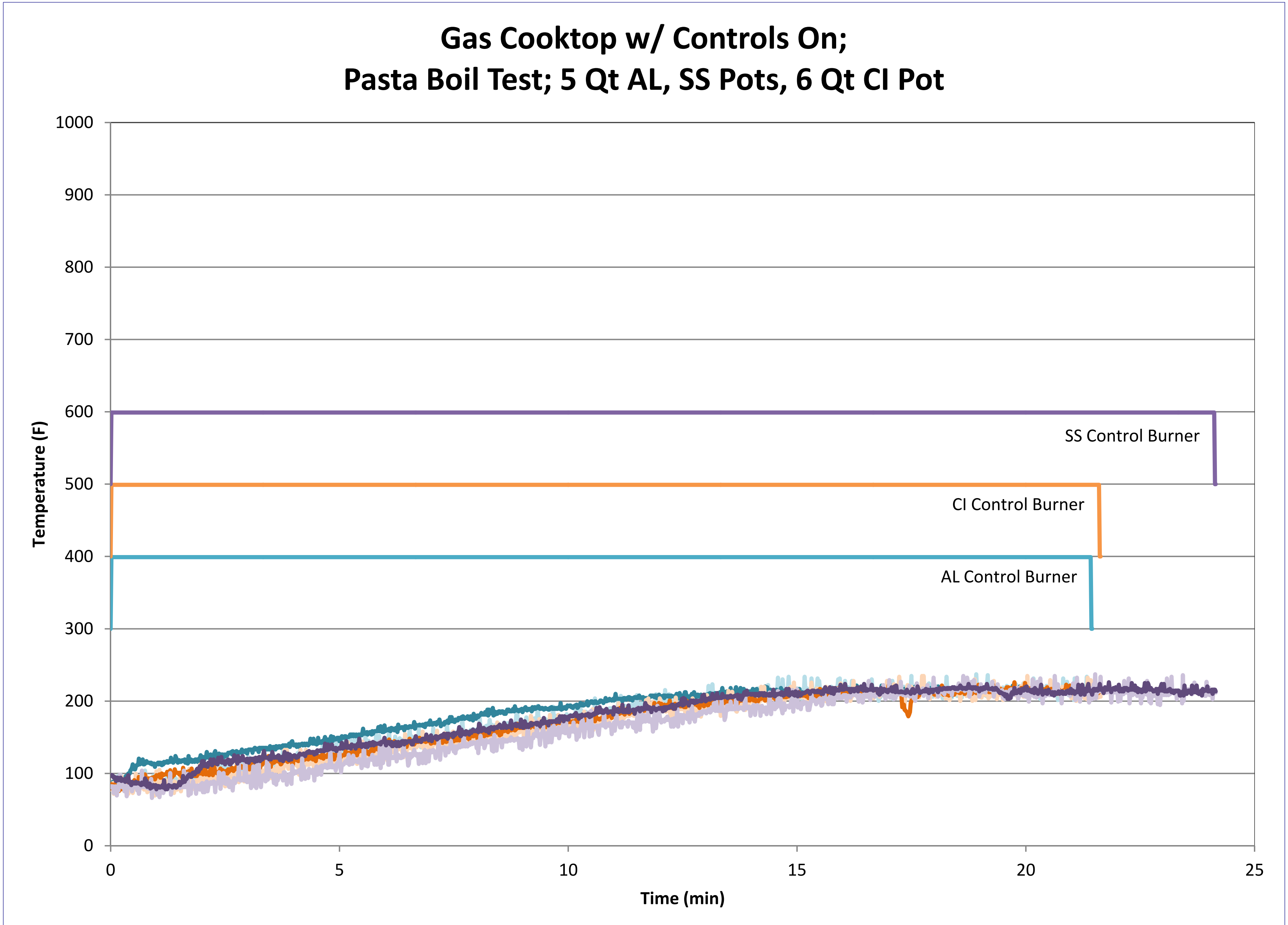
Gas Cooktop w/ Controls On; Dry Cook Test; 10" Pan



Pasta boil testing

- Four quarts of water were placed in a 5-quart pot (in the case of cast iron, 6-quart).
- The burner was turned to High and remained there for the duration of the test.
- When the water had reached a rolling boil, 1 pound of angel hair was added to the pot and cooked for 4 minutes.

- The controls did not activate at any point during the gas testing.


Gas Cooktop w/ Controls On;
Pasta Boil Test; 5 Qt AL, SS Pots, 6 Qt CI Pot
Temperature (F)
Time (min)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
SS Control Burner
CI Control Burner
AL Control Burner

PRIMAIRA

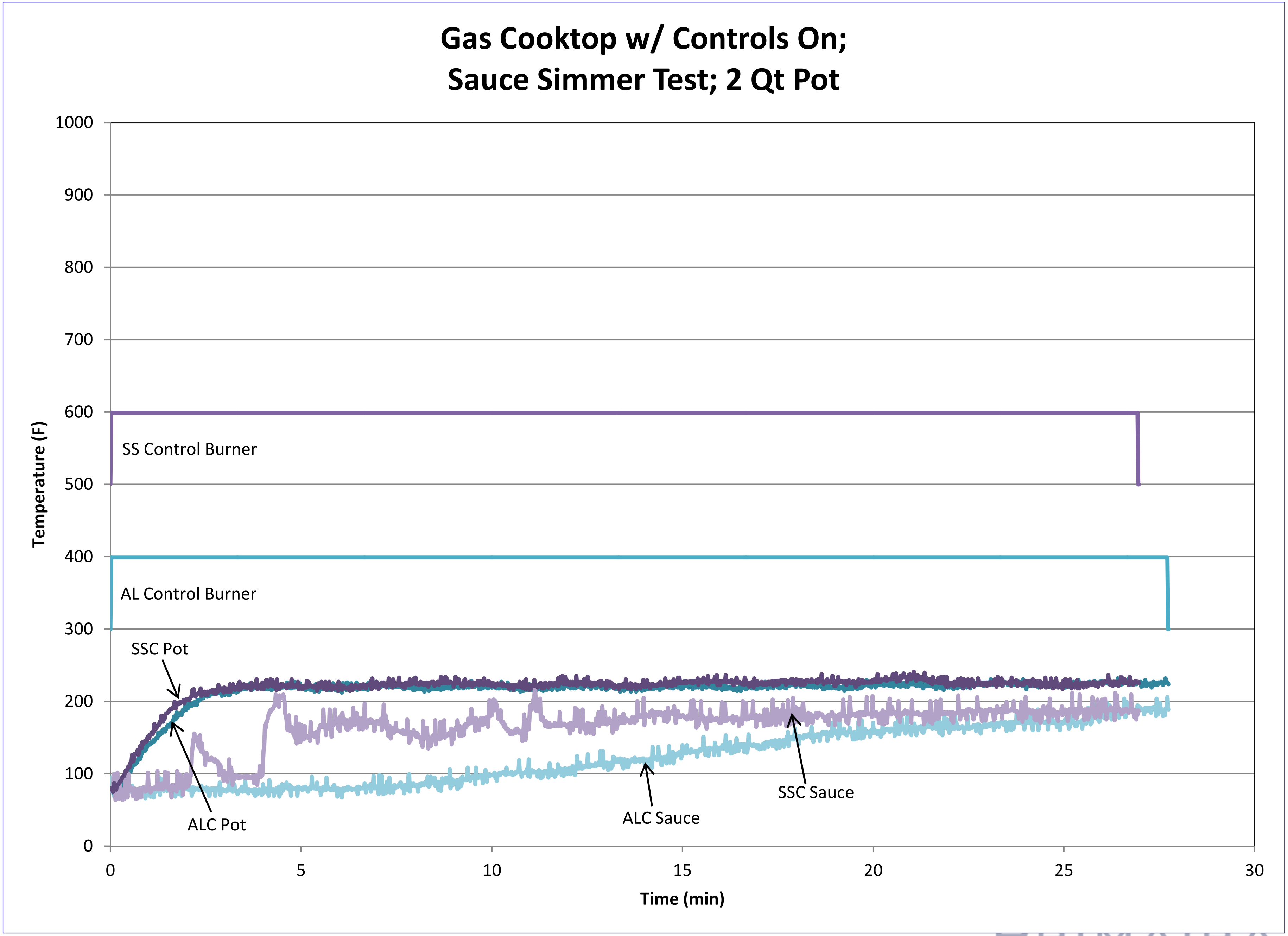
Sauce simmer

- One quart of jarred tomato sauce was placed in a 2-quart pot and brought to a simmer and allowed to remain there for 10 minutes.
- The burner was turned to Hi at first but then lowered so that sauce was gently bubbling rather than spattering.

- **Note:** temperature uniformity was low, as the “media” thermocouple would continue to register temperatures under 100°F while the sauce was bubbling in places.

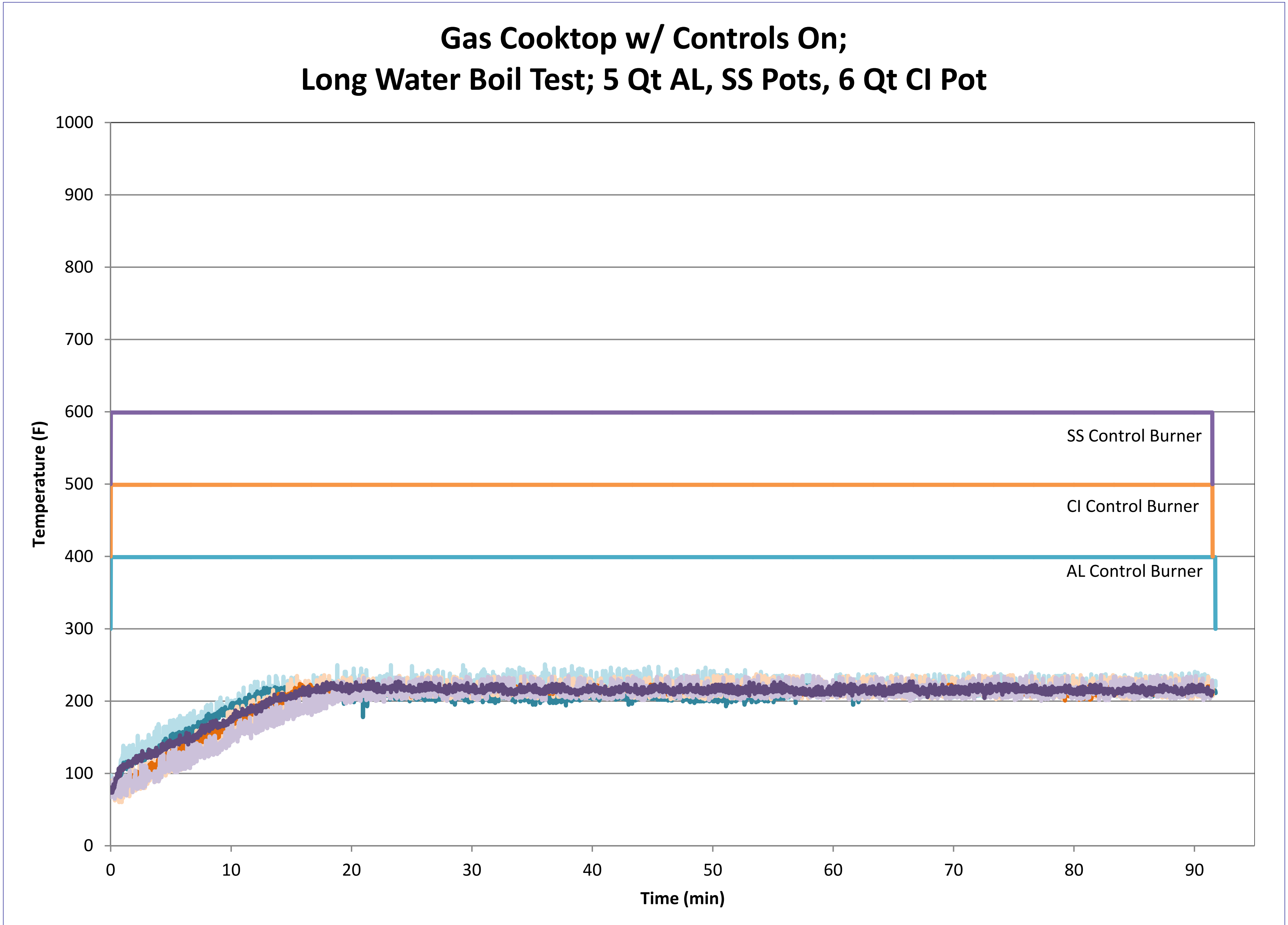
- The controls did not activate at any point during the gas testing.

PRIMAIRA


Gas Cooktop w/ Controls On;
Sauce Simmer Test; 2 Qt Pot
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
SS Control Burner
AL Control Burner
SSC Pot
ALC Pot
ALC Sauce
SSC Sauce
0
5
10
15
20
25
30
Time (min)

Long boil

- A 5 or 6 quart pot was filled with 4 quarts of room-temperature tap water (70-80 F).
- The burner was switched to Hi and data collected for 90 minutes.


Gas Cooktop w/ Controls On;
Long Water Boil Test; 5 Qt AL, SS Pots, 6 Qt CI Pot
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
SS Control Burner
CI Control Burner
AL Control Burner
0
10
20
30
40
50
60
70
80
90
Time (min)

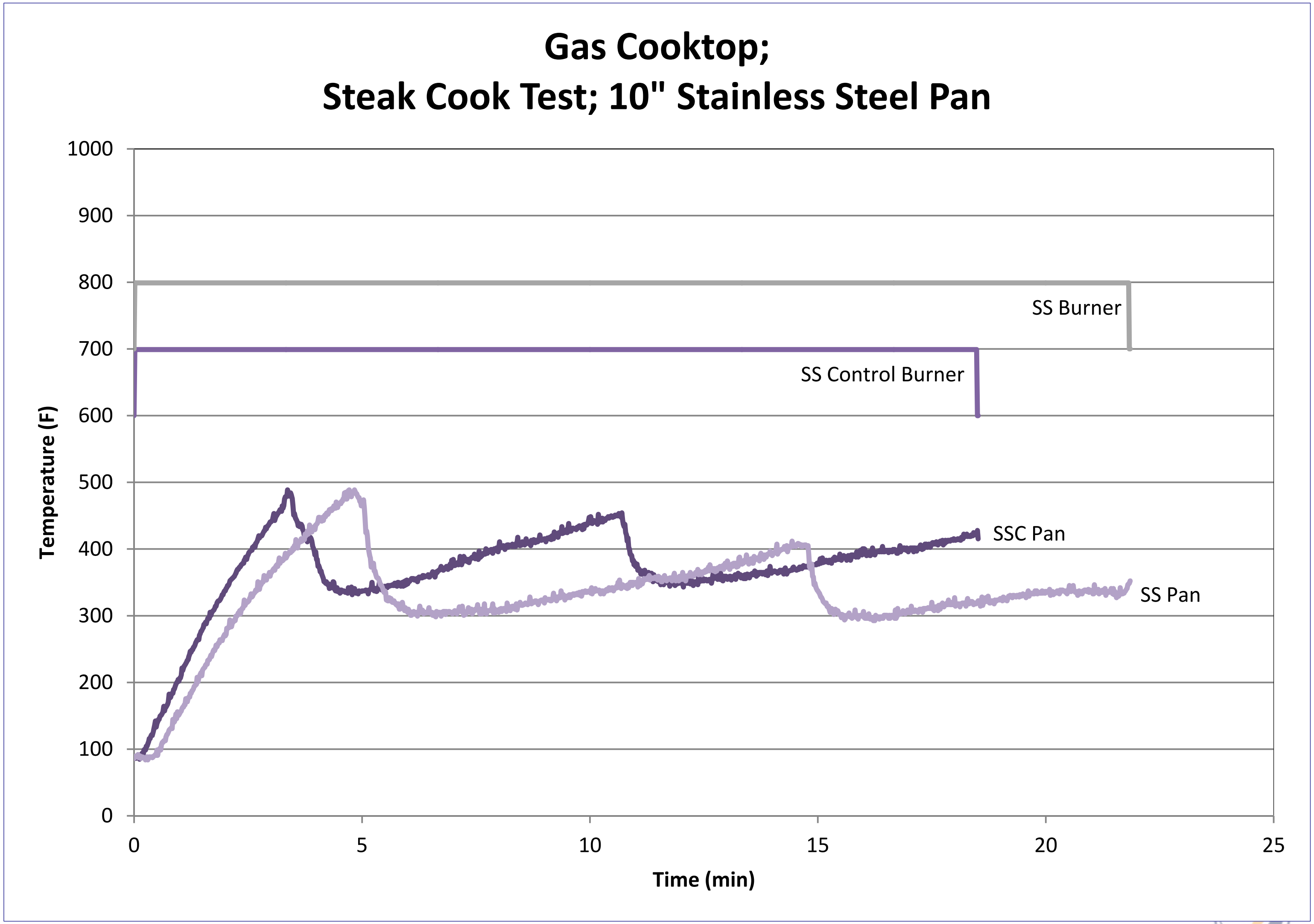
PRIMAIRA

Steak Test – Overview

- The pan was heated with 30mL of vegetable oil on the "6" setting until smoking hot.
- Two steaks, dried thoroughly and seasoned, weighing roughly 1 pound each and generally 1 ¼" thick, were placed in the hot pan and cooked for 5-7 minutes on each side, until medium rare.
- Steaks were allowed to rest for five minutes, and then sliced into quarters and doneness determined.

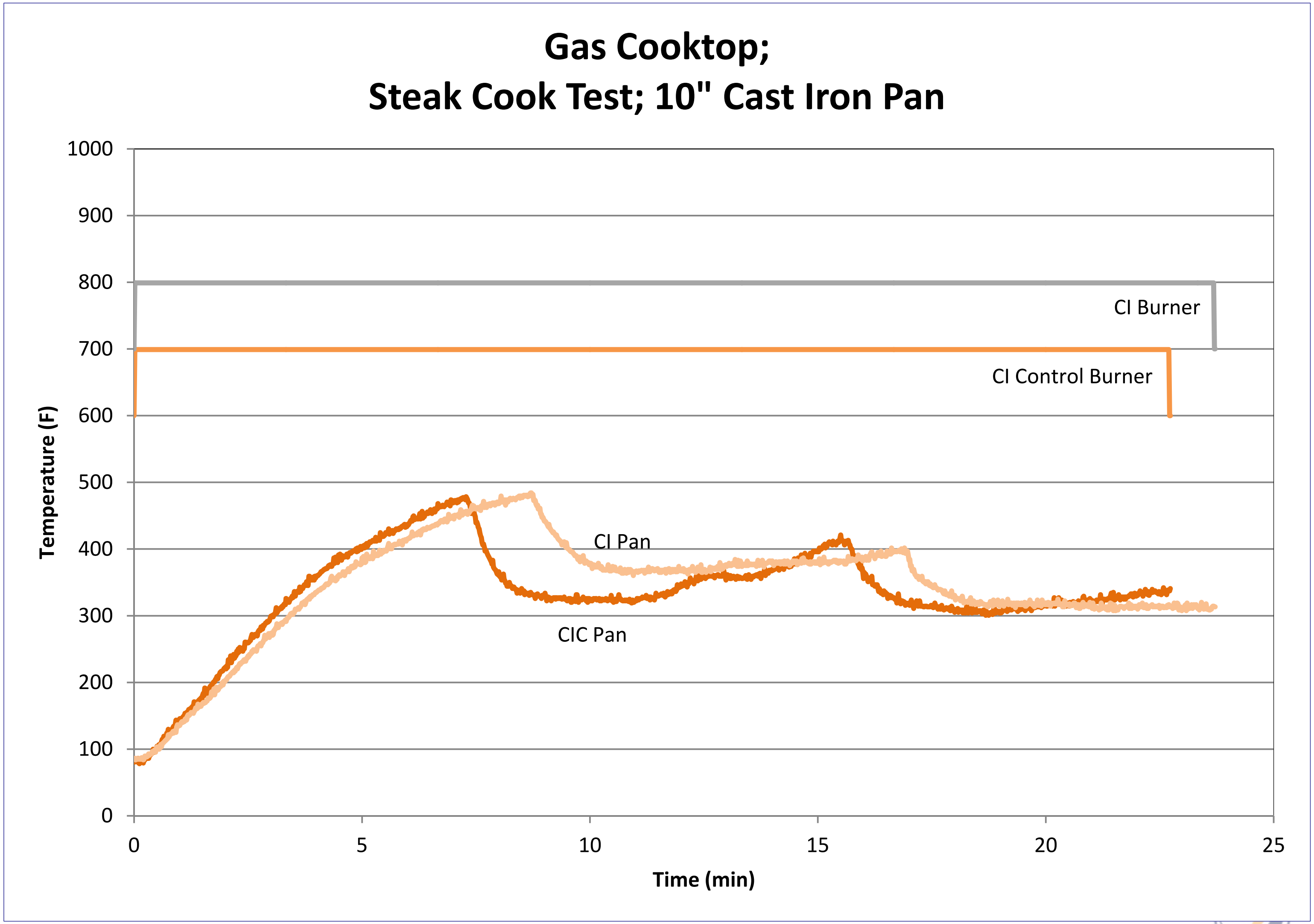
PRIMAIRA

Steak test comparing stainless steel pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



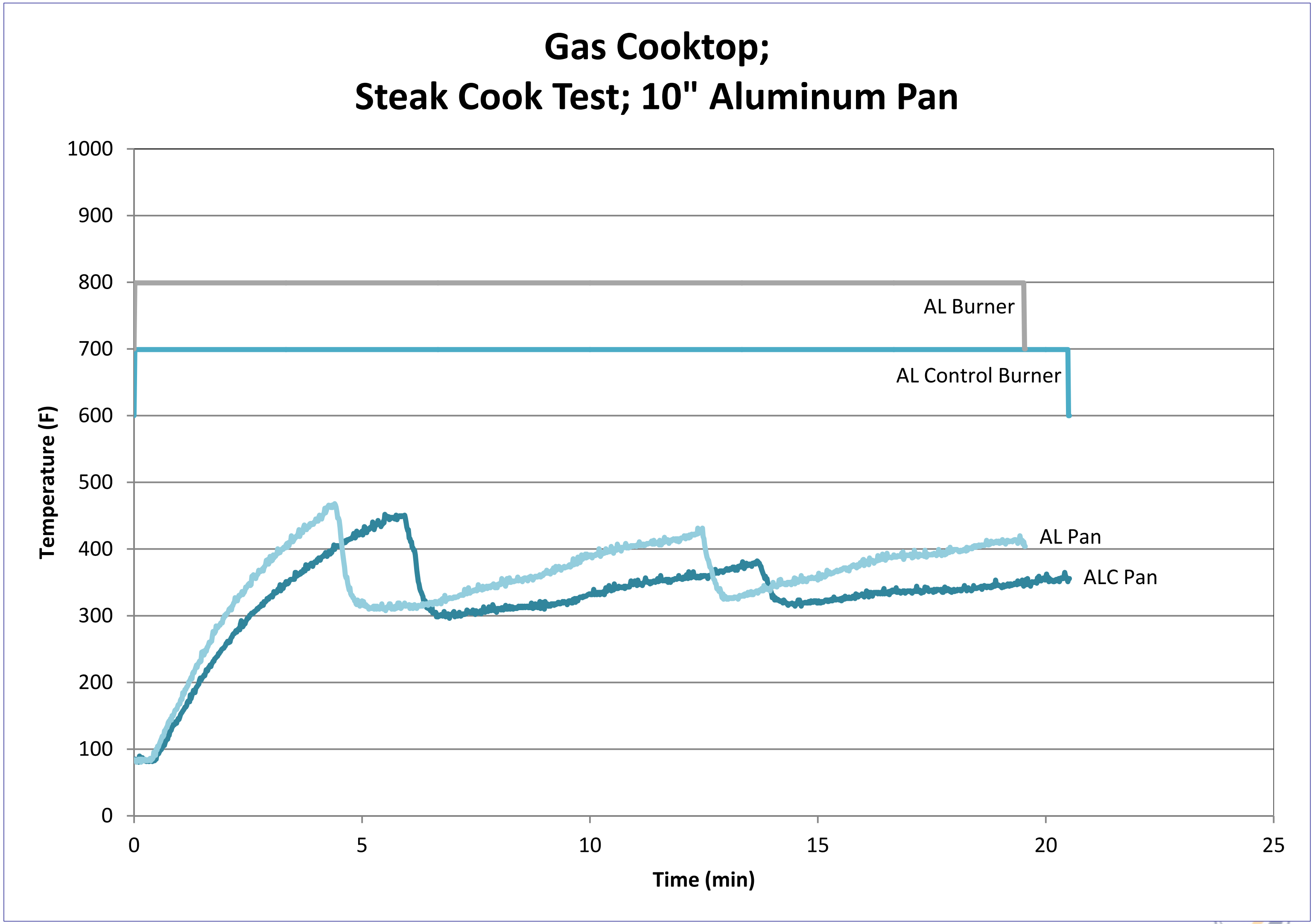
PRIMAIRA

Steak test comparing cast iron pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



PRIMAIRA

Steak test comparing aluminum pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



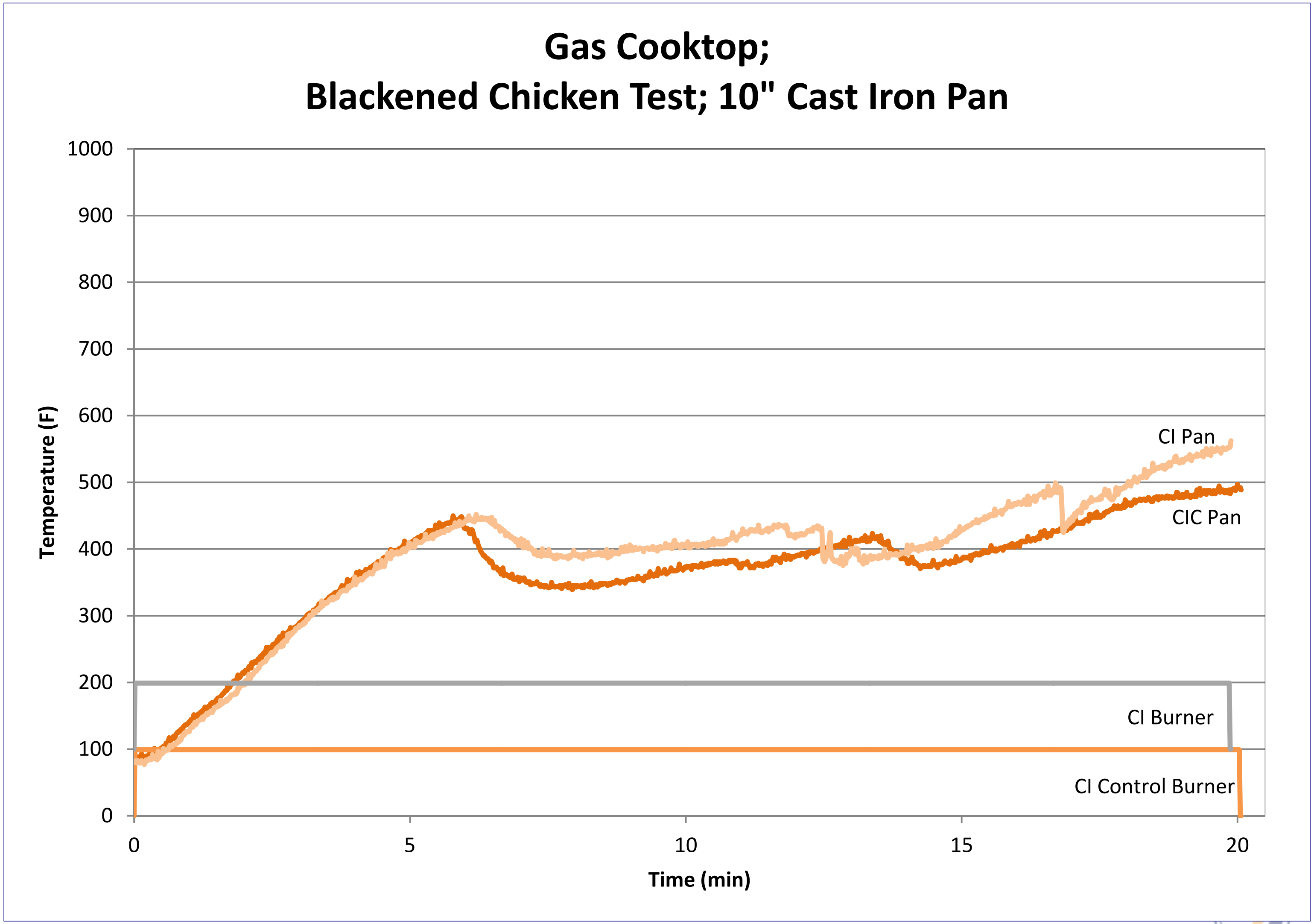
PRIMAIRA

Blackening Chicken

- One large chicken breast, roughly half a pound, was split in half to ½" thickness.
- 30mL of oil was heated until smoking in a pan, and chicken was added and cooked until blackened on each side.
- The chicken was sliced to show degree of doneness.

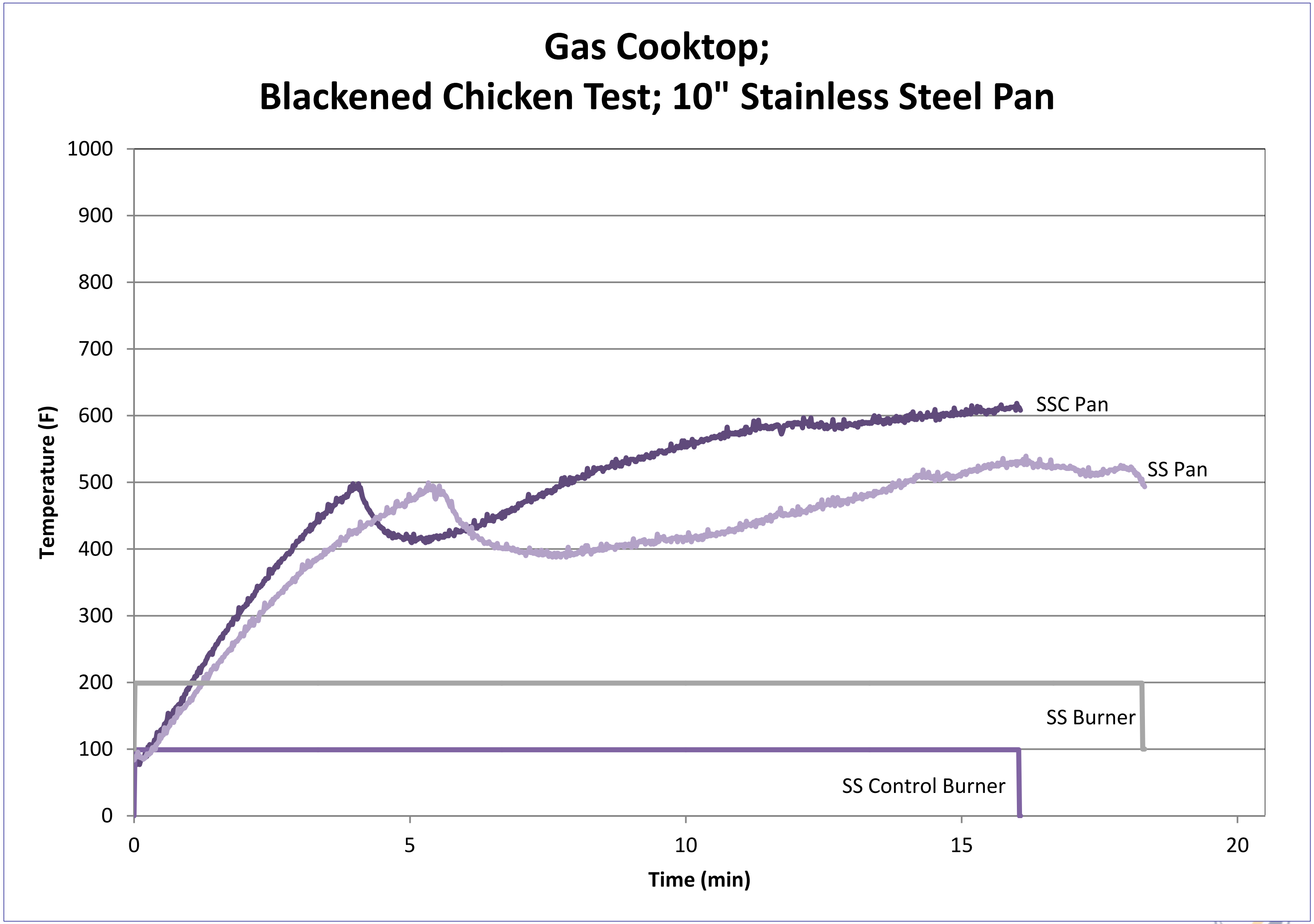
PRIMAIRA

Blackening chicken test comparing cast iron pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



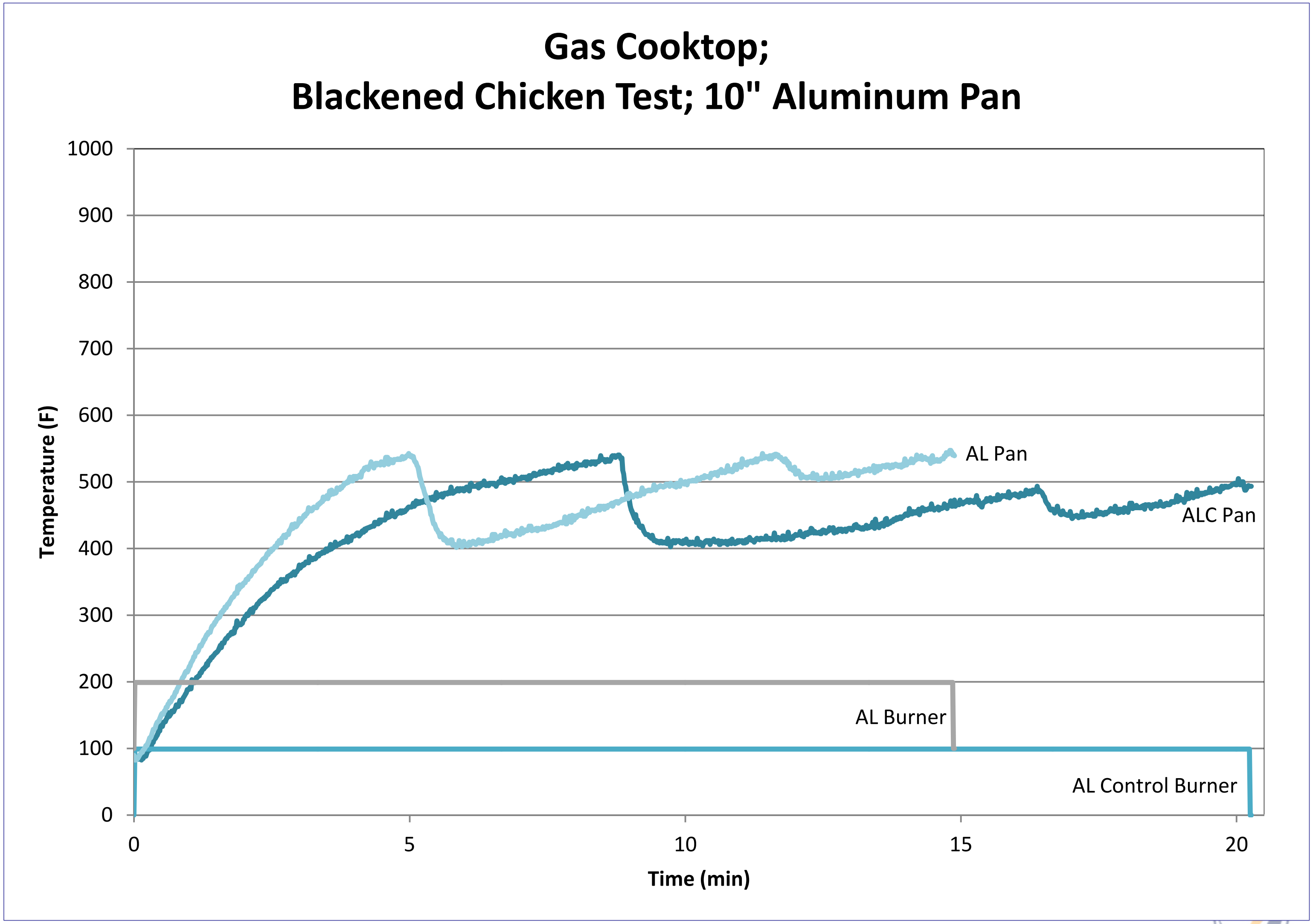
PRIMAIRA

Blackening chicken test comparing stainless steel pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



PRIMAIRA

Blackening chicken test comparing aluminum pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



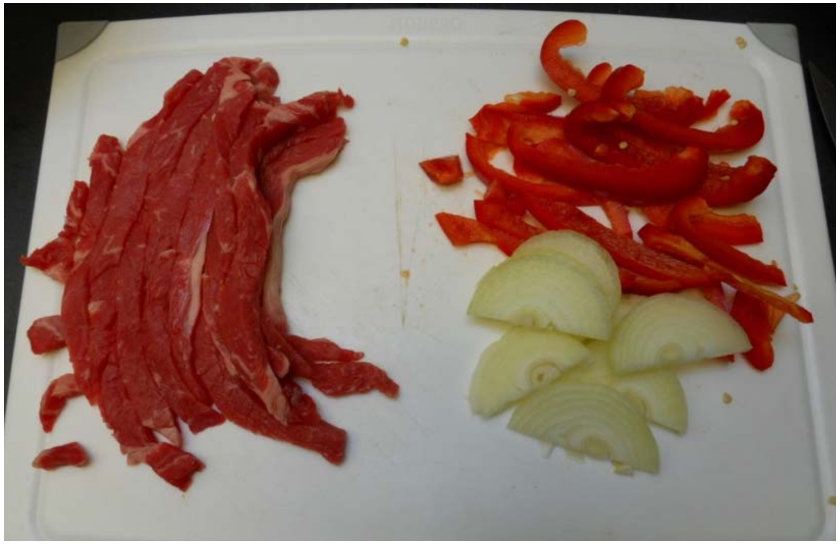
PRIMAIRA

Stir Fry

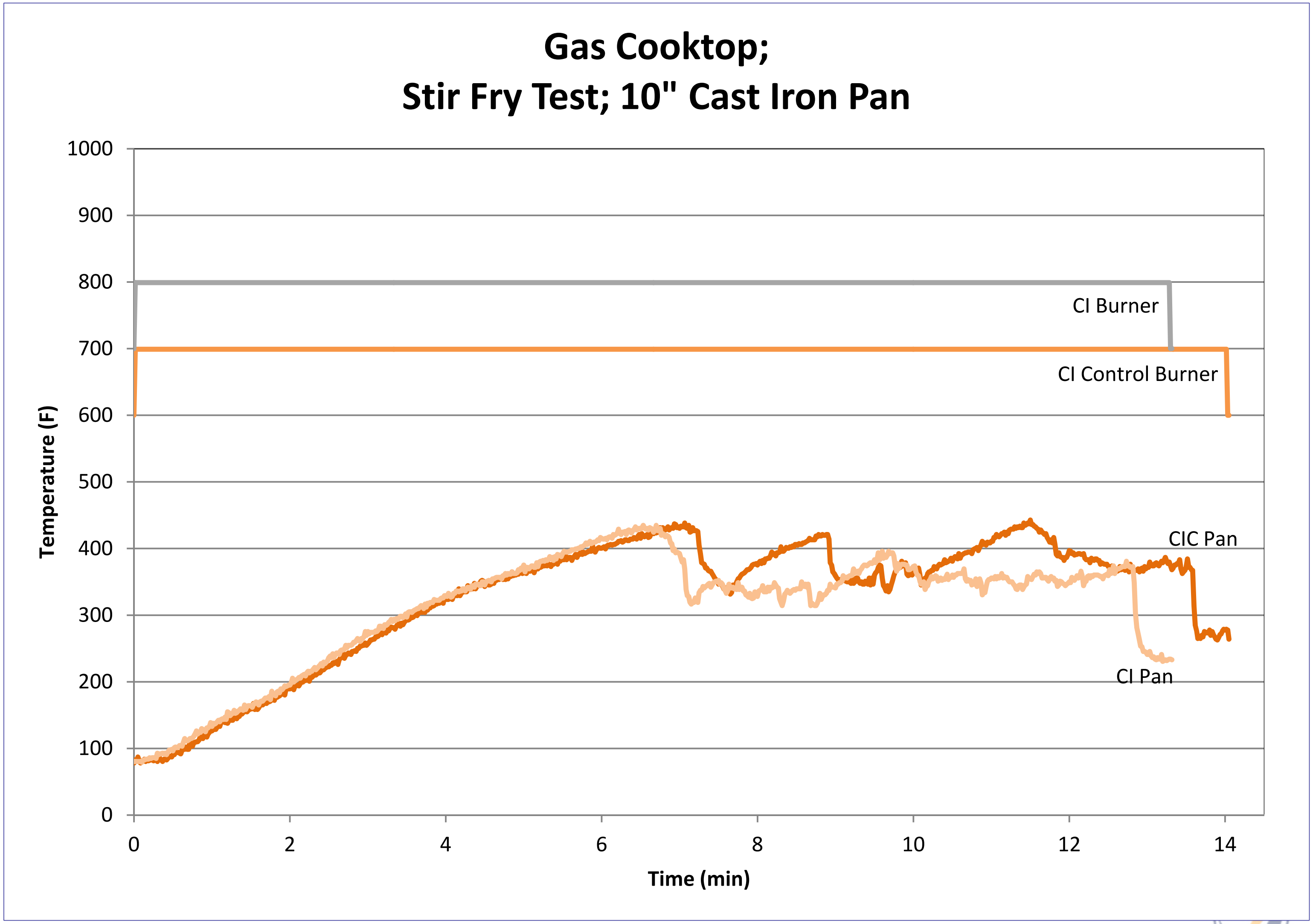
- ½ pound of thinly cut strip steak, ½ a red bell pepper and ½ an onion were thinly sliced.
- 20mL of vegetable oil were heated in the pan until smoking, and half of the steak was added and cooked rapidly, using tongs to toss, until browned on all sides. This steak was removed to a bowl and the rest of the steak added and cooked in the same manner, then removed.
- More oil was placed in the pan and allowed to heat up briefly, then the vegetables were added to the pan and cooked until tender. The steak was added back to the pan with the juices and warmed with the vegetables for about 20 seconds.

Stir Fry Continued

- The controls activated only with the electric cooktop, and then only briefly. They did not have a noticeable impact on the outcome of the stir-fry.

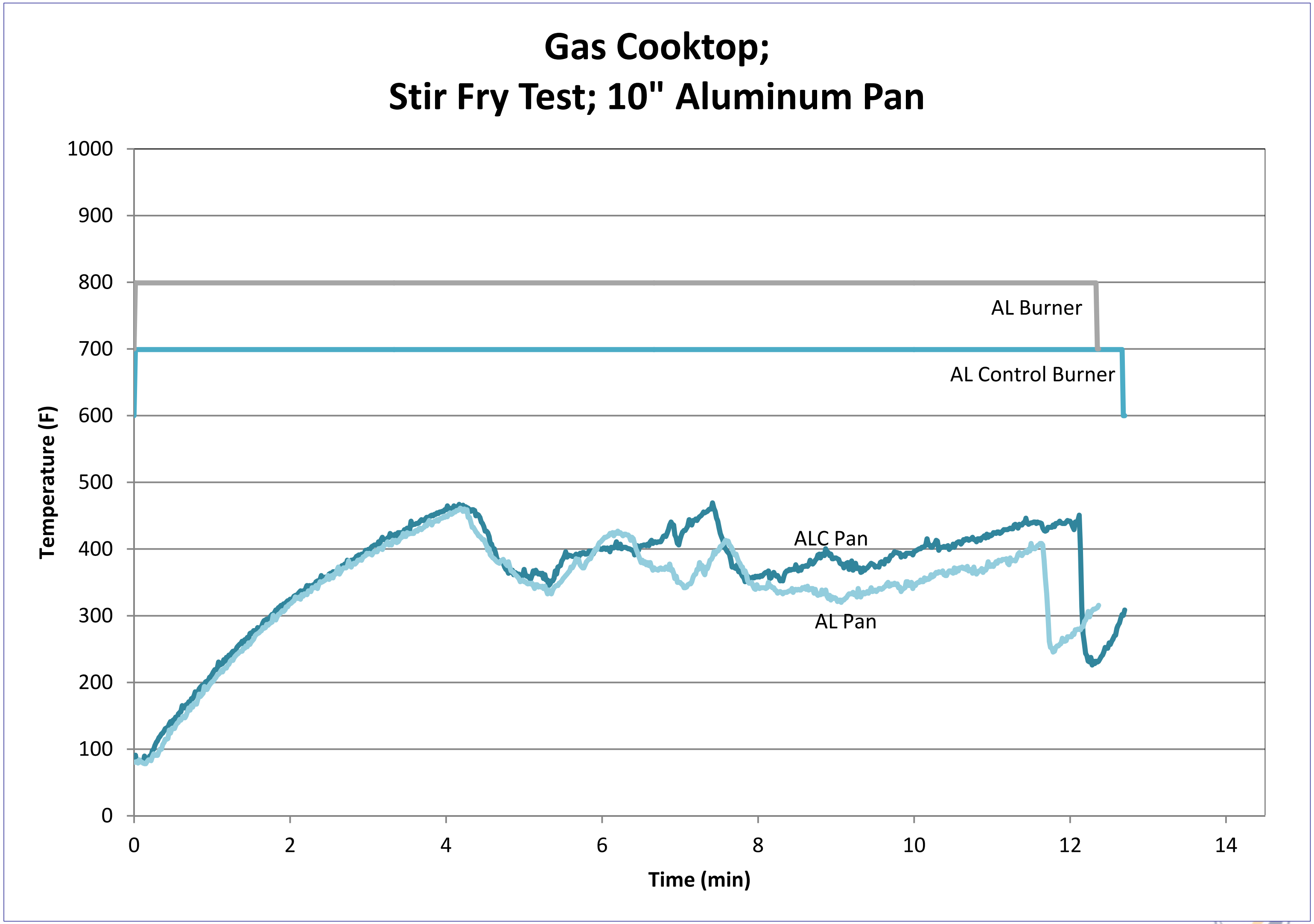


Stir fry test comparing cast iron pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



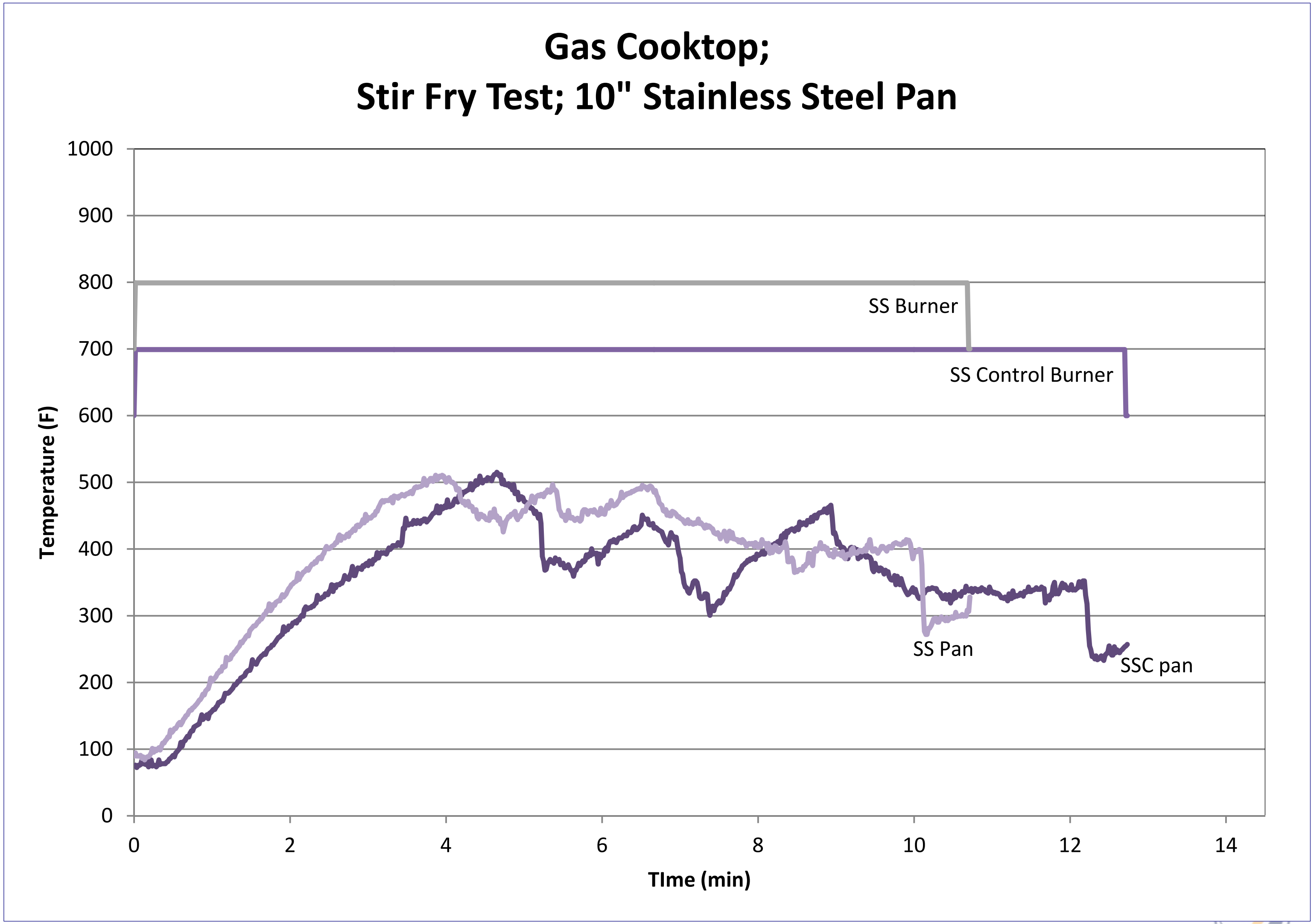
PRIMAIRA

Stir fry test comparing aluminum pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



PRIMAIRA

Stir fry test comparing stainless steel pan temperatures with the fire mitigation controls activated vs. the fire mitigation controls deactivated. The gas cooktop was set to high for this test.



PRIMAIRA

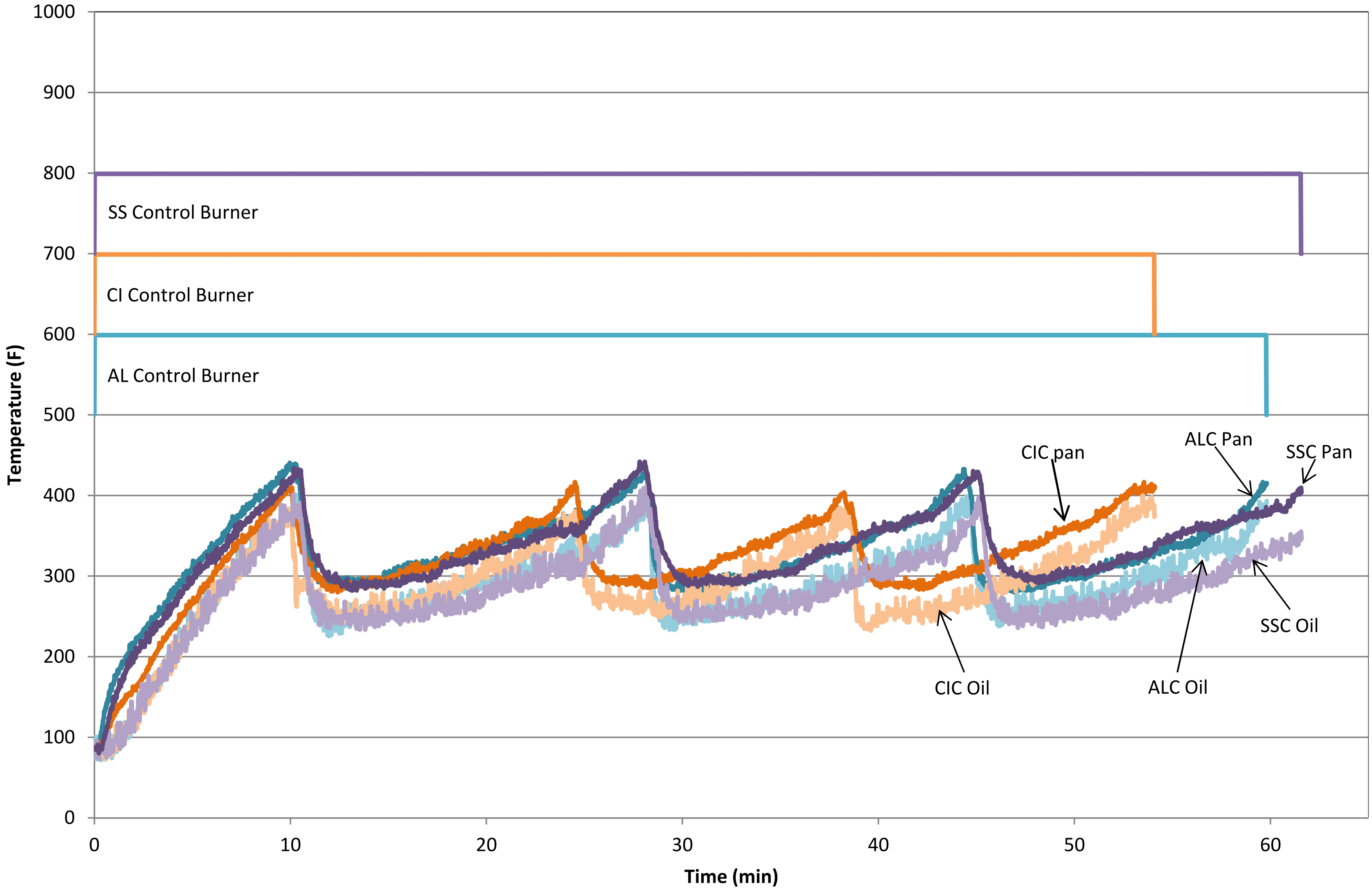
Shallow Batch Frying

- 800 mL of Canola oil was poured into a pan and the burner turned to Hi.
- Once the oil reached 380º F, 400g of frozen french fries were added, spread out, and cooked until golden brown and crispy and then removed.
- Once the oil had reached 380º F again, the process was repeated twice.

- The controls did not activate at any point during the batch frying tests.

PRIMAIRA

Gas Cooktop w/ Controls On; Heat Recovery Test; 10" Pan



PRIMAIRA

Appendix F:

Detailed Test Results for Electric Glass Ceramic Cooktop

Primaira, LLC
30 Commerce Way, Suite 300A
Woburn, MA 01801
tel 781 937 - 0202
fax 781 937 - 0229
www.primaira.com

CPSC Cooktop Controls

Glass Ceramic Cooktop: 240V

Testing: Glass Ceramic Cooktop @ 240V

- **Nine types of tests were carried out in Glass Ceramic Cooktop @ 240V:**
  - **Skillet Tests**:
    - Dry cook
    - Steak fry
    - Blackened meat
    - Stir fry
    - Heat recovery
  - **Pot Tests**:
    - Pasta boil
    - Heating 1 quart of water
    - Sauce simmer
    - Long water boil

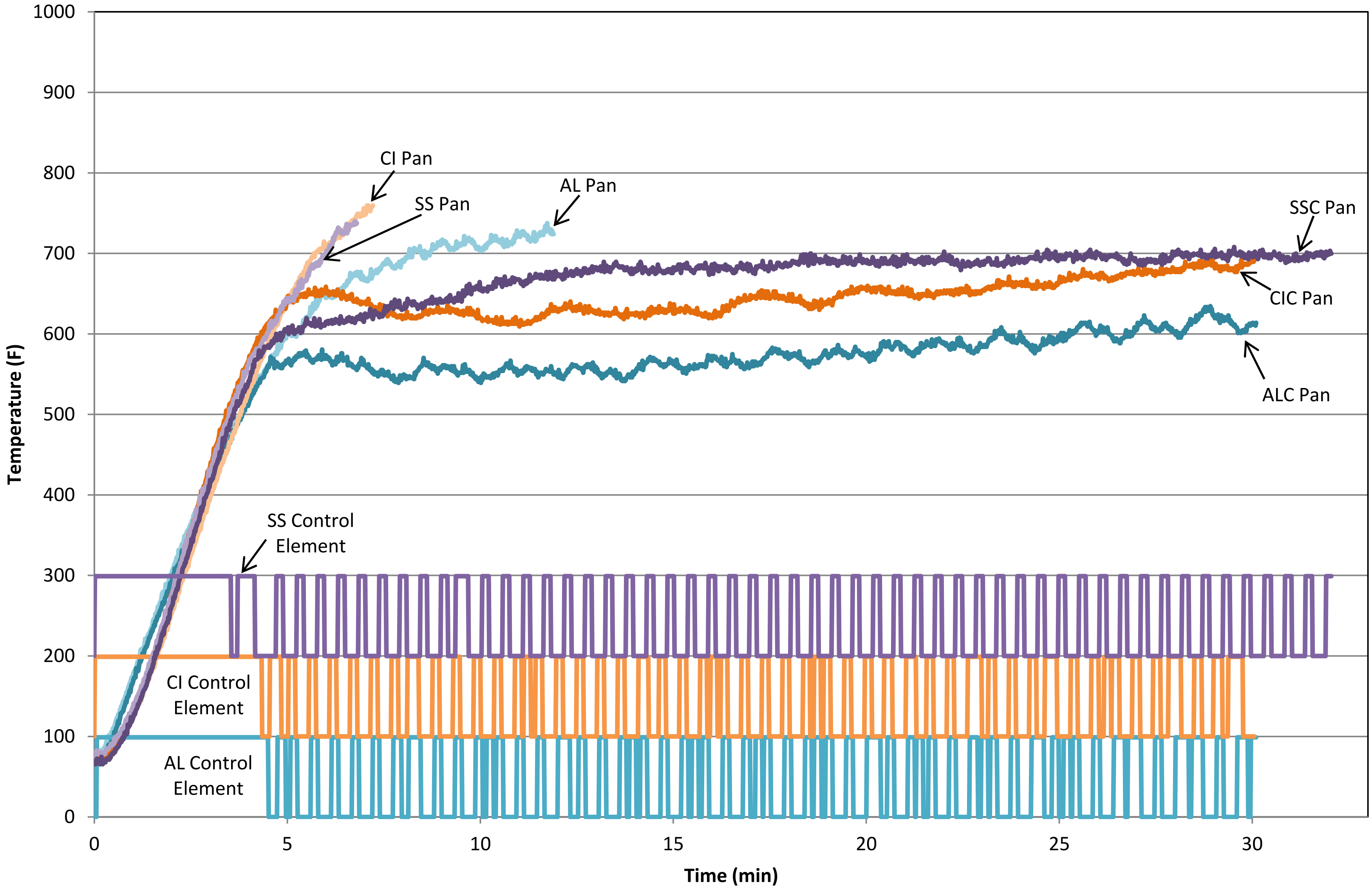
PRIMAIRA

Dry Cook Test: Glass Ceramic Cooktop @ 240V

- 10” aluminum, cast iron, and stainless steel skillets (empty) were heated for several minutes on “high” setting

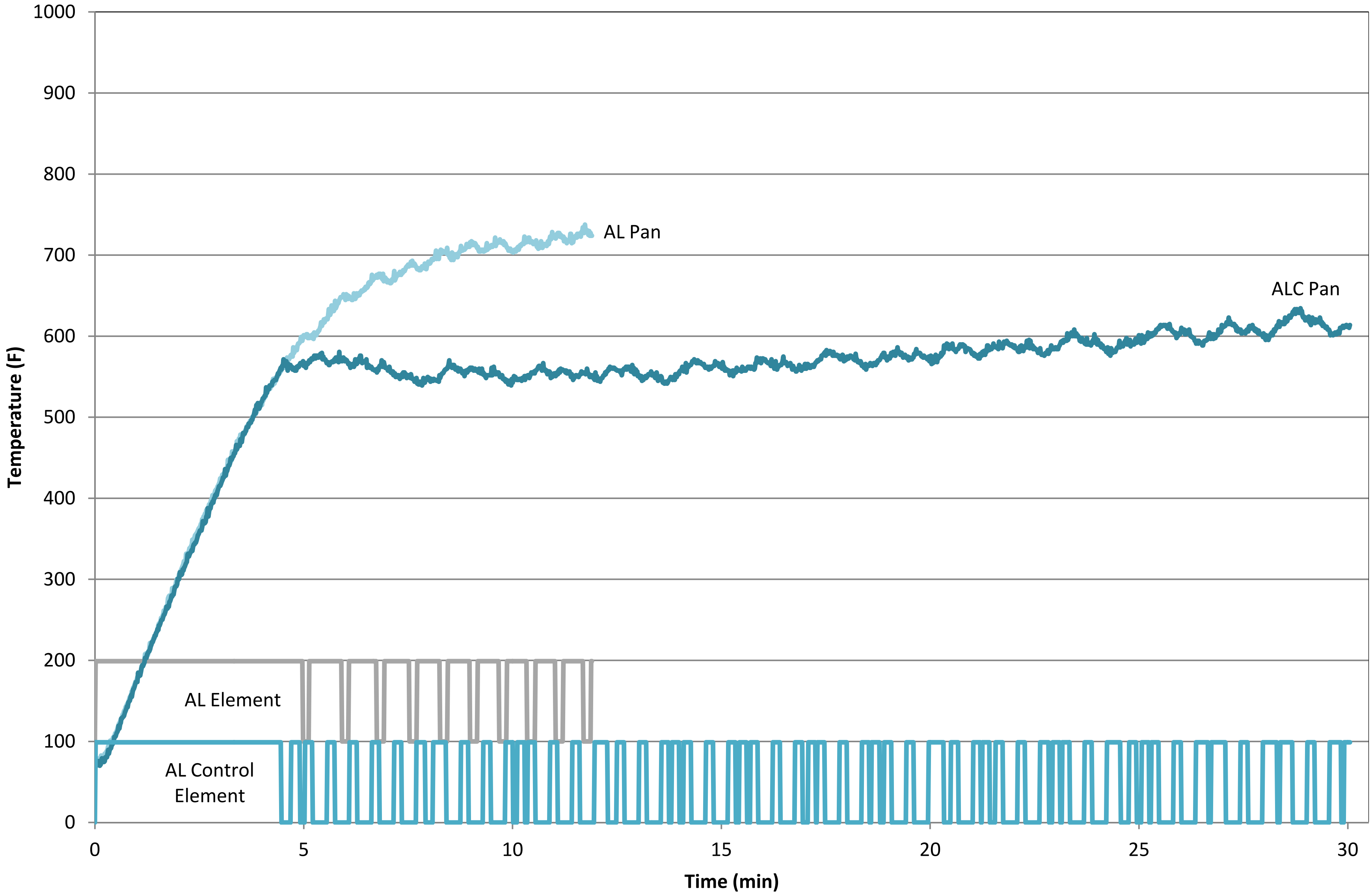
PRIMAIRA

Glass Ceramic Cooktop @ 240V; Dry Cook Tests; 10" Pan

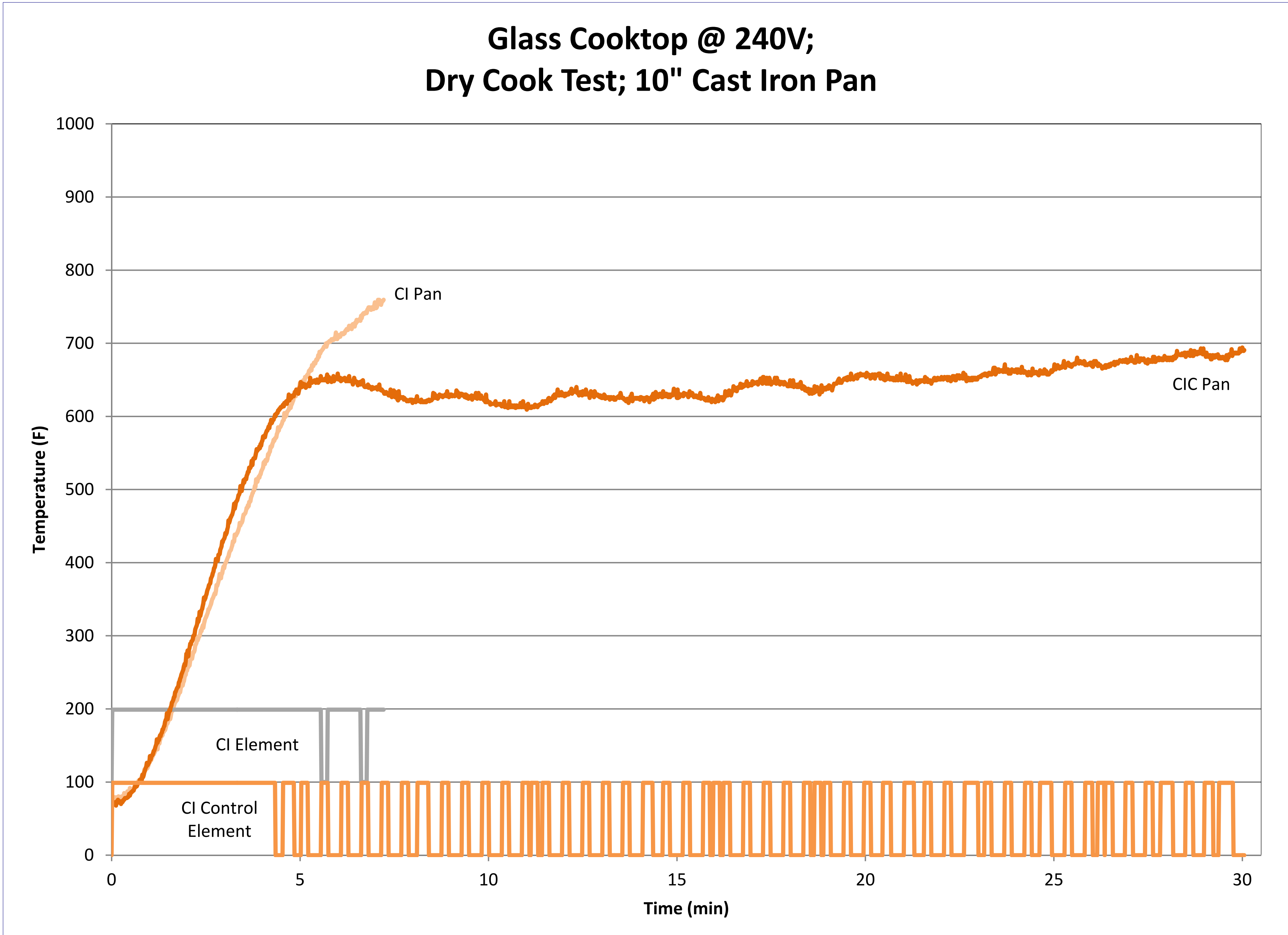


PRIMAIRA

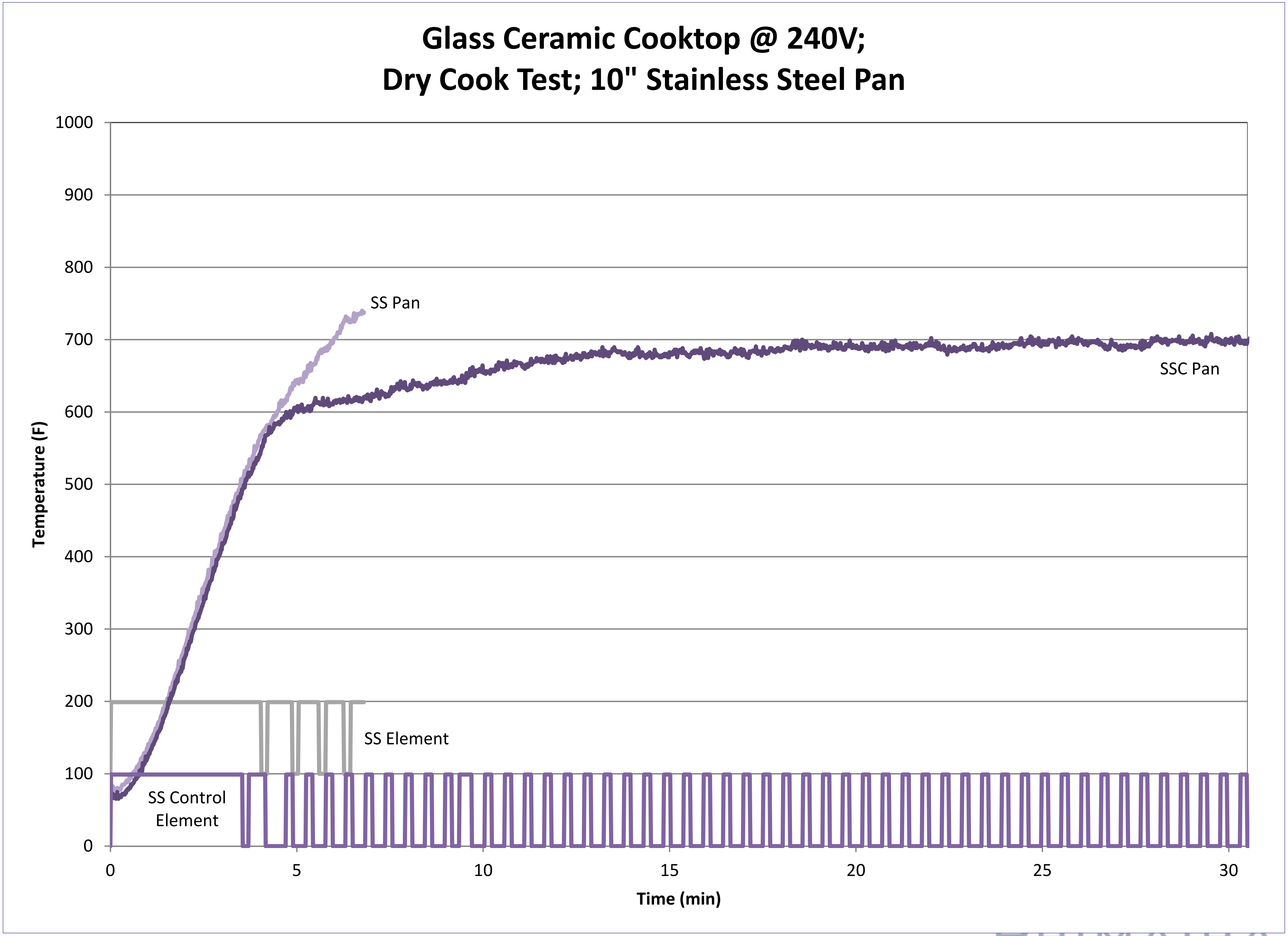
Glass Ceramic Cooktop @ 240V;
Dry Cook Test; 10" Aluminum Pan



PRIMAIRA


Glass Cooktop @ 240V;
Dry Cook Test; 10" Cast Iron Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
Time (min)
0
5
10
15
20
25
30
CI Pan
CIC Pan
CI Element
CI Control
Element

PRIMAIRA

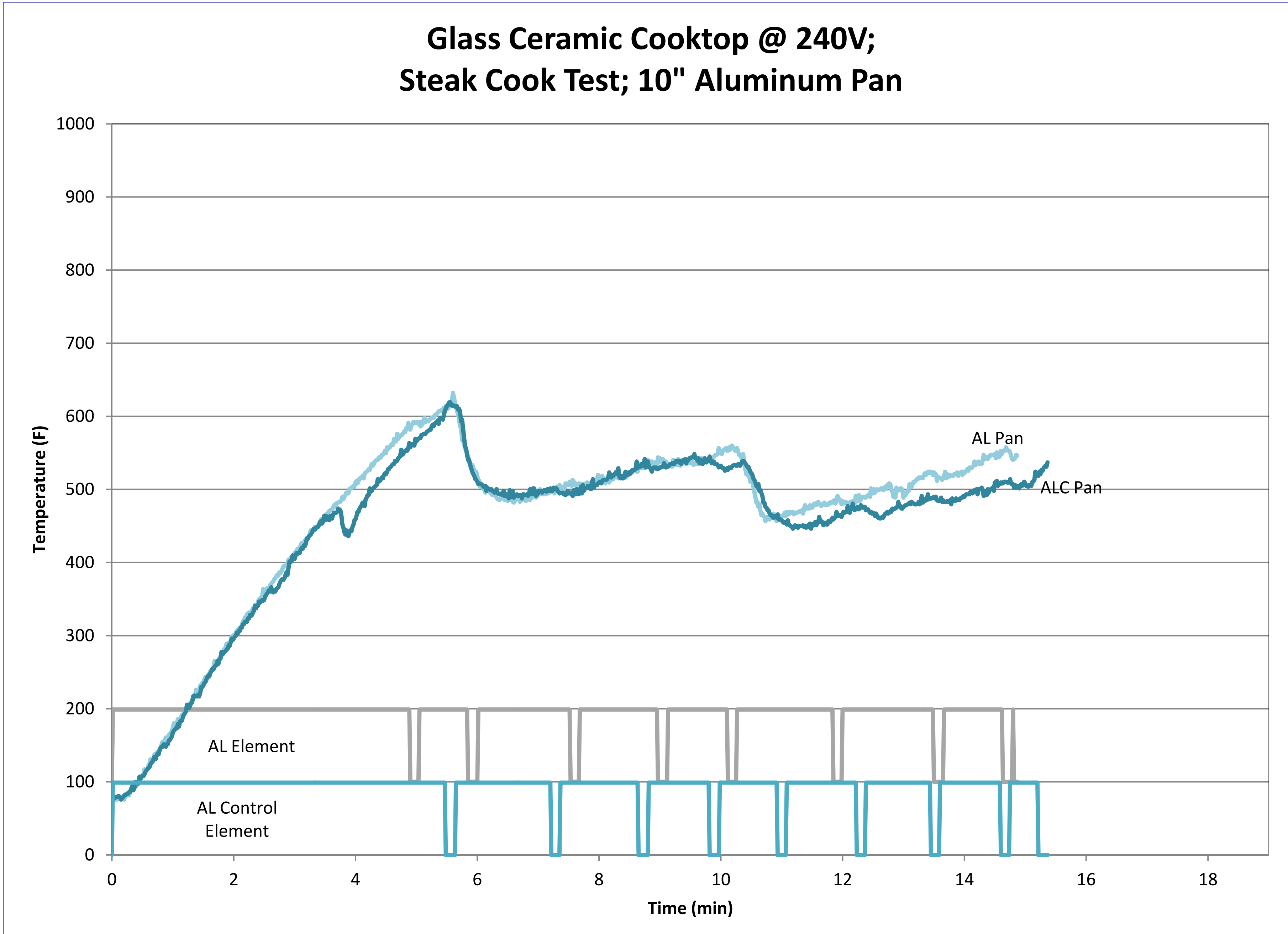

Glass Ceramic Cooktop @ 240V;
Dry Cook Test; 10" Stainless Steel Pan
Temperature (F)
Time (min)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
SS Pan
SSC Pan
SS Element
SS Control Element

PRIMAIRA

Steak Fry Test: Glass Ceramic Cooktop @ 240V

- Enough oil added to 10” skillet to coat bottom surface
- Element set to “high” for entire test
- Skillet heated until oil starts to smoke
- 2 raw steaks added to pan, fried until just starting to char on each side

PRIMAIRA

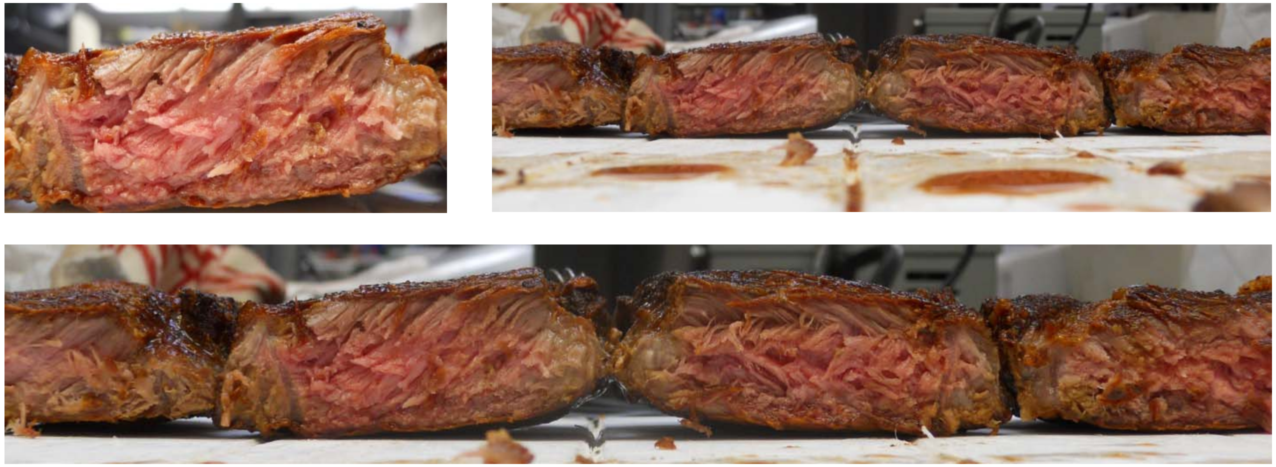

Glass Ceramic Cooktop @ 240V;
Steak Cook Test; 10" Aluminum Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
Time (min)
AL Pan
ALC Pan
AL Element
AL Control
Element

Aluminum, no Controls

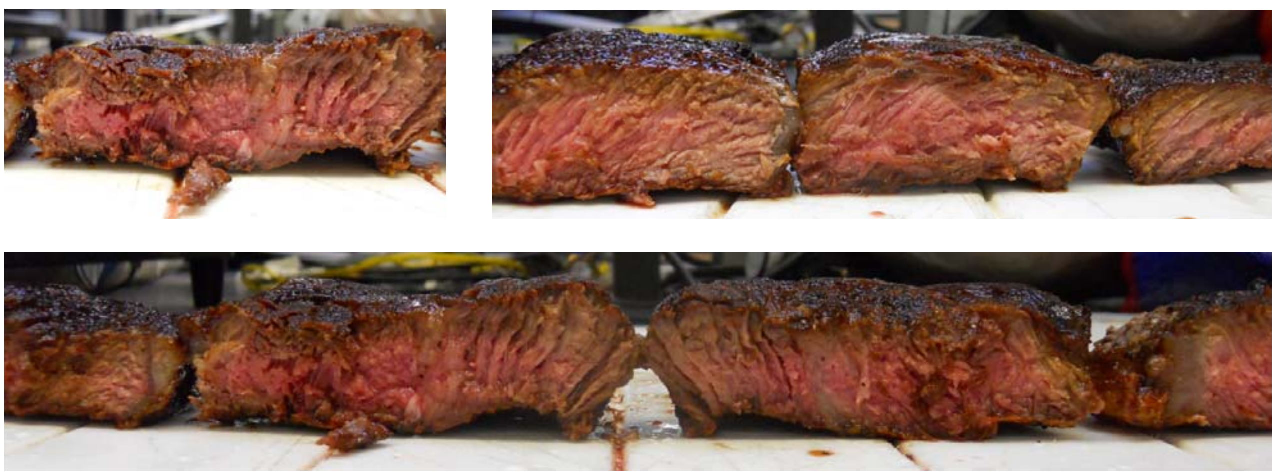
Aluminum w/ Controls

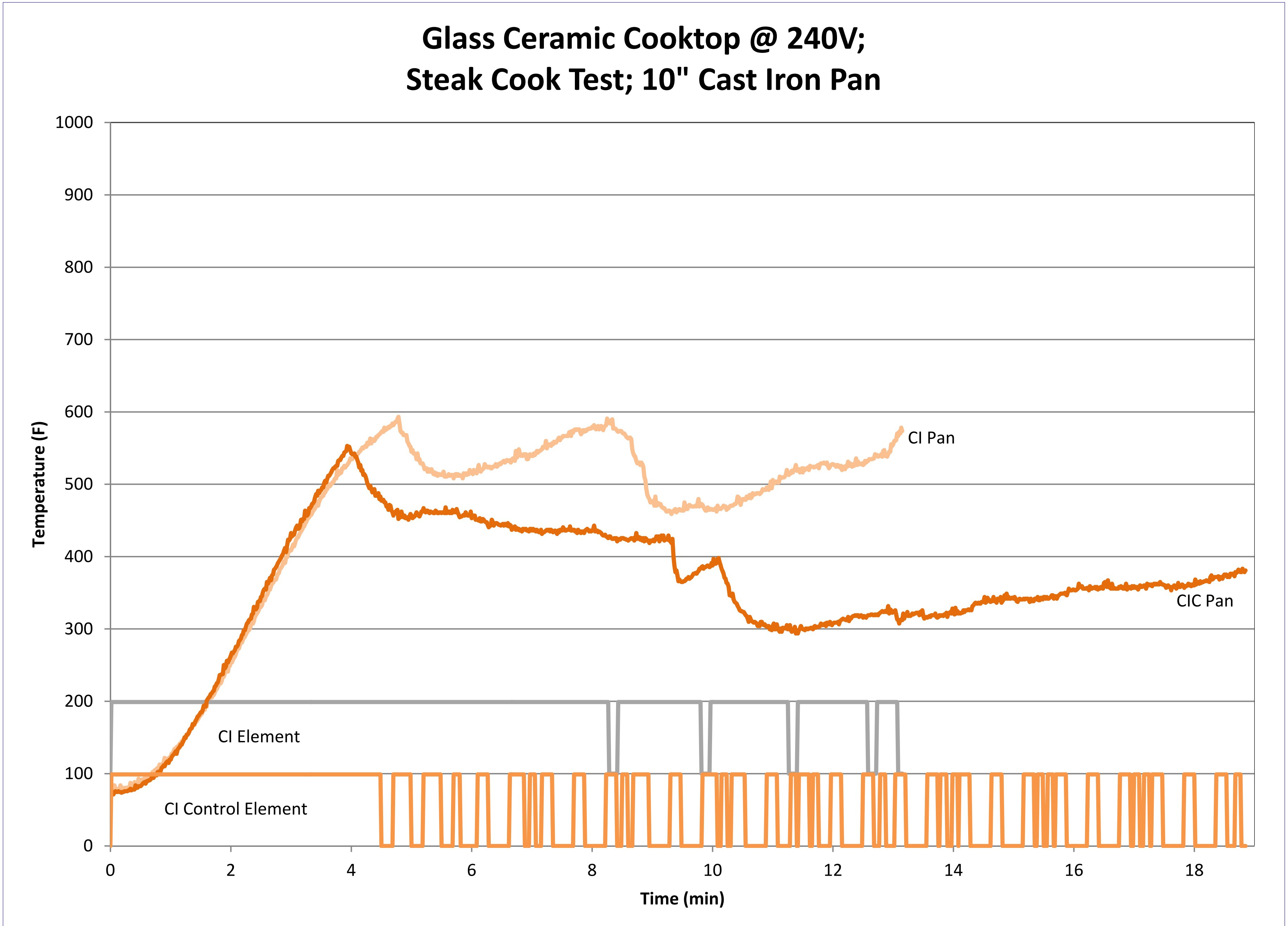
PRIMAIRA

Aluminum, no controls:



Aluminum w/ controls:





Glass Ceramic Cooktop @ 240V;
Steak Cook Test; 10" Cast Iron Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
Time (min)
CI Pan
CIC Pan
CI Element
CI Control Element

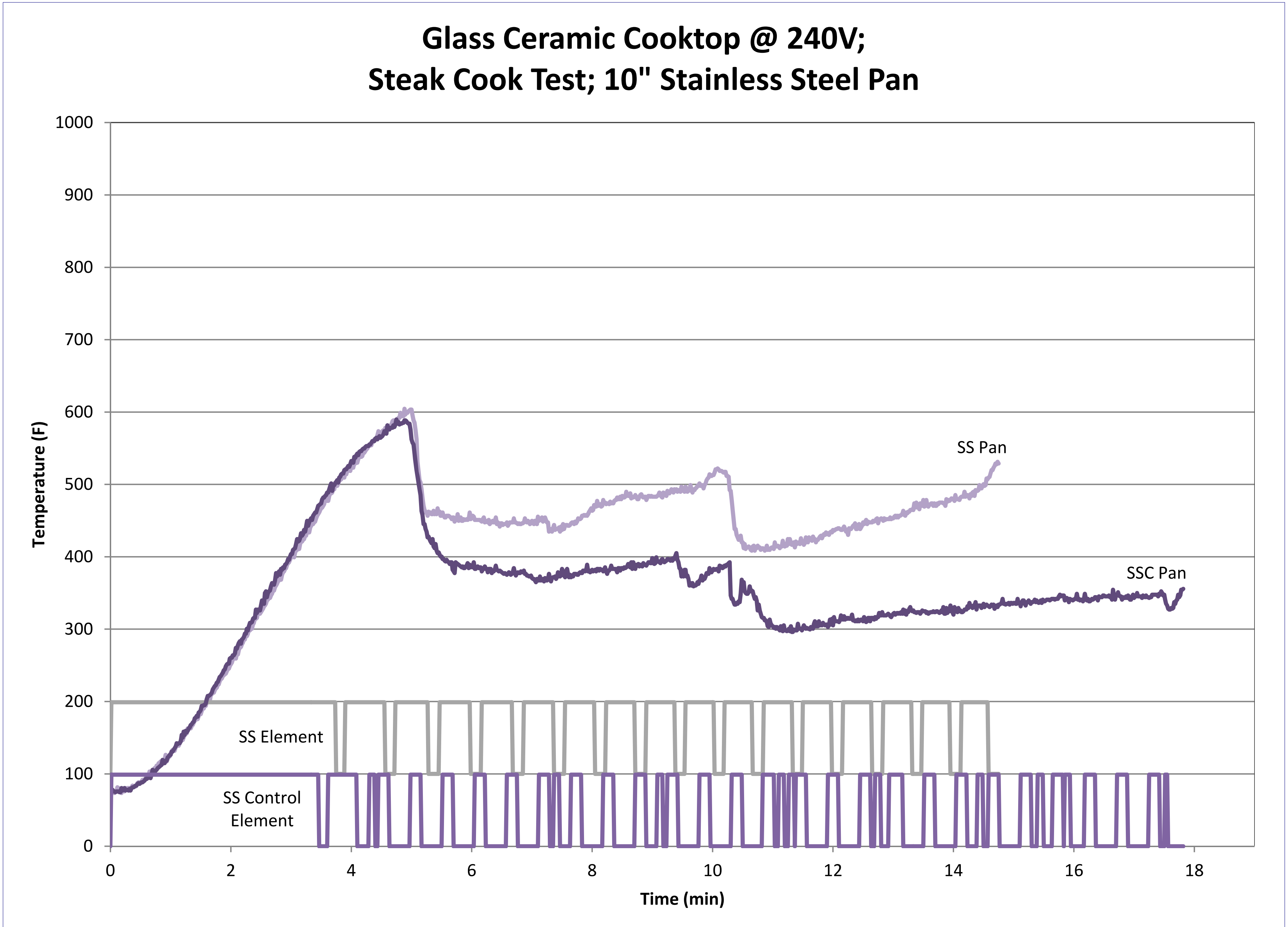
PRIMAIRA

Cast Iron, no Controls

Cast Iron w/ Controls

Cast Iron, no controls:

Cast Iron w/ controls:

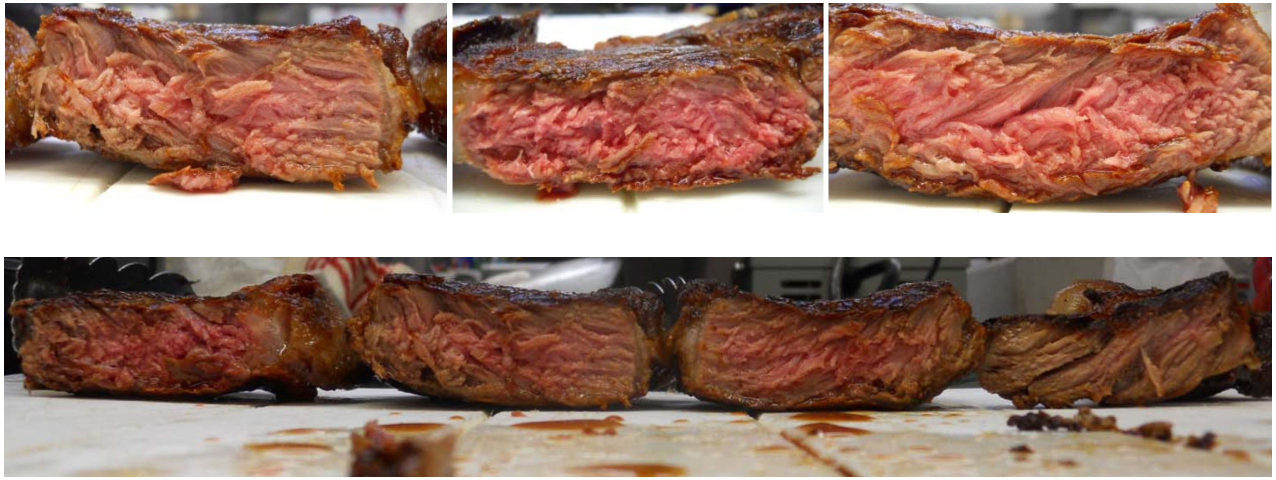

Glass Ceramic Cooktop @ 240V;
Steak Cook Test; 10" Stainless Steel Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
Time (min)
SS Pan
SSC Pan
SS Element
SS Control Element

Stainless Steel, no Controls

Stainless Steel w/ Controls

PRIMAIRA

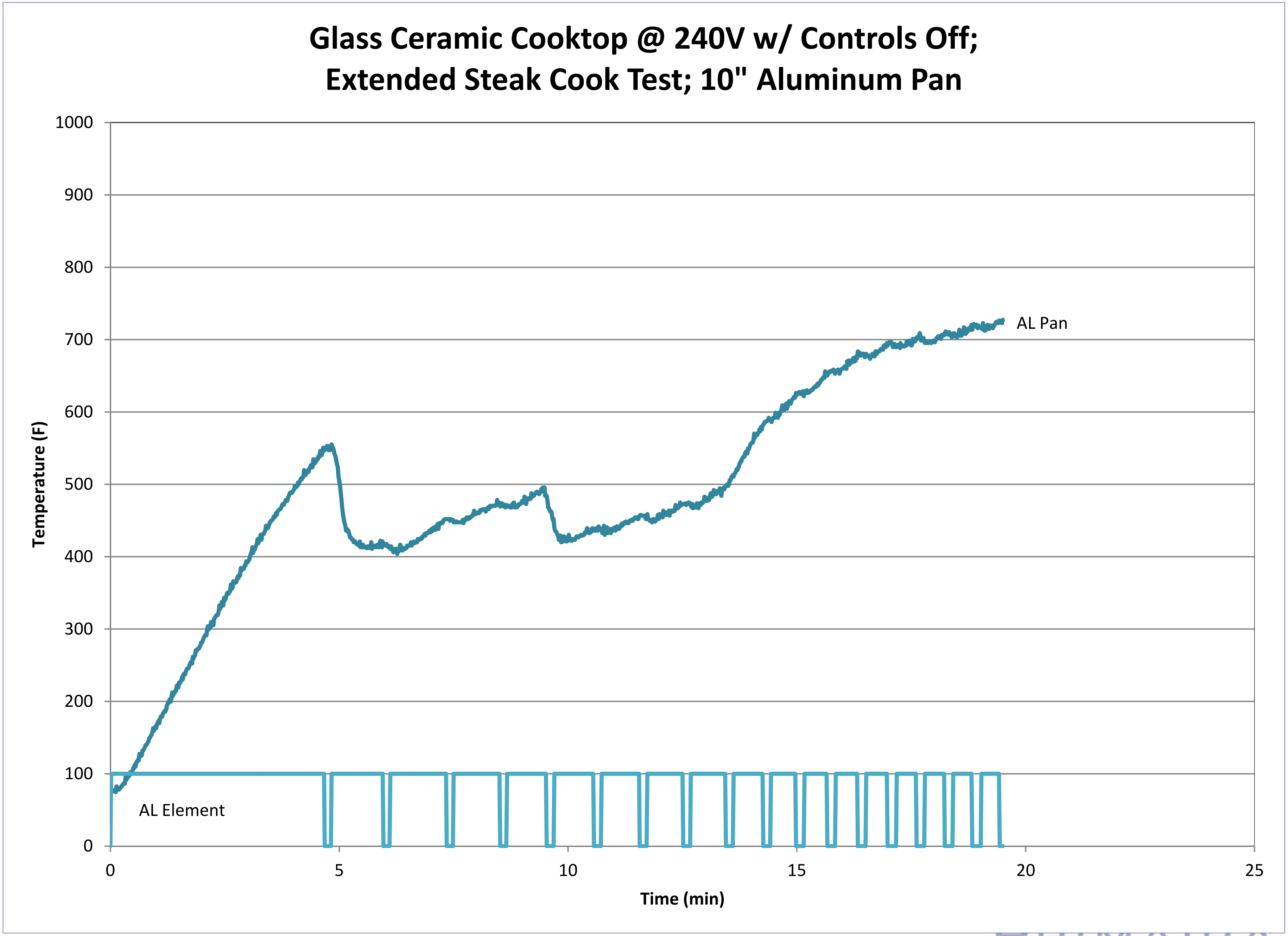
Stainless Steel, no controls:



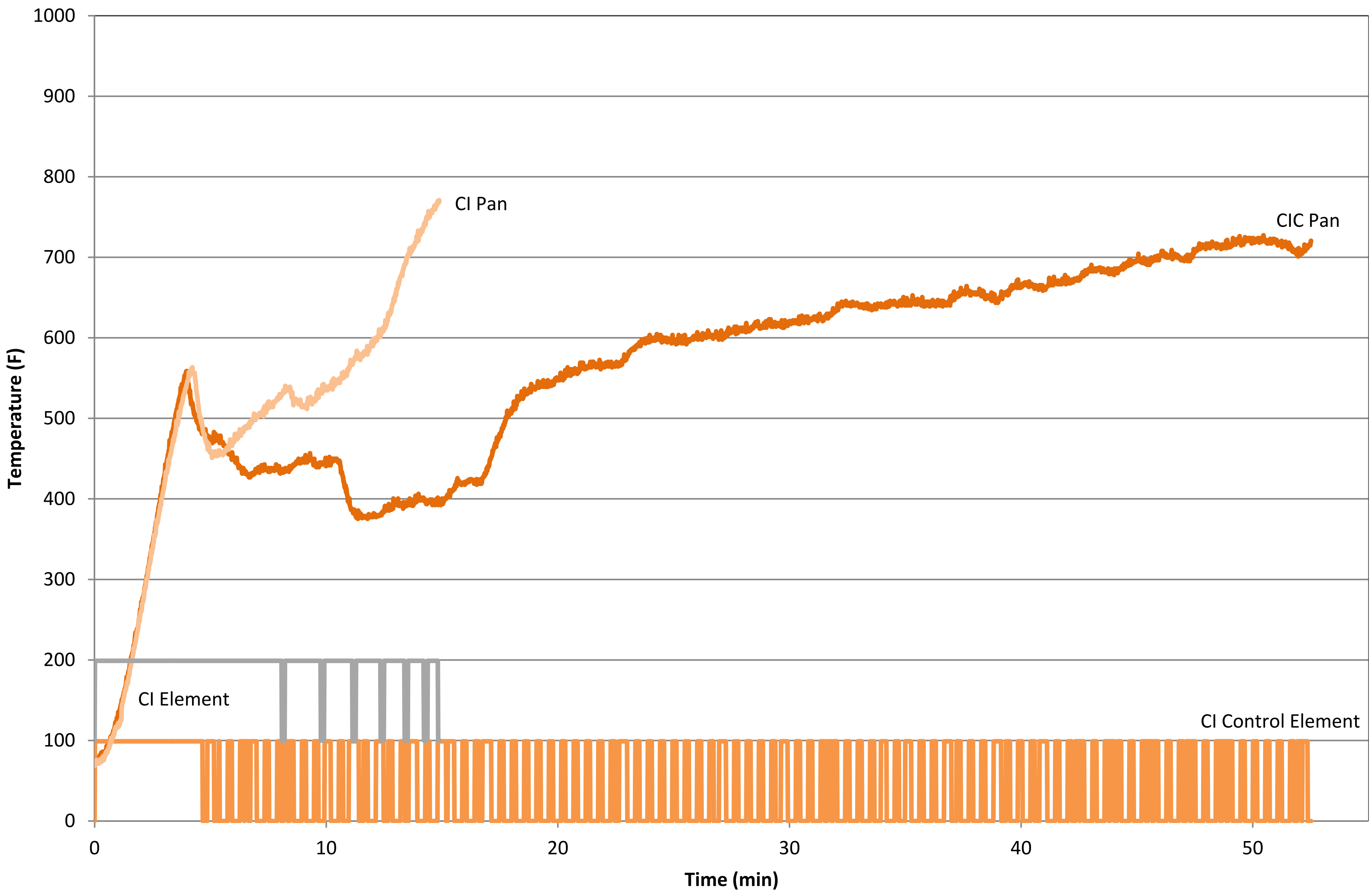
Stainless Steel w/ controls:

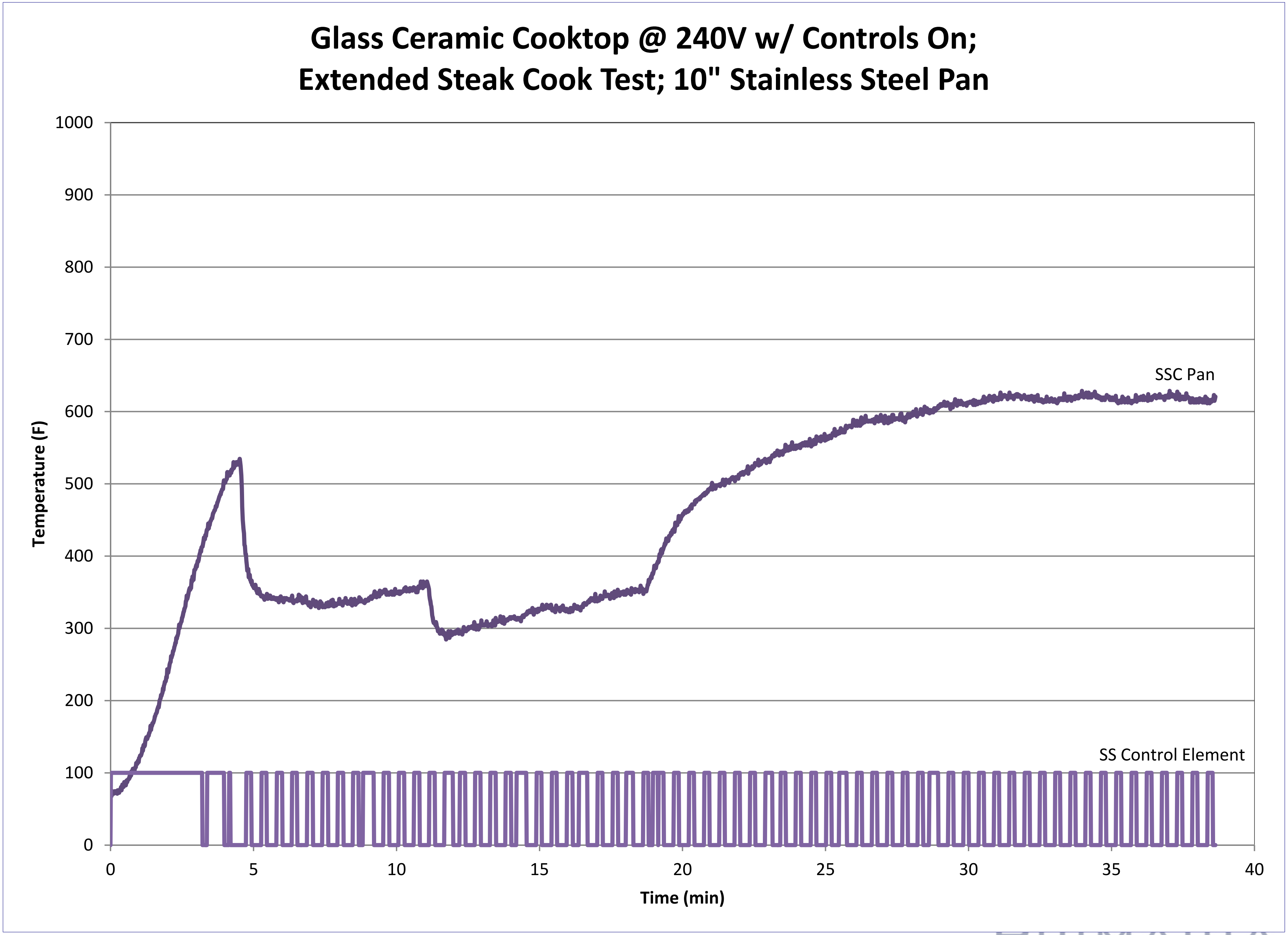
Extended Steak Test: Glass Ceramic Cooktop @ 240V

- Steak was cooked just as in the standard steak test
- Steaks were removed from pan once fully cooked
- Element was left on and pan with oil and char residue was allowed to continue heating
- The purpose of the test was to determine whether the controls would be activated by the change in temperature associated with the end of a cooking test


Glass Ceramic Cooktop @ 240V w/ Controls Off;
Extended Steak Cook Test; 10" Aluminum Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
Time (min)
AL Pan
AL Element
PRIMAIRA

Glass Ceramic Cooktop @ 240V;
Extended Steak Cook Test; 10" Cast Iron Pan





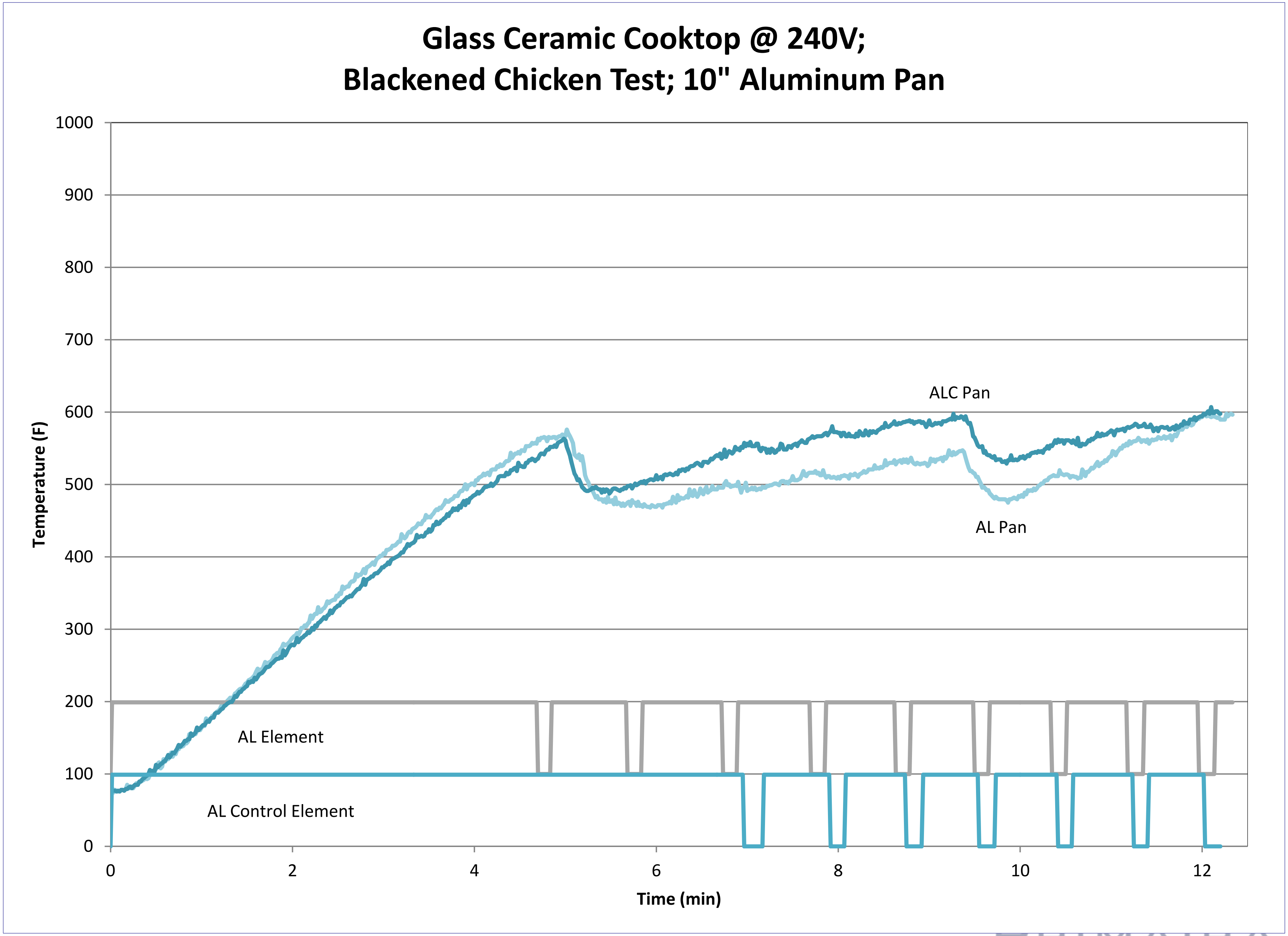
Glass Ceramic Cooktop @ 240V w/ Controls On;
Extended Steak Cook Test; 10" Stainless Steel Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
Time (min)
SSC Pan
SS Control Element

PRIMAIRA

Blackened Chicken Test: Glass Ceramic Cooktop @ 240V

- Boneless chicken breasts weighing ~200g were cut in half to a width of ½” or slightly less
- 30 mL of oil was added to the frying pan, and heated on high until smoking
- Chicken breast halves were then added to frying pan
- For non-control test, chicken was cooked on first side until it started to blacken, then flipped and cooked until second side was blackened in parts (second side had less surface area touching pan, so less blackened area)
- For control test, chicken was added to heated oil and cooked for the same amount of time on each side as the non-control test for each type of pan

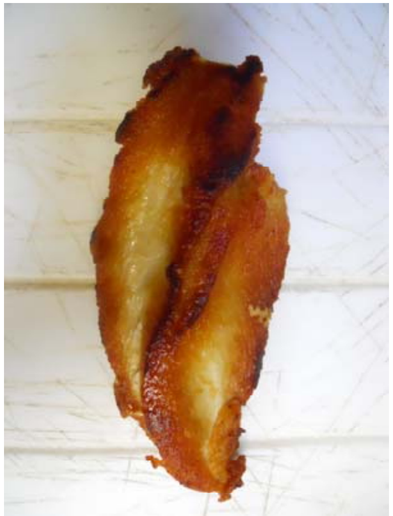
PRIMAIRA



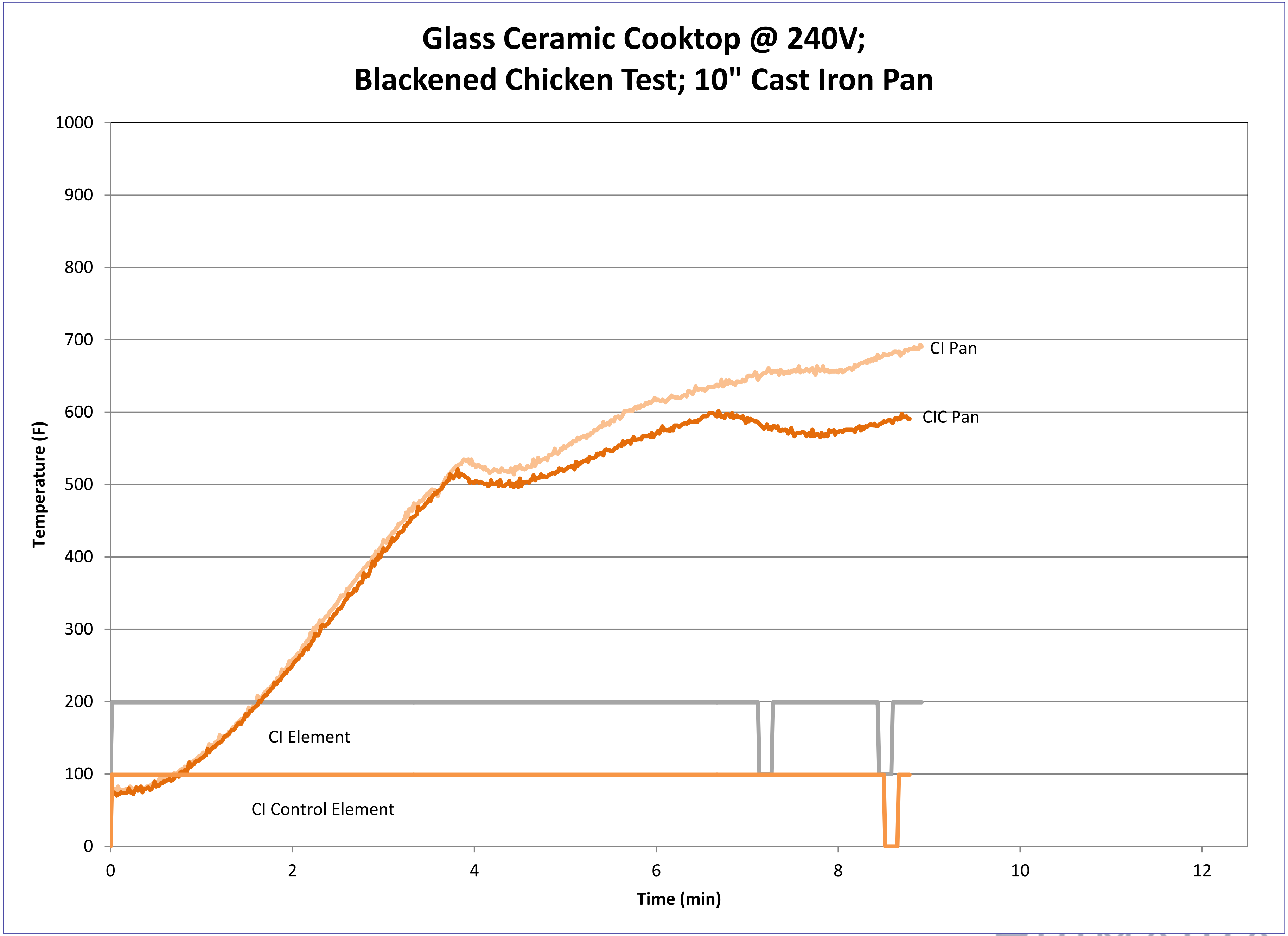
Glass Ceramic Cooktop @ 240V;
Blackened Chicken Test; 10" Aluminum Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
Time (min)
0
2
4
6
8
10
12
ALC Pan
AL Pan
AL Element
AL Control Element

PRIMATRA

Aluminum, no Controls



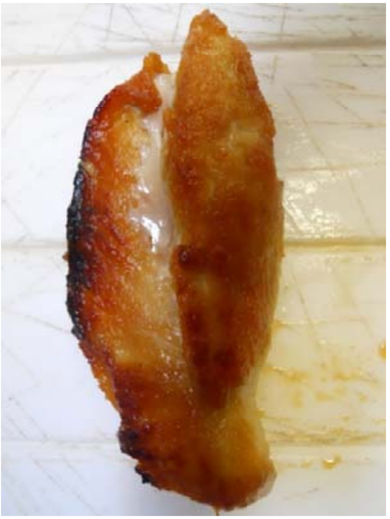
Aluminum w/ Controls

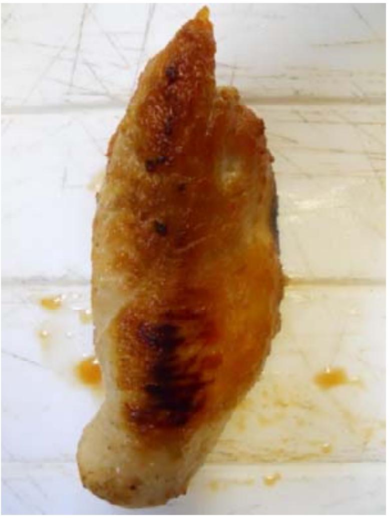


Glass Ceramic Cooktop @ 240V;
Blackened Chicken Test; 10" Cast Iron Pan
1000
900
800
700
600
500
400
300
200
100
0
Temperature (F)
0
2
4
6
8
10
12
Time (min)
CI Pan
CIC Pan
CI Element
CI Control Element

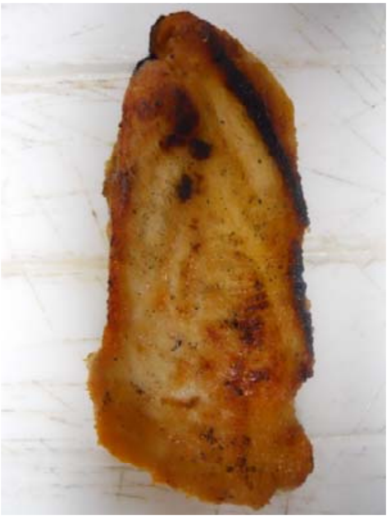
PRIMAIRA

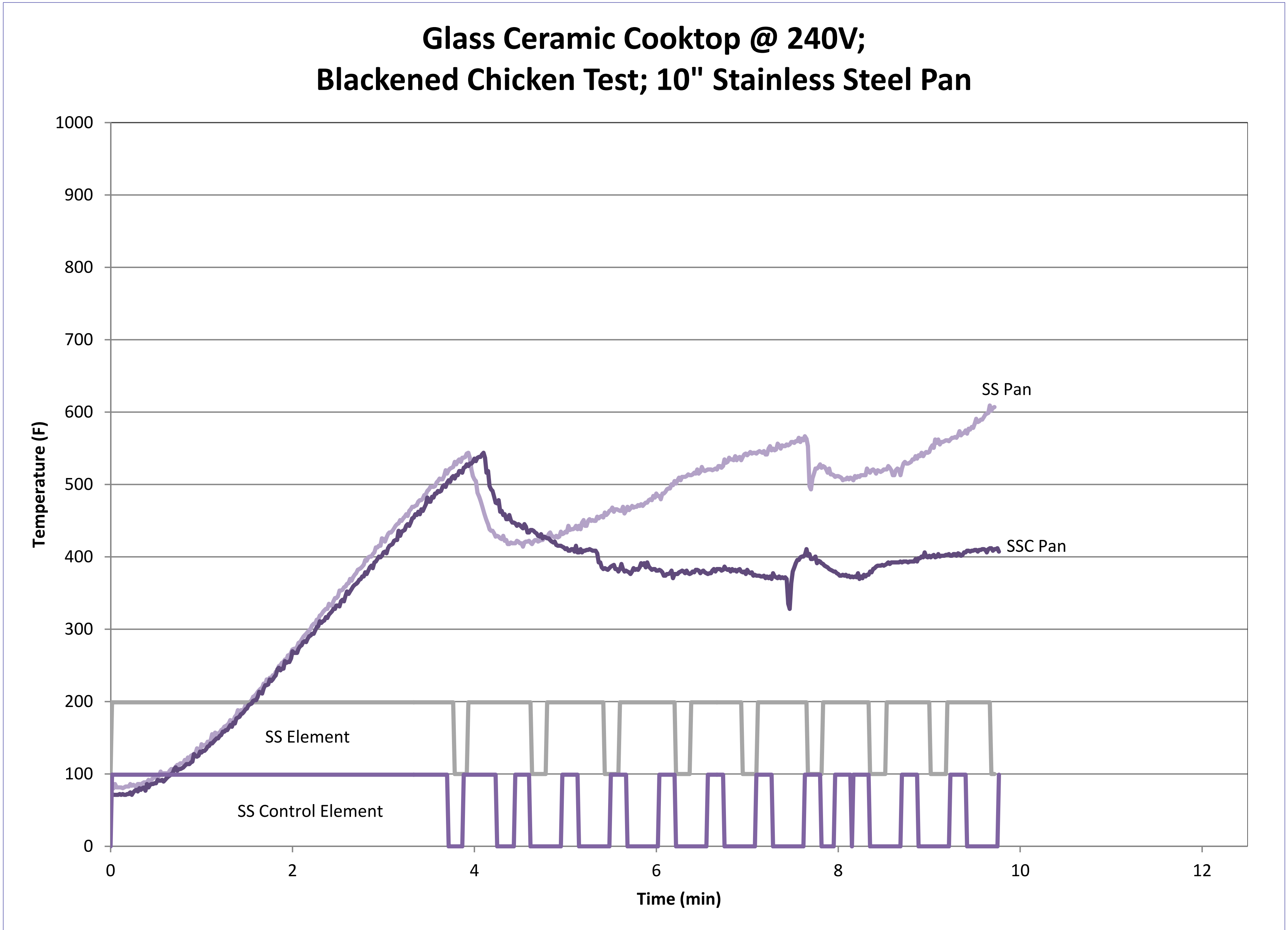
Cast Iron, no Controls





Cast Iron w/ Controls





Glass Ceramic Cooktop @ 240V;
Blackened Chicken Test; 10" Stainless Steel Pan
Temperature (F)
Time (min)
SS Pan
SSC Pan
SS Element
SS Control Element
0
100
200
300
400
500
600
700
800
900
1000
0
2
4
6
8
10
12

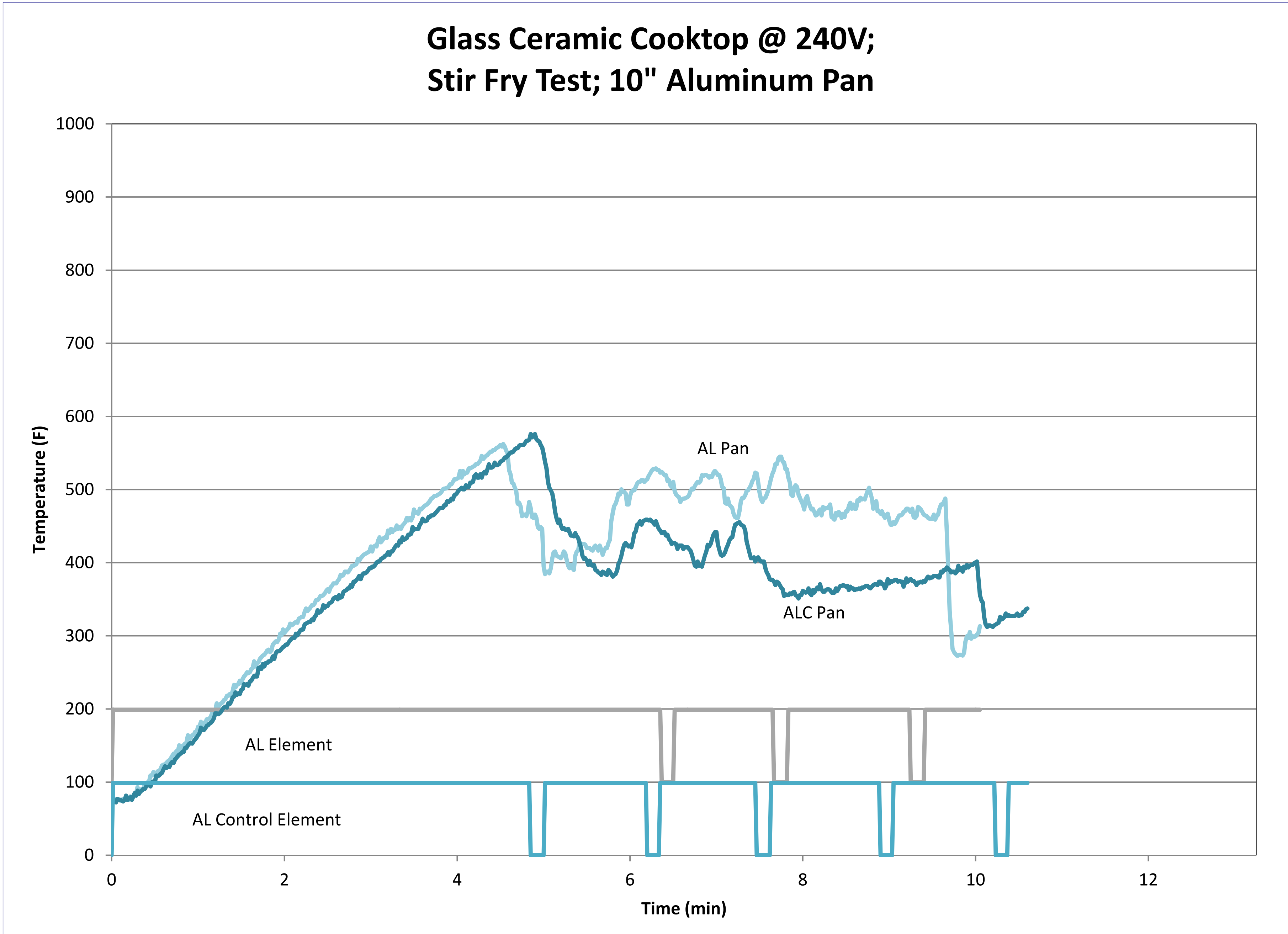
Stainless Steel, no Controls

Stainless Steel w/ Controls

Stir Fry Test: Glass Ceramic Cooktop @ 240V

- ½ an onion was sliced thinly crosswise, and ½ a red pepper was sliced thinly lengthwise
- ½ pound of thin strip steak was cut into thin pieces
- 20 mL of oil was heated on frying pan until smoking (~500F)
- Half of steak was added and quickly tossed with tongs, then removed and placed in a covered container
- The other half of the steak was then cooked and added to the same container
- More oil was added to pan and allowed to heat up, then vegetables were added and cooked until tender
- Steak was added back to mixture and allowed to heat with vegetables for ~20 seconds

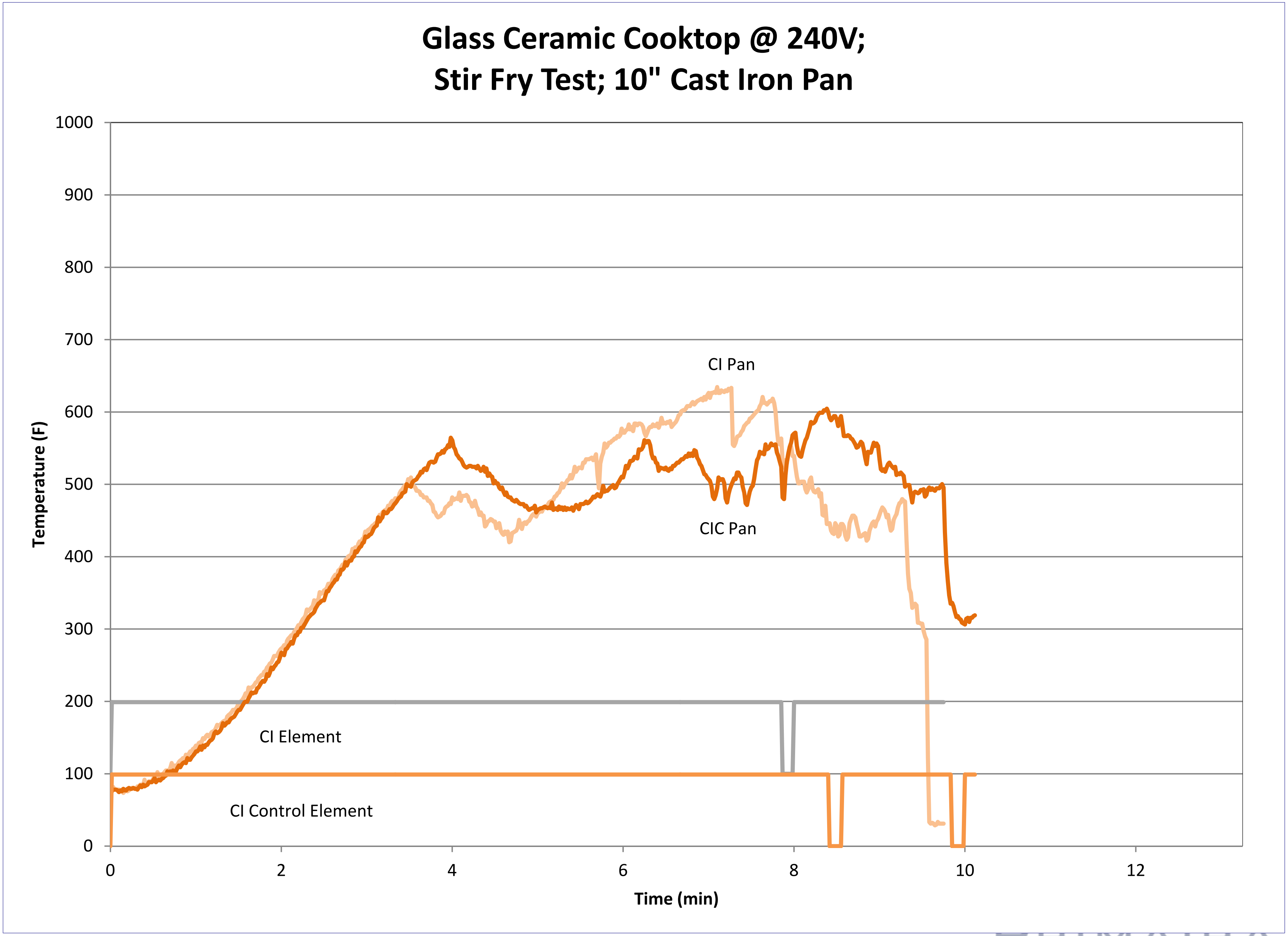
Stir Fry Test:


Glass Ceramic Cooktop @ 240V;
Stir Fry Test; 10" Aluminum Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
Time (min)
AL Pan
ALC Pan
AL Element
AL Control Element

PRIMAIRA

Aluminum, no Controls

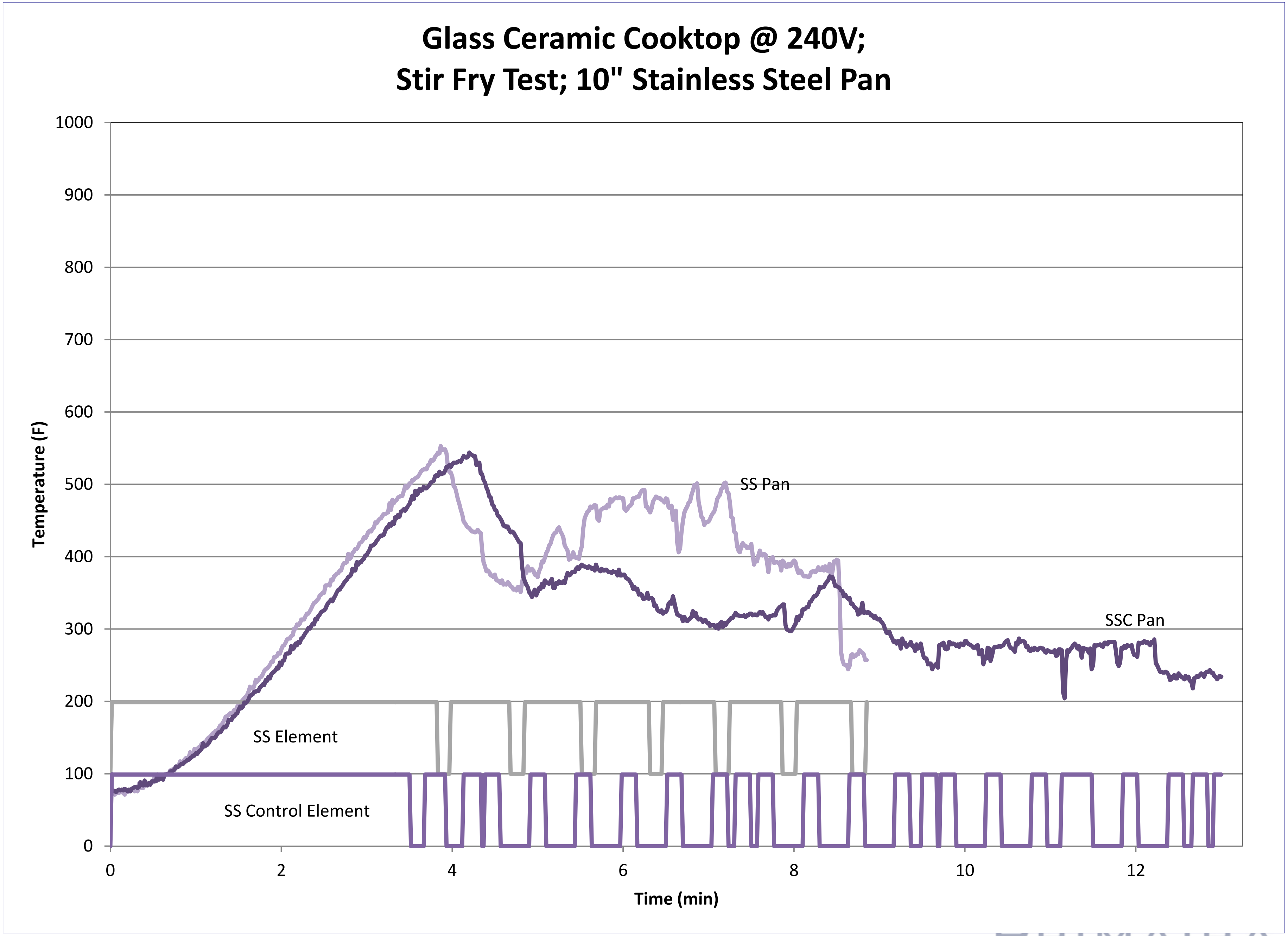
Aluminum w/ Controls


Glass Ceramic Cooktop @ 240V;
Stir Fry Test; 10" Cast Iron Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
Time (min)
CI Pan
CIC Pan
CI Element
CI Control Element

PRIMAIRA

Cast Iron, no Controls

Cast Iron w/ Controls



Glass Ceramic Cooktop @ 240V;
Stir Fry Test; 10" Stainless Steel Pan
1000
900
800
700
600
500
400
300
200
100
0
Temperature (F)
0
2
4
6
8
10
12
Time (min)
SS Pan
SSC Pan
SS Element
SS Control Element

PRIMAIRA

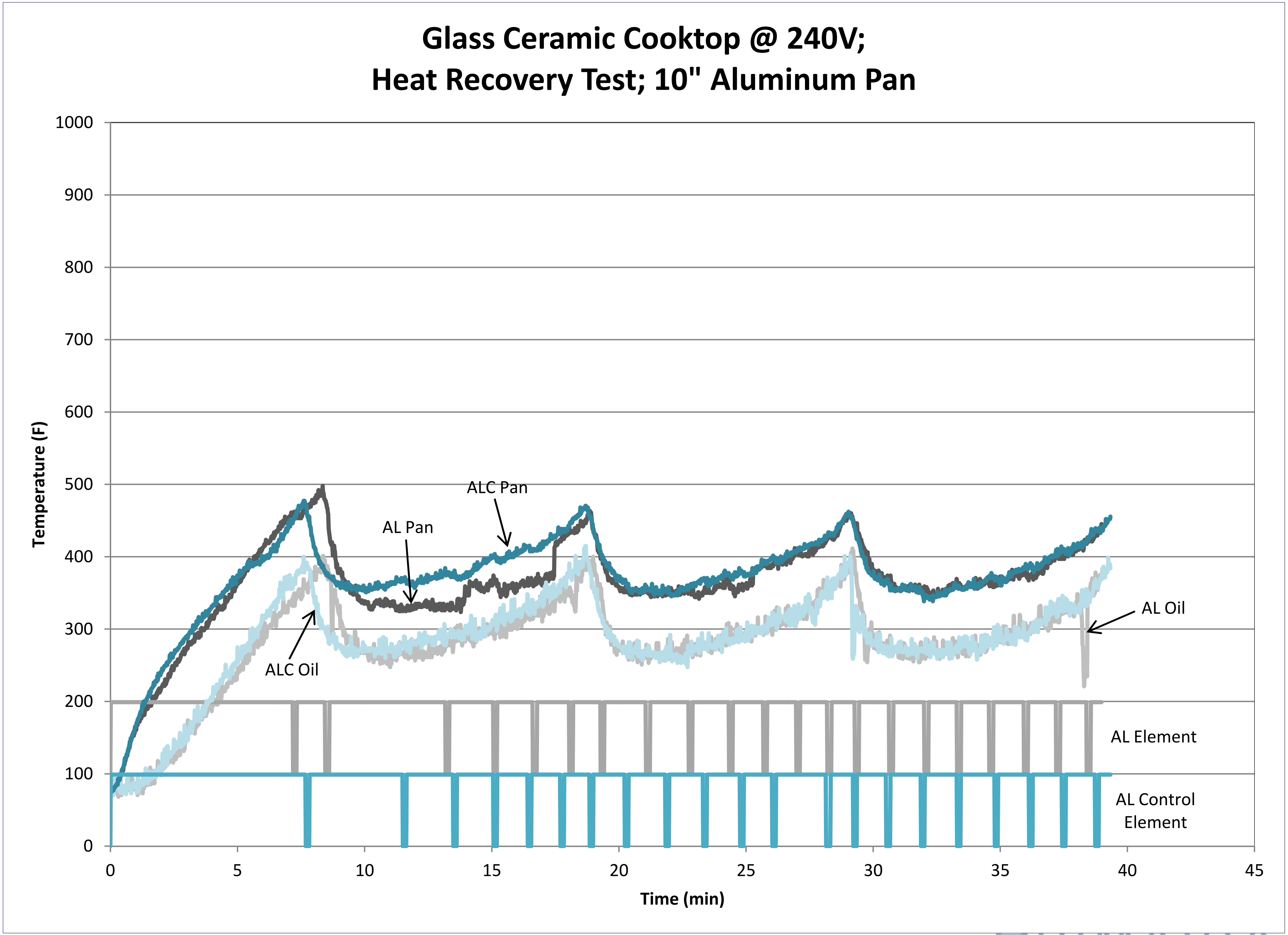
Stainless Steel, no Controls

Stainless Steel w/ Controls

PRIMAIRA

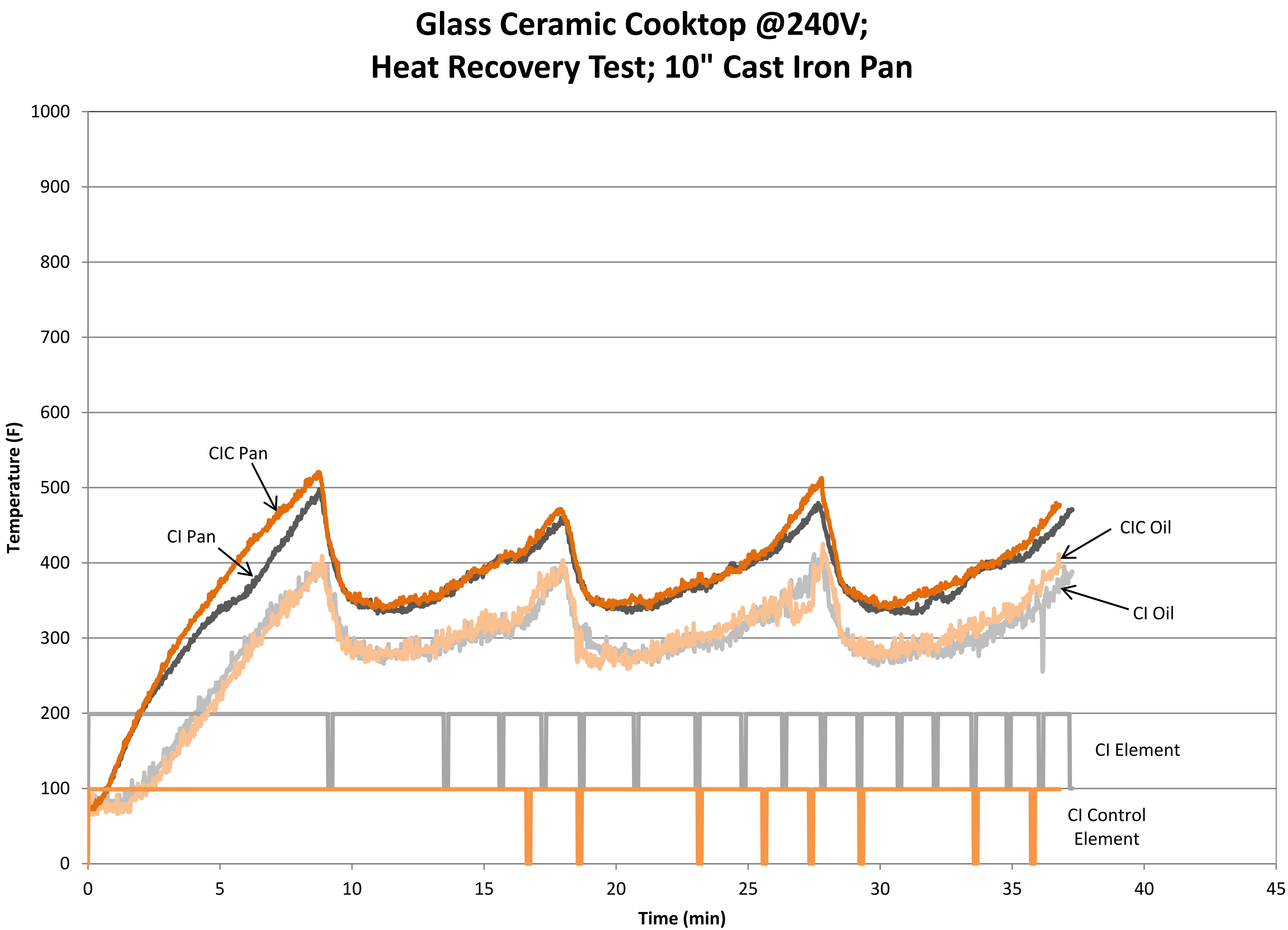
Heat Recovery Test: Glass Ceramic Cooktop @ 240V

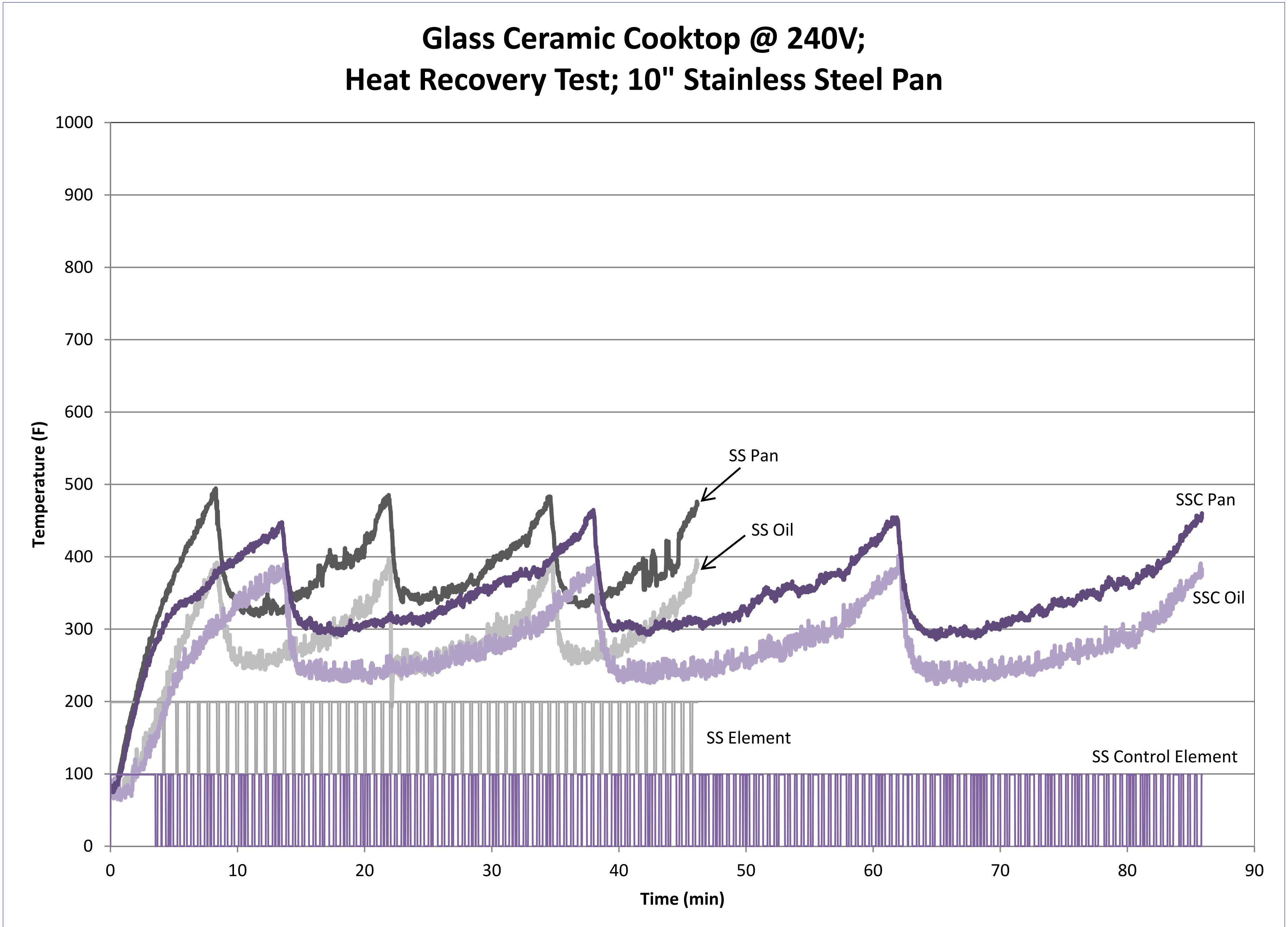
- 800 mL of Canola oil was added to a skillet, and heated to 380°F
- 400g of frozen French fries were added to hot oil, and cooked until golden brown and crispy, then removed
- Oil was allowed to heat back up to 380°F again
- Process was repeated for 2 more batches of French fries



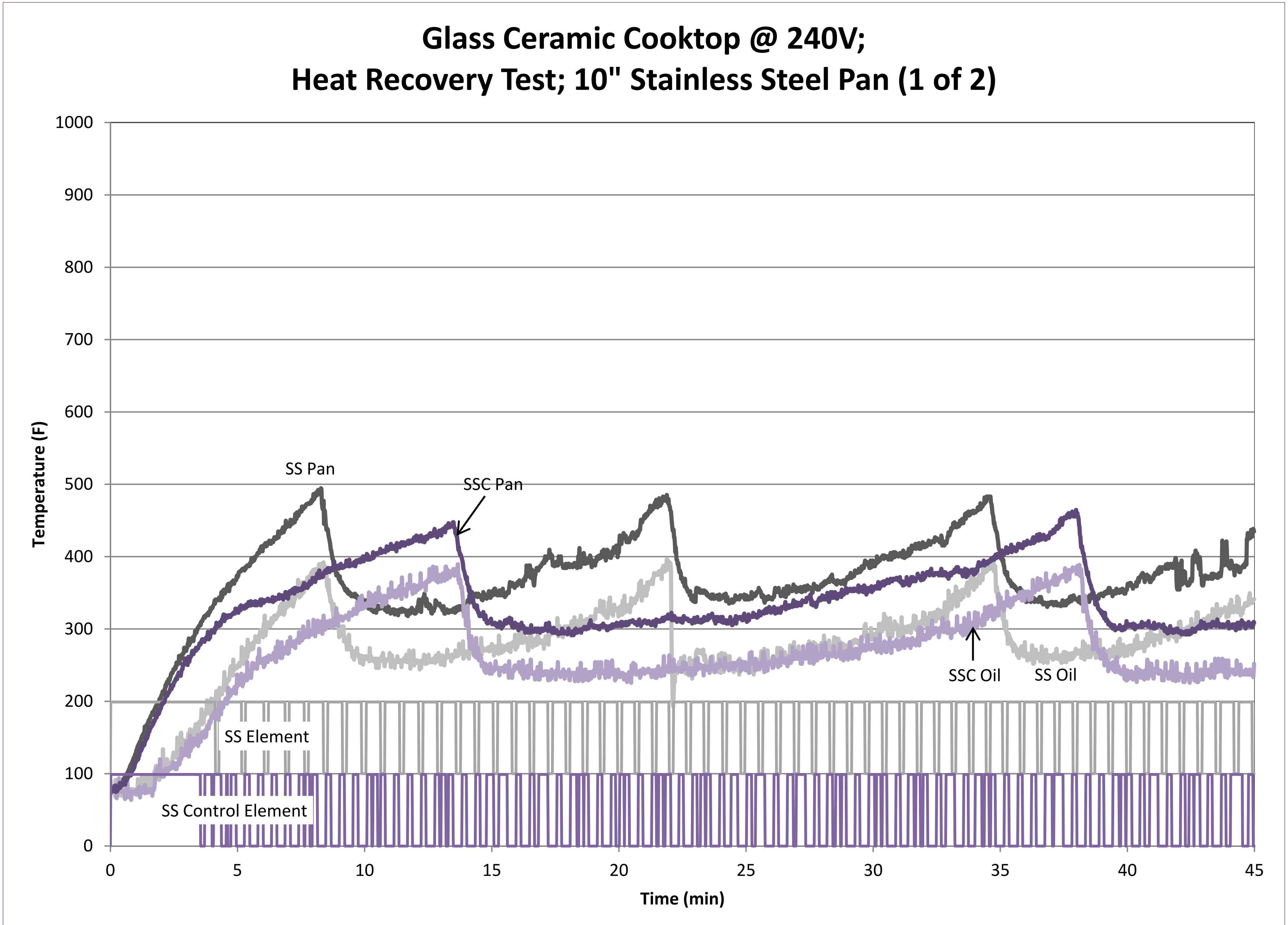
Glass Ceramic Cooktop @ 240V;
Heat Recovery Test; 10" Aluminum Pan
Temperature (F)
Time (min)
ALC Pan
AL Pan
ALC Oil
AL Oil
AL Element
AL Control Element
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45

PRIMAIRA


Glass Ceramic Cooktop @240V;
Heat Recovery Test; 10" Cast Iron Pan
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
Time (min)
0
5
10
15
20
25
30
35
40
45
CIC Pan
CI Pan
CIC Oil
CI Oil
CI Element
CI Control
Element


Glass Ceramic Cooktop @ 240V;
Heat Recovery Test; 10" Stainless Steel Pan
Temperature (F)
Time (min)
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
SS Pan
SS Oil
SSC Pan
SSC Oil
SS Element
SS Control Element

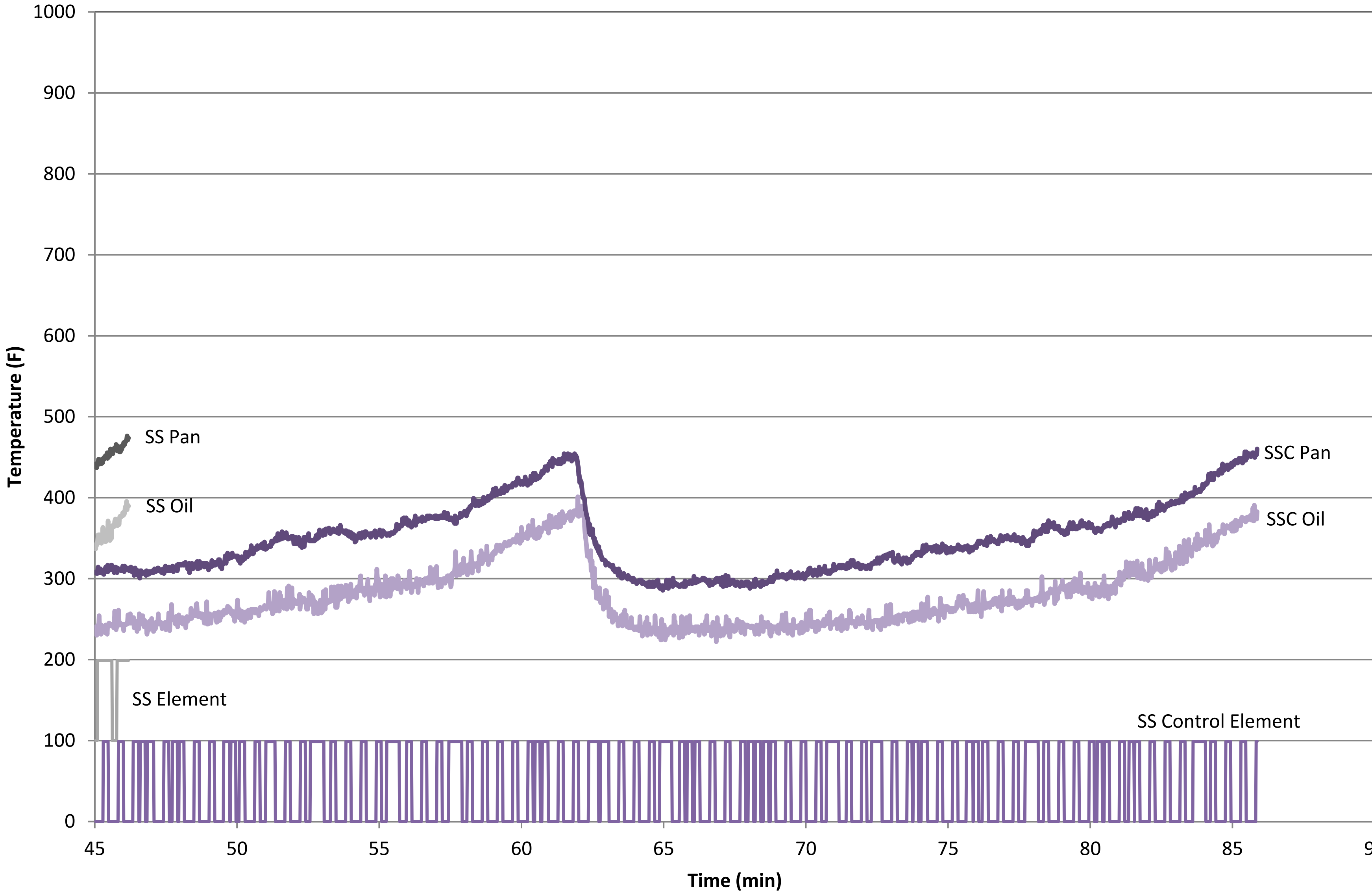
PRIMAIRA



Glass Ceramic Cooktop @ 240V;
Heat Recovery Test; 10" Stainless Steel Pan (1 of 2)
Temperature (F)
Time (min)
SS Pan
SSC Pan
SSC Oil
SS Oil
SS Element
SS Control Element
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45

PRIMAIRA

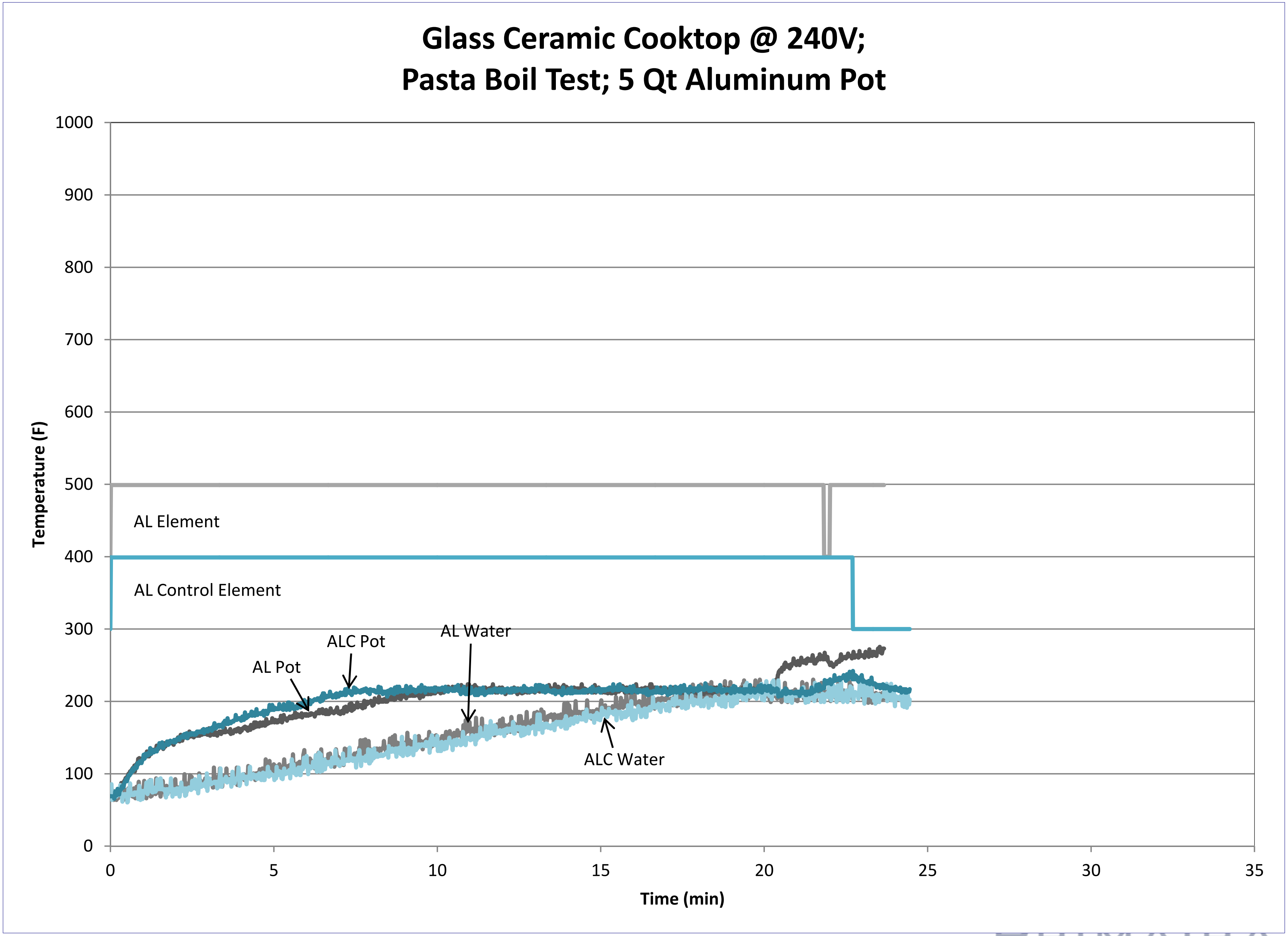
Glass Ceramic Cooktop @ 240V; Heat Recovery Test; 10" Stainless Steel Pan (2 of 2)

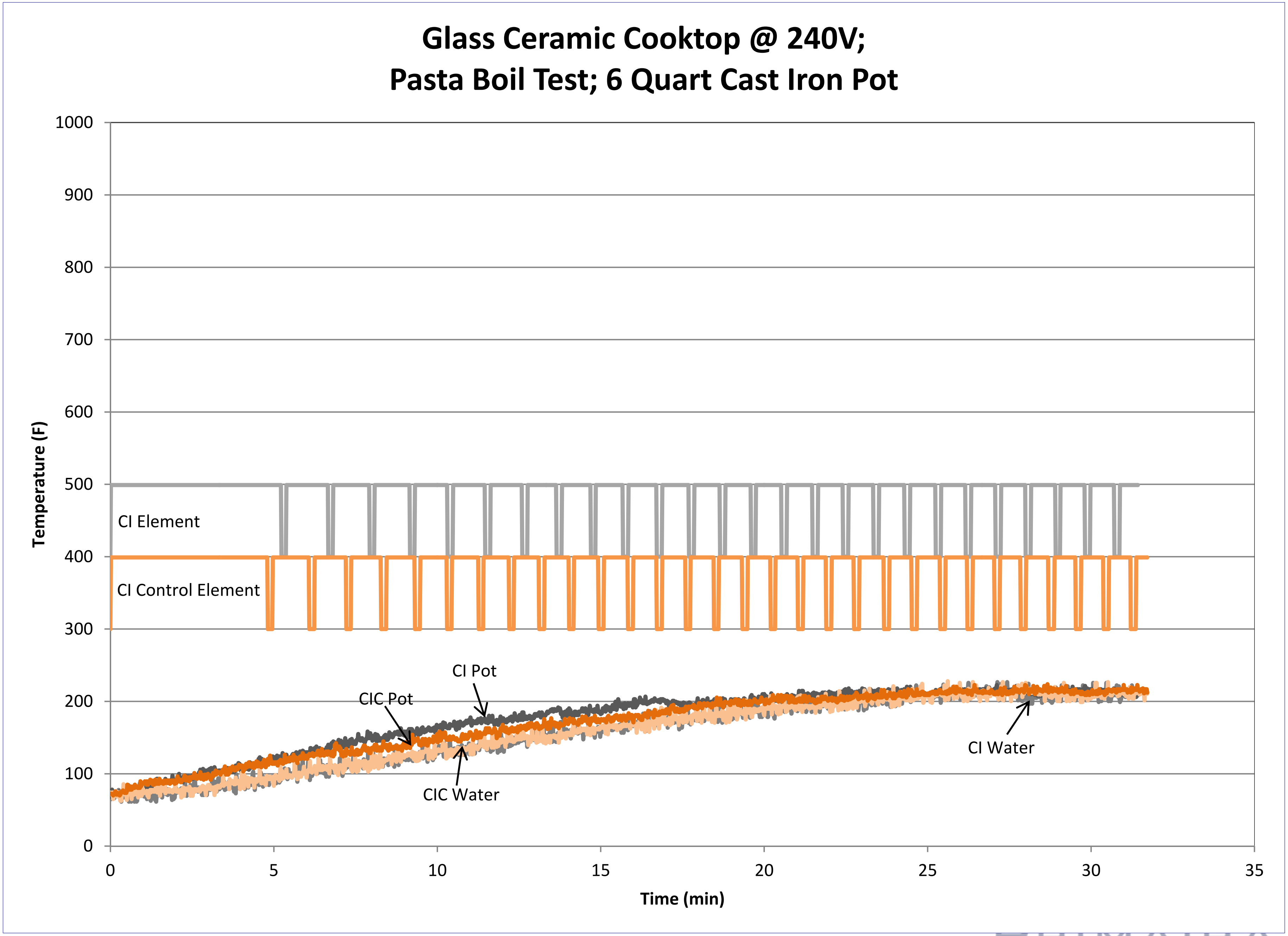


PRIMAIRA

Pasta Boil Test: Glass Ceramic Cooktop @ 240V

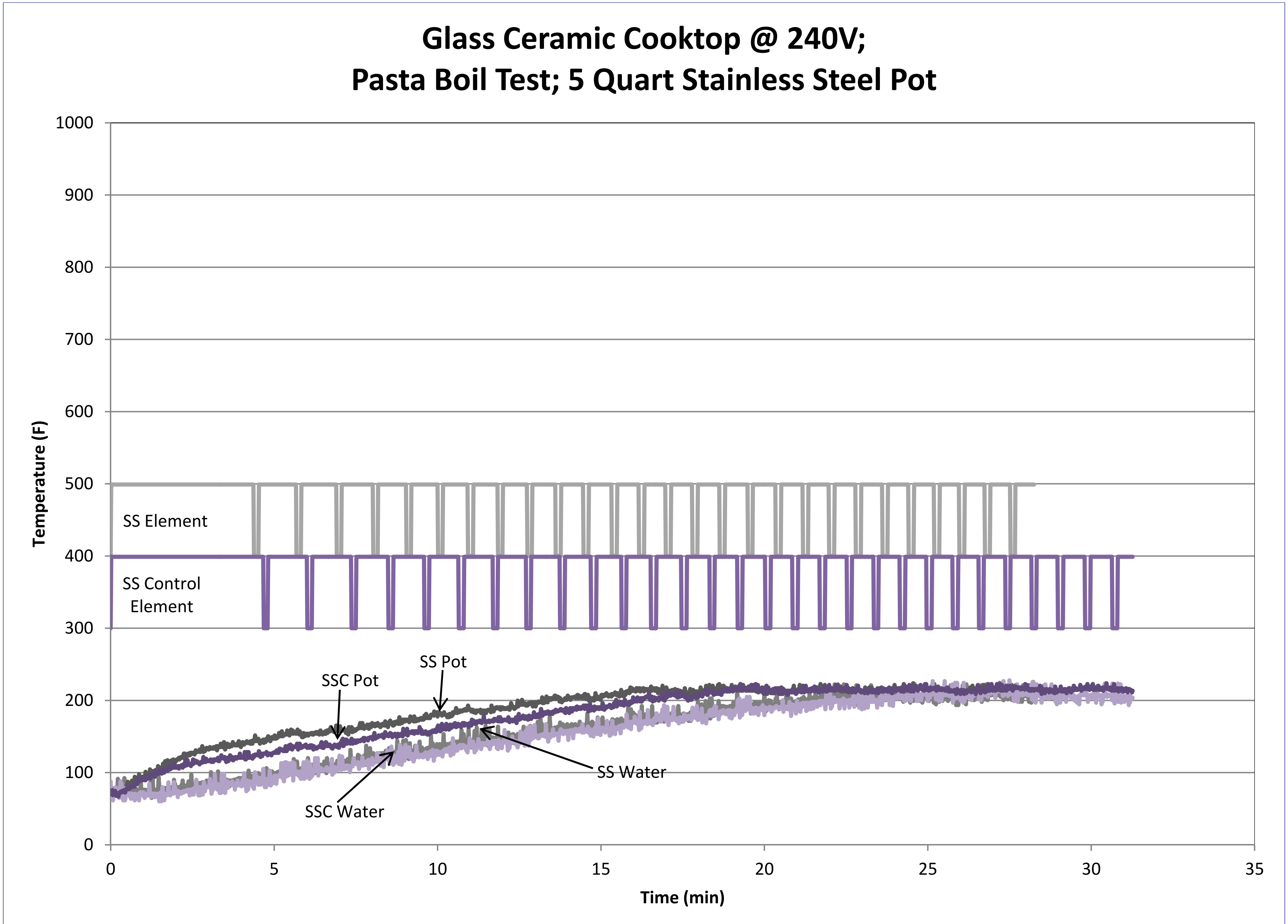
- 4 quarts of water were brought to a boil in 5 quart aluminum and stainless steel and 6 quart cast iron pots
- Once water reached a rolling boil, 1 pound of angel hair pasta was added and cooked for 4 minutes


Glass Ceramic Cooktop @ 240V;
Pasta Boil Test; 5 Qt Aluminum Pot
Temperature (F)
Time (min)
AL Element
AL Control Element
AL Water
ALC Pot
AL Pot
ALC Water
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35



Glass Ceramic Cooktop @ 240V;
Pasta Boil Test; 6 Quart Cast Iron Pot
Temperature (F)
Time (min)
CI Element
CI Control Element
CI Pot
CIC Pot
CIC Water
CI Water
0
100
200
300
400
500
600
700
800
900
1000
0
5
10
15
20
25
30
35

PRIMAIRA



Glass Ceramic Cooktop @ 240V;
Pasta Boil Test; 5 Quart Stainless Steel Pot
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
SS Element
SS Control
Element
SS Pot
SSC Pot
SS Water
SSC Water
0
5
10
15
20
25
30
35
Time (min)

PRIMAIRA

1 Quart Water Heat Test: Glass Ceramic Cooktop @ 240V

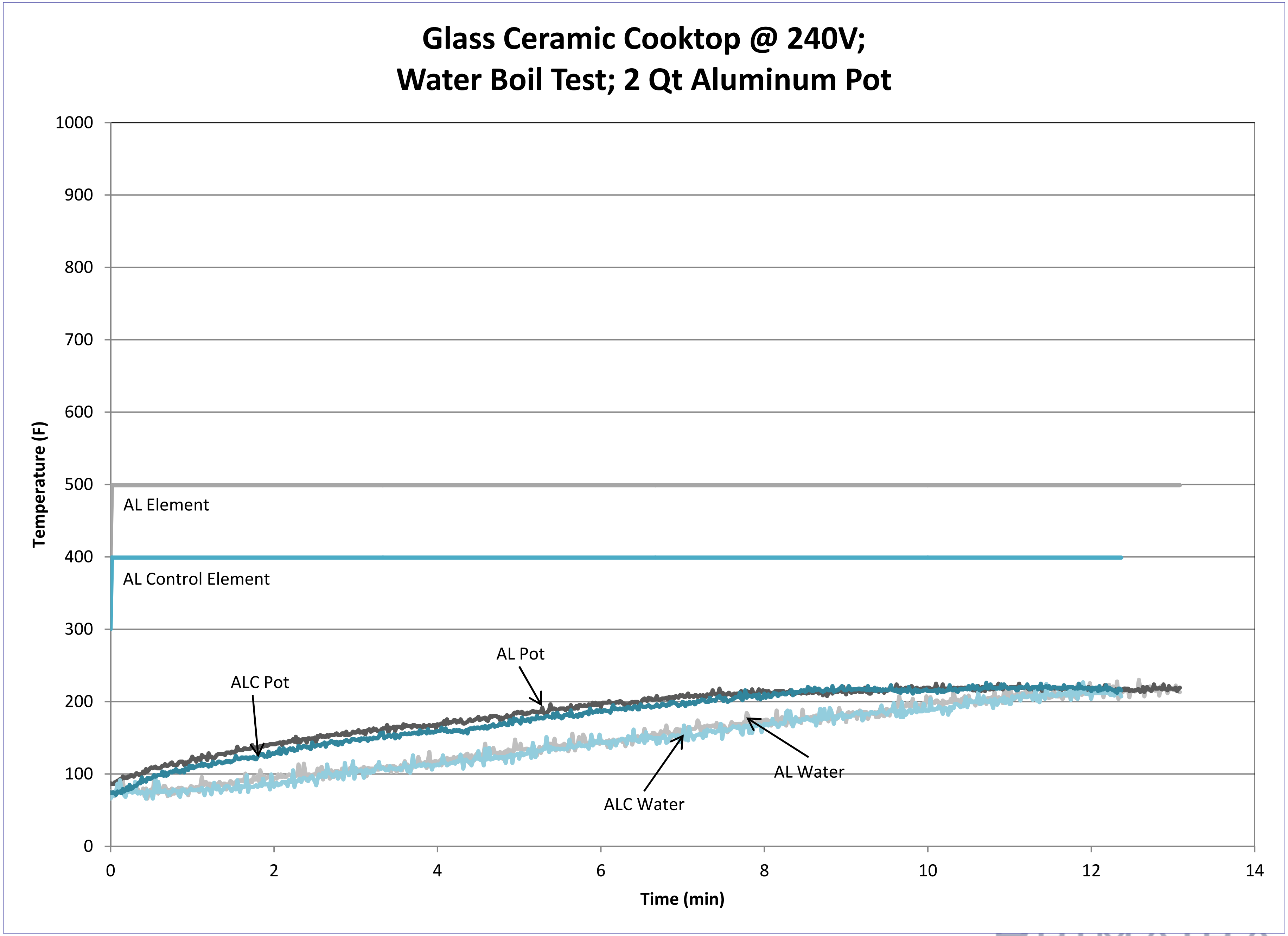
- 1 quart of water was heated in 2 quart aluminum and stainless steel pots
- Water was heated from 75°F to 190°F

PRIMAIRA

Time to Heat 1 Quart of Water 75°F – 190°F:

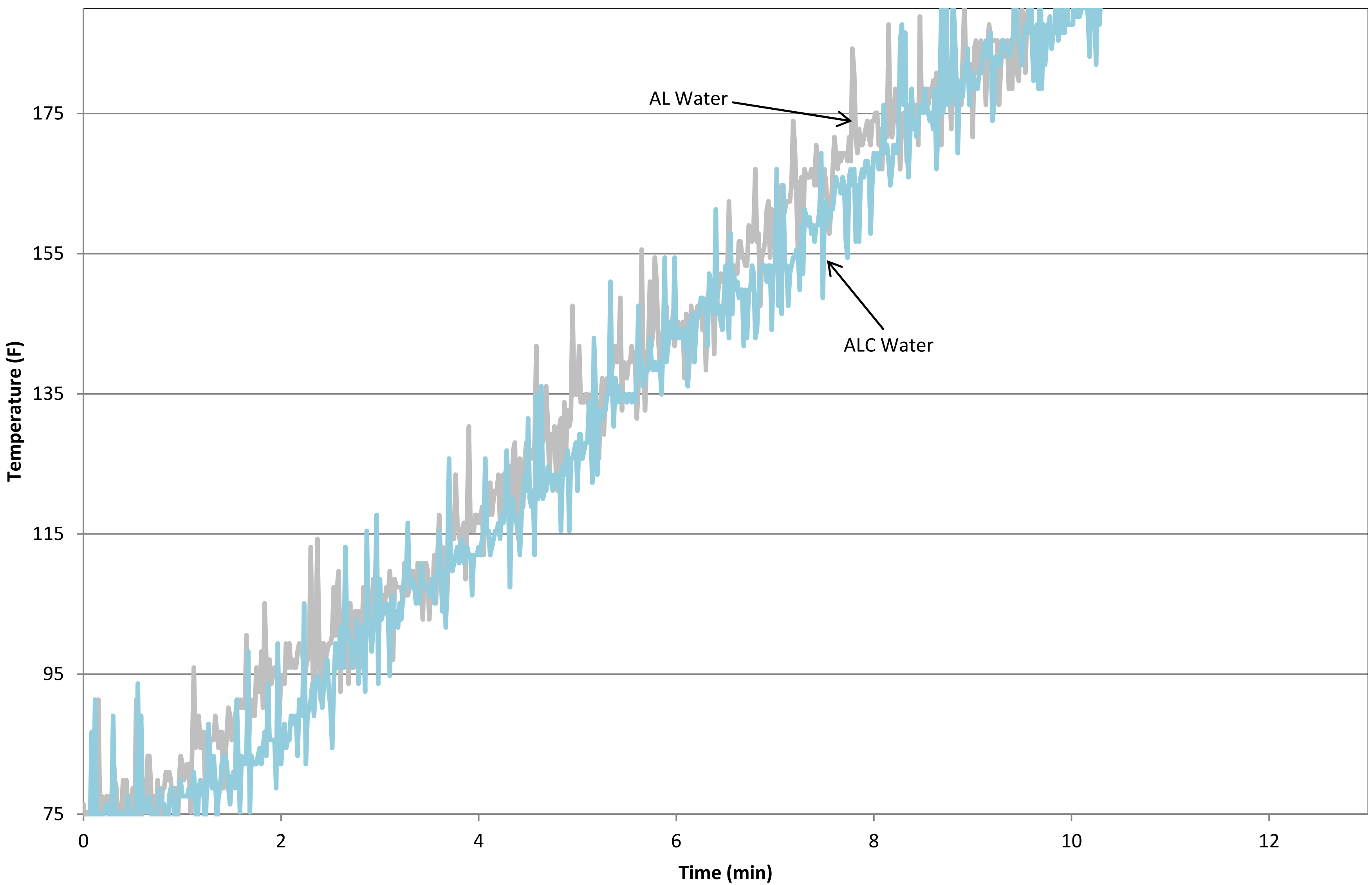
	Time To Heat 75°F-190°F (min)
Aluminum, no Control	8:57
Aluminum w/ Control	9:31
Stainless Steel, no Control	9:53
Stainless Steel w/ Control	9:54

PRIMAIRA

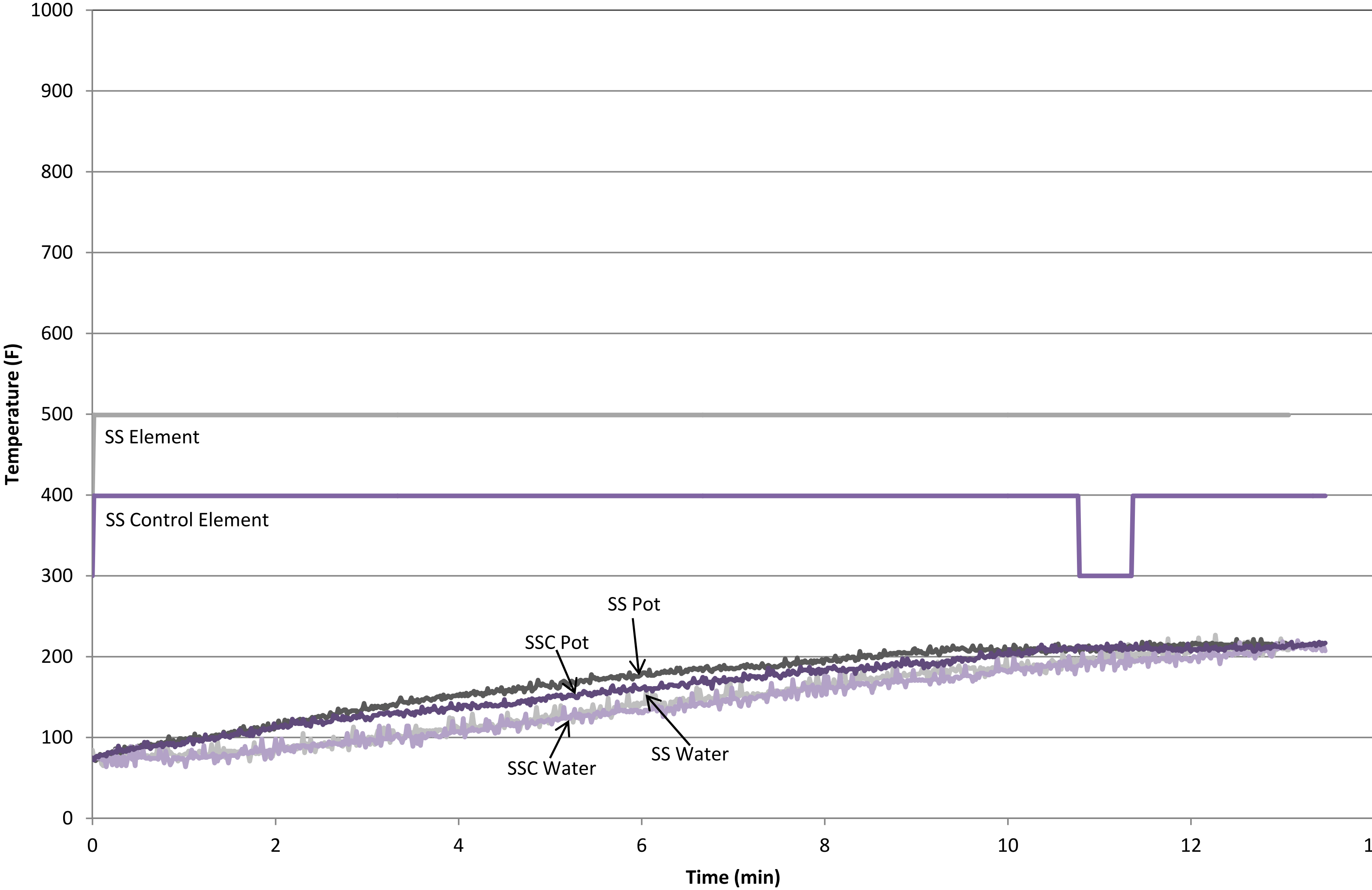

Glass Ceramic Cooktop @ 240V;
Water Boil Test; 2 Qt Aluminum Pot
1000
900
800
700
600
500
400
300
200
100
0
Temperature (F)
AL Element
AL Control Element
AL Pot
ALC Pot
AL Water
ALC Water
0
2
4
6
8
10
12
14
Time (min)

PRIMATRA

Glass Ceramic Cooktop @ 240V; Water Boil Test; 2 Qt Aluminum Pot (75°F – 190°F)

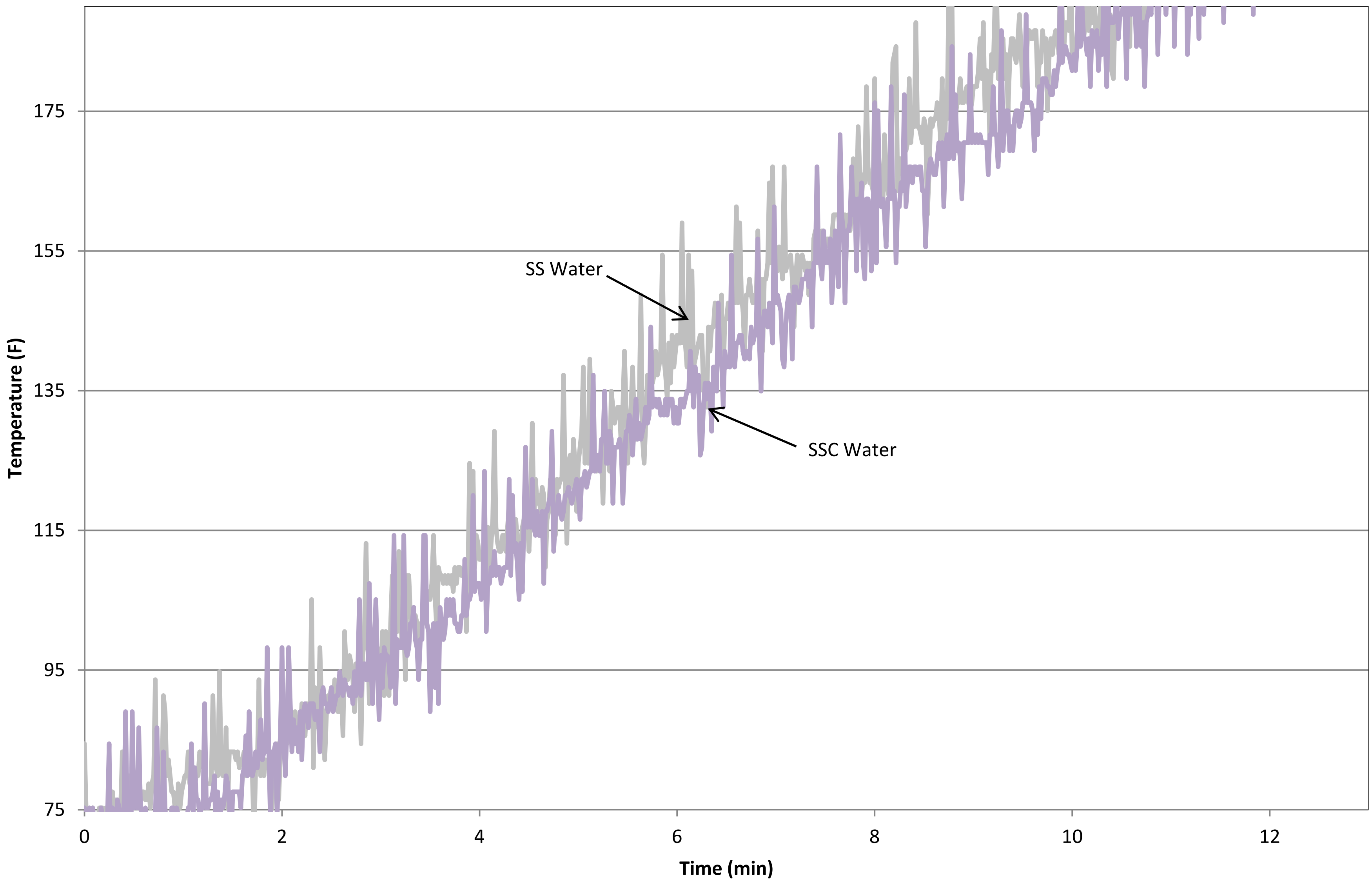


Glass Ceramic Cooktop @ 240V; Water Boil Test; 2 Qt Stainless Steel Pot



PRIMAIRA

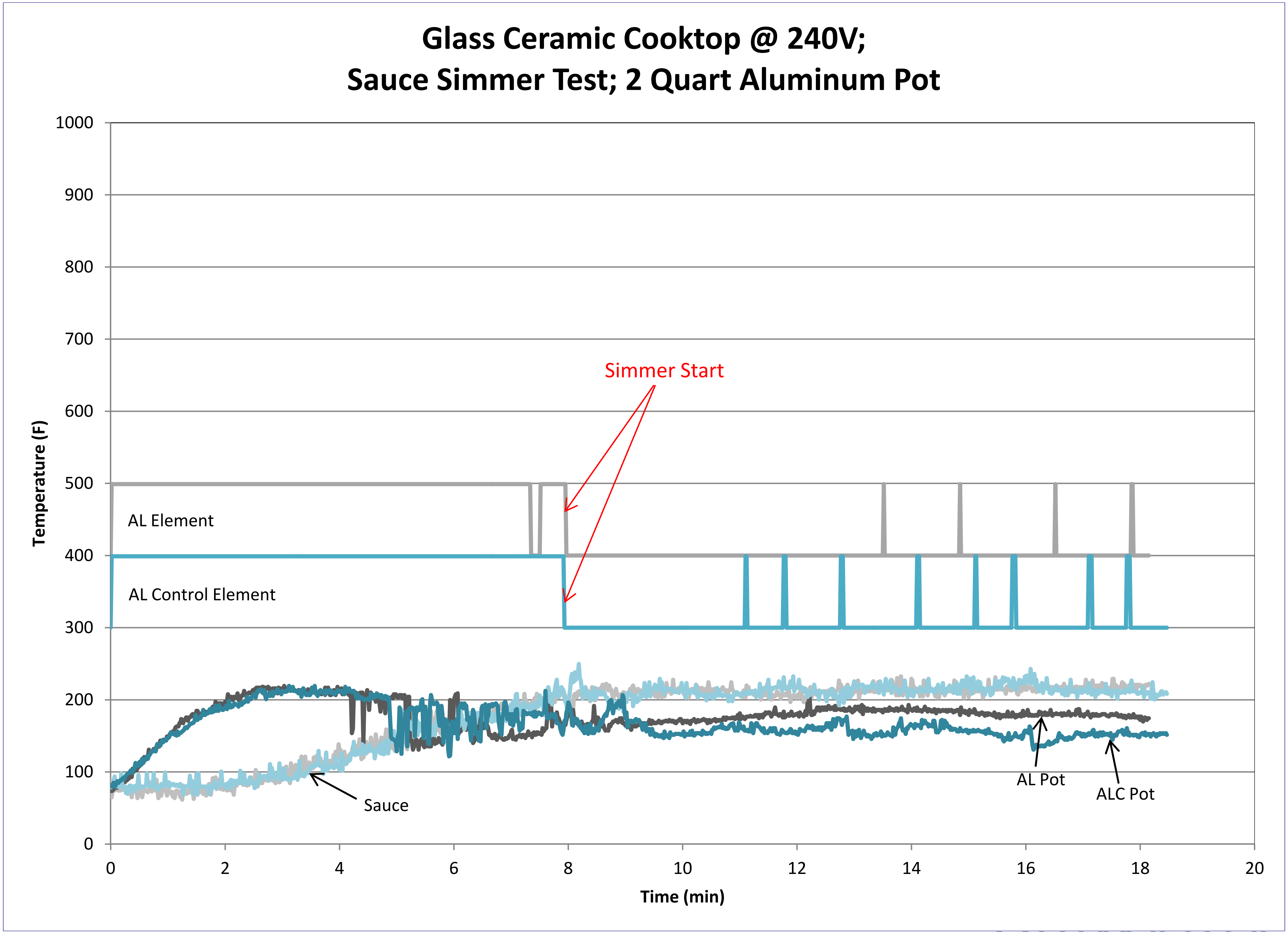
Glass Ceramic Cooktop @ 240V;
Water Boil Test; 2 Qt Stainless Steel Pot (75°F – 190°F)



PRIMAIRA

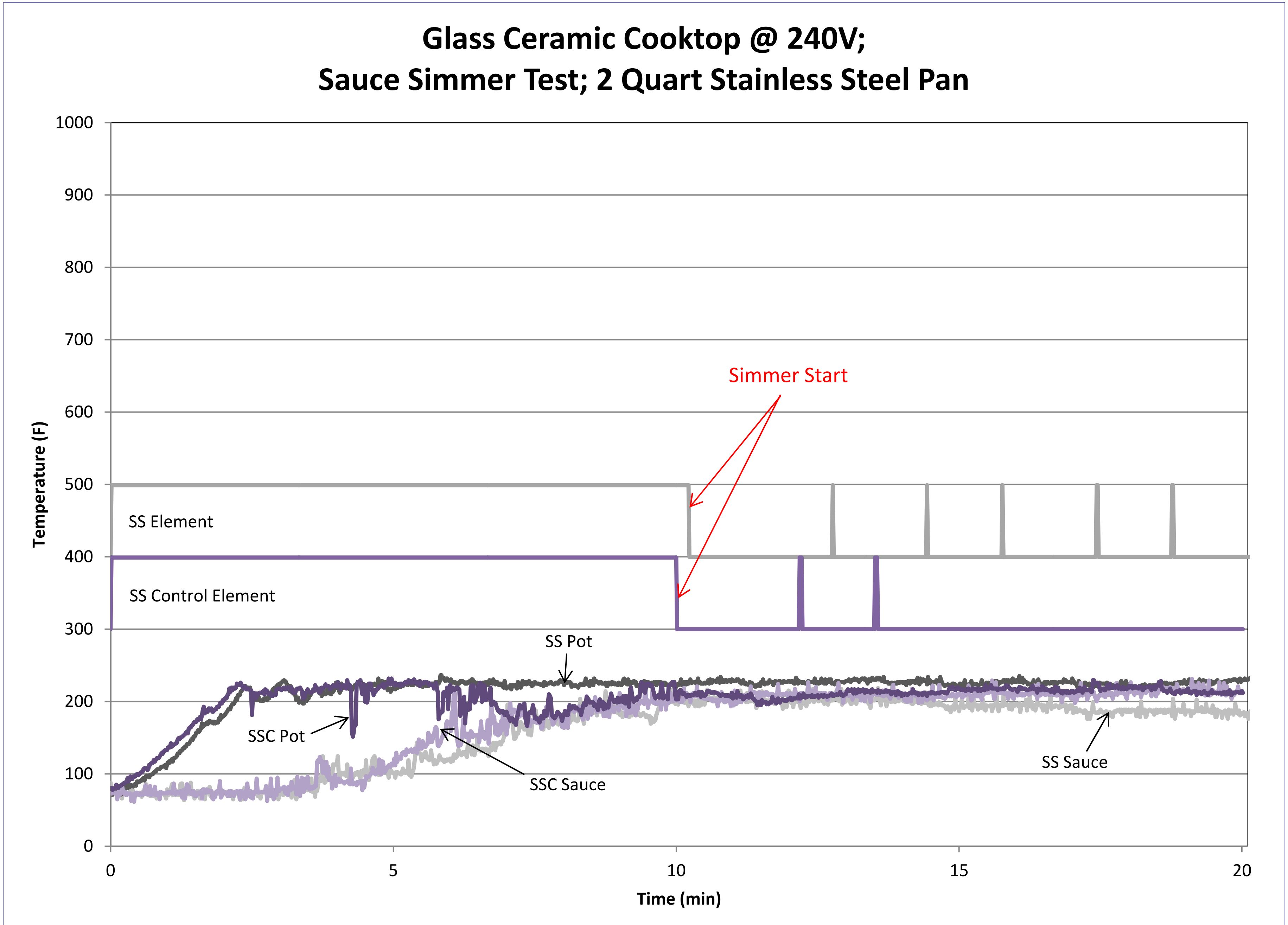
Sauce Simmer Test: Glass Ceramic Cooktop @ 240V

- A 1 quart jar of tomato sauce was emptied into 2 quart aluminum and stainless steel pots
- Sauce was heated on high and stirred continuously, then decreased to 3 when sauce began boiling
- Sauce was left to simmer for 10 minutes, stirring occasionally



Glass Ceramic Cooktop @ 240V;
Sauce Simmer Test; 2 Quart Aluminum Pot
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
Simmer Start
AL Element
AL Control Element
Sauce
AL Pot
ALC Pot
0
2
4
6
8
10
12
14
16
18
20
Time (min)

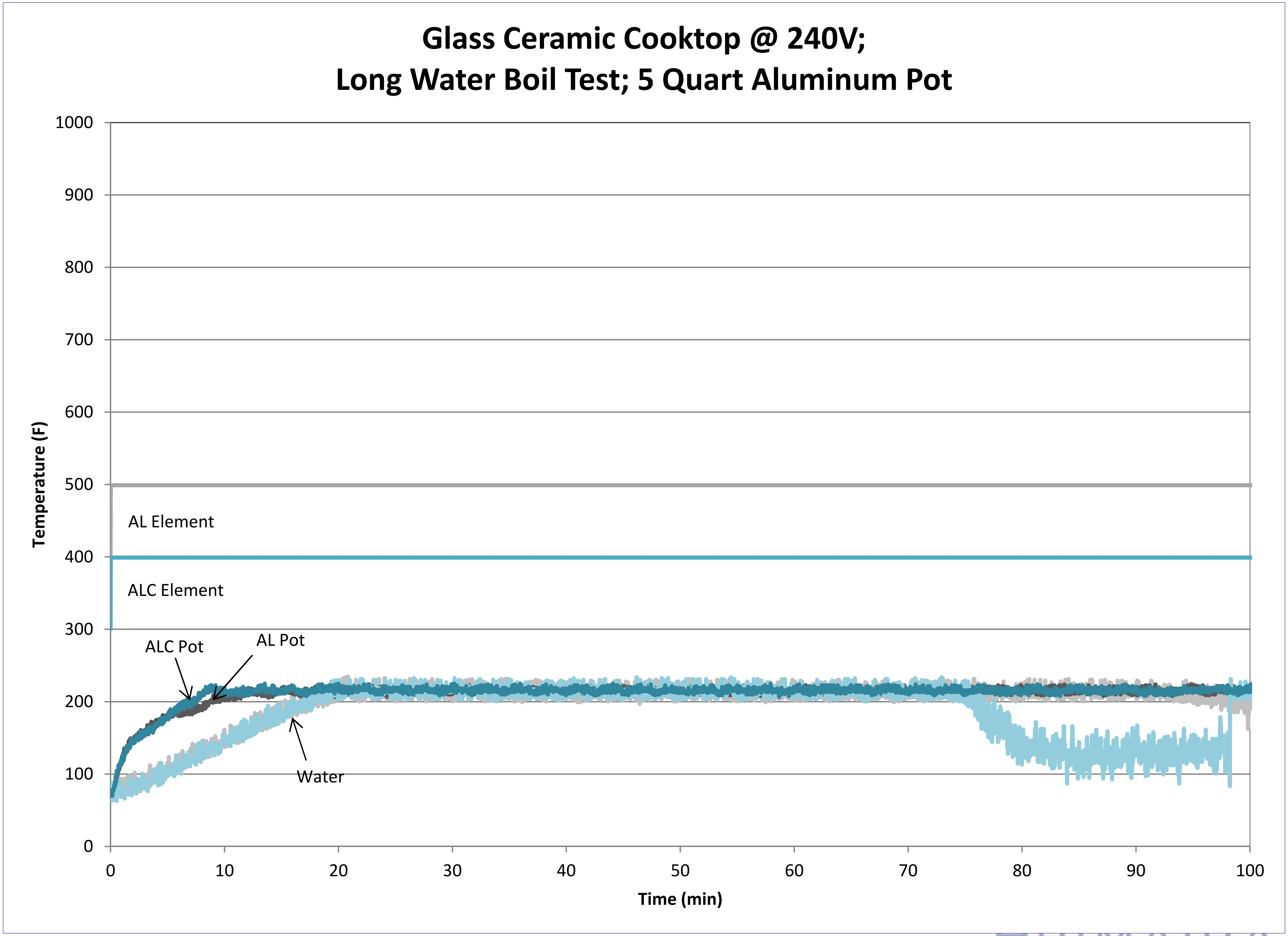
PRIMAIRA


Glass Ceramic Cooktop @ 240V;
Sauce Simmer Test; 2 Quart Stainless Steel Pan
Temperature (F)
Time (min)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
Simmer Start
SS Element
SS Control Element
SS Pot
SSC Pot
SSC Sauce
SS Sauce
PRIMAIRA

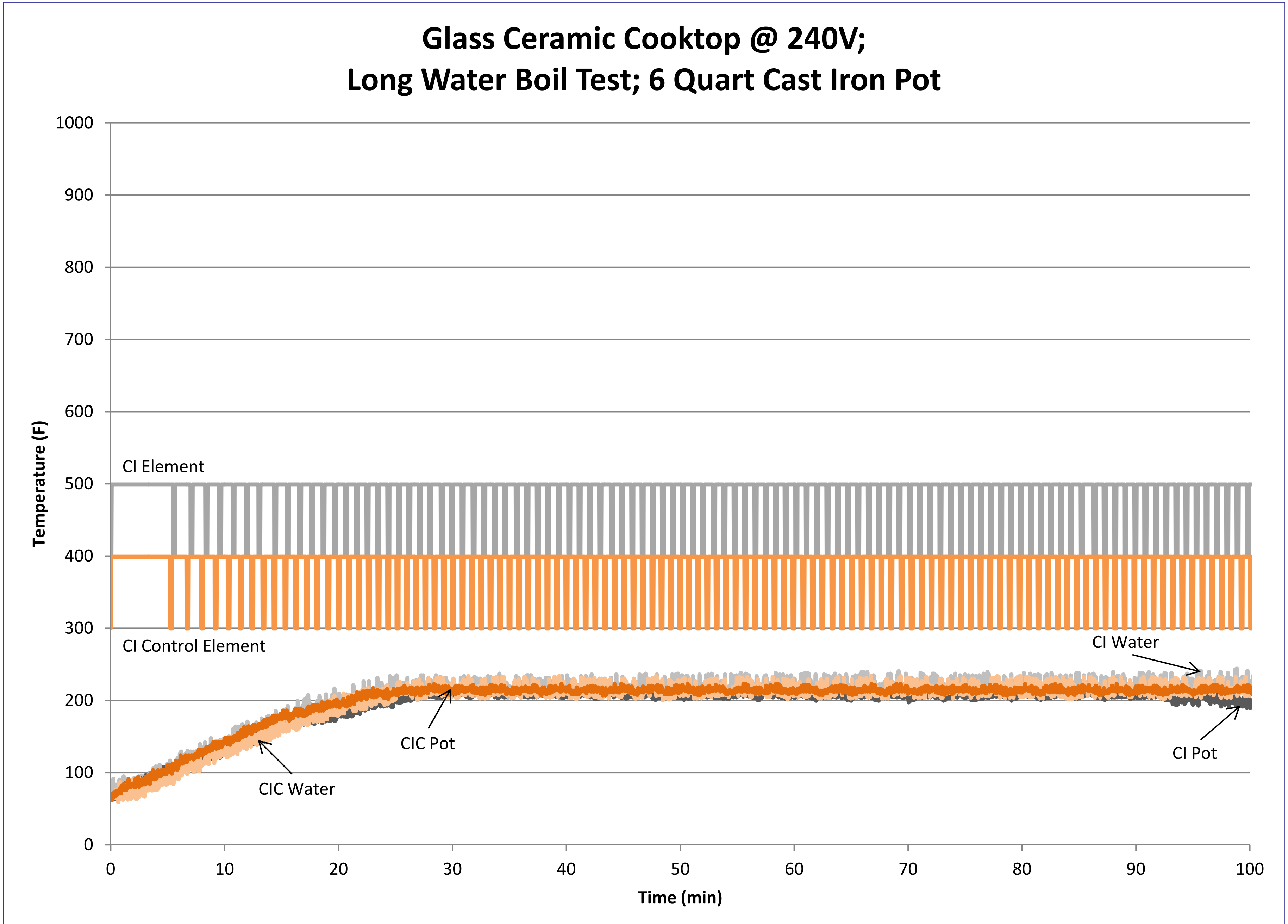
Long Water Boil Test: Glass Ceramic Cooktop @ 240V

- 4 quarts of water brought to a boil in a 5 quart (6 in the case of cast iron) pot, and allowed to continue boiling for 90 minutes

PRIMAIRA


Glass Ceramic Cooktop @ 240V;
Long Water Boil Test; 5 Quart Aluminum Pot
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
AL Element
ALC Element
ALC Pot
AL Pot
Water
0
10
20
30
40
50
60
70
80
90
100
Time (min)

PRIMAIRA


Glass Ceramic Cooktop @ 240V;
Long Water Boil Test; 6 Quart Cast Iron Pot
Temperature (F)
Time (min)
CI Element
CI Control Element
CI Water
CIC Pot
CIC Water
CI Pot
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100
PRIMAIRA

Glass Ceramic Cooktop @ 240V;
Long Water Boil Test; 5 Quart Stainless Steel Pot
Temperature (F)
Time (min)
SS Element
SS Control Element
SS, SSC Pot
Water
0
100
200
300
400
500
600
700
800
900
1000
0
10
20
30
40
50
60
70
80
90
100

PRIMAIRA

Time to Heat 4 Quarts of Water 75°F – 190°F: Glass Ceramic Cooktop @ 240V

	AL	ALC	CI	CIC	SS	SSC
Pasta Boil	14:05	15:30	18:33	18:20	18:14	18:13
Long Boil	15:20	15:17	16:41	18:32	18:33	18:55
Water Boil	14:06	14:28	17:28	18:30	18:13	18:56
AVG	**14:30**	**15:05**	**17:34**	**18:27**	**18:20**	**18:44**

PRIMAIRA