

Radiant Chambers for Fast Cook of Testing and Simulation

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1 INTRODUCTION

Two radiant chambers have been built and tested, Figure 1. They provide a uniform radiation field for testing small items. They have been calibrated with thermocouple rakes and cylindrical steel calorimeters. The radiation fields are unexpectedly uniform and have axial and circumferential uniformity. The chambers use eight 250-Watt cylindrical halogen bulbs. The bulbs are enclosed in inexpensive work light housings readily available at home centers. A variac has been used to control the heat flux. Since fast-cook heating of test items is believed to be 90% radiative, the chambers provide good tests for many items.

The chambers have been used to test instruments before putting them in large fuel fires. They have also been used to obtain highly controlled laboratory data for development of computer simulations, explaining experimental data from equipment being tested during development, and converging computer simulations when there was uncertainty in material property data.

Calibration data are presented along with results from testing a 7-inch (180-millimeter (mm)) rocket motor chamber with insulation and simulated propellant. Temperature versus time data was recorded by fifteen (15) thermocouples to measure the heat flow along each of five thermal paths from the outer surface of the motor, through the insulation, and into the propellant. The data were used to resolve problems caused by uncertainty in property data for the motor chamber and insulation in a finite element model used to analyze a restrained firing of a missile in a shipboard launcher.

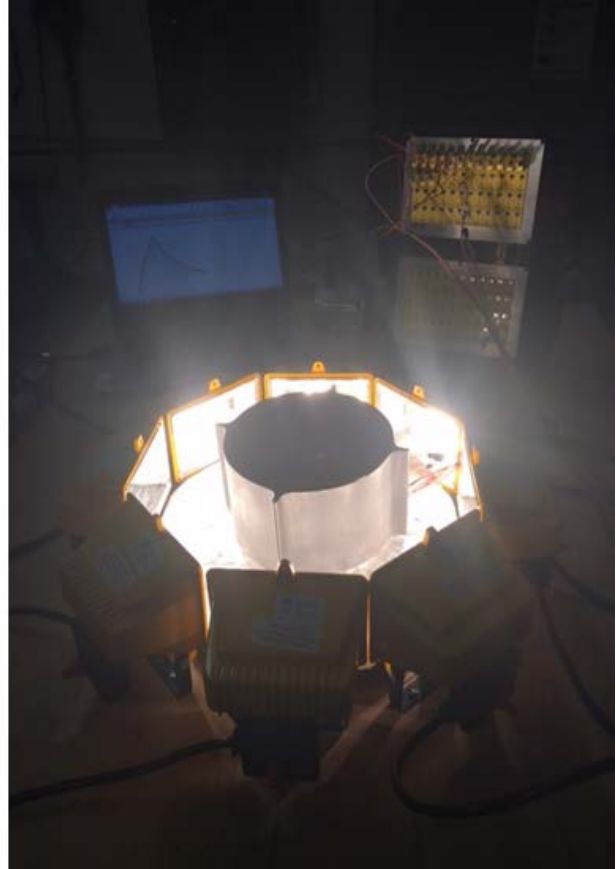
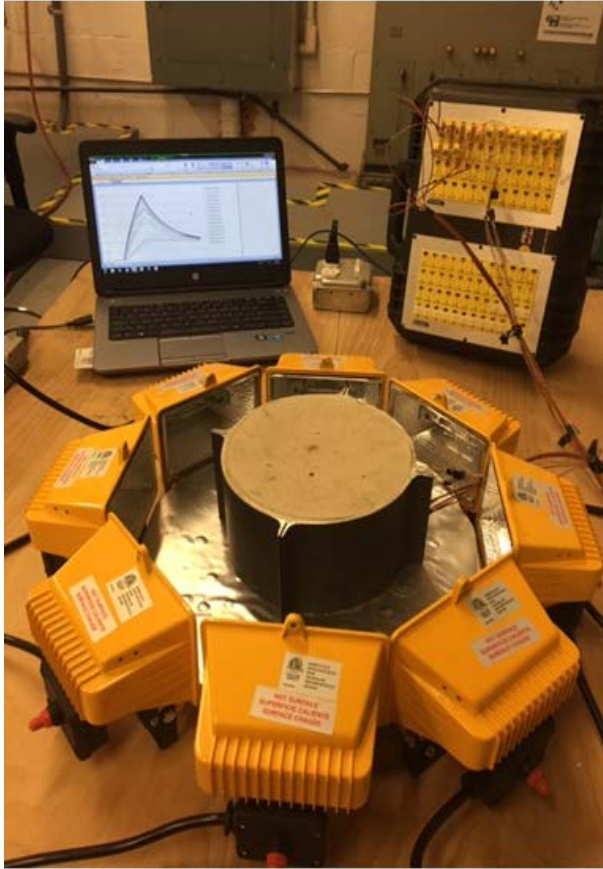


Figure 1. Radiant chamber set up for testing a segment of a rocket motor with inert propellant. The test item has thermocouples to measure the temperature along three thermal paths to the propellant. Temperatures are measured on the outer surface of the motor, the inner surface between the motor and insulation, and between the insulation and the propellant. The computer screen shows the data traces which were viewed in real time as the test evolved. The power was turned off when the motor would have cooked off, which is when the traces turn down and the motor cools.

2 TEMPERATURE AND HEAT FLUX CALIBRATION

Calibration data for a single 250 Watt halogen lamp is shown in figure 2.

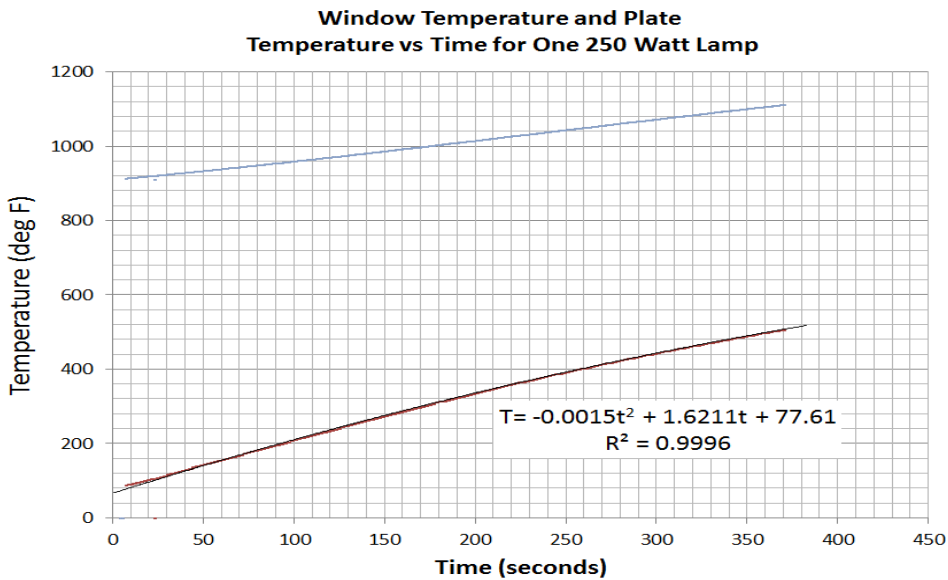


Figure 2. Window temperature and plate temperature versus time for one 250 Watt lamp.

The following paragraphs show how the combined radiation from the octagonal array of heat lamps can produce a uniform radiation field in a chamber. For the testing a set of calorimeters were made from standard 2-inch (trade size) pipe nipples 4 inches long. The first calorimeter had circumferential thermocouples on the inside. The temperature was measured at nine locations in a mid-plane through the calorimeter, figure 3. With nine locations being radiated by eight lamps, any circumferential variation should be detected. The data show there is very little variation around the circumference, figure 4.



Figure 4. Calorimeter for showing angular uniformity of temperature. Thermocouples are welded to the calorimeter at nine locations around the inner circumference.

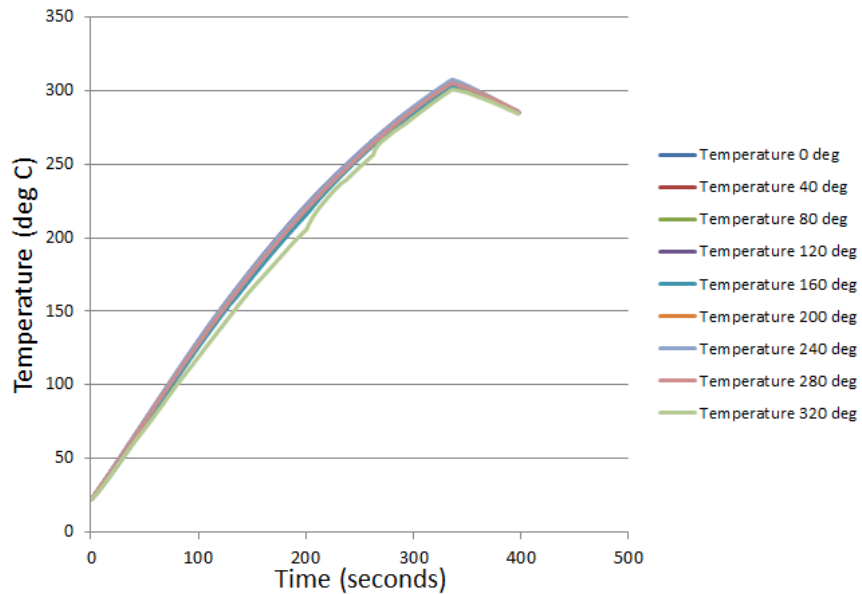


Figure 5. Temperature around the circumference of calorimeter at 40 degree intervals. Since there are eight lamps at 45 degree intervals, any aliasing of the data due to uneven radiation from the lamps would have been apparent in the data.

The temperature was measured at three locations along the surface of a calorimeter in the axial direction, figure 6. Measurements were made inside and outside of the calorimeter. The

temperature versus time traces fall neatly on one line for the entire time of exposure. At any time the temperatures are nearly the same everywhere, indicating good axial uniformity. The average temperature at each was calculated and plotted. Figure 7 is a graph showing a formula for the average temperature versus time. The value of r is a measure of the accuracy of the equation, with $r = 1$ being perfect.



Figure 6. Calorimeter for calibrating heat flux and showing uniformity of temperature and heat flux. Three axial stations were monitored on both surfaces of the calorimeter.

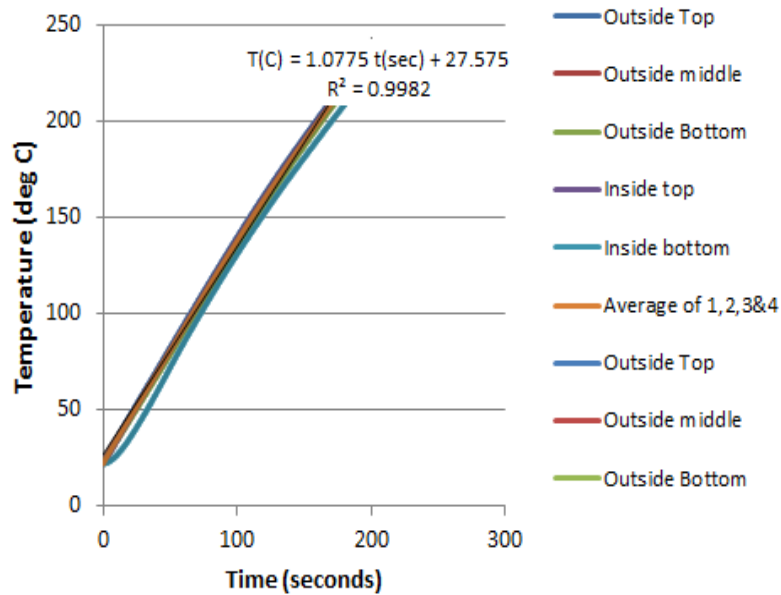


Figure 7. Temperature versus time from calorimeter thermocouples.

The absorbed heat flux was calculated. The results are shown figure 8. The formula for the heat flux versus time was differentiated to get the heating rate. Q is the heat absorbed. This was used to calculate a heating power of 499 Watts. The absorbed heat flux was 30.4 kW/m², which is very useful for designing and testing systems for STANAG 4240, Fast Heating (cook-off) Test.

Compute Heat Flux			
dT/dt		1.078	Kelvins/sec
mass		0.517	kg
specific heat		896	j/kgK
C heat cacity		463	j/K
dQ/dt=mcdT/dt		499	J/s watts
		0.499	kw
diameter		2.391	in
		0.0607	m
circumference		0.191	m
length		3.391	in
		0.0861	m
area		0.01642	sq m
absorbed heat flux		30.4	kw/sq m

Figure 8. Heat flux calibration. The figure shows how the absorbed heat flux was calculated for the calorimeter. The absorbed heat flux was 30.4 kW/m². This is representative of the heat flux into the energetic material in fast cook off testing.

Checking and calibrating instruments

Figure 9 shows a Differential Flame Thermometer (DFT) being checked out in the radiant chamber prior to an important test in a fast cook-off pit. The DFT is an instrument for measuring heat flux. The DFT has a thermocouple on the back face of a thin Inconel plate, with insulation. The temperature can be differentiated, and the heat flux calculated using properties of the plate as provided by the manufacturer.

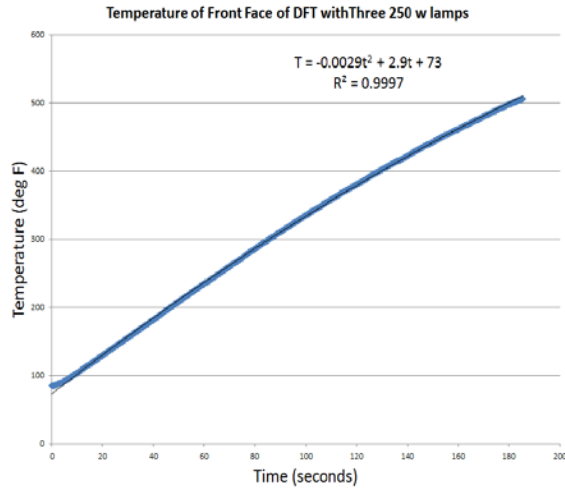
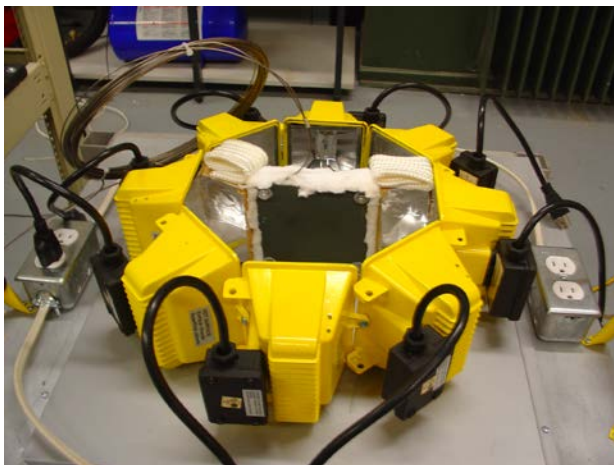


Figure 9. Differential Flame Thermometer (DFT) being tested in a radiant chamber, and resulting temperature versus time on the inside face of the DFT.

Figure 10 shows a cylindrical calorimeter with thermopiles on two diametrically opposed faces to measure the heat flux into the instrument. The thermopiles provide a direct measurement of the heat flux, not requiring differentiation of temperature data. A thermocouple was placed on the centerline in the middle of the cylinder. The instruments were used in fast cook off tests in the propane fuel fast cook-off facility at WTD-91 in Meppen, Germany.

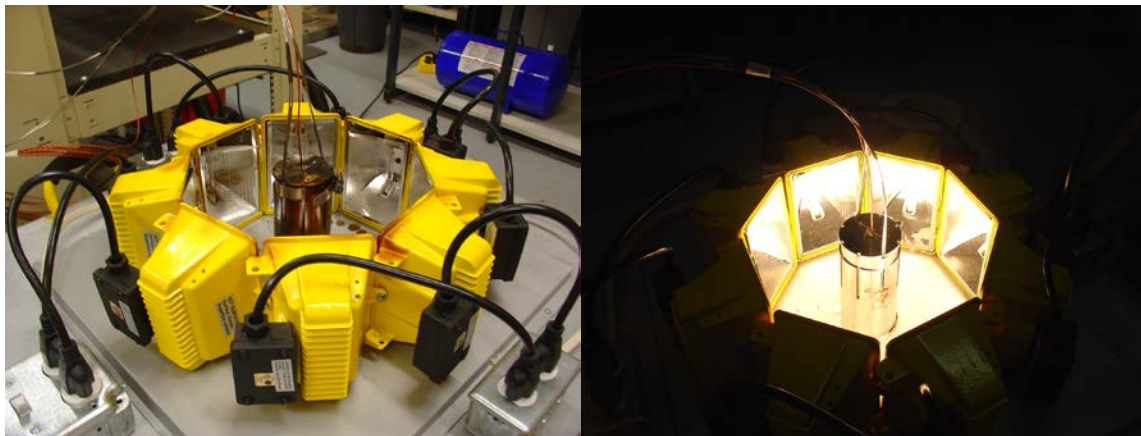


Figure 10. Thermopile calorimeter being checked out in radiant chamber

The data from the calorimeter is shown by figure 11.

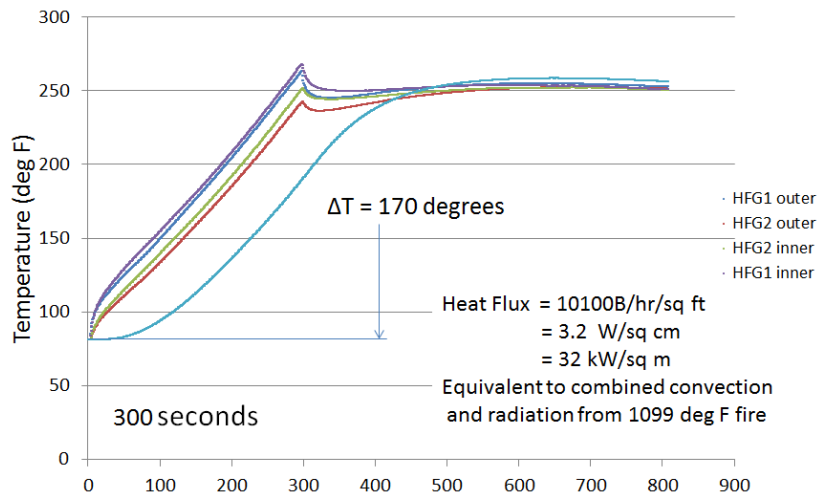


Figure 11. Signals from the four thermopiles signals of the heat flux calorimeter. Each thermopile has two places to extract a measurement. The fifth signal is from a thermocouple on the centerline of the instrument. Heat fluxes in the range of 20-30 kW/m² are typical of the heat fluxes into the energetic material at cook-off for many items that have been tested. Figure 12 shows a calorimeter in a radiant chamber with the heat flux set at 25 kW/m².

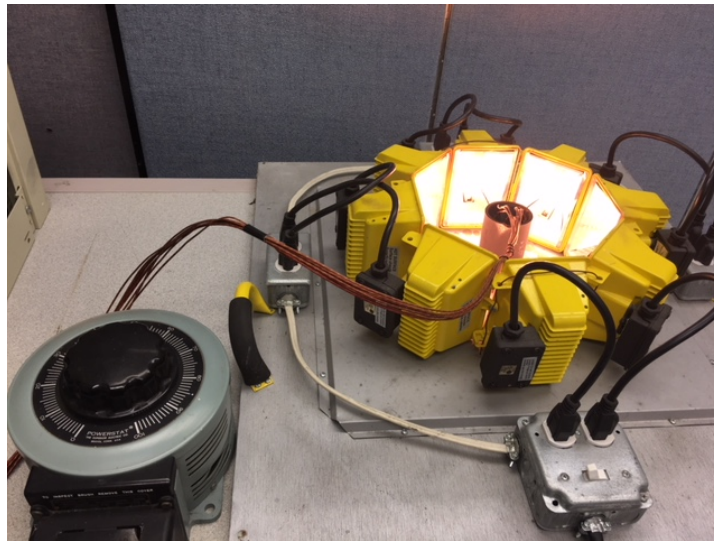


Figure 13. Calorimeter in a radiant chamber set to produce a heat flux of 25 kW/m².

3. Magazine Safety Test

There was a full-scale test of a rocket motor undergoing a restrained firing in a missile launcher. A restrained firing is a shipboard casualty in which a missile is fired, but for some reason does not leave the ship. There is a concern that the heat produced could cause ignition of an adjacent round. There were problems interpreting the data from the test. A unit was built-up using a segment of the aluminum motor that was actually used in the test. The motor was instrumented with thermocouples and loaded with inert propellant simulant.



Figure 14. Interior instrumentation showing thermocouples to measure the temperature at the interface between the insulation and propellant.



Figure 15. Motor with simulated propellant.

The test in the radiant chamber yielded material property data for the “as built” rocket motor. It was then conclusively determined that the adjacent round in the magazine safety test would not have cooked off.

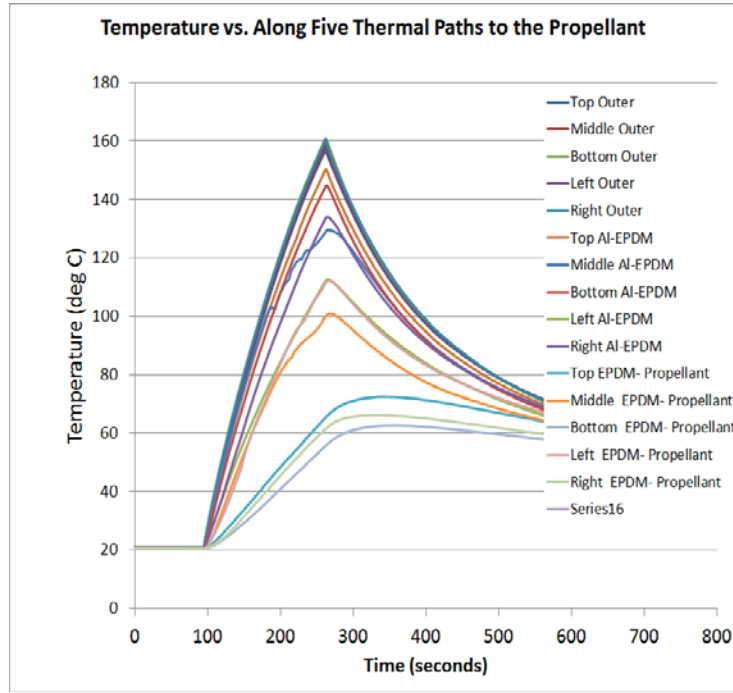


Figure 16. Records from thermocouples on five thermal paths to propellant.

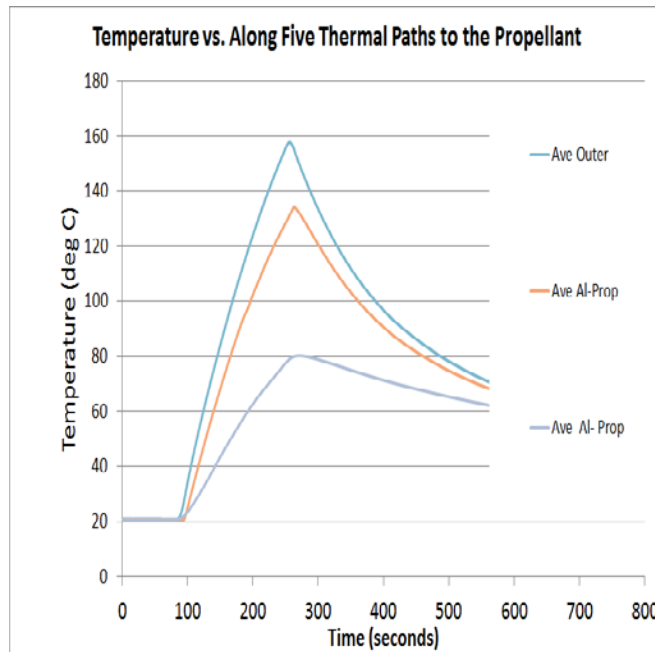


Figure 17. Average values of temperature versus time at the interfaces for heat flux calculations.
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3 SUMMARY AND CONCLUSIONS

- Radiant chambers have been built to simulate the radiant heating in fast cook-off fires.
- The radiant chambers show good uniformity in temperature.
- The chambers provide a broad range of heat fluxes, which span the range of heat flux into propellant in enclosed systems (20–25 kw/m²) to absorbed radiation on the outer surface of test items in fuel fires 90 kw/m².
- The heat flux meets the heat flux requirement for STANAG 4240 Fast Cook-Off Testing.
- The chambers have been used for testing instruments and test items prior to exposure to fires.
- The chambers have been used to solve complex problems in fast cook-off and magazine safety testing.