Comparing Fire Response of Simulated Rocket Motors in Steel and Carbon Fiber Composite Missile Launching Canisters

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Abstract

The paper explains the results from a two-part experiment that was designed to provide data on the thermal response of encanistered missiles in fast cook-off testing. The first part is the fire response in a liquid fuel fire. The second part will be a propane fuel fire. A steel canister and a carbon fiber composite canister were used. The test and data analysis are complete for the liquid fuel fire and are the subject of the paper.

The tests were designed to document the complete thermal path from the fire, through the missile launching canister, and into propellant in simulated rocket motors. The thermal path starts in the fire with radiation and forced convection heating of the canister, then conduction through the canister wall, radiation and natural convection between the canister and the rocket motor case, conduction through the case, conduction through a thin layer of insulation, and into the propellant. Temperature versus time was measured in the fire and at each interface all the way to the propellant.

Each canister contained three simulated rocket motor segments separated by insulating partitions. The motors used different materials for the cases. Some of the motors used steel cases; the others used aluminum, titanium, and carbon fiber composite cases. Two types of insulation between the case and the propellant were represented, EPDM rubber and cork. Two propellant simulants were used, one a careful representation of an operational motor, the other an inexpensive mineral based material.

The results show the time-dependent fire temperature, the temperature at each interface, and calculations of the heat flux into the simulated propellant. There was a thermal event inside the carbon fiber composite canister. All but one of the simulated propellants received heat in the range of 20–25 kW/m^2. The outlier was an aluminum chamber with cork insulation. Calculations showed the heat flux would have been in the same range had the motor used EPDM insulation.

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1 PURPOSE OF EXPERIMENT

The purpose of the experiment was as follows:

- Gather comparative data on steel and carbon fiber composite missile launching canisters
- Assess relative performance of steel, aluminum, and carbon fiber composite rocket motor chamber materials
- Obtain data for converging and validating finite element models
- Obtain data for later comparison to propane gas fuel fire cook-off fires

As shown in Figure 1, two canister segments were insulated from each other and joined in the middle of the pit, one meter above the fuel. Approximately eighty (80) channels of thermocouple and displacement data were recorded during the test.

Figure 1. Steel and carbon fiber canisters in Dahlgren fast cook-off pit.

As shown in Figure 2, thermocouples were placed inside and outside each face of the canisters to measure the temperature and calculate the heat flux. The inner and outer thermocouples were aligned to measure along a straight path from the fire to the propellant. The fire thermocouples were placed on the line 50 millimeters (mm) from the canister. The instrumentation cables were brought out through a conduit. A linear variable distance transformer (LVDT) measured the sagging deformation of the composite canister. The horizontal pipe was for a string to pull the movable element of the LVDT, which was located outside of the fire.

Figure 2. Thermocouples on canisters.

Figure 3 is a pictorial view of the assembly on the test stand. The actual arrangement as tested is shown in Figure 4. As shown in Figure 5, the canisters were assembled into modules for insertion into the canister segments. The motors were of the center perforation type, with one cylindrical perforation. The perforations were aligned and thermocouples were installed in free air in the perforations.

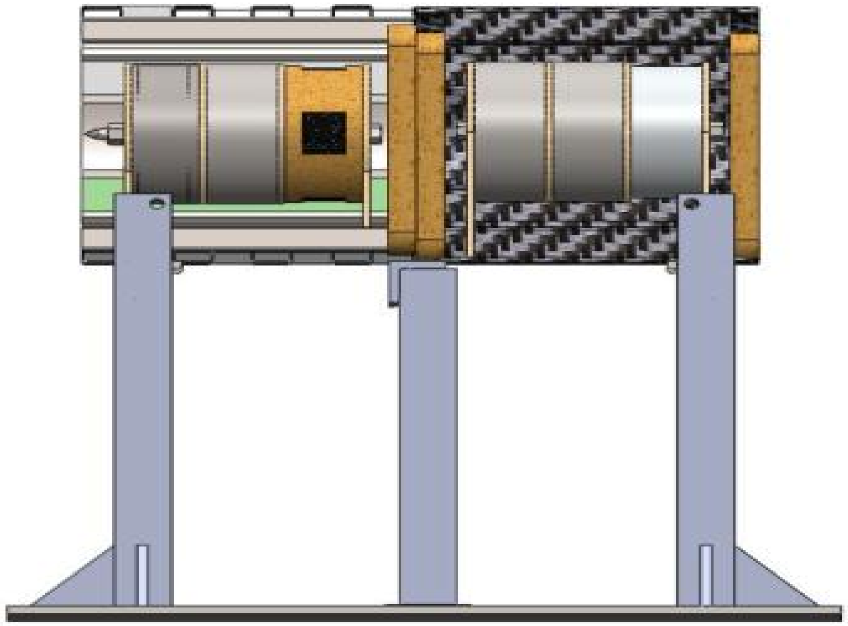


Figure 3. Representative rocket motor chambers.

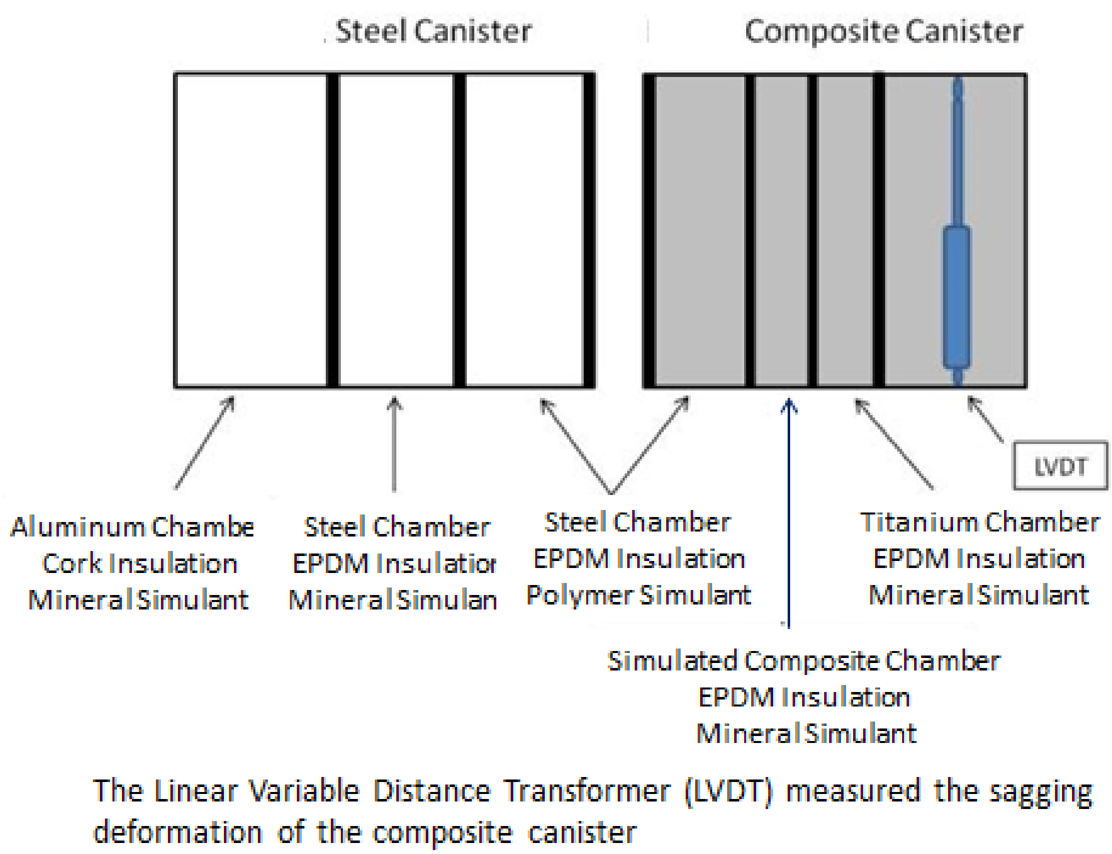


Figure 4. Simulated motor chamber segments.

Figure 5 shows the motor segments with instrumentation.

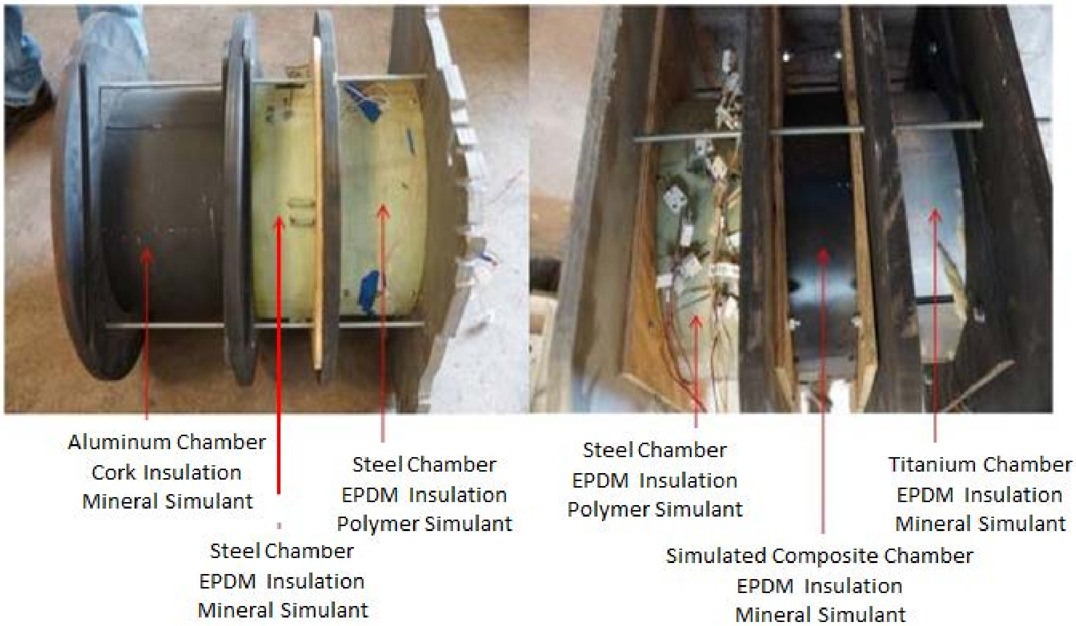


Figure 5. Motor segments with instrumentation.

2 EXPERIMENTAL DATA

The flow of heat from the fire through the four faces of each canister was measured. A thermal event occurred in the carbon fiber composite canister, as shown in Figure 6. As can be seen in the internal surfaces plot, there was a thermal event inside the canisters. This was attributed to the carbon fiber epoxy material igniting at the known auto ignition temperature for the material.

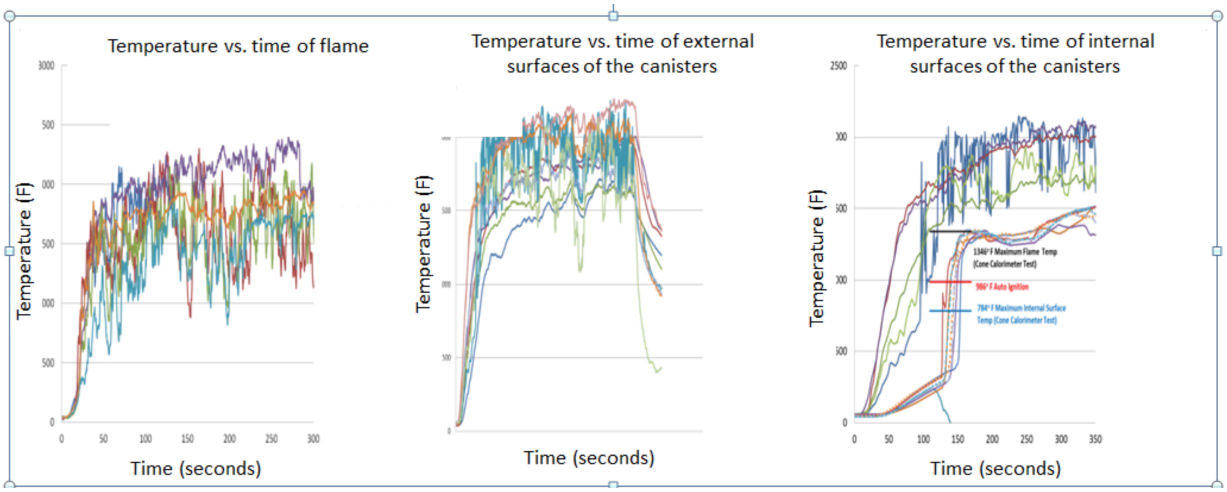


Figure 6. Temperatures versus time along the path from the fire to the internal surfaces of the canisters.

Figure 7 shows the teperatures along thermal paths into a motor with a steel chamber in the steel canister. The details along the paths are different, but all converge on 1,250 to 1,300°F at a time of 180 seconds. The differences in the fire and canister walls, mainly due to wind, are all averaged out inside the canister. This is not to say that the wind has no effect on the results, it only says that the effects of the wind condition during the test aren't sensed by the motor after 3 minutes in the fire. The wind generates turbulence, which increases the efficiency of combustion, increases the temperature, increases radiation according to T^4, and increases the convective heating by the fire.

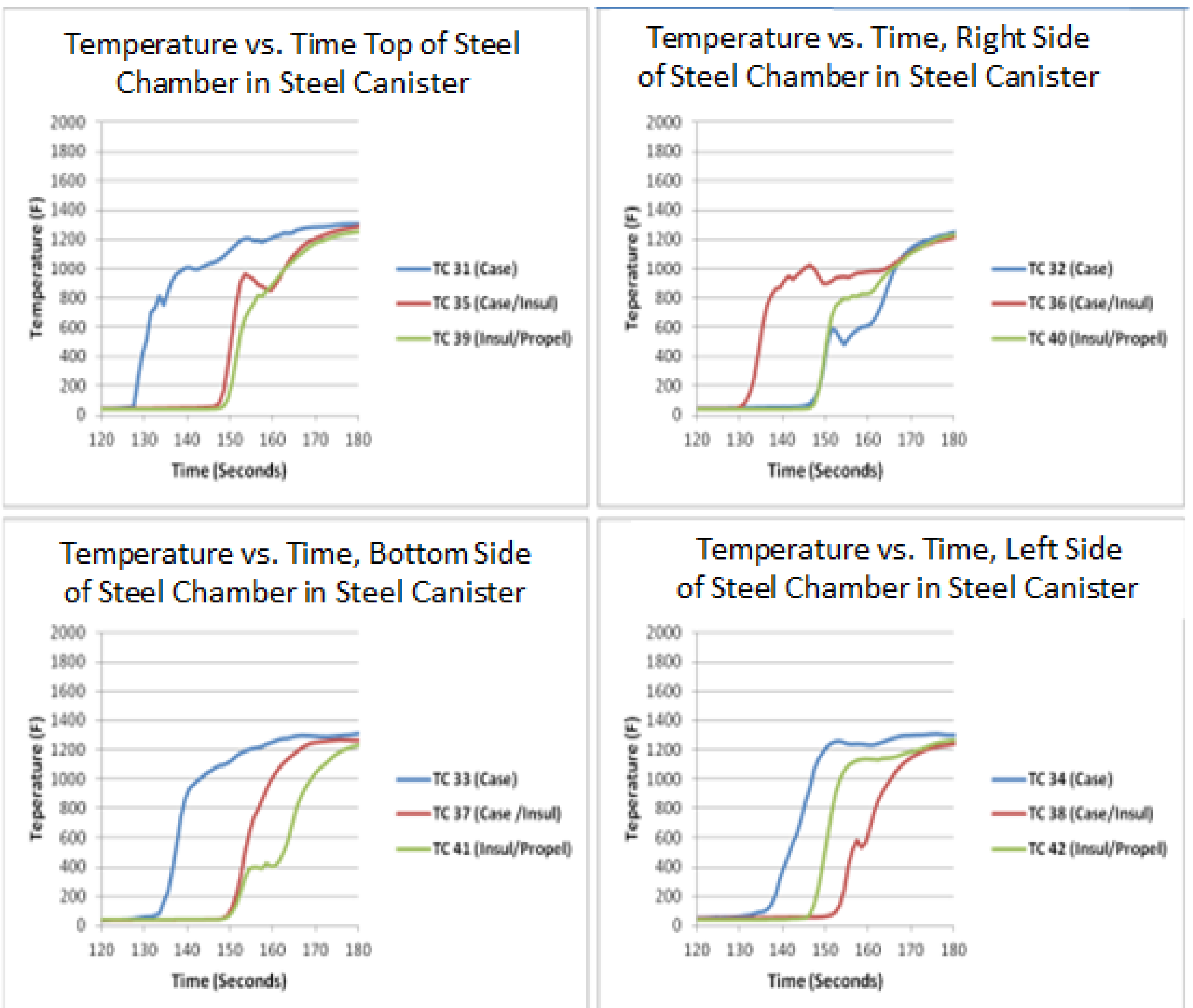


Figure 7. Temperatures along thermal paths into a motor with a steel chamber in the steel canister.

Figure 8 shows temperatures along similar paths to an identical motor with a steel chamber in the carbon fiber composite canister. Again, there are differences along each path, but the temperatures converge on 1,250°F after 3 minutes in the fire.

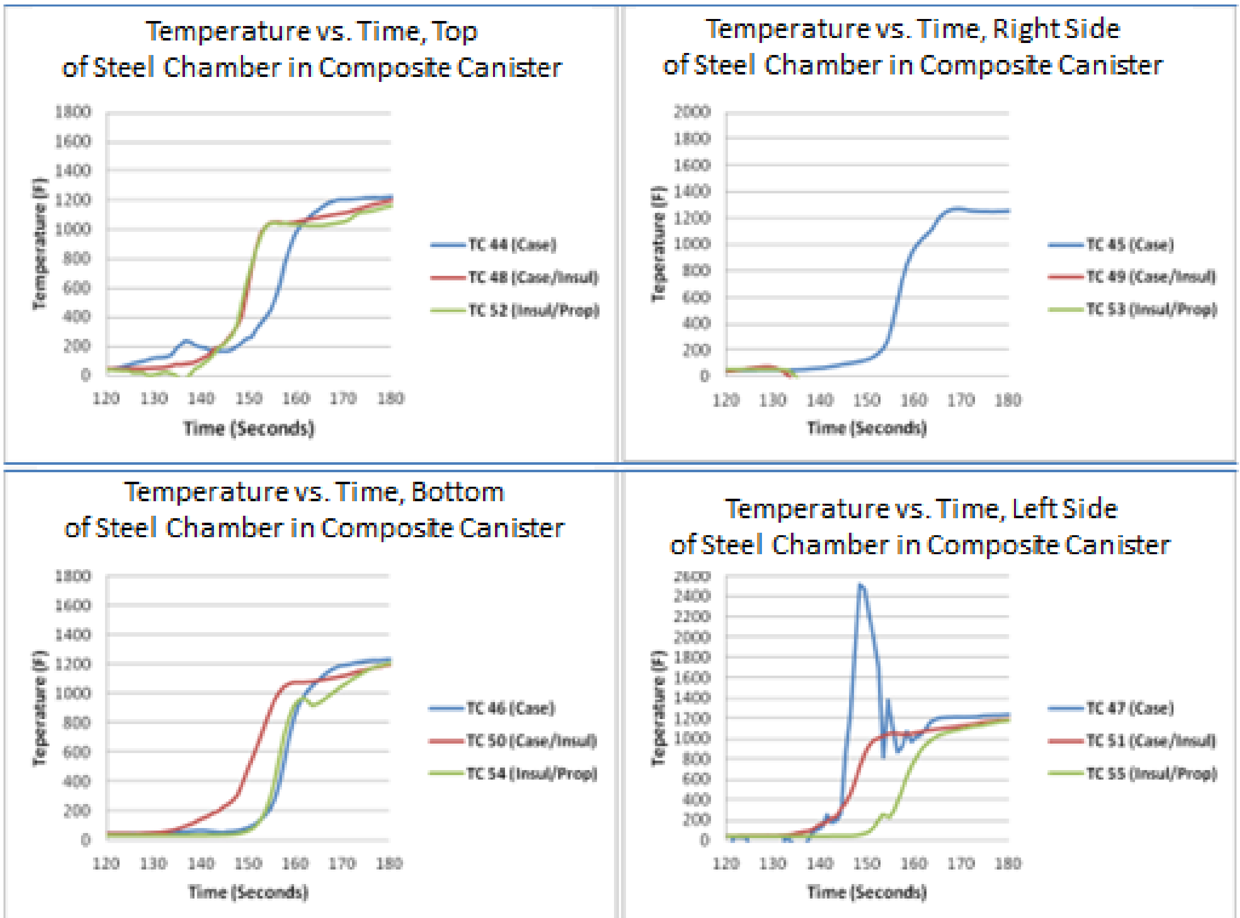


Figure 8. Temperature versus time along thermal paths into a motor with a steel case in the carbon fiber composite canister.

The effects of the thermal event are apparent in the data traces from the left side of the canister (Figure 9). There was a sudden temperature rise to 2,400°F, which quickly droped back down to 1,000°F. Two data traces from the right side were lost at the time of the thermal event. Perhaps they were casualties. Again, all the temperatures converge to 1,250°F after 3 minutes in the fire. Therefore, it does not seem to matter to the motor whether it was in a steel canister or a composite canister.

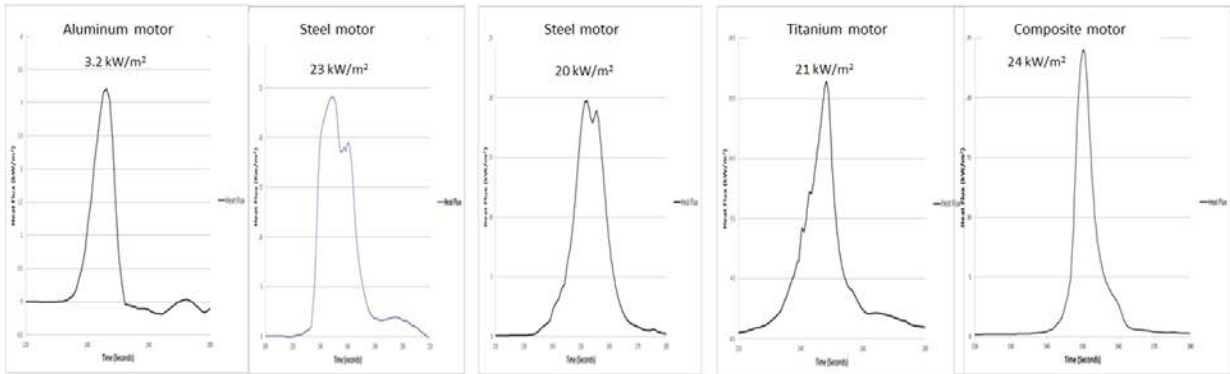


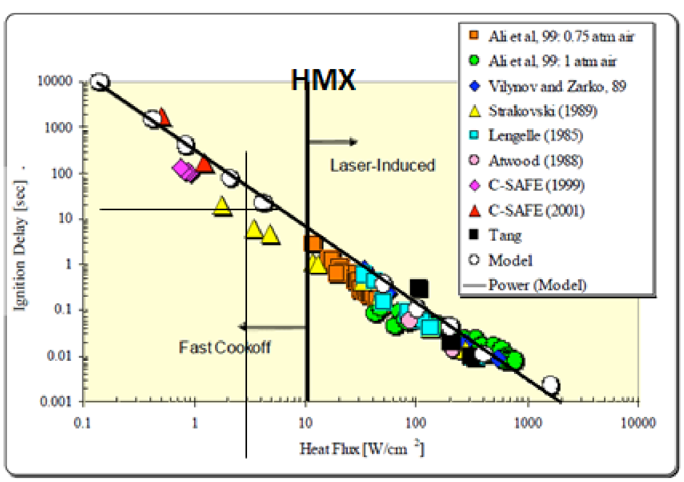
Figure 9. Heat fluxes into propellant.

The heat fluxes into the propellant were all around 20–24 kW/m^2. Figure 10 shows a curve for time to cook-off versus heat flux for HMX explosive. This would cause cook-off at approximately 1 minute after this heat flux is attained, in either canister, for a propellant like HMX.

Calculations showed the heat flux into the propellant of the aluminum chamber motor would have been in the 20–24 kW/m^2 if the insulation would have been EPDM.

There was not much difference between the heat flux into the sophisticated propellant simulant and the inexpensive mineral-based simulant.

Data for heat flux versus time to reaction is needed for other energetic materials. The very tight clustering of the data along a straight line, as shown in Figure 10, suggests this may be a very fundamental property of explosives. If so, all cook-off reaction times could be classified by one data point on the curve (e.g., time to reaction for heat flux of 1 w/m^2), and the slope of the curve.



Ignition delay versus heat flux

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Figure 10. Estimated time to cook-off for HMX explosive.

As shown in Figure 11, the canisters retained their shapes throughout the fire.

Figure 11. Post-test remains.

3. SUMMARY AND CONCLUSIONS

The summary and conclusions are as follows:

- Experimental data for six simulated rocket motors were obtained using a steel missile launching canister and a carbon fiber composite canister.
- The data showed similar rocket motor thermal responses in either canister type, and all motor types with EPDM insulation.
- The peak heat fluxes into the motors were in the range of 20 –24 kW/m^2.
- There was little deformation of the carbon fiber composite canister.
- Data are now available to validate computer models of fast cook with a variety of chamber materials and steel and carbon fiber canisters.