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ENGINEERING ANALYSIS CLOSING REPORT

SUBJECT: Speed Control Deactivation Switch Fires.

EA No: EA05-005 **Date Opened:** 22-Mar-2005 **Date Closed:** -Aug-06

BASIS: ODI opened PE04-078 on November 19, 2004 to investigate 36 alleged speed control deactivation switch (SCDS) failures and related engine compartment fires that occurred in model year (MY) 2000 Ford F-150's, Expeditions and Lincoln Navigators. These fires started with the vehicle parked and the ignition in the off position. In January 2005, Ford announced it was recalling (Recall #05V-017) over 730,000 vehicles including certain MY 2000 Ford F150, Expedition, Lincoln Navigator and certain MY 2001 Ford F150 Supercrew trucks due to an extremely high SCDS failure/fire rate when compared with other vehicles using the same switch. At the time of the recall, the root cause for the failure of the SCDS was unknown.

Although prior SCDS recalls addressed vehicles with high fire rates, the root cause of the SCDS fires remained unknown. Because other vehicles using the same switch in a substantially similar environment continued to have switch failures and engine compartment fires, both Ford and NHTSA continued to aggressively investigate the issue.

On March 22, 2005, ODI elevated this investigation to an Engineering Analysis (EA05-005) in order to complete a more in depth analysis of the root cause of the SCDS failures. EA05-005 also increased the scope of vehicles being investigated to 3.7 million MY 1995 – 2002 Ford F150 and MY 1997 – 2002 Ford Expedition and Lincoln Navigator vehicles. At the time the investigation was elevated, ODI was aware of 218 key off fires in parked subject vehicles. These fires had not been verified by ODI as having been likely caused by a defective SCDS.

ODI developed an extensive testing and analysis program during this investigation to understand the root cause of the SCDS failures and understand why certain Ford model / model year vehicles had very high rates of key off engine compartment fire, while other models using the same part number SCDS had very low rates of fire. Understanding the failure mode would enable ODI and Ford to identify what additional vehicles should be recalled and remedied.

SUBJECT VEHICLES: The subject vehicles of this investigation EA05-005 and its predecessor PE04-078 include 1995 – 2005 Ford F150, 1997 – 2002 Ford Expedition, 1997 – 2002 Lincoln Navigator vehicles equipped with electronic speed control.

To complete a comparative analysis of the subject vehicles ODI requested certain detailed information from Ford related to the subject vehicles as well as peer vehicles including MY 1995 – 2002 Ford F150 without Cruise Control, MY 2003 – 2004 Ford F150, MY 2003 -2004 Ford Expedition, MY 2003 – 2004 Lincoln Navigator, MY 1995 – 1996 Ford Bronco, MY 1998 – 2001 Ford Explorer, MY 1998 – 2002 Ford Ranger, and MY 1995 – 2002 Ford Econoline vehicles. ODI requested similar information from General Motors on MY 1995 – 2002 CK1500 trucks, and from Daimler Chrysler on MY 1995 – 2002 Dodge Ram 1500 trucks. These

Information Request letters and the associated manufacture responses can be found in the public file for EA05-005.

ALLEGED DEFECT: Failure of the speed control deactivation switch that results in switch overheating or fire (Figures 1. and 2.).

Figure 1. SCDS Fire Initiation.

Figure 2. SCDS Fire Initiation Close Up.

SUBJECT SWITCH DESCRIPTION: The subject component is a hydraulic pressure switch, manufactured by Texas Instruments (TI), which functions as a redundant safety switch to interrupt power to the speed control servo during brake applications. The normally closed switch opens at brake system pressures produced by approximately 5-10 lbs of pedal force, breaking the circuit to the speed control servo and causing the speed control to disengage. The deactivation switch is mounted on the brake master cylinder, which is located at the rear bulkhead on the left (driver's) side of the engine compartment (Figure 3.). The SCDS may be oriented so that it mounts in the Master Cylinder in a vertically up, vertically down, or angled down position.

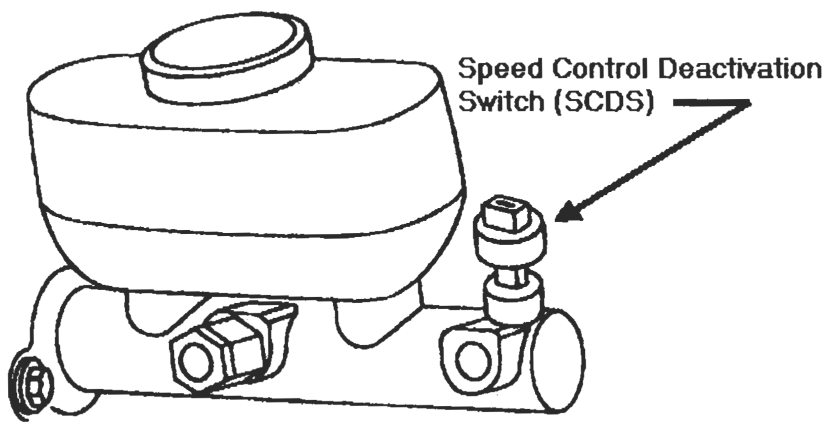

Figure 3. Speed Control Deactivation Switch Location.

The switch has two sides, a "wet" side that interfaces with the brake master cylinder and hydraulic brake fluid, and a "dry" side that interfaces with the electrical wiring to the cruise control servo and contains electrical contacts that open and close disengaging the cruise control when the brakes are applied. A multi-layer diaphragm and gasket seal the interface between the hydraulic and electrical sides of the switch (Figure 12.). The diaphragm consists of three layers of Kapton 500FN131 (Kapton sandwich), a high performance polyimide polymer film supplied by DuPont. Each Kapton FN layer is a composite structure consisting of a 3 mil (76.2 μm) core of Kapton HN film with 1 mil (25.4 μm) laminates of Teflon FEP on each side. TI used three layers of Teflon-coated Kapton to enhance the durability of the switch. The Kapton sandwich (hexport seal, middle seal, and washer seal) is clamped between the hexport cup and the washer with a gasket on the hexport side (Figure 12.).

The Teflon-Kapton-Teflon system is used because water degrades the mechanical properties of Kapton and brake fluid is hygroscopic (i.e., will absorb water from humid air). Teflon, which is unaffected by water, provides a boundary layer to protect the Kapton substrate from moisture in the brake fluid. Hydrolytic degradation of the Kapton is a function of: (1) the concentration of water in the brake fluid; (2) the amount of time the Kapton is exposed to water-contaminated brake fluid; and (3) temperature.

In operation, brake fluid pressure acts against the switch converter through the Kapton diaphragm and actuates a switch snap disk. Actuation of the snap disk allows the sprung arm of the switch movable contact to lift off the stationary contact (Figure 12.), breaking the speed control circuit to the servo clutch. When brake pressure fluid drops, the snap disk is released, forcing the contacts back together through a transfer pin resetting the switch and resuming speed control function.

On the subject vehicles, the SCDS receives uninterrupted voltage from the battery so that it is Powered All the Time (PAT). The switch contacts normally conduct up to 0.75 amps to the speed control clutch when speed control is engaged and 0.005 amps when not engaged. A 15 or 20 amp (depending on model) fuse provides over-current protection for the speed control circuit.

FAILURE MECHANISM: There are two significant stages in a failure associated with the alleged defect. The first stage involves the development of a leak path from the hydraulic side of the switch to the electrical side of the switch. The second stage involves the corrosion of the switch contacts and the development of a resistive short to ground that generates heat in the switch cavity, which can result in melting of the plastic base and, in some cases, fire.

The leak results from fatigue failure of the Kapton allowing brake fluid to move from the hydraulic side of the switch to the electrical side of the switch. Fatiguing of the Kapton diaphragm results in cracks initiating in the Teflon layer (Figure 13.) of the laminate. Once the Teflon layer has been breached, the Kapton is then compromised by the water that is contained in the brake fluid. DuPont, the manufacturer of the Kapton material, indicates that hydrolytic degradation of the Kapton can be caused by water-contaminated brake fluid penetrating a cracked Teflon layer. A Kapton substrate that has been degraded from such exposure can become brittle and crack. Figure 14. shows a Kapton crack that appears to have resulted from fatigue imposed by over cycling the material.

Once a leak develops, water-contaminated brake fluid makes its way into the electrical cavity of the switch and corrodes the switch electrical contacts. A brake fluid slurry may fill the gap between the electrical contacts and the grounded hexport body acting as an electrolytic medium. In this condition, conductive metal atoms are deposited on the negative electrode and can grow (dendrites) on the grounded base plate (cathode) towards the energized switch (anode). As dendrites grow and accumulate, their electrical resistance drops and their current carrying capacity increases. If the dendrites complete an electrical pathway between power and ground, increased heat and arcing can cause brass and copper beads to form in the plastic base. If the plastic housing experiences high enough temperatures, ignition of the switch might result in an open flame. In some instances, the combustion is confined to the switch housing. But, in other cases, depending on factors like orientation of the switch and the proximity of other combustive material, flames can propagate to the area surrounding the brake switch.

SCDS failure is sometimes detected by evidence of brake fluid leakage (e.g., brake fluid on the pavement, brake fluid observed dripping from the switch, low brake fluid level in the reservoir, low brake pedal). Continued contact corrosion can also result in the speed control becoming inoperative (this effect can also result from water intrusion through the connector seal or from mechanical failure of switch components, such as a sticking transfer pin). Inoperative speed control is the most commonly reported symptom of switch failure.

The short circuit condition within the SCDS may also cause the fuse protecting the circuit to open and provide additional symptoms of switch failure. These include: (1) difficulty shifting the vehicle out of PARK; (2) inoperative brake lamps; and (3) brake warning light illumination on the dash. If the fuse opens, the subject switch and stop lamp switch are isolated from battery voltage and the speed control, stop lamps, and brake-transmission shift interlock become inoperative. The operator will not be able to shift out of PARK. A switch fire cannot occur after the fuse has opened, unless the fuse is replaced without diagnosing the problem and replacing the SCDS.

CONTRIBUTING FACTORS: Three primary factors contribute to the alleged defect. These include the vacuum pressure (duration and magnitude) generated by the master cylinder on the brake system when the brake pedal is released, the orientation of the SCDS in the master cylinder, and power being supplied to the SCDS at all times.

Brake System Vacuum. Repetitive cycling fatigue of the Kapton and Teflon laminates is believed to cause cracks in the switch diaphragms. When the design specifications for the SCDS were created, they included a requirement for the switch to withstand 500,000 pressure impulse cycles at 2 Hz with the following conditions: 107°C (224°F) ambient temperature, 135°C (275°F) brake fluid temperature, and 0 to 1450psi cycling pressure. The design specifications also contain a requirement for 100% of the switches produced to pass a calibration test. The calibration test validates that the opening and closing pressures of the switch are within specification.

In order to maintain stable calibration settings on the switches, the manufacturer applies one or more pressure cycles to the switch. These pre-calibration pressure cycles cause the Kapton diaphragm material to take a permanent "set" where the material conforms to a "valley" formed by the button on the converter and the washer (Figure 12.). Figures 4. and 5. show cross sections of the Kapton material inside the SCDS. Figure 4. shows the Kapton as it exists just after the SCDS is assembled. Figure 5. shows the permanent set taken by the Kapton after having been through the calibration test.

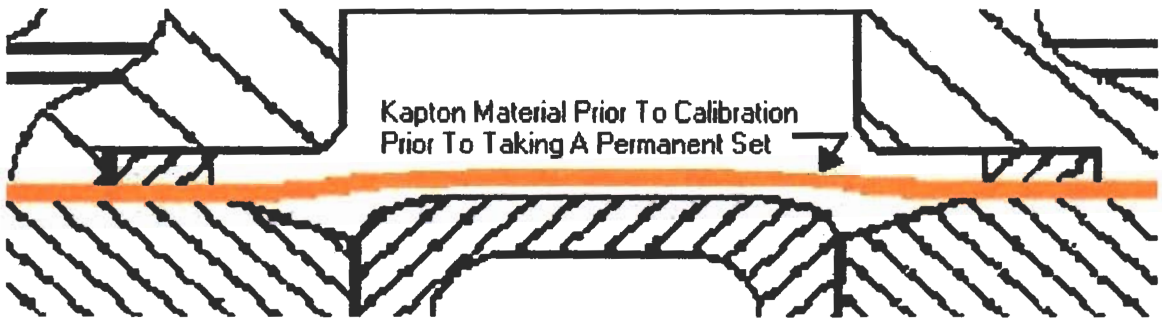

Figure 4. Kapton As Manufactured Condition.

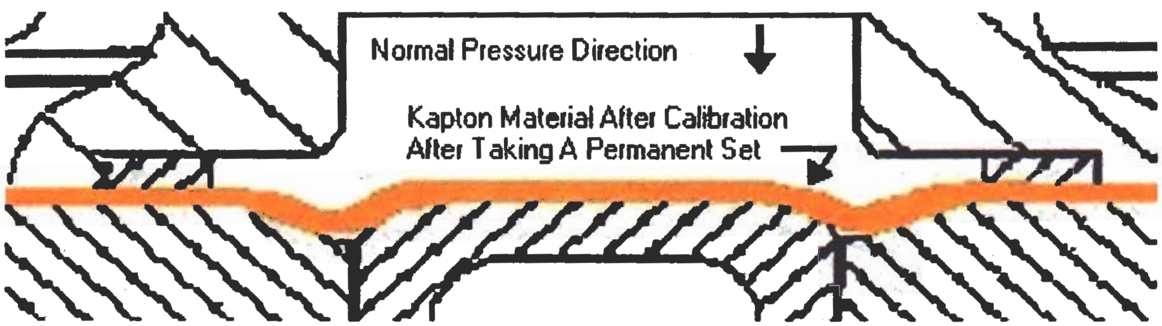

Figure 5. Kapton With Permanent Set

Impulse cycle testing is performed on the switches in order to demonstrate that the switch is capable of surviving the expected lifetime of brake applications on the vehicle. However the design specifications apparently did not account for a vacuum pressure experienced by some Ford model vehicles just after a braking event, when the brake pedal is released by the driver. The duration and magnitude of the vacuum pressure varies from model to model and model year to model year. In some models the magnitude of the vacuum pressure is great enough to cause the Kapton "set" to invert or "oil can". This change in orientation of the Kapton material each time the brake pedal is released causes the Kapton material to fatigue and wear out much sooner than if the diaphragm had only experienced pressure applications in one direction. Figure 6. shows the Kapton orientation when a vacuum pressure is being applied.

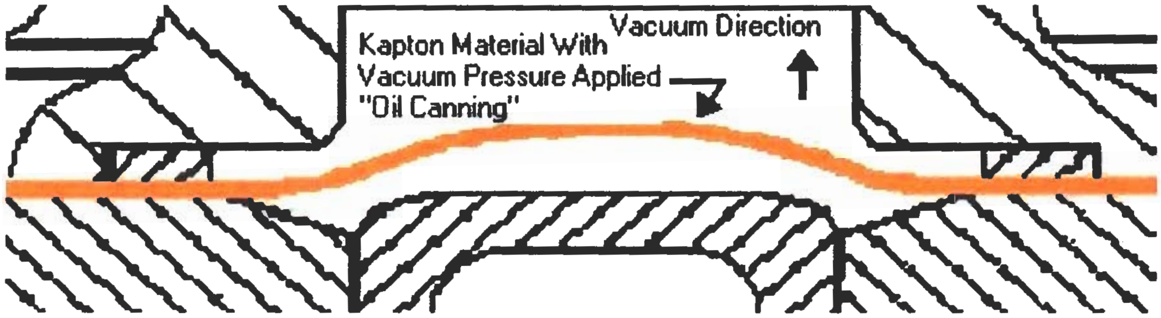

Figure 6. Kapton With Vacuum Applied.

SCDS Orientation. Orientation of the SCDS as mounted in the Master Cylinder is another factor contributing to the alleged defect. When the electrical contacts start to corrode and corrosion products, metallic debris, and electrolysis products start to form, they move downward in the solution inside of the electrical cavity. These corrosion products move downward as a result of being denser than the brake fluid solution. Normal vehicle vibration also helps facilitate the downward settling of these products. In order for the short circuit to develop, these corrosion products must settle in such a way that dendrite growth might start and develop. When the SCDS is mounted in the master cylinder in a vertically down orientation (Figure 7.) it is believed that the metallic corrosion products settle in the plastic base of the switch completely away from the grounded hexport body. With the metallic debris settled away from the grounded hexport body, dendrite growth is inhibited and a short circuit does not develop. When the SCDS is mounted in a vertically up or angled down orientation (Figures 8. and 9.), the metallic corrosion products can settle in such a way that dendrite growth can develop.

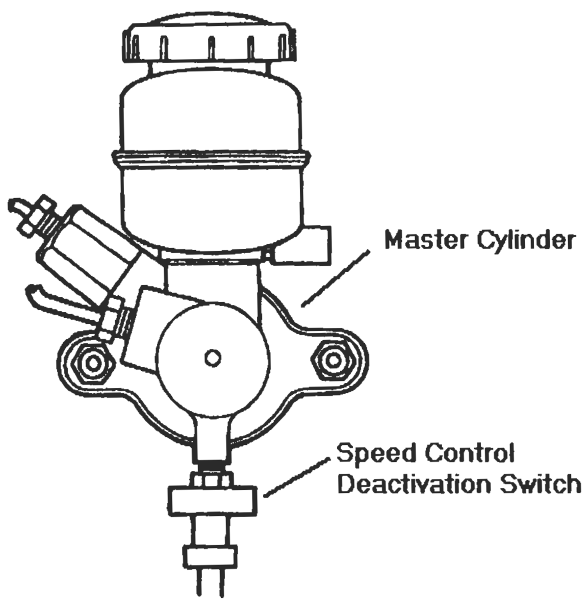

Figure 7. SCDS Vertical Down.

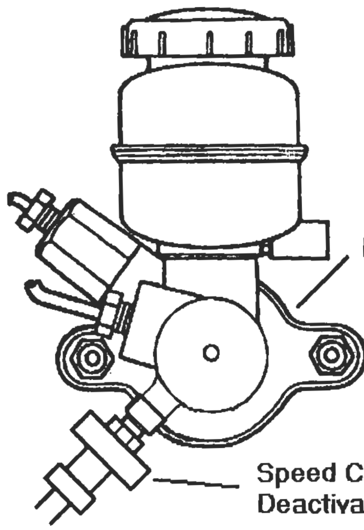

Figure 8. SCDS Angled Down.

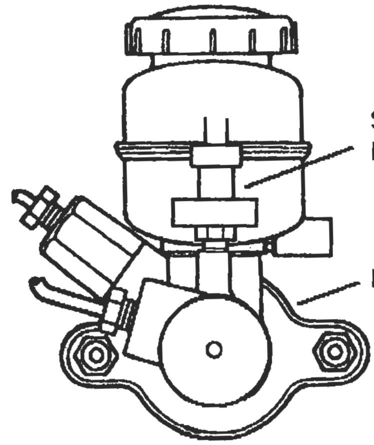

Figure 9. SCDS Vertical Up.

Continuous Power. Ford has used the TI SCDS in many of its model / model year vehicles. However the design of the circuit that contains the SCDS is not the same in all models or model years. Ford has two designs. Some Ford models have the SCDS located in a circuit that is powered at all times regardless of whether the key is in the ignition or not. Other models have the SCDS in a circuit that loses power when the ignition is turned to the off position. In some cases Ford changed the circuit design from PAT to non-PAT from model year to model year within one model. This change of circuit design from non-PAT to PAT occurred on the Explorer and Rangers models as shown in Table7.

Combination of factors required for failure. The three factors discussed above have been discovered / tested and shown to cause fires in a SCDS while a vehicle is parked with the ignition off if they all occur on that vehicle in a specific way. First, the SCDS must be located in a circuit that is powered at all times. If the circuit on the vehicle that contains the SCDS is not powered, there is no source to produce the energy required to start heating any of the SCDS components. The second factor is a requirement that the vehicle have a brake system design that generates a vacuum in the brake system high enough to flip the orientation of the Kapton diaphragms in the SCDS. When the Kapton seals fail in an SCDS it is most likely the result of fatiguing of the material. It has been shown that this fatiguing can result from repeated pressure cycling of the material when the cycle includes a vacuum at the end of the cycle strong enough to flip its orientation. The third factor requires that the SCDS is mounted in the master cylinder in any other orientation than vertically down. When the SCDS is mounted in a vertically down orientation, and the SCDS has developed a leak, the corrosion products that develop within the electrical cavity settle in the switch away from the grounded base. When the corrosion products settle in this way they are not likely to promote the development of a short circuit. In summary; in order for a SCDS to fail and start fire in a vehicle while it is parked with the ignition in the off position, as a result of these three factors, the vehicle must: (1) have a PAT SCDS circuit; (2) have a brake system that generates a high enough vacuum to flip the Kapton orientation, and (3) have a SCDS orientation that is not vertically down.

SUPPORT INFORMATION (Analysis and Testing):

SCDS Collection. In order to conduct various tests of the SCDS an aggressive effort was initiated to collect a large number of SCDS and brake fluid samples. The focus was to collect switches and brake fluid samples in one of three conditions from two groups of vehicles. The three conditions were: (1) switches that had some damage related to the alleged defect; (2) switches that did not have any apparent damage; and (3) switches that were new and never installed in a vehicle. The two groups of vehicles were those that had a very high fire complaint rate and those that had a very low fire complaint rate. This collection effort resulted in over 300 switches and brake fluid samples collected from around the country. A Ford Field Engineer was assigned to work with ODI personnel in order to assist in obtaining switches from vehicles located at Ford dealerships and auto auction lots. Switches and brake fluid samples were also gathered from consumers who called ODI to complain about an incident involving their SCDS and from auto salvage yards. New switches were obtained from Texas instruments. The switches collected during this effort were used for live burn testing, detailed chemical and polymer analysis, vacuum testing, cycle endurance testing, and electrolysis analysis. Prior to being used for any testing the switches were photographed and x-rayed. This catalog of photos and x-rays was used as a set of reference images to evaluate and determine the condition of newly collected switches and if they were likely involved in a fire caused by the switch.

Live Burn Testing. A primary piece of evidence in determining where and how a fire started is the burn patterns left on the vehicle after the fire is extinguished. These burn patterns can assist in determining how long the fire had been burning, how hot the fire got, and where the fire originated. When ODI receives a complaint related to a vehicle fire and the vehicle is involved in an ongoing investigation, photographs of the burned vehicle are sought from the owner, the insurance company, or the fire investigator who inspected the vehicle. Once obtained, these photographs are compared to the burn patterns on a vehicle that was known to have had a fire caused by the defect being investigated.

ODI observed four live vehicle burn tests to assist in determining if a fire reported to the agency was likely caused by the SCDS, and to prove that a SCDS could start a fire that could spread to the rest of the vehicle. The live burn tests were started by using a defective SCDS that was on the verge of catching fire. The vehicles were instrumented with under-hood cameras and 6 thermocouples located throughout the engine compartment. The vehicle fires were also video recorded from the exterior. The data and burn patterns collected from this series of live burns showed that a defective SCDS could catch fire and the fire could then spread to the remainder of the vehicle. The under-hood cameras and thermocouples documented how the fire spread, how hot certain areas got and how long it took for certain areas of the engine compartment to get involved in the fire (Figure 18.). This data, along with the burn patterns that were documented after the fires were extinguished (Figure 17), were used as a reference in evaluating complainant vehicle fires. Along with eye witness testimony, owner interviews, and physical evidence, the fire test data assisted ODI in determining if a complainant vehicle fire was likely to have been caused by a defective SCDS.

NIST SCDS Analysis. ODI contacted the National Institute of Standards and Technology (NIST) to perform a detailed comparative analysis of switches and brake fluid samples removed from vehicles that had a high rate of SCDS failure and vehicles that had a low rate of SCDS failure. NIST analyzed 70 switches and brake fluid samples to ascertain what differences in the mechanical properties of the active parts or SCDS construction might contribute to the switch failures. These switches were broken up into groups of "Damaged" and "No Damage" based on their condition. The group of "No Damage" switches was further broken down into two sub groups of "likely to fail" and "likely not to fail" based on the failure rate of the vehicle from which they were removed. The idea was to compare switches that had failed to switches that were not likely to fail during their lifetime and to switches that were likely to fail during their lifetime to determine if some unique characteristics existed in the "likely to fail" switches that would cause them to fail. The list of analyses and tests that NIST completed was as follows:

Polymers Group

a. Disassembly, documentation and resistance testing of collected switches;
b. Mechanical measurements of switch components;
c. Thermal analysis of Kapton (Differential Scanning Calorimetry, Thermogravimetric Analysis);
d. Electron microscopy of Kapton;
e. Dimensional analysis of switch components;
f. Density of Kapton; and
g. Infra-Red spectroscopy analysis of Kapton

Analytical Chemistry Group

a. Analysis of brake fluid collected from vehicles;
b. X-ray analysis of particulate sample;
c. X-ray analysis of fluid samples;
d. Fourier Transform Infrared Spectroscopy analysis of as received fluid for any major contaminants;
e. Gas Chromatography/Mass Spectrometry analysis;
f. Residue brake fluid analysis;
g. Infrared Analysis of residue break fluid and break fluid from reservoir; and
h. PH and conductivity

The NIST analyses found that there were no unique characteristics in the "likely to fail" switches that would increase their propensity to fail and develop a leak in the Kapton diaphragm. Nor did the NIST analyses find any issue with the brake fluid that might lead to SCDS failures. What NIST did identify as a common characteristic of the "damaged" switches was their failure mode. NIST found that the Kapton in the "damaged" switches had a common failure patterns and they believed the pattern was caused by fatiguing of the material.

Based on the results of the NIST analyses, ODI re-directed its focus away from potential switch design, brake fluid composition, or manufacturing issues. Instead, ODI began to focus on what vehicle characteristic might be causing the Kapton diaphragm to be experiencing a change in orientation ("oil canning") that would fatigue the Kapton material. A copy of the NIST test report will be placed in the public file for EA05-005.

Pressure/Temperature Testing. ODI reviewed the environmental conditions that might be causing the Kapton material to fail as a result of fatigue. Pressure and temperature were identified as being environmental conditions that might affect the material properties of Kapton. Both pressure and temperature measurement data were gathered on various model / model year Ford vehicles. The pressure data was taken at the port in the master cylinder where the SCDS would normally be installed. Pressure data was gathered for various stopping scenarios. These scenarios included light braking style stops through panic stops where the Antilock Braking System (ABS) engaged. The temperature data gathered included the under-hood temperature and the SCDS temperature during both normal operating conditions and the hot soak period after the vehicle was turned off. The results of this testing showed that neither brake system pressure or SCDS temperature were significantly different for model / model year vehicles with a high or low rate of SCDS failure.

Electrolysis/Dendrite Growth Testing. The sequence of events following a leak developing in the Kapton diaphragm that lead to a fire were not understood when this investigation was opened. ODI and Ford performed extensive testing to determine what causes a SCDS with a brake fluid leak to potentially catch fire. Understanding this process would help to identify why certain model vehicles had a low or high rate of key off engine compartment fires related to the SCDS and what vehicles were at risk of having engine compartment fires related to the SCDS.

ODI and Ford both developed testing programs involving filling the base of a SCDS containing the electrical contacts with brake fluid. The contacts were then connected to a power supply and the switch was monitored. The brake fluid along with corrosion products contained in the electrical cavity created an electrolytic cell (Figures 10. and 11.).

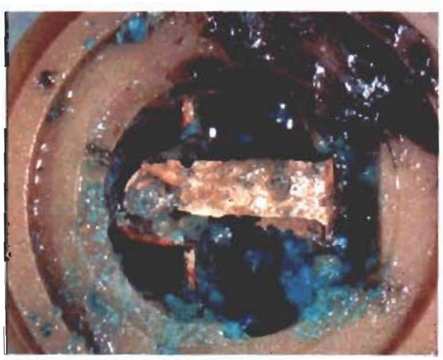

Figure 10. Corrosion Of Electrical Contacts.

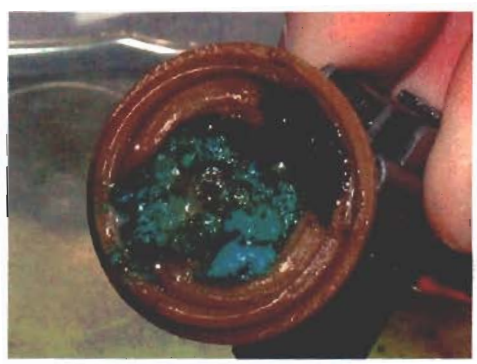

Figure 11. Electrolysis Products.

Once this cell was formed, a process was shown to occur that could result in the switch catching fire. This process is described by Ford's expert as follows:

> Leaked brake fluid that fills the gap between the switch and the base plate acts as an electrolytic medium through which mobile ions can be exchanged between the energized switch components and the grounded base plate under electrical bias. Under such circumstances, the metal from the positive electrode (anode) oxidizes and the metal ions dissolve in the electrolyte. They are swept along the electric field and reduced to metal atoms at the negative electrode (cathode). The metal atoms are deposited on the negative electrode in this process of electro-chemical migration. As a result conductive dendrites grow on the grounded base plate (cathode) towards the energized switch (anode). Dendrites continue to grow as long as there is a DC electric field, electrolyte and mobile ions. The rate of dendritic growth is affected by a number of factors that include: electrode material and its solubility in the electrolyte; ion mobility; conductivity of the electrolyte; viscosity of the electrolyte; electric field strength and temperature, among other factors. Dendritic growth is likely to initiate at locations where the electric field is strongest, such as at the edge of the ring in the center of the base metal, where the abrupt geometry increases the electric field strength and the power and ground conductors are in closest proximity. Due to the relatively small feature sizes associated with early dendrites, their electrical resistance is relatively high with very limited current carrying capacity. As dendrites grow and accumulate, their electrical resistance drops and their current carrying capacity increases. Electrical current is conducted through the dendrites as they grow. If the dendrites complete an electrical pathway between power and ground, Joule heating due to this conducted current can cause melting of the dendrites (fusing open of dendrites) and pyrolysis of any organic materials in the vicinity, such as the plastic housing (made of Noryl, a GE plastic), due to heat radiation. Melting of dendrites and pyrolysis of organics leaves behind a conductive mixture of carbon and metallic particles as a byproduct. If the electric field were strong enough between such conductive particles, dielectric breakdown in the form of arcing can occur. For a densely packed mixture of conductive particles, arcing can happen at low voltages, such as 12V DC. The effective impedance of such a mixture may also be high enough in some cases such that the conducted currents could be limited to below 20 amps. Arcing generates high local temperatures, which leads to further pyrolysis of the plastic housing thus promoting more frequent arcing. This thermal runaway situation can lead to localized temperatures that are sufficiently high that they can melt the metal of the fixed terminal. The spring-loaded arm can also be exposed to elevated local temperatures and melt, especially if it is in contact with the energized fixed terminal becoming an energy source for the arcing. The melting of the fixed terminal would continue to propagate towards the 12V DC energy source until all the arcing is interrupted and an open circuit is created. The brass and copper beads observed are the re-solidified melted terminal metal. During this process, if the plastic housing experiences high enough temperatures such that the external surface develops a local glowing spot, this hot spot may result in ignition and open flaming outside of the switch.

The test results showed how a leak in the Kapton seals could then result in arcing and melting of the plastic base on the SCDS. This arcing and melting correlated well with the physical evidence collected from vehicles with SCDS related fires. The switches that were collected from vehicles with SCDS related fires were analyzed and found to have brass and copper beads as explained by the dendrite growth tests. The faces of the hexport bodies of these switches were analyzed using Scanning Electron Microscopy (SEM) and found to have been plated with metals including copper, brass, and silver that would be explained by the electrolysis found to occur during testing. The report describing the tests completed by the ODI Vehicle Research and Test Center (VRTC) will be placed in the public file for investigation EA05-005.

Examples of arc generated brass and copper beads and the resulting melted base of a failed SCDS can be seen in x-ray images and photos of a failed switch obtained by ODI from a complainant's vehicle (Figures15. and 16.). This x-ray image is one of over fifty that ODI has taken of failed switches that have been collected from complainant vehicles. These x-ray images are consistent with ODI's analysis and the analyses performed by and for Ford.

Vacuum Testing. Conclusions from the work NIST performed were that the Kapton diaphragms were failing as a result of fatigue. ODI examined data that showed a slight vacuum at the end of the brake system pressure cycle on some Ford vehicles. This vacuum data was the result of testing that had been completed for an issue unrelated to this investigation. The review of this data initiated the decision to test if some level of vacuum in the brake system might flip or "oil can" the Kapton diaphragm. VRTC configured a SCDS so that both pressure and vacuum could be applied to the switch. Sections of the switch were removed so that the Kapton could be observed. This testing showed that if approximately 5psi vacuum were applied to the SCDS, the Kapton would flip orientation (Figure 6.). After making the determination that the Kapton could flip orientation at a specific vacuum pressure, a series of vehicles were tested to determine what levels of vacuum were generated within their brake systems. Results of this testing showed that there were three levels of vacuum generated among the various Ford model vehicles that were manufactured with TI SCDS. The vacuum levels appeared to be related to the diameter of the master cylinder as the larger diameter master cylinders produced larger vacuums than did the smaller diameter versions. Of the three vacuum levels, two generate greater vacuum pressure than the -5psi required to flip the Kapton orientation. Ambient temperature also influenced the amount of vacuum generated in the brake system. VRTC conducted vacuum tests in a temperature controlled chamber and identified distinct patterns and ranges of vacuum based on vehicle model and ambient temperature (Figure 19.)

Based on the temperature controlled vacuum testing that was performed by VRTC, Ford tested model / MY vehicles with SCDS that were PAT and mounted in the master cylinder to determine their respective vacuum level. The results of this vacuum testing and the orientation of the SCDS for each of the tested models is shown in Table 1.

SCDS Orientation		Vacuum Level		
		High	Medium	Low
	Vertical Up	1994 - 1996 E150 1994 - 2002 F150 1994 - 1996 Bronco* 1997 - 2002 Expedition/Navigator	1994 - 1996 E250 1994 - 1996 E350 1994 - 1997 SuperDuty	1998 - 2002 Ranger 1997 - 2001 Explorer/Mountaineer**
	Angled Down	2000 - 2002 Excursion 1999 - 2002 SuperDuty (Gas)	1996 - 2002 E450	
	Vertical Down	1997 - 2002 E150	1997 - 2002 E250 1997 - 2002 E350	

Recalled
* Model Not tested. Vacuum level based on master cylinder design
** 1998 Explorer Recalled

Table 1. Vacuum Levels and Switch Orientations for PAT SCDS Equipped Vehicles.

Note that not all of the vehicles listed in Table 1. were subject vehicles of this investigation, but were vehicles with a PAT SCDS mounted in the vehicles master cylinder.

Ford durability specification. Ford's durability specification requires that the SCDS not leak after 500,000 impulse cycles at 2 Hz with the following conditions: 107°C (224°F) ambient temperature, 135°C (275°F) brake fluid temperature, 0 to 1450psi cycling pressure, and 100 percent DOT 3 (no moisture content). These values are well above the maximum temperature, 101°C (213°F), and pressure, 1200-1300psi, which the switches experience in service.

With regard to the number and magnitude of pressure cycles, Ford submitted information for investigation EA02-025 for 1992 Crown Victoria indicating that severe usage customers (90th Percentile Drivers) apply the brakes approximately 1.8 million times in 150,000 miles of service with an estimated durability index of 4.31×10^8. Ford estimated that the average customer applies the brakes approximately 740 thousand times in 150,000 miles of service with an estimated durability index of 1.79×10^8. According to Ford, the impulse test (500,000 cycles @ 1450 psi) in the durability specification has a durability index of 7.25×10^8, approximately 68 percent greater than the 90th Percentile Driver after 150,000 miles.

Switch durability testing. In order to prove that high vacuum pressure in the brake system could cause the SCDS to fail on certain vehicles, ODI and Ford impulse tested a collection of SCDS to failure according to Ford's durability specification. However a vacuum cycle would be added to the end of the impulse pressure cycle. Both the Ford and ODI tests were configured to have two groups of switches that would be cycled. The first group would be cycled according to the Ford durability specification but would have a vacuum cycle added to the end of the pressure cycle that mirrored a typical vacuum cycle measured from a group of Ford Rangers. The Ford Rangers were selected because they were measured to have the weakest vacuums during testing and would not be likely to flip the Kapton orientation. This first group of switches was named the "Low Profile" group.

The second group of switches tested also followed the Ford durability specification but used a vacuum profile that mirrored a typical Ford F150 at the end of the pressure cycle. The vacuums generated in this type of vehicle were strong enough to flip the Kapton orientation. This group was named the "High Profile" group. The results were that the "Low Profile" group of switches did not develop leaks until an average of 777,652 cycles. This result was slightly higher than a group of switches that were tested previously without a vacuum added to the end of the pressure cycle. The "High Profile" switches were found to start developing leaks at an average of 415,037 cycles, or approximately 54 percent of the "Low Profile" switches.

Based on these results, ODI and Ford were convinced that the magnitude of the vacuum at the end of the brake pressure cycle could have a significant impact on the life expectancy of the SCDS.

Evidence Collection. The amount and quality of the evidence varied considerably in the engine compartment fire complaints reported to ODI. Therefore, to better assess which fires had evidence of SCDS involvement, ODI carefully analyzed all of the available information and called consumers to gather additional information when necessary. ODI sought any photographs taken of the vehicle during or after the fire, receipts for any service performed before or after the fire, eyewitness accounts of the fire, cause and origin reports written by a professional fire investigator, physical evidence including the SCDS removed from the vehicle, and the owners testimony as to what events occurred before the fire. ODI often contacted insurance companies, fire investigators, attorneys, and eye witnesses in order to gather the required evidence. ODI attempted to collected this type and quantity of evidence for over 1,400 alleged fires.

Once collected, the evidence related to a complainant's fire was used to evaluate if the fire appeared to be caused by a failed SCDS. ODI established the following criteria to determine whether an incident would be counted as a "Yes": (1) the fire originated in the area where the speed control deactivation switch is located (left-rear corner of the engine compartment, near the master cylinder) and (2) there was evidence of speed control deactivation switch failure prior to the fire (e.g., inoperable speed control, speed control deactivation switch fuse open – sometimes repeatedly, difficulty shifting out of PARK, evidence of brake fluid leakage from the switch) or (3) evidence of speed control switch failure was discovered during post-fire forensic examination.

The complainants could often not be contacted. The owners may have moved or changed contact information. ODI then mailed a certified letter to the last known address to try and contact the owner. If the owner could not be contacted, the complaint was marked as a "No". This "No" did not mean that the fire was not related to the SCDS, but that not enough data could be collected to make a determination.

Failure data: After reviewing all of the fires reported to ODI and Ford during investigations PE04-078 and EA05-005, there were a total of 1,472 engine compartment fire incidents reported on Ford model vehicles equipped with a SCDS that was powered all the time and mounted in the master cylinder and where the key position was either off or unknown. A breakdown of the Ford and ODI reported incidents by model and model year is provided in Tables 2. and 3. ODI did not request complaint information from Ford on the Excursion or Superduty models. For this reason Ford did not report the number of engine compartment fire related complaints to ODI on these models. Also, the number reported to ODI only represents complaints received by Ford through June 22, 2005. The number of complaints reported by ODI represents claims on Explorer, Econoline, Excursion, Ranger, and Superduty models through June 29, 2006, and on the F150, Bronco and Expedition/Navigator through September 7, 2005.

Using the criteria described in the Evidence Collection section above ODI identified a total of 65 of the 1,472 complaints that we believed were related to SCDS failures. A breakdown of these incidents by model and model year is provided in Table 4.

ODI determined the failure rates for the various models using only the ODI complaint data. ODI had not requested Ford to send complaint information on all of the models so calculating rates with Ford data included for only some of the models would not allow for direct rate comparisons. Also, the Ford complaint data only represented complaints through June 22, 2005 and so would not be affective in determining the current rates. The failure rates as determined by using only ODI complaints are shown in Table 5.

ODI Complaints (Not Confirmed SCDS Fires)								
Model	1996	1997	1998	1999	2000	2001	2002	Total All MY PAT
BRONCO	11							11
ECONOLINE	10	1	1	1	1	0	1	15
EXCURSION*					27	4	2	33
EXPEDITION		31	46	34	92	24	7	234
EXPLORER		3	60	5	10	7		85
F150	51	159	40	16	129	66	6	467
FSuperDuty*	11	13	0	8	14	11	3	60
RANGER			2	2				4
* Not A Subject Or Peer Model Of This Investigation						PAT Total		909

Table 2. ODI Complaints - Key Off Engine Compartment Fire.

Ford Complaints (Not Confirmed SCDS Fires)								
Model	1996	1997	1998	1999	2000	2001	2002	Total
ECONOLINE	7	6	0	4	6	6	8	37
EXPEDITION		24	19	19	35	4	6	107
EXPLORER			40	16	18	20		94
F150		78	18	14	105	49	12	276
RANGER			9	9	16	11	4	49
							Total	563

Table 3. Ford Complaints - Key Off Engine Compartment Fire.

ODI / Ford Complaints (Confirmed SCDS Fires)								
Model	1996	1997	1998	1999	2000	2001	2002	Total All MY PAT
BRONCO								0
ECONOLINE	5						1	6
EXCURSION*					14	2		16
EXPEDITION			1					1
EXPLORER			17	2	3	2		24
F150	2	10	2			1		15
FSuperDuty*								0
RANGER			1	1	1			3
* Not A Subject Or Peer Model Of This Investigation							PAT Total	65

Table 4. ODI / Ford Complaints - Key Off Engine Compartment Fire (Confirmed).

ODI Complaint Rates (Not Confirmed SCDS Fires)								
Model	1996	1997	1998	1999	2000	2001	2002	Rate All MY PAT
BRONCO	39.2							39.2
ECONOLINE	24.4	1.0	1.2	1.0	1.3	0.0	1.4	2.7
EXCURSION*					41.4	11.5	7.4	26.0
EXPEDITION		15.8	19.4	14.2	38.9	13.7	7.4	19.8
EXPLORER		0.8	14.7	1.2	2.9	2.1		4.5
F150	30.7	27.7	10.2	3.9	35.6	15.0	1.4	16.8
FSuperDuty*	21.2	21.0		5.3	12.4	10.7	3.4	10.6
RANGER			1.2	1.3	0.0	0.0	0.0	0.5
* Not A Subject Or Peer Model Of This Investigation					Rate All Models/MYs PAT			11.4

Table 5. ODI Complaint Rates - Key Off Engine Compartment Fire.

In order to better understand if the SCDS was the true cause of the fires in the Ford model vehicles equipped with cruise control, ODI determined the key off engine compartment fire failure rates on some peer Ford models manufactured without cruise control. ODI also determined the key off engine compartment fire failure rates for some peer Ford models that were manufactured with cruise control but where the SCDS was not PAT. A third group of peers that ODI collected complaint information on and determined complaint rates for were General Motors CK 1500 trucks and Daimler Chrysler Ram 1500 trucks. A comparison of these failure rates is shown in Figure 20.

A summary of the above complaint related information is shown in Table 6. Although there have been four alleged fatalities, neither ODI nor Ford are aware of any fatalities or injuries that are related to a fire confirmed to have been the result of a defective SCDS.

Category	ODI	Ford	Total
Complaints	909	563	1472
Fires (Confirmed)	60	5	65
Injury incidents	0	0	0
Injuries	0	0	0
Fatal incidents	0	0	0
Fatalities	0	0	0

Table 6. Failure Summary Subject / Peer Vehicles.

ODI ANALYSIS: Comparing the failure rates of the Ford model vehicles manufacture with a PAT SCDS to the failure rates of models built with a non-PAT SCDS or without a SCDS at all shows that the PAT SCDS equipped vehicles demonstrate a much higher rate of failure. The average failure rate for these PAT SCDS vehicles is 17.7 fires per hundred thousand vehicles (R.100K). The average failure rate for vehicles that do not have power supplied to the SCDS at all times is 1.0 R/100K and the rate for vehicles that do not have a SCDS installed is 0.7 R/100K. This difference in rate would suggest that the PAT SCDS is the likely cause of the elevated fire rates on the vehicles so equipped.

In comparing the Ford models that have a high rate of key off, engine compartment fire (Figure 20.) to the models that exhibit the three factors identified as the primary factors in causing SCDS related fires (Table 1.), it can be seen that the models exhibiting these factors are also the models with the highest rate of fire. This correlation provides support for the position that these three factors: (1) The SCDS is contained in a PAT circuit; (2) The SCDS is mounted in a vertically up or angled down orientation; (3) The brake system produces vacuum levels that cause the Kapton diaphragms within the SCDS to flip orientation; are the likely root cause for the fire related failures of the SCDS.

Using the same methods of comparison shows that models that exhibit low brake system vacuum, have SCDS mounted in a vertical down orientation, or do not have PAT SCDS have key off engine compartment fire rates that are nearly the same as vehicles that do not contain a SCDS.

With the three recalls that Ford has announced, all of the models that were built with a TI SCDS and that exhibit the three factors that can cause the switch to fail resulting in a fire while the ignition is in the off position, will be candidates for a free remedy (Table 7.).

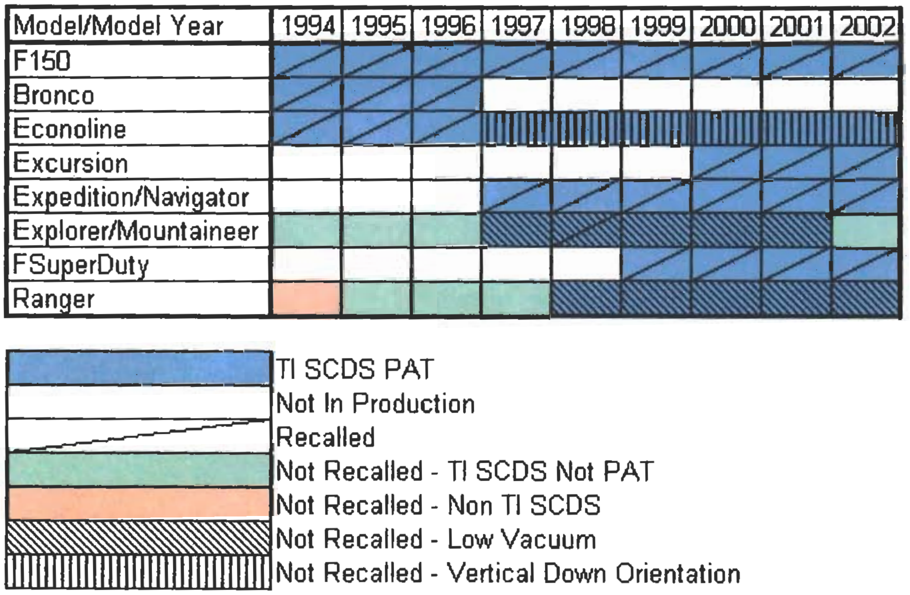

Table 7. Ford Models With Cruise Control – Summary.

Work performed by NIST, VRTC and Ford lead ODI to conclude that the root cause of the failures is that the Kapton diaphragms are compromised and leak brake fluid as a result of a fatigue failure. The NIST analysis indicates the Kapton film used in the Texas Instrument switches throughout its manufacturing history are close to identical. No chemical or material differences were discovered in the 70 samples which NIST analyzed, rather the Kapton failed primarily as the result of fatigue due to differences in vacuum created within the switch. This vacuum was a factor that was not included during the original switch durability testing. Ford categorize the SCDS vacuum readings as low (2 -5psi), medium (5 – 7psi.) and high (7 – 13psi). The medium and high vacuum creates enough of a vacuum to flip the orientation of the Kapton that compromises the material and allows the brake fluid contaminate the electrical cavity within the switch. Once the electrical cavity is contaminated with brake fluid, a chemical deterioration occurs resulting in a slurry. Dendrite is formed or the electrical contacts simply corrode and eventually fail. Depending on the switch orientation (downward, angled, or upward) the electrical contact, upon corroding into multiple pieces settles to the bottom of the switch and causes a short. However, if the switch is oriented down, (the electrical cavity points downward) the contact is not likely to short to ground after the corrosion event is complete. Switches that do short will eventually overheat possibly resulting in a fire. Left undetected, the fire can spread, normally to the plastic master cylinder reservoir eventually engulfing the engine compartment in flames. Recovered switches, upon examination and x-ray exhibit the failures described above. A table has been created which shows switch orientation and vacuum by models tested, identifying the differences by model, model years for the combination of switch orientation vs. vacuum level. ODI's analysis of fire rates by vehicle vacuum and switch orientation indicates that vehicles with the higher fire failure rate correlate to medium and high vacuum in conjunction with an upward or angled orientation of the SCDS. Vehicles that experience the factors that lead to SCDS failure and the vehicles experiencing high field fire complaint rates correlate very well with one exception, that being the 1998 Explorer.

1998 Ford Explorer: The complaint rates for SCDS related fires on the 1998 Ford Explorer are similar to previous Ford recalls. However, all other Explorers (1999 – 2002) and all Rangers (1998 - 2002), which are the same platform and drive-line have very low fire complaint rates. Of the 12 months of 1998 Explorer production, fire complaint data indicates only two build months that are overrepresented with fire complaints. ODI obtained a 1998 Explorer with a failed SCDS and determined the vacuum level in the brake system to be low/moderate. For this reason, Ford continues to test Explorer vehicles to determine contributing factors to these vehicle failures. Both ODI and Ford believe that there is another influence on the 1998 Explorer which contributes to its higher rate. Potential influences could include driver profile, master cylinder pushrod length, vacuum at fill, or chassis / frame vibration. Although Ford will continue its test program to resolve this matter, it has agreed to include the 1998 Explorer in the latest recall.

ODI is confident that the 1998 Explorer is the only Ford vehicle manufactured with a TI SCDS that will have switch fires caused by a secondary failure mode and not the three factors discussed previously. Because failures of the SCDS resulting in fires on recalled vehicles historically begin after the vehicles have been in service for three to four years, it is possible to identify if a trend is likely in the non-recalled population. Ford stopped manufacturing vehicles equipped with a TI SCDS in MY 2002. The 2002 MY vehicles have been in service for four to five years. ODI believes that a SCDS failure trend in these vehicles would already be identifiable, regardless of the cause. At this point, no non-recalled models have shown an increasing trend of key off, engine compartment fires in vehicles that are PAT and have the TI SCDS switch.

REASON FOR CLOSING: EA05-005 is closed with Ford's actions in recalls 05V-017, 05V-388, and 06V-286 recalling approximately 6.7 million vehicles equipped with Texas Instruments Speed Control Deactivation Switches. The brake systems in these recalled vehicles generate a vacuum that can potentially cause the SCDS to fail and in certain switch installation orientations, catch fire. Ford is also including the entire population of 1998 Explorers. Ford has informed ODI that testing to determine the cause of failure on the 1998 Explorers will continue after this investigation is closed. ODI believes that the vehicles exhibiting the factors causing SCDS failure described in this report correlate well with the observed failure rates on these vehicles by model and model year. The closing of this investigation does not constitute a finding by NHTSA that a safety-related defect does not exist in the non-recalled vehicles manufactured with SCDS that are not included in Ford's recalls. ODI will continue to monitor the non-recalled population for incidence of engine compartment fires. The agency reserves the right to take further action if warranted by the circumstances.

Safety Defects Engineer — Date: 8/2/06

I Concur:

Richard P. Boyd

Chief, Medium and Heavy Duty Vehicle Division — Date: 8/2/06

Director, Office of Defects Investigation — **Date**: 8-2-06

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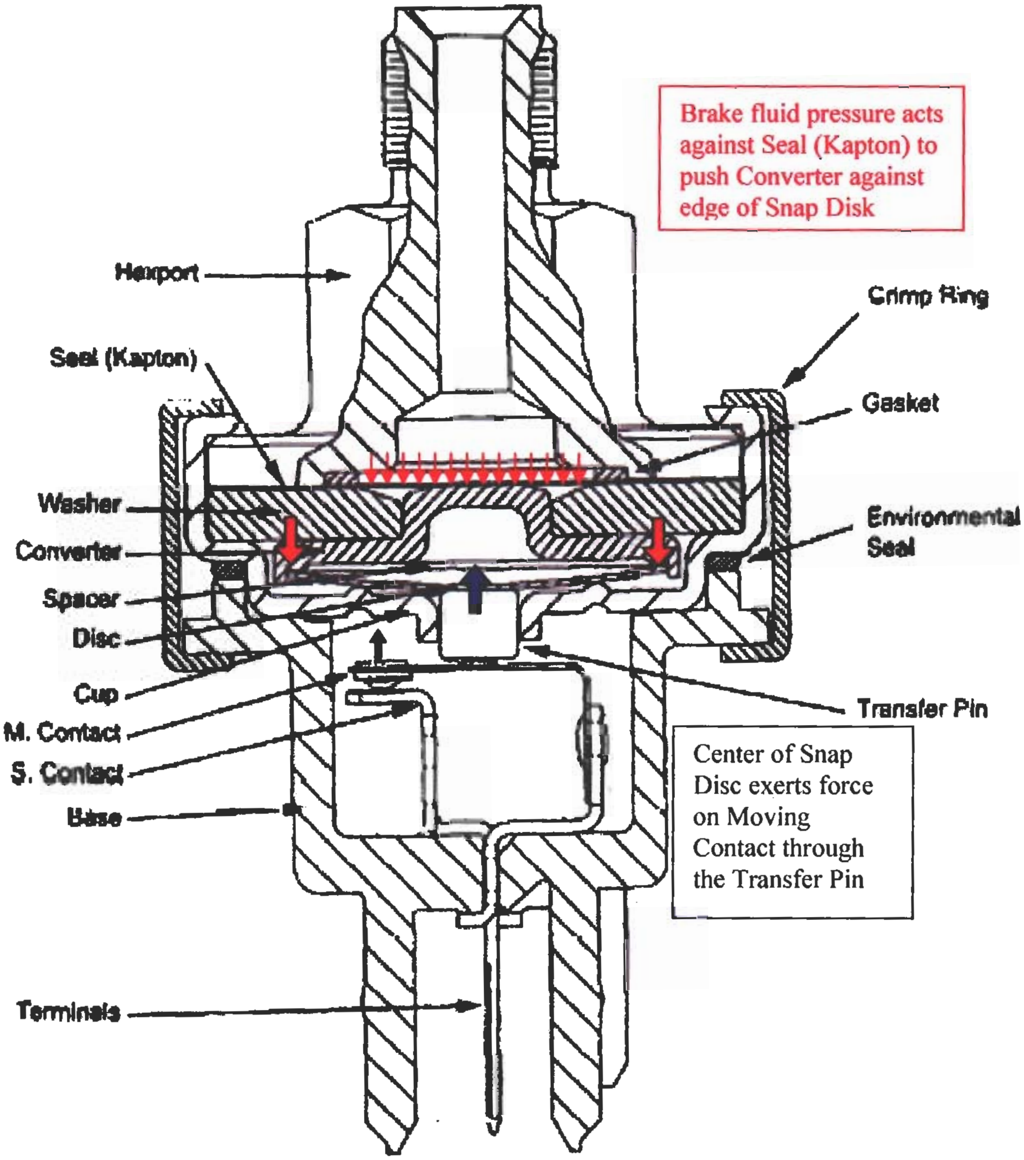

Figure 12. Speed Control Deactivation Switch.

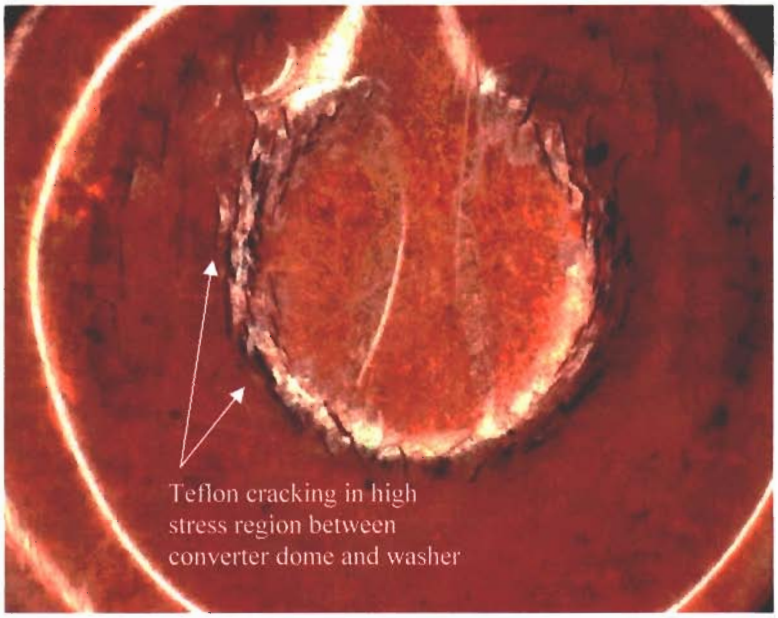

Figure 13. Teflon cracking.

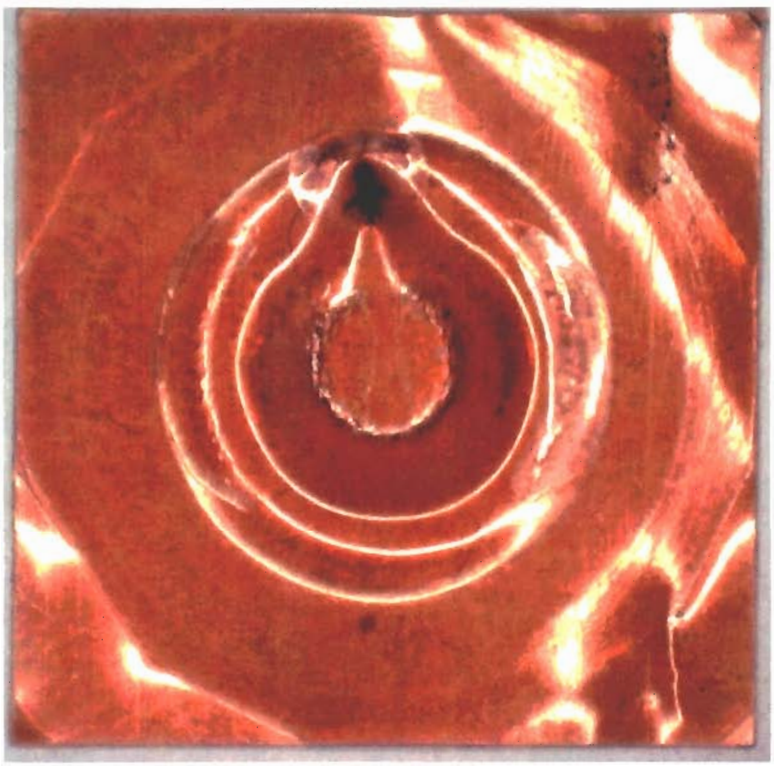

Figure 14. Crack through Kapton substrate with "Tear Drop" failure pattern.

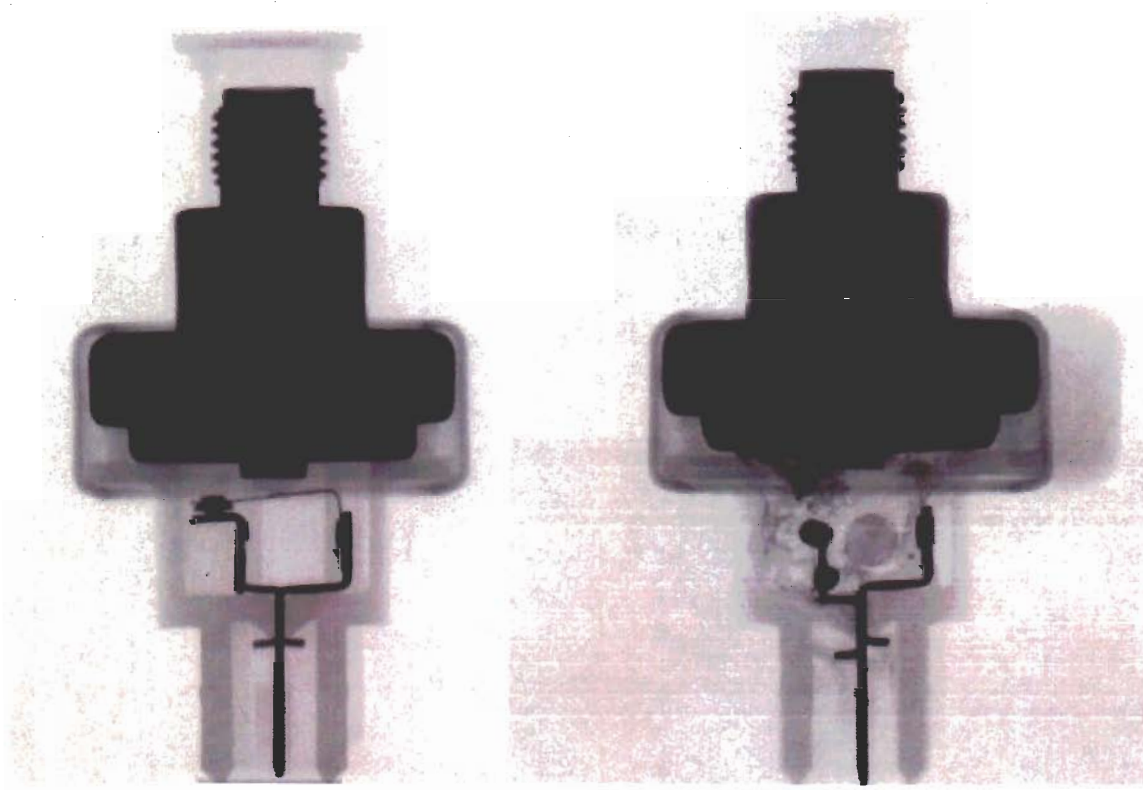

Figure 15. SCDS electrical cavity before and after contact corrosion and arcing.

Figure 16. SCDS with melted base.

Figure 17. Burns Patterns On Test Vehicle.

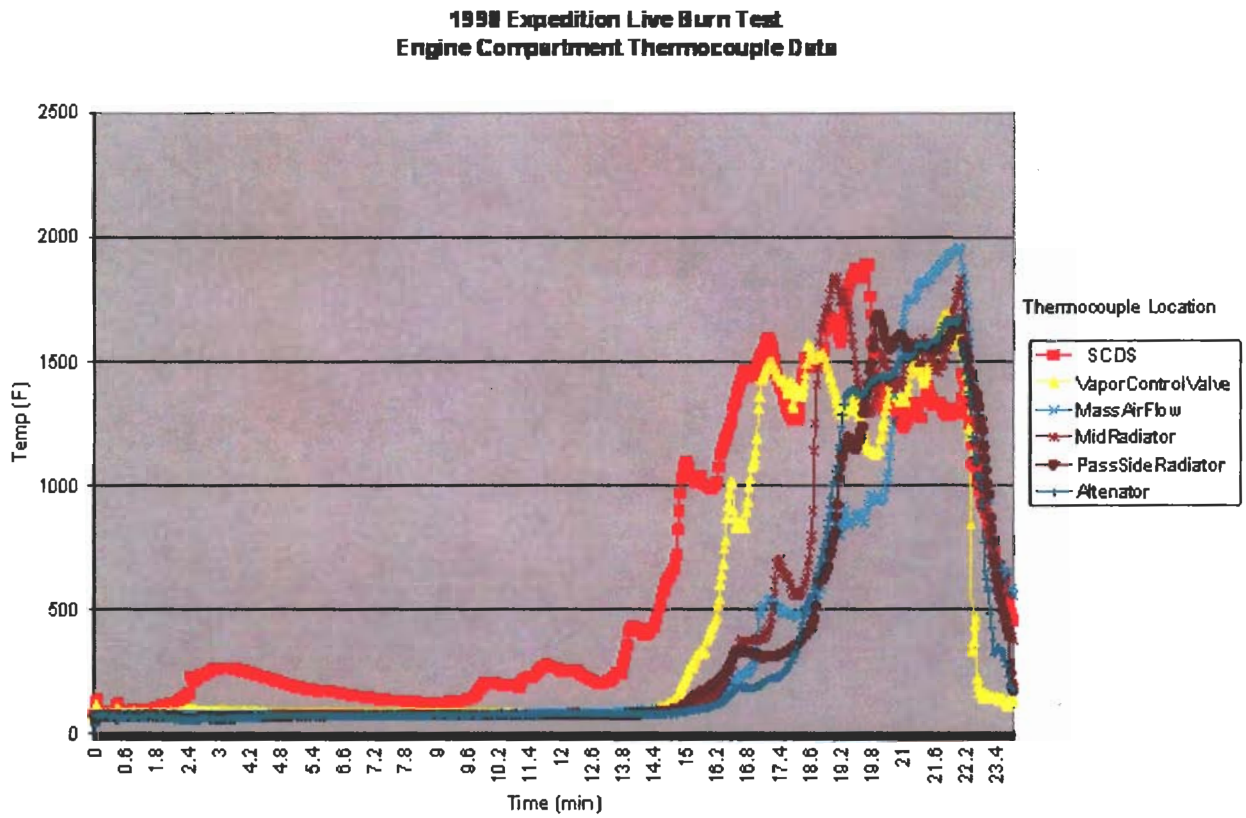

Figure 18. Thermocouple Data From Live Burn Test Vehicle.

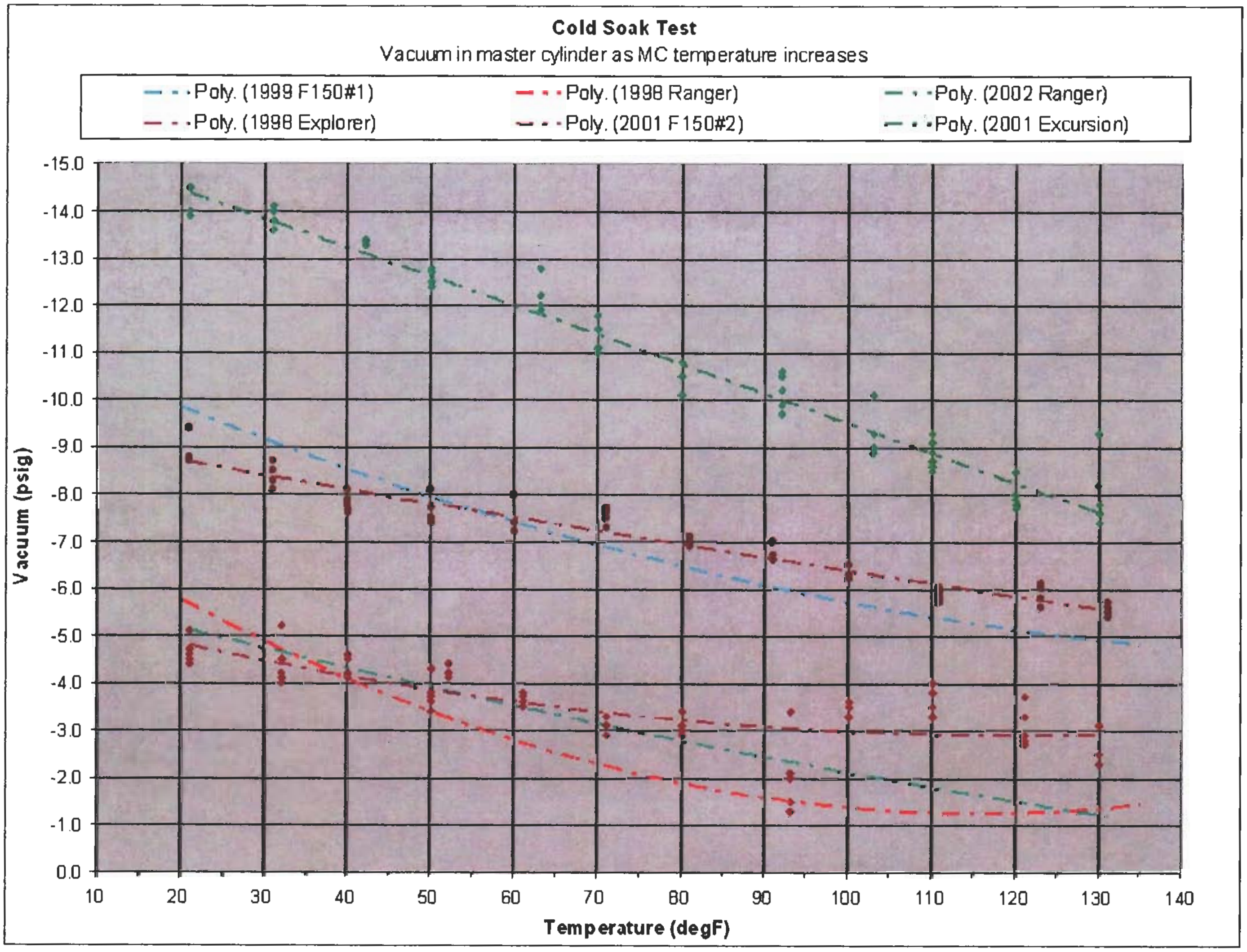

Figure 19. Temperature Controlled Vacuum Test Data.

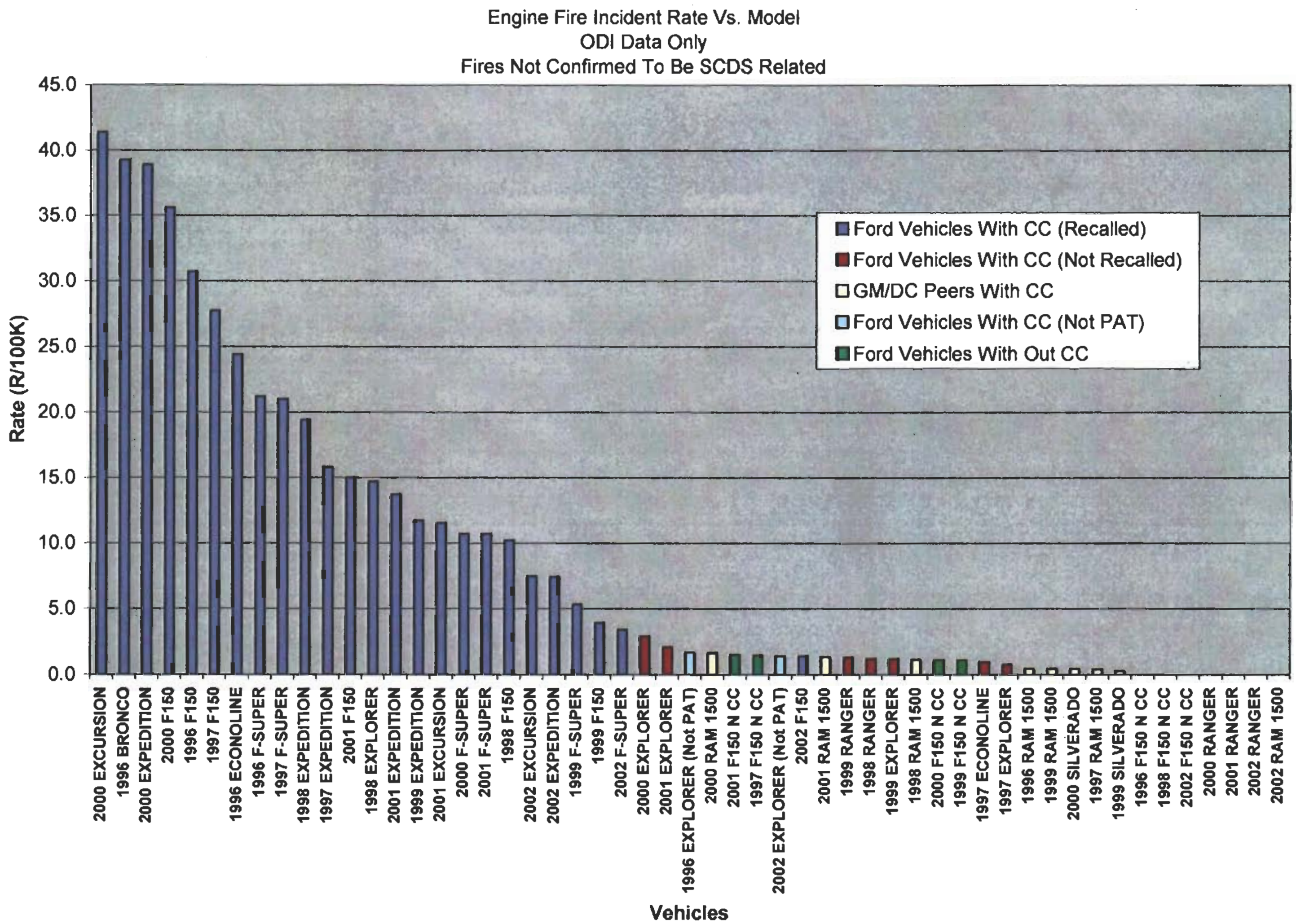

Figure 20. Key Off Engine Compartment Fire Complaint Rate Data.