

# Asbestos Free Insulation Development for the Space Shuttle Solid Propellant Rocket Motor (RSRM)

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# **Asbestos Free Insulation Development for the Space Shuttle Solid Propellant Rocket Motor (RSRM)**

## **ABSTRACT**

Asbestos has been used for many years as an ablation inhibitor in insulating materials. It has been a constituent of the AS/NBR insulation used to protect the steel case of the RSRM (Reusable Solid Rocket Motor) since its inception. This paper discusses the development of a potential replacement RSRM insulation design, several of the numerous design issues that were worked and processing problems that were resolved. The earlier design demonstration on FSM-5 (Flight Support Motor) of the selected 7% and 11% Kevlar<sup>®</sup> filled EPDM (KF/EPDM) candidate materials was expanded. Full-scale process simulation articles were built and FSM-8 was manufactured using multiple Asbestos Free (AF) components and materials.

Two major problems had to be overcome in developing the AF design. First, bondline corrosion, which occurred in the double-cured region of the aft dome, had to be eliminated. Second, KF/EPDM creates high levels of electrostatic energy (ESE), which does not readily dissipate from the insulation surface. An uncontrolled electrostatic discharge (ESD) of this surface energy during many phases of production could create serious safety hazards. Numerous processing changes were implemented and a conductive paint was developed to prevent exposed external insulation surfaces from generating ESE/ESD.

Additionally, special internal instrumentation was incorporated into FSM-8 to record real-time internal motor environment data. These data included inhibitor insulation erosion rates and internal thermal environments. The FSM-8 static test was successfully conducted in February 2000 and much valuable data were obtained to characterize the AF insulation design.

## **INTRODUCTION**

The primary insulation used on the current space shuttle RSRM is an asbestos and silicon dioxide filled acrylonitrile butadiene rubber (AS/NBR). Asbestos is also used in some RSRM adhesives, liner and castable inhibitor. Asbestos is a commercial term for a group of naturally occurring fibrous crystals made of hydrated silicates. Some forms of asbestos are considered a serious health hazard. Since the current regulatory policy in the United States does not differentiate between types of asbestos, the use of all asbestos could be restricted with little warning, which could affect production of the RSRM. Elimination of asbestos containing materials is also motivated by liability issues during the handling and processing of asbestos containing materials and the recurring costs associated with OSHA regulation compliance and indemnification. (4)

A development program was initiated in 1986 and numerous Asbestos Free (AF) insulation candidates were evaluated using seventy-pound charge (SPC) motors and Modified NASA (MNASA) motors. Kevlar<sup>®</sup> filled ethylene propylene diene monomer (KF/EPDM) insulation had previously been selected for use in several solid rocket motors (SICBM, CASTOR 4B, CASTOR 120). Several modifications of this KF/EPDM formulation were made to meet structural and ablation requirements and a 7% KF/EPDM was selected as the primary insulation for the AF RSRM.

This paper discusses the AF insulation design and some results of a full-scale static test using AF materials in the major components of the motor. The resolution of two major problems that had to be overcome in developing the AF design is also discussed. First, bondline corrosion, which occurred in the double-cured region of the aft dome, had to be eliminated. Second, KF/EPDM creates a high level of electrostatic energy (ESE), which does not readily dissipate from the insulation surface. An uncontrolled electrostatic discharge (ESD) of this surface energy during many phases of production could create serious safety hazards. Numerous processing changes were implemented and a conductive paint was developed to prevent exposed external insulation surfaces from generating ESE/ESD.

## **OVERVIEW**

The thermal-ablative insulation development effort began by evaluating several families of base polymers (polyisoprene, styrene-butadiene, silicone, EPDM, NBR, etc.), fiber fillers (Kevlar<sup>®</sup>, Kynol<sup>®</sup>, polybenzimidazole, etc.), flame retardant and curative packages. The insulations were developed to provide erosion performance. The best formulations for erosion resistance were a family of Kevlar<sup>®</sup> fiber filled materials. An initial 11% KF/EPDM

formulation had been developed with a resin curative system and had been used in several space launch and strategic SRMs. The AF program developed a sulfur cured 7% KF/EPDM as the primary insulation. A sulfur-based cure was selected over a resin-based cure system for similarity of shrink characteristics with AS/NBR, higher strain capability and lower stiffness while sacrificing some ablation capability and perhaps across-ply fracture toughness. A backup 11% KF/EPDM was formulated to be similar to the 7% KF/EPDM that could be used in the aft dome in case of unexpectedly severe 7% KF/EPDM ablation with motor scale-up. Results of detailed structural characterization of the 7% KF/EPDM design showed the 7% KF/EPDM to have marginal across-ply and perpendicular to fiber stress and interlaminar fracture toughness capabilities. The marginal interlaminar capabilities result from the base polymers, Kevlar<sup>®</sup>, fire retardant and antioxidant fillers used to meet other process and design requirements. A silica filled NBR (SF/NBR) was selected for use in high structural load regions such as the propellant stress relief flap terminus. (1)

The original AF design goal was to have a single material replacement for the RSRM. The design would directly substitute an equal thickness of 7% KF/EPDM in place of AS/NBR and an increased thickness of 7% KF/EPDM in place of carbon fiber filled EPDM (CF/EPDM) in the aft dome. During the development process, the AF insulation was tested in progressively larger sub-scale motors. The KF/EPDM was first tested in seventy-pound propellant charge (SPC) motors. The SPC motor consists of an end burning propellant grain and attached blast tube. KF/EPDM rubbers and the RSRM baselines of CF/EPDM rubber and AS/NBR were then tested in modified National Aeronautic and Space Administration (NASA) motors. The NASA motor has a 1/5 scale RSRM aft segment blast tube and a 10,000-pound, center perforated propellant charge. The NASA motor surpasses the SPC motor in reliability of results, but it has greater costs and cycle time. Thermal-ablative capability of 7% KF/EPDM in sub-scale motors was equivalent to AS/NBR. The thermal-ablative capability of 11% KF/EPDM was equivalent to CF/EPDM and its erosion rate was up to 40% lower than AS/NBR. (1)

The 7% KF/EPDM and 11% KF/EPDM were tested in the aft dome and partial aft segment regions of the full-scale static motor designated FSM-5. The 11% KF/EPDM performed as expected and equivalent to CF/EPDM in all but the two aft-most ablation stations designated 9.3 and 10.7-inch stations (measured axially from the nozzle boss). The within-motor variation was less than or equivalent to CF/EPDM. The CF/EPDM also shows increased ablation in these aft-most stations on static test motors, but is much less severe. The 7% KF/EPDM performed slightly worse than expected, in general. The surprising result was that 7% KF/EPDM performed better than the 11% KF/EPDM at the 9.3-inch station. This condition was likely due to the asymmetrical erosion caused by nozzle vectoring. The results of the FSM-5 full-scale static test showed that the baseline CF/EPDM was vastly superior to both KF/EPDM materials in the aft dome environment. CF/EPDM is used in RSRM aft domes because of its high thermal-ablative resistance. CF/EPDM remained the aft dome insulation for severe exposure regions in the AF design. (1)

## **RESULTS AND DISCUSSION**

### **Asbestos Free Insulation Design Configuration**

The AF insulation design that resulted following FSM-5 uses four insulation materials to satisfy competing structural and thermal-ablative requirements. A 7% KF/EPDM was selected as the overall best replacement insulation for igniter components, nozzle flex boot and the internal acreage regions of each segment. A comparison of the RSRM versus the AF RSRM is shown in Figure 1. The aft dome design uses 11% KF/EPDM as a substrate to CF/EPDM in a sandwich construction similar to the current RSRM. The CF/EPDM was implemented as a result of the severe erosion experienced on FSM-5 in the aft dome region. The 11% KF/EPDM was developed for highly ablative environments with low structural loads. The detailed aft dome design is shown in Figure 2. The 11% KF/EPDM substrate provides greater erosion margin than the AS/NBR with minimal impact on production and cost.

The AF design uses 7% KF/EPDM in the case cylinder regions of each segment, in the igniter components and in the nozzle flex boot. The cured KF/EPDM is an orthotropic material. As such, it was shown to have marginal across-ply and perpendicular to fiber stress and interlaminar fracture toughness capabilities. Because of the lower tensile capability of the KF/EPDM in the across-ply and perpendicular to ply orientations, structural safety factors could not be met in several high stress regions. In these regions, SF/NBR was used to satisfy the structural requirements. SF/NBR provides much higher structural capabilities with minimal impact on production. The areas in the segments, the igniter and the adapter where SF/NBR was used are low thermal exposure environments. Therefore, the lower thermal capability of the SF/NBR provided adequate protection for these areas of the motor.

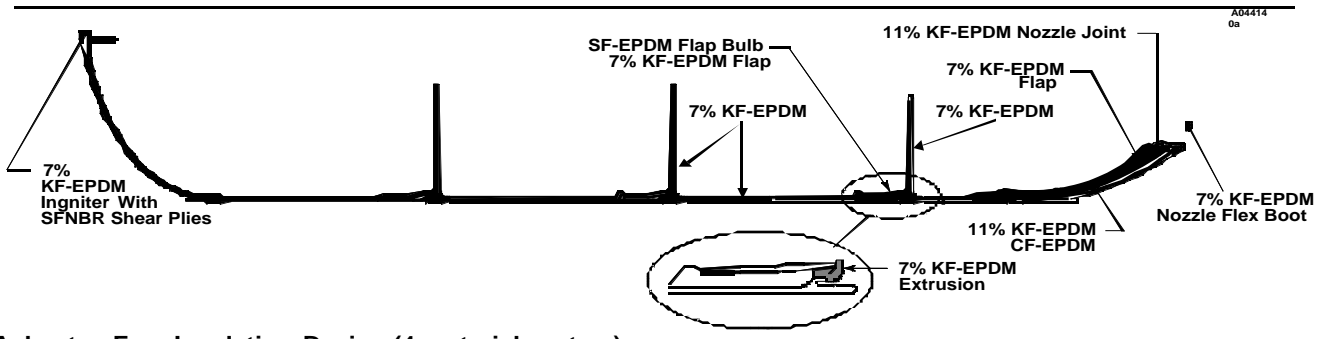
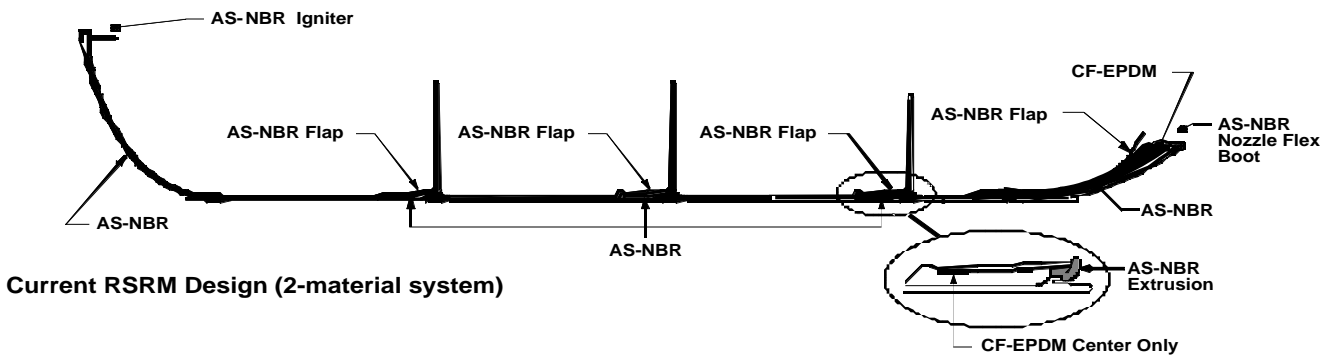


Figure 1 – Comparison of RSRM and AF Insulation Designs

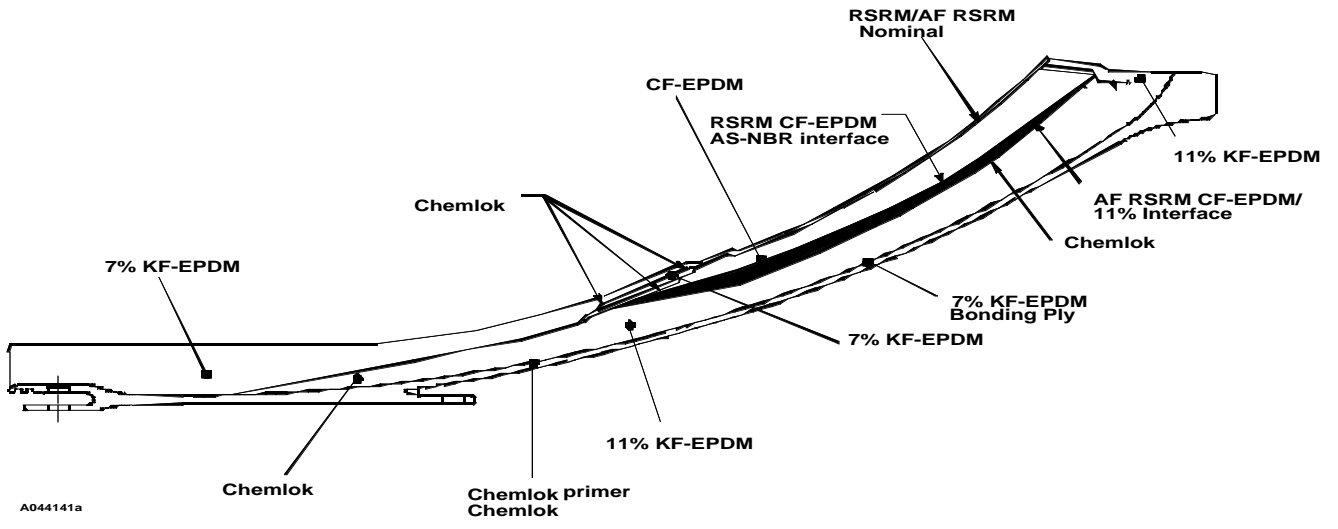


Figure 2 – AF Aft Dome Insulation Design

## **FSM-8 Design Demonstration**

The intention of the AF insulation development program was to mature the design to the point that a demonstration of all major design features and components would be completed. Favorable results from a full-scale static test would confirm the validity of the design. However, full qualification of the design would require additional static tests and other qualification efforts. Thus, FSM-8 was selected as the demonstration test bed for the AF design. To cover the major design features, AF insulation, materials and processes were implemented on key portions of the static test motor in support of the AF replacement program. These areas are listed below and shown in Figure 3.

Internal insulation – igniter chamber (ID, OD and seal disks), adapter, initiator (helmet and seal disk) forward segment igniter boot region, aft/center segment, aft segment and nozzle flex boot

Joints – igniter inner (to adapter) and outer (to forward dome) joints, aft field joint

Liner – igniter chamber, initiator, aft/center segment and aft segment

Castable inhibitor – forward segment and aft/center segment

Forward-facing molded inhibitor – aft/center segment and aft segment

Adhesive – initiator, igniter chamber, initiator to adapter joint, seal disk bonds and insulation repairs

Erosion data from MNASA motors indicated that the performance of the AF insulation would be similar to the RSRM insulation. However, since the only actual performance data from a full-scale motor was in the aft dome region of FSM-5, the insulation thickness was increased in untested regions to meet a 2.0 thermal safety factor. Minimal impact was expected due to the increased insulation thickness for either ballistic or thermal performance.

As mentioned, the initiator to adapter joint was completed with AF adhesive. The igniter inner joint, mating the igniter adapter to the igniter chamber, was made of AF insulation. In order to have an AF igniter outer joint, the insulation at the forward dome mating surface was made of 7% KF/EPDM. The aft and aft/center segments, made of AF insulation, were mated to form an AF aft field joint. Because the center field joint would have mated dissimilar materials and served no demonstration function, the mating surface of the aft/center segment was changed to match the AS/NBR of the forward/center segment. A conflict of demonstration objectives existed on the FSM-8 nozzle-to-case joint. Because this joint had previously been successfully demonstrated on FSM-5, the mating surface material at the nozzle-to-case joint was changed to AS/NBR.

The igniter chamber and initiator were lined with AF liner, as were the entire aft/center and aft segments. The AF liner was similar to the RSRM liner except the asbestos fibers were replaced with Snow-Tex clay (silica) and a different thixotropic agent was used.

The AF castable inhibitor was applied to the FSM-8 forward segment to demonstrate the full-face inhibitor and to the aft/center segment, which is a short face inhibitor. The AF castable inhibitor was a material similar to the AF liner except for the amount of thixotrope used.

The RSRM forward-facing inhibitor thickness was maintained even though this was a first time demonstration on a full-scale motor. To compensate for the unproven inhibitor performance, the acreage insulation was increased to protect against inhibitor failure at motor ignition. This affected the insulation thickness in the acreage areas immediately aft of the inhibitors on the aft segment and on the aft/center segment.

AF adhesive was part of the AF baseline processes and was also used for insulation repairs. The adhesive was the same epoxy adhesive used on the RSRM with the asbestos fibers being replaced with Kevlar<sup>®</sup> fibers. The fiber loading required in the epoxy was less with the Kevlar<sup>®</sup> fibers because of their higher strength. The AF adhesive was used to secondarily bond several insulated components where the insulation had already been cured. The insulation bondlines that use the asbestos filled adhesive on the RSRM were completed using the AF adhesive on FSM-8. In addition, the igniter nozzle was a press-cured phenolic ring that was bonded to the steel case with the AF adhesive.

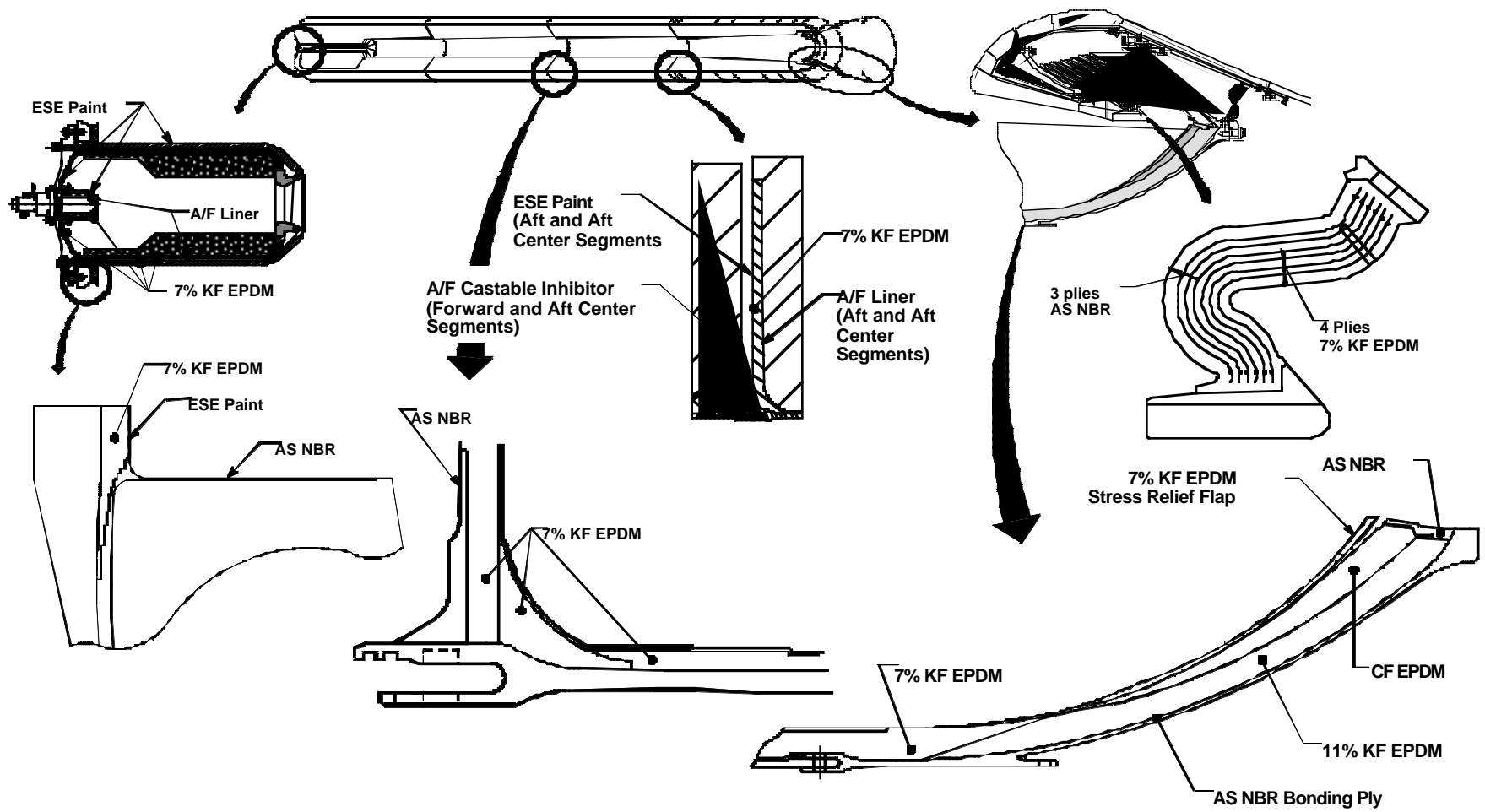


Figure 3 – FSM-8 Asbestos Free Insulation Configuration

## **Bondline Corrosion Corrective Action**

Originally the AF insulation design had selected a Chemlok<sup>®</sup> 205 and Chemlok<sup>®</sup> 236X as the adhesive/primer system for the case to KF/EPDM insulation bondline. During subsequent process variability testing, indications of corrosion were found at the test specimen bondline. The corrosion on the specimens was generally accompanied by reductions in bondline strength, some of which were significant. Extensive testing was completed using design of experiment techniques to determine the cause of the bondline induced failures. The results indicated there were 6 factors that have some influence on the bondline corrosion formation. These factors were cure temperature, cure time, Chemlok<sup>®</sup> 205 age, Chemlok<sup>®</sup> 236X age, Chemlok<sup>®</sup> 205 thickness and Chemlok<sup>®</sup> 236X thickness.

An additional test effort was conducted to determine corrective actions that would eliminate the corrosion from the bondline. Three potential corrective actions were investigated. The corrective actions were to modify the cure cycle, to replace the Chemlok<sup>®</sup> 236X or to modify the Chemlok<sup>®</sup> 236X by adding a Dow Epoxy Resin 331 (DER331) additive to the Chemlok<sup>®</sup>. It was concluded from this testing, that using the Chemlok<sup>®</sup> 236X with the modified cure cycle was an acceptable solution to the corrosion problem. Significant corrosion reductions were observed at all processing variable conditions and no corrosion was seen with the nominal process conditions. It was also found that the replacement Chemlok<sup>®</sup> was clearly better than Chemlok<sup>®</sup> 236X or Chemlok<sup>®</sup> 236X/DER331 adhesives for corrosion inhibition and strength. This was particularly evident for the more corrosive environment using 2 year-old Chemlok<sup>®</sup> 205 primer under extended cure times and at the high side of the allowable cure temperature range.

The decision was made to replace Chemlok<sup>®</sup> 236X at the case to KF/EPDM insulation bondline because the replacement provided equal or better corrosion resistance and strength when using new Chemlok<sup>®</sup> 205. The more robust Chemlok<sup>®</sup> adhesive system provided by the replacement also allows greater process and material variations without creating bondline corrosion. This was the baseline planned for demonstration on FSM-8.

Prior to the actual build of the FSM-8 insulated components, process simulation articles were fabricated to evaluate the design and practice the manufacturing processes used in this design. The process simulation articles were built in a normal production environment using AF production procedures and materials. Part of the normal procedures was to construct witness panels that follow the full-scale hardware and were intended to represent, as close as possible, the material and bondlines that exist on the hardware. When the witness panels that represent the aft dome insulation configuration were tested, a shift in the bondline failure mode was noted. These witness panels typically fail cohesively within the insulation itself, indicating that the bondline is somewhat stronger than the material. However, the peel specimens indicated reduced peel strengths from what had been measured in the past and some failures were at the bondline rather than cohesive failures within the insulation.

An investigation of this bondline failure mode shift was initiated since this was the first time this observation had been seen on the program. Further laboratory investigation of this failure mode shift revealed that the Chemlok<sup>®</sup> system contains ingredients that may react with moisture in a slow exothermic reaction that occurs above 220 °F. During the extended cure times above 220 °F that the aft dome insulation bondline experiences, the reaction can occur and weaken the Chemlok<sup>®</sup> to KF/EPDM bond. KF/EPDM is cold stored prior to installation, which can result in moisture condensation on the rubber surface. This moisture can be trapped at the insulation to case interface and may not be absorbed into the rubber because of the hydrophobic nature of EPDMs. The RSRM does not experience this problem. The bond strength reduction and failure mode shift were duplicated in lab testing. The major contributors were determined to be full-scale double cure cycles, older Chemlok<sup>®</sup> 205 primer and higher moisture content in the bondline. The shift does not occur for shorter cure cycles, but only occurs with the extended cure times associated with the double cured aft dome. The final conclusion was that a combination of conditions in the aft dome must be present for the failure mode shift to occur, but their occurrence was a possibility on a full-scale motor in the aft dome region.

For FSM-8, a temporary solution to the problem was to install a thin ply of AS/NBR against the case and then vulcanize KF/EPDM to this ply. All of the bondlines that were created for this revised configuration had previously been tested and therefore represented an acceptable solution. This configuration had also previously been built on an earlier process simulation article. Other alternative solutions had not been fully developed at that time and any further development effort would have delayed the static test firing.

## **ESE/ESD Issue and Resolution**

The AS/NBR used on the RSRM is a naturally dissipative insulation, which resists static charge generation. Any charge that is created dissipates throughout the insulation to the case and to a ground source. KF/EPDM is a very non-conductive and highly static producing insulation. This creates two major potential hazards during processing. The first hazard is from flammable vapor/air mixture ignition and the second is propellant ignition through a discharge from the insulation surface due to triboelectric charge build-up that cannot migrate to ground. The general approach to eliminating these potential hazards was to engineer the hazards out of the AF design and production processes rather than prove that the high voltage electrical charge generated during motor processing would not have sufficient energy to ignite vapors or propellant.

Process materials and operations were reviewed where improvements or changes could be made to reduce or eliminate the ESE/ESD potential. Slowing down contact-electrification type operations controlled many ESE generation processes. Use of ionizers, dissipative floor mats, conductive shoes and eliminating dry wipes were implemented. Vapor levels present in operations involving flammable solvents were monitored to ensure concentration levels were below acceptable limits. Wet abrading was required on all insulation surface repairs. Operators were retrained in dealing with ESE hazards. Inert process simulation articles were used to test changes made to the processes and to monitor levels of ESE generation. These implemented changes were sufficient to create safe operating environments in all areas and were demonstrated by monitoring hardware and personnel.

Other changes were made to the engineering design. For example, abrasion and cleaning of the RSRM field joints and igniter joints mating surfaces was done on loaded segments. Testing determined that abrasion of these joints could be completed on the insulated components prior to loading with propellant without creating a hazard and without impacting the bondline strength. Prior to lining, the RSRM cured internal insulated segment is hand cleaned with a flammable solvent, which has the potential to create a flammable vapor/air mixture inside the segment. It was noted that operators do routinely contact the KF/EPDM and could generate ESE in localized areas. To eliminate this potential hazard, another cleaning solvent, which is non-static producing and non-flammable, was tested for cured insulation and demonstrated on FSM-8.

The largest ESE/ESD concern existed for the exposed external surfaces of KF/EPDM. These surfaces are susceptible to contact-electrification both during planned processing as well as from incidental contact. The first approach to this issue was to select or develop a static dissipative paint that would mimic the bulk dissipative properties of AS/NBR. Even though conductive paints are used in several industries, an acceptable dissipative paint could not be found. Therefore, it was determined to modify the Hypalon<sup>®</sup> paint used to cover the RSRM forward-facing inhibitors and make it dissipative by using doped semiconductor additives from the paint industry. Several Electro-Conductive powders were selected to achieve the targeted surface resistivity. Several of the additives were able to initially match the desired surface resistivity, but the surface resistivity of each paint formulation varied after exposure to humidity, temperature and deformations. The data suggested that each of these type exposures changed the spatial relationship of the conductive powder, which affected the number of connecting paths within the paint. Since segment exposure to these conditions could not be controlled, the final resistivity would vary depending on the initial resistivity and the degree of exposure to these environments.

The solution of this issue was to make the ESE paint more conductive by increasing the concentration of Electro-Conductive powders in the Hypalon paint. A conductive paint complicated the processing by requiring that it be grounded at all times, but it allowed paint exposure to a much wider range of processing environments. The conductive paint was developed, tested on process simulation articles and then all live operations were monitored during the entire FSM-8 production process to assure safe operations.

The ESE/ESD hazards were successfully managed for FSM-8, although most operations were much more complicated and required more monitoring than was desired. An effort has been undertaken to modify the KF/EPDM itself and make it dissipative like AS/NBR. Several lab mixes of rubber have matched the AS/NBR ESE properties. However, any modification would be best if the thermal-ablative and structural material properties are not reduced. Combinations of conductive additives and polymer replacements have been tested. Full-scale production batches are planned and will be tested for acceptable material properties.



## FSM-8 Test Results

FSM-8 was successfully static tested on February 17, 2000. The post-test evaluations indicated the components fabricated with AF insulation, liner or adhesives, performed as expected. Post-test inspections of the segments indicated no abnormal erosion or other abnormal conditions.

### AF Igniter Components

The AF insulation in all igniter components performed as expected and all minimum thermal safety factors were acceptable. Generally, the igniter AF insulation performance was equal to that of the baseline AS/NBR insulation. No abnormal conditions were found. The Material Decomposition Depths (MDDs) for the FSM-8 igniter chamber and adapter were calculated from pre-fire and post-test insulation thicknesses. Data evaluations show that median MDDs for the FSM-8 igniter were slightly less than those for the FSM database for all but two stations. The increased MDDs at these two stations were only slightly higher. The adapter insulation performed as expected. The igniter chamber outer insulation appeared nominal. The 7% KF/EPDM had a thick char cap remaining. The underlying KF/EPDM was intact and uniform with small bubbles in the heat affected layer. No anomalous conditions were noted. The AF initiator helmet performed nominally. The entire helmet was intact and remained bonded to the initiator chamber. Heat effects and char of the KF/EPDM helmet were typical of static tested motors.

### AF Internal Insulation

The performance of the AF insulation in the FSM-8 segments was as expected and no abnormal conditions were observed. The aft dome region of the motor experiences the most severe erosion environment. AF insulation had previously been tested in the aft dome of FSM-5 and some areas of severe pocket erosion resulted. The revised AF design on the FSM-8 aft dome region, with CF/EPDM used on the flame front, indicated no abnormal erosion. In the aft dome region where KF/EPDM was exposed, the MDDs were equal to or slightly better than the static test database. Aft of station 215, which is near the middle of the segment, to the stiffener factory joint, the MDDs were slightly higher than the database. Forward of station 215, in the low exposure locations of the segment, the MDDs were higher than the database. This may be due to different performance characteristics such as how the char layer was established or may have been affected by the AF liner that was also used on this segment. If the liner erosion were more severe for the AF liner, then the resulting MDDs would show this impact most dramatically in the low exposure areas.

Erosion performance of the AF 7% KF/EPDM in the aft segment acreage areas was near the predicted performance. Plots of performance, as shown by comparing median MDDs for FSM-8 aft segment versus the FSM static test database, are included in Figure 4. Similar observations can be made for the center/aft segment. Figure 5 indicates the 7% KF/EPDM has lower MDDs in the higher exposure region at the aft end of the segment. From station 40 going forward in the segment to station 275, these stations represent low exposure areas, which again indicate higher MDDs for FSM-8 than the database. The stations forward of 275 had liner remaining post-test and indicated no insulation erosion. All minimum safety factors for the AF case acreage insulation were acceptable.

### AF Nozzle Hybrid Flex Boot

Some concern existed regarding the first-time use of 7% KF/EPDM in the nozzle flex boot. Although char tenacity tests had been conducted, it was still unknown how the AF insulation would perform with the standard nozzle vectoring duty cycle during a static test. The first 4 plies of the FSM-8 flex boot were 7% KF/EPDM and the remaining 3 plies were AS/NBR. Post-test inspections of the flex boot revealed it was in good condition. Of the original 7 plies of insulation, the number of remaining plies was nominal and was well within the static test experience. All performance thermal safety factor requirements were met.

### AF Joints

The aft field joint was fabricated of AF insulation. The joint appeared to have remained sealed during motor operation with no leak paths observed. The post-test inspection of the pressure sensitive adhesive applied to

the joint mating surfaces indicated that typical bondline contact had been made. The exposed joint surfaces showed typical erosion. The igniter inner and outer joints also performed as designed and exhibited no leak paths.

#### AF Liner and Castable Inhibitor

The AF liner that remained was heavily heat-affected, but intact, and appeared to function well with no indication of unacceptable performance. Inspection of the acreage insulation gave no indication of liner or castable inhibitor failures that would result in increased erosion or might be indicated by pressure blips during motor operation.

#### AF Forward-facing Inhibitors

The AF forward-facing inhibitor heights were normal for a static test and indicated no abnormal areas of missing material. The remaining forward-facing inhibitors were measured on the aft and center/aft segments. Both of these inhibitors were made from 7% KF/EPDM and performed similar to the baseline AS/NBR insulation. The median remaining AF inhibitor heights were only slightly different than the median remaining static test inhibitor heights.

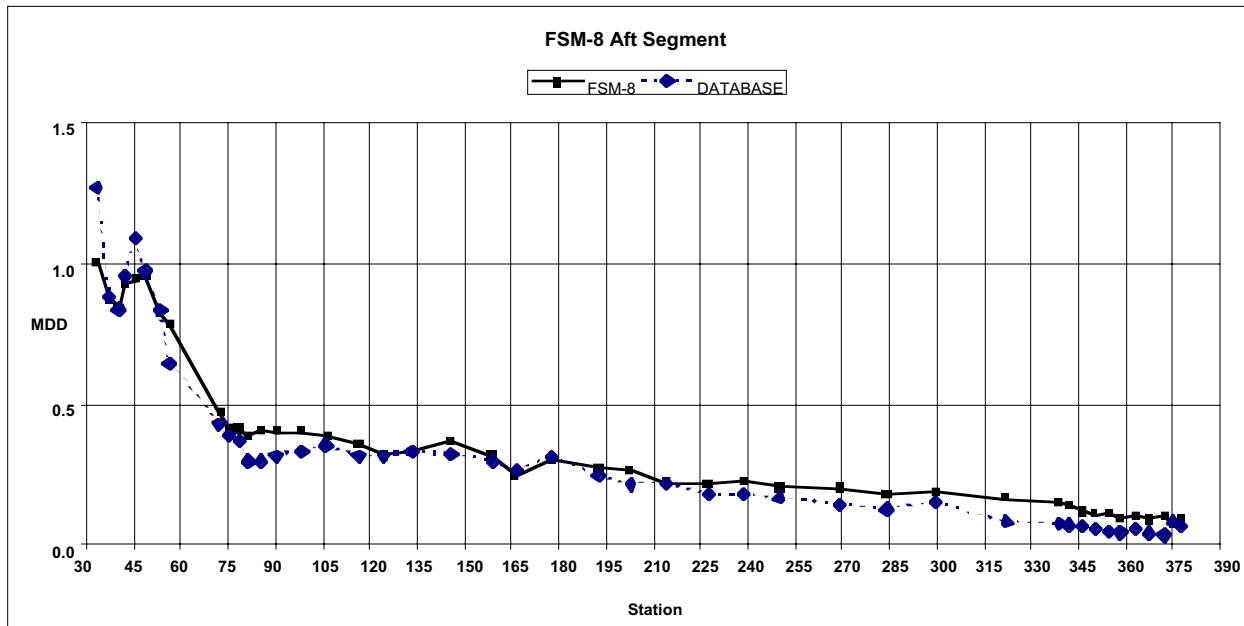


Figure 4 – Aft Segment Comparison of FSM-8 to Database

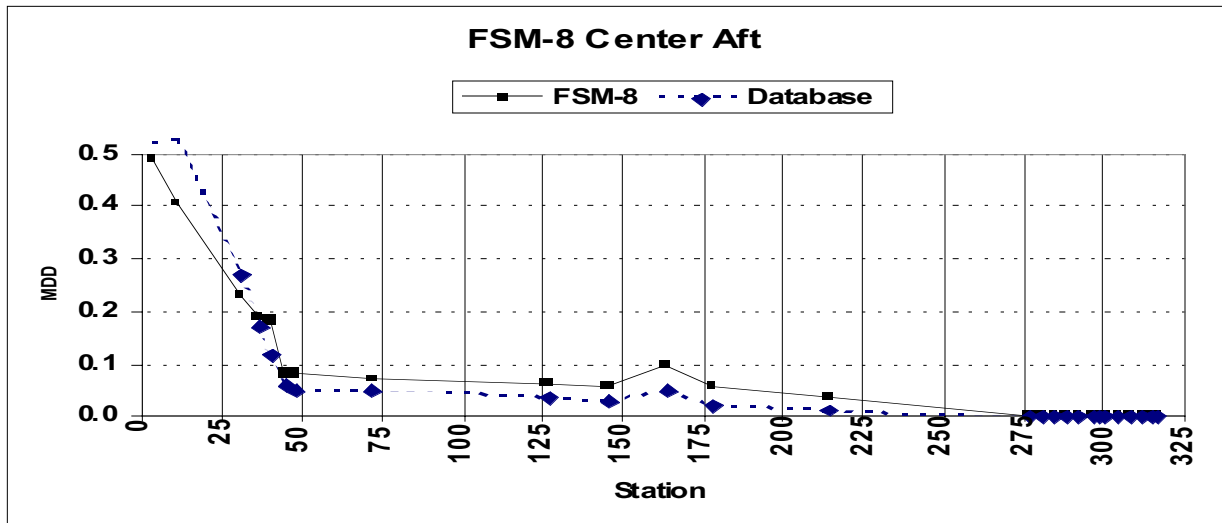


Figure 5 – Center/Aft Segment Comparison of FSM-8 to Database

### Real-time Instrumentation Data

The RSRM forward-facing inhibitors restrict propellant surface burning on the forward face of the aft and center segments by insulating the propellant grain from the hot combustion gases, even though the inhibitors themselves are thermally ablating in the severe thermal environment. In the past, attempts have been made to predict the thermal performance of these inhibitors. However, since there is only a stub remaining for the aft joint and center joint inhibitors, it has been impossible to confirm the accuracy of these analyses. The FSM-8 aft and aft/center segment inhibitors were made of AF 7% KF/EPDM. These inhibitors were instrumented to obtain measured real-time inhibitor char line recession data for model calibration purposes and for a direct measurement of inhibitor safety factors. The instrumentation consisted of thermocouples and eroding potentiometers. The eroding potentiometer consisted of two small (3 mils diameter) twisted resistive wires that were polyimide insulated. (2) The wires were placed in the inhibitor during insulation lay-up parallel to the direction of erosion. During motor operation, the inhibitor eroded away, exposing the tip of the instrument to the heat of the internal motor environment, causing it to recede also. As the wires were heated, the polyimide insulation broke down at or near the tip and made an electrical junction. The electrical resistance of the wire pair decreased as its length receded and was measured as a function of time. Because the breakdown of the polyimide occurred near the pyrolysis/char interface of the decomposing insulation, the eroding potentiometer measured the continuous real-time char line recession of the inhibitors.

FSM-8 demonstrated the performance of the 7% KF/EPDM inhibitors in the motor environment. Real-time inhibitor eroding potentiometer and thermocouple data were successfully collected during motor operation for the first time on FSM-8. The comparison of the thermocouple data with the eroding potentiometer data gave good agreement, which indicated that the potentiometers worked well. The data showed the 7% KF/EPDM inhibitors performed well and there were no abnormally high char rates. The measured data verified that the thermal safety factors were greater than the 1.5 requirement for an assumed minimum inhibitor thickness. (3)

### Conclusion

An Asbestos Free insulation design was successfully demonstrated on a full-scale Flight Support Motor. Major components were manufactured and shown to function well and as expected. Insulation thermal performance safety factors were calculated based on pre-test and post-test measurements and were found to meet all requirements. Several design issues were worked and acceptable solutions demonstrated. Some additional development work was started to make the design less complicated from a production standpoint. Further demonstration of the final design will be required prior to implementing an asbestos free insulation onto flight motors.

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