United States Environmental Protection Agency

Office of Transportation and Air Quality

EPA420-R-06-006
March 2006

EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines < 50 Horsepower

Appendix C -

Design/Conduct Failure Modes and Effects Analysis for Small SI Equipment and Engines

EPA420-R-06-006
March 2006

EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines < 50 Horsepower

Appendix C - Design/Conduct Failure Modes and Effects Analysis for Small SI Equipment and Engines

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
Southwest Research Institute
Engine, Emissions, & Vehicle Research Division
EPA Contract No. EP-C-05-018
Work Assignment No. 0-10

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) issued Work Assignment 1-10, “Design/Conduct FMEAs for Small SI Equipment and Engines” to Southwest Research Institute® (SwRI®). The work was to analyze the potential safety impact of possible Phase 3 emissions standards, which include a 35% reduction in $HC+NO_X$ exhaust emissions and evaporative emission standards on small spark-ignited (SI) engines (<19kW). The standards are expected to result in the use of exhaust catalysts and evaporative emission control systems on small spark-ignited (SI) engines (<19kW). Since catalysts are exothermic (a process that produces heat) in operation, the addition of catalysts to future products required that potential incremental safety impacts be evaluated and understood.

A team of representatives from SwRI, EPA, and Consumer Product Safety Commission (CPSC) contributed to the completion of this work assignment. The EPA set the direction for the study and provided data and technical information on the Phase 2 and Phase 3 products under review. The CPSC provided product safety information from multiple databases which was helpful in identifying potential failure modes for the study. SwRI contributed the experienced engine experts, the FMEA process experience and conducted the independent FMEA analysis.

A Design Failure Mode and Effects Analysis (FMEA) format was selected to evaluate the incremental safety impact between existing Phase 2 products (current production models) and the expected Phase 3 products. The scope of the assignment included Class I and Class II engine systems, which relate to walk-behind and riding lawn mowers, respectively. These equipment types represent the majority of sales for small SI engines and this is also the area where EPA has received comment from various stakeholders in pre-proposal discussions. A Process FMEA format was chosen to evaluate common human interactions with the mower equipment. Three Process FMEAs were conducted to evaluate the safety impact associated with equipment refueling, storage, and maintenance. These FMEA results were then used to assess if the addition of a catalyst or fuel evaporative emission control would pose any incremental safety impact associated with these processes.

The SAE J1739 FMEA procedure was the basis for the format for the FMEA. This document states that “An FMEA can be described as a systematic group of activities intended to: (a) recognize and evaluate the potential failure of a product/process and the effects of that failure, (b) identify actions that could eliminate or reduce the chance of the potential failure occurring, and (c) document the process. It is complementary to the process of defining what a design or process must do to satisfy the customer”.

The FMEA process identifies Potential Failure Modes and Potential Effect(s) of Failure. Each Potential Effect(s) of Failure is classified with regards to Safety, Regulatory, Performance, or Other. The main focus of this analysis was to draw attention to the Safety related items. The Risk Priority Number (RPN) was calculated for Phase 2 and prototype Phase 3 engines for each line item in the FMEA. The delta RPN was calculated by subtracting RPN (Phase 2) from RPN (Phase 3): Delta RPN = Ph3 RPN – Ph2 RPN.

Three cases were observed in the analysis:

a. Delta RPN = 0: Many Safety line items show no significant changes in Risk Priority Number (RPN) between current Phase 2 prototype Phase 3 engines.

b. Delta RPN > 0: A number of Safety line items show that RPN is reduced in the prototype Phase 3 engines due to improved design and better reliability.

c. Delta RPN < 0: One Safety line item in each Class (I & II) shows that the RPN is higher for the Phase 3 engine.

The Phase 3 engine definition within this report (Table 3) is the basis for the Phase 3 engine system analyzed in this analysis. It is based on a number of engine prototypes, catalyst prototypes, thermal data, field, dyno and emission testing by EPA. The main features of this engine over the majority of existing Phase 2 engines include:

a. Application of catalyst (moderate activity 30-50%) designed to minimize CO oxidation, maximize NO_x reduction, with low HC oxidation efficiency at high exhaust-flow-rates and high HC oxidation efficiency at low-exhaust flowrates. This design is expected to minimize catalyst exotherm.

b. Cooling and shrouding of engine and muffler to minimize surface temperatures. Use of heat shielding and/or air-gap insulated exhaust components to minimize surface temperatures.

c. Improved component design and manufacturing processes to reduce Air-Fuel ratio production variability to stabilize engine performance and emissions.

d. Evaporative emission controls: hoses, tank, cap, and running loss system.

The prototype Phase 3 engine evaluated by the FMEA team had less potential to cause fires and operator burns than some equipment now in production. EPA's thermal data on Phase 2 and Phase 3 product showed muffler heat shield temperatures were equivalent or cooler.

EPA is considering evaporative requirements, some of which will also reduce the occurrence of fuel leaks, and subsequently fire and burn risks. Leaks will be reduced during tipping of equipment with the following controls to reduce running loss emissions: 1) use of fuel caps with no venting or with venting through a tortuous path (to control diffusion-related venting emissions), and 2) a restriction, a limited flow orifice or a valve, placed in the vent line to the engine to keep the engine manifold vacuum from drawing too much vapor from the fuel tank (route the vapor to the engine intake to be burned by the engine). Other possibilities to reduce fuel leakage include moving the fuel tanks away from heat sources and using a tethered cap. Leaks from the tanks and lines will be lessened due to the material improvements likely to be made to reduce permeation from these components.

Three processes were identified for FMEA analysis: refueling, equipment storage, and maintenance. The FMEAs were done to identify if there could be any potential for increased concern of Phase 3 engine systems with catalyst mufflers compared to the current Phase 2 product. Due to the fact that these processes are done with the engine off, the processes were analyzed with respect to worst case outcomes after shut-off. It was concluded that there were no additional areas of concern with Phase 3 prototypes versus Phase 2 engine designs. This was based on redesign associated with meeting Phase 3 fuel evaporative emission control requirements and EPA's thermal data that showed the muffler's hot soak temperatures were comparable, or potentially reduced, with properly designed Phase 3 catalyst systems. In case of fuel spills due to tipping of equipment, there is the potential for lower occurrence ranking due to fuel system modifications and upgrades associated with meeting the fuel evaporative emission control requirements EPA is considering. Reductions in vapor emissions during storage would occur as a result of using less permeable tanks and lines.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS / ABBREVIATIONS

ASTM	American Society for Testing and Materials
ANSI	American National Standards Institute
ASAE	American Society of Agricultural Engineers
C	Centigrade
CEC	Coordinating European Council
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CPSC	Consumer Product Safety Commission
ECM	Engine Control Module
EEC	European Economic Community
EGO	Exhaust-Gas-Oxygen
EFI	Electronic Fuel Injection
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FMEA	Failure Mode and Effects Analyses
HC	Hydrocarbon
ISO	International Standards Organization
INDP	In-Depth Investigations
IPII	Injury/Potential Injury Incident File
kg	Kilogram
MAP	Manifold Absolute Pressure)
NEISS	National Electronic Injury Surveillance System
NFIRS	National Fire Incident Reporting System
NFPA	National Fire Protection Association
NO_X	Nitrous Oxide
NMMA	National Marine Manufacturers Association)
NVFEL	National Vehicle and Fuel Emissions Laboratory
O2	Oxygen
OEM	Original Equipment Manufacturer
OHV	Overhead Valve
RPN	Risk Priority Number
SAE	Society of Automotive Engineers
SI	Spark Ignited
SwRI®	Southwest Research Institute®
SV	Side Valve
T_{Boil}	Boiling Temperature
T_{ig}	Ignition Temperature
t_{ig}	Ignition Time
USDA	United States Department of Agriculture
°	Degree
Φ_{max}	Equivalence Ratio

1.0 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) issued Work Assignment 1-10, "Design/Conduct FMEAs for Small SI Equipment and Engines" to Southwest Research Institute® (SwRI®) to analyze the potential safety impact of new emission standards, which are expected to result in the use of exhaust catalysts and evaporative emissions control systems on small spark-ignited (SI) engines (<19kW). Please see Attachment 1 for the work assignment details. The overall product population in this market is dominated by walk-behind mowers (Class I) and ride-on (Class II) lawn and garden equipment. Based on the Consumer Product Safety Commission's National Electronic Injury Surveillance System (NEISS) database from 2000 through 2004 there were significantly more thermal burns associated with lawn mowers than for generators and power washers. The CPSC recall database for the same period also included many more recalls for fire and burn associated with lawn and garden equipment than any other product. Consequently, the walk-behind and ride-on mower engines represented the primary focus of this study.

The objective of this work assignment was to design and perform Failure Mode and Effects Analyses (FMEA) on Class I and Class II engine systems. The FMEA technique is an industry-accepted tool that is used to assess product risk associated with potential failure modes. This FMEA study was focused on identifying and assessing the potential incremental safety impact between the current engine products that meet the Phase 2 emission standards, and future engine designs for expected Phase 3 emission standards. It is expected that a number of improvements in engine design including air-fuel ratio control and a catalyst will be utilized to meet Phase 3 emissions standards. SwRI has conducted a Design FMEA with the existing Phase 2 product (current production models) compared to the expected Phase 3 product. The analyzed configurations of Phase 3 products were based on Phase 2 engine models that have been modified by the EPA to meet the new emissions requirements. The modifications are listed in Table 3.

The SwRI FMEA team represents 100 years of experience in engine design, development and testing. The expertise used in the assessment of the Phase 2 and Phase 3 products included: engineering judgment, engineering expertise, engine test experience with this class of product, previous experience applying catalysts to this type of product, review of Phase 3 engine prototypes and data from the EPA, review of data from the CPSC, and personal knowledge of the product from a consumer perspective.

The Work Assignment included four main tasks:

Task 1:

SwRI was to select a team of experts and define the approach to be taken to conduct the FMEA assessments. The team was selected and the approach was to use the Design and Process FMEA methods as a guide for the subsequent analysis.

Task 2:

SwRI presented an overall plan that described how the FMEA would be conducted. SwRI reviewed the catalyst concepts and data for the tests conducted by the EPA that evaluated catalyst-equipped prototype engines and equipment. EPA provided engineering expertise that assisted in this analysis process. The CPSC provided product safety information from multiple databases which was helpful during the Failure Mode and Effects Analysis (FMEA) study. Brief descriptions of these databases are indicated below:

- CPSC's National Electronic Injury Surveillance System (NEISS) is comprised of a sample of hospitals that are statistically representative of hospital emergency rooms nationwide. From the data collected, estimates can be made of the numbers of injuries associated with consumer products and treated in hospital emergency departments.

- CPSC's In-Depth Investigations (INDP) file contains summaries of reports of investigations into events surrounding product-related injuries or incidents. Based on victim/witness interviews, the reports provide details about incident sequence, human behavior, and product involvement.

- CPSC's Injury/Potential Injury Incident File (IPII) contains summaries, indexed by consumer product, of Hotline reports, product-related newspaper accounts, reports from medical examiners, and letters to CPSC.

- The National Fire Incident Reporting System (NFIRS) is a database of fires attended by the fire service. NFIRS provides data at the product level and is not a probability sample. The information from the NFIRS database is weighted up to the National Fire Protection Association (NFPA) survey to provide national annual product-level estimates.

- In addition the SwRI team had access to the recall summaries posted at CPSC's public website.

Task 3:

SwRI conducted an FMEA considering multiple engines and pieces of equipment. The FMEA was performed for the Phase 2 and prototype Phase 3 small-spark ignited (SI) engines and related equipment. This was performed for both Class I and Class II engines. The analysis was based on the SwRI FMEA team's knowledge of Phase 2 products and the Phase 3 hardware configurations provided by EPA. Three Process FMEAs were also performed, to assess the potential increase in safety impact associated with the use of the lawncare equipment. The FMEA team included staff from EPA and CPSC, as well as SwRI.

Task 4:

The final report is presented as the primary task requirement that was generated from the FMEAs. Future presentations by SwRI in support of this project will be provided as requested by EPA.

2.0 FMEA BACKGROUND / DESCRIPTION

The Failure Mode and Effects Analysis (FMEA) is one of many quality improvement techniques that have been developed and successfully applied in industry over the last 40 years. The FMEA process focuses on potential failures and the resulting effects, and is recommended by a number of U.S. and International Standards organizations. The FMEA is a tool that systematically evaluates potential product hazards, effects, and the likelihood of those potential hazards occurring. It also provides a systematic means for estimating risk. The FMEA guide used throughout this study was the SAE standard, J1739. This analysis was conducted using the Design FMEA and Process FMEA formats.

The methodology of a Design FMEA has four primary aspects: (1) use of a systematic approach and sound engineering judgment to anticipate how and how often a particular design could fail to perform its intended function, (2) identification of the likely consequences of the failures, (3) to clearly identify the critical failure modes, and (4) to identify the actions necessary (typically controlled by the manufacturer) to eliminate or reduce the risk associated with the potential failure modes.

The Process FMEA technique is similar to that described for the Design FMEA except that the Process FMEA addresses how and how often processes can fail to result in the intended outcome, rather than how and how often components can fail to perform the intended function.

A FMEA is conducted by a team of people (typically 4 to 6 members), and is not effective if the FMEA is completed by a single person. The selection of the members of the team is important. The team should consist of cross-functional members, if possible, to promote a variety of perspectives. The most effective FMEA teams are comprised of members who have technical knowledge of the subject, and who are willing to participate in open discussions and be willing to accept team consensus to reach the best assessment. The team leader is typically a process leader and facilitator of the FMEA. Typically, the FMEA process is used to identify a wide range of product problems including performance, safety, durability, and other user satisfaction issues. This study focused on the incremental safety impact associated with the application of catalysts to small SI engines and equipment.

As with any tool, there are limitations to the FMEA process. The FMEA process is very detailed, to the point of being tedious and time consuming when complex systems are being analyzed. The FMEA technique deals primarily with single point failures, and usually does not address the effect of combinations of failures. It is important to capture all of the practical failure modes, while avoiding highly improbable failure modes that are of minimal consequence.

3.0 THE SWRI APPROACH FOR THE SMALL ENGINE FMEA PROJECT

A. FMEA Team Make-up

The team selection is critical for an FMEA process. The SwRI team was selected considering the knowledge and expertise required for conducting the subject FMEA. Team members are engineers and have the technical skills required for the task. In addition, the team members have skills beyond the requisite technical skills which allow a broader view of the problem.

The SwRI FMEA team consisted of four core team members and one reviewer. All are experienced SwRI staff members. Brief resumes are included below:

Jeff White (Core Team): Mr. White has been contributing to the development of cleaner engines and vehicles for over 25 years. Mr. White has performed emission research programs for a wide range of applications including light-duty vehicles, heavy-duty truck and bus engines, and many types of small and nonroad engines. Jeff and his colleagues have performed numerous studies on small engines, focusing principally on development of strategies and technologies to reduce emissions. Work has addressed both 2-stroke and 4-stroke designs, as well as diesel and alternative-fueled engines.

Tom Boberg (Core Team): Mr. Boberg is the FMEA team leader, facilitator and an experienced FMEA process user. He has 27 years experience with the design, development and production release of engines. He currently is Manager of the Gas and Large Engine Section at SwRI. Tom has previously participated in several dozen of Design and Process FMEA analyses over the last 13 years as a participant, leader and facilitator.

Jim Carroll (Core Team): Mr. Carroll has 25 years experience in off-highway engines and emissions testing. He has managed projects for engine certification, emissions development, catalyst development, component durability, emissions reduction and test cycle procedure development. He has worked with off-road engines for 15 years and has participated in baseline studies for regulatory agencies, and emission reduction strategy development and engine certification.

Kevin Castile (Core Team): Mr. Castile has over 23 years of experience in the engine lubricants industry. He is currently the Project Manager of the Leisure Marine and Small Engine Lubricants Section. Over the last seven years he has authored, co-authored, and updated industry standard lubricant specifications for ASTM (American Society for Testing and Materials), CEC (Coordinating European Council), ISO (International Standards Organization), and NMMA (National Marine Manufacturers Association).

Barry Badders (Reviewer): Mr. Badders has a Bachelors Degree in Mechanical Engineering with an emphasis on thermal systems, heat transfer and fluid dynamics. Mr. Badders will be obtaining his Masters Degree in Fire Protection Engineering from the University of Maryland in May 2006. After obtaining his undergraduate degree, he worked as a consultant for 4.5 years, during which time he received his Professional Engineer’s License in the state of Texas and

Florida. Mr. Badders works in the Southwest Research Institute's Department of Fire Technology as a group leader responsible for the Engineering and Research Section. His job functions include fire modeling using computational fluid dynamics and finite element methods. He also conducts research and customized testing to study the effects of fire and related phenomena.

B. Cases to be studied

The purpose of this Work Assignment was to identify and assess incremental safety impact between the current, Phase 2 versions of a number of small SI equipment/engines, and the same equipment and engines that have been modified to meet Phase 3 concept emission standards. As part of their technology assessment work, EPA modified a number of OEM Phase 2 engine and equipment configurations in such a manner that they met the exhaust emission standards being considered by EPA staff. The emission standards that are under consideration by EPA are shown in Table 1, below.

Table 1. EPA Phase 3 Concept Emission Standards

Exhaust Emissions

	$HC+NO_X$* g/kW-hr	**CO g/kW-hr**	**Year**	**Useful Life (hours)**
Class I	10.0	610	2010	125/250/500
Class II	8.0	610	2011	250/500/1000
Classes 3 - 5	No Changes			
**$HC+NO_X$ standard is based on averaging; new standards would not apply to snow equipment.*				

Evaporative Controls

	Class I	**Class II**	**Classes 3 - 5**	**Standard**
Hose and Tank Permeation	2009	2009	2009	15 g/m^2 & 1.5 g/m^2
Running Loss	2010	2011	n/a	Design/Test

Following the initial meeting with the EPA, the scope of the FMEA was refined to include conducting two Design FMEAs and three Process FMEAs. The Design FMEAs focused on potential subsystem/component failures of Class I and Class II lawn mower products. The Process FMEAs relate to user activities of equipment refueling, equipment storage, and engine maintenance. These activities were supported by the detailed review of Class I and Class II, Phase 2, and prototype Phase 3 engines and equipment available at the EPA in Ann Arbor, Michigan on October 3rd and 4th 2005. The equipment that was reviewed is listed in Table 2. Table 2 is a summary of Attachment 2 which presents photographs of production, Phase 2, lawn and garden equipment and prototype Phase 3 engines and modified equipment. Figures A2-1 through A2-24 shows Class I engines, catalysts, mufflers, and equipment; Figures A2-25 through A2-41 show Class II engines, catalysts, mufflers, and equipment. These images document the design changes implemented by the EPA in the course of their Phase 3 design impact analysis.

Table 2. Summary of Attachment 2 Photographs

Figure No.	Figure - Title	Notes
A2-1	Stock Briggs Quantum Side Valve Complete Engine	Purchased locally by EPA
A2-2	Stock Briggs Quantum European Catalytic Muffler	Three stamped steel parts, plus mat-wrapped ceramic catalyst (400cpsi, 20 cc)
A2-3	Stock Briggs Quantum SV Close-Up Of Front Of European Catalytic Muffler	Muffler is direct replacement for non-catalyzed muffler, available from Briggs distributors. Note Briggs logo on right.
A2-4	Stock Briggs Quantum SV Close-Up Of Back Of European Catalytic Muffler	Supplemental air inlets are visible.
A2-5	Stock Briggs Quantum SV European Catalytic Muffler Shroud	Outlet side of muffler.
A2-6	Stock Briggs Quantum SV European Catalytic Muffler Interior	Center stamping and catalyst.
A2-7	Stock Briggs Quantum SV Center European Catalytic Muffler Interior With Substrate Removed	Center stamping with catalyst removed showing catalyst and wrap
A2-8	Stock Briggs Quantum SV European Catalytic Muffler Supplemental Air Venturi	Venturi is formed at supplemental air inlet. Muffler located at exhaust port connection helps homogenize exhaust gas mixture.
A2-9	Stock Honda GVC 160 Without Muffler	Cooling air flow directed toward muffler by upper block casting.
A2-10	Stock Honda GVC 160 Muffler With Shroud	Muffler with air cooling shroud and touch guard.
A2-11	EPA Prototype Catalyzed Muffler In Shroud For Honda GVC 160	Prototype catalyzed muffler and shroud. Air injection by internal venturi with air in through external pipe.
A2-12	EPA Prototype Muffler With Exhaust Gas Cooling Air Ejector Around Exhaust For Honda GVC 160	Ejector tube around exhaust outlet draws cooling air across outlet though exhaust flow dynamics.
A2-13	EPA Prototype Muffler Air Ejection Tube For Honda GVC 160	Cooling air ejector tube.
A2-14	EPA Prototype Muffler Ceramic Substrate For Honda GVC 160	Ceramic substrate encased in steel mounting support.
A2-15	Tube Catalyst For Insertion In Exhaust Port	First low surface area controls catalyst activity, reduces plugging, and reduces cost.
A2-16	Prototype Low Cell Density Metal Substrate Catalyst	Low cell density controls exothermic reactions.
A2-17	Wire Mesh Catalyst In Muffler	Metal mesh substrate controls catalytic activity, and reduces plugging.
A2-18	Wire Mesh Catalyst Removed From Muffler	Substrate removed showing support structure in muffler.
A2-19	Stock Honda GVC160 Mower	Purchased locally by EPA.
A2-20	Briggs QUANTUM SV With Briggs European Catalyzed Muffler	Briggs engine with muffler from Fig. 2 plus touch shield. Additional catalyst, spark arrestor, and exhaust flow diffuser added to muffler

A2-21	Briggs Intek OHV Engine With Dual Substrate European Muffler And Cooling Air Duct	EPA prototype catalyzed muffler. Additional catalyst added to muffler. Shroud at top of muffler to divert cooling air behind muffler.
A2-22	Stock Briggs Intek OHV Engine With Stock Muffler	Purchased locally by EPA.
A2-23	Stock Tecumseh LV195EA	Purchased locally by EPA.
A2-24	Briggs Dual Metallic Substrate European Muffler On Tecumseh LV195EA	Catalyzed muffler purchased from Briggs in Europe.
A2-25	Stock Kawasaki FH 601D	Purchased locally by EPA
A2-26	Stock Kawasaki FH 601D Muffler	Stock muffler for comparison to Fig. 27.
A2-27	Kawasaki FH 601D With Air Injection & Catalyst	EPA prototype catalyzed muffler. Air injection tube at top center. Secondary air is injected between two Palladium Rhodium converters.
A2-28	Triple Pass Catalyst With Double Wall fabricated by EPA.	Double wall reduces surface temperature and fire and burn risk.
A2-29	Stock Muffler for Kohler CV490 With Inserted Catalyst	Stock Class II muffler modified with catalyst and then re-assembled.
A2-30	Stock Muffler for Kohler CV490 With Inserted Catalyst	Stock Class II muffler modified with catalyst and then re-assembled.
A2-31	High Efficiency Dual Catalyst Ahead Of Muffler fabricated by EPA.	Class II muffler modified by attaching dual catalyst ahead of muffler.
A2-32	Briggs Intek OHV 31P777 Showing No Head Cooling Fins	Head cooling achieved through conduction from cylinder, plus air convection. Note tight shrouding around cylinder to duct cooling air.
A2-33	Kohler CH26 With Stock Muffler Without Catalyst, With EFI With EGO Sensor Feedback	EGO (Exhaust Gas Oxygen) Closed-loop air/fuel ratio control system added to engine.
A2-34	Kohler Catalyzed Muffler For CH26 EFI Engine With Feedback EGO Sensor	Catalyzed muffler for Kohler in Fig. 33 with oxygen sensor.
A2-35	Prototype Briggs 31P777 Intek with Oil Cooler	Stock engine had 140C oil temperature.(no cooling fins on head). Oil cooler (thermostat opens @ 110 °C) added to reduce high temperature in order to age 250 hour motor to 500 hours.
A2-36	Prototype Briggs 31P777 Intek With Air Ducted To Catalyst Muffler with open loop EFI	Additional shrouding ducts the cooling air from the engine past exhaust system, and reduces debris collection.
A2-37	Prototype Briggs 31P777 Intek Close-Up Of ECU & Fuel Injector	ECU and fuel injector from Asian motorcycle. The Intake manifold modified by EPA to accept injector.
A2-38	Stock Briggs 31P777 Intek on Riding Mower	Purchased locally by EPA.
A2-39	Stock Kohler CV490 Riding Mower	Purchased locally by EPA.
A2-40	Kohler CV490 Riding Mower With Catalyzed Muffler & Modified Shroud Cooling & EFI	Additional shrouding ducts cooling air from engine past the exhaust system, to reduce debris collection.

Prototype Phase 3 engines were developed by EPA to demonstrate that small SI engines can meet tighter emission standards at reasonable cost without an incremental increase in safety risk. To that end, four Class I engines were chosen which represent 75 percent of the market's sales, and two Class II engines were chosen which represent 25 percent of the market. The Class II engine market is not dominated by a few sales leaders as is the case with Class I engines. EPA chose a variety of engines that included side-valve (SV) and overhead-valve (OHV) designs, low- and high-cost engines, and both residential-use and commercial-use engines.

During the course of EPA's technology assessment, it investigated a range of engine control and aftertreatment technologies to reduce emissions. These included the application of alternative catalytic converter substrates such as ceramic (Figures A2-7 and A2-14), wire mesh (Figures A2-17), metal tube (Figure A2-15), and metal foil (Figure A2-16). The substrates were coated with a range of washcoat materials and noble metal loadings to control emission reduction efficiency and exhaust system temperature.

One of the catalytic converters tested was a production design from the European market (Figure A2-3). The rest of the test catalytic converters were fabricated and installed by EPA after modifying a production muffler (Figures A2-13 for Class I and A2-29 for Class II) or by placing the catalyst ahead of the production muffler (Figure A2-31).

EPA's criteria for choosing catalyst formulations included:

- minimize heat rejection
- provide appropriate level of emission control and durability
- minimize cost

Catalytic converters are exothermic (gives off heat). The addition of a catalyst increases the total mass of the exhaust system and will retain heat. With this being considered, the EPA objective for Phase 3 engines was that prototype exhaust system designs was to control surface temperatures to the current Phase 2 engine temperature levels. Infrared imaging equipment was used to measure both production and prototype engine surface temperatures during operation in the laboratory, in the field, and after the engines were turned off.

Thermal images and temperature levels measured by the imaging equipment were supplied to the FMEA team by EPA. These data showed that several prototype Phase 3 systems exhibited much lower peak surface temperatures during operation and hot soak than current Phase 2 systems. Peak temperatures are important because they represent the point of greatest risk for fire and burn.

Noble metals used by catalyst manufacturers to promote emission reduction include platinum (Pt), palladium (Pd), and rhodium (Rh). The catalyst reduction efficiencies are a function of a number of variables including: catalyst formulation, exhaust gas composition, the exhaust gas temperature, and the exhaust gas flow rate. The catalyst operating temperature is dictated by the reduction efficiency. Carbon monoxide is oxidized within the converter to carbon dioxide in the presence of oxygen. Since these engines have higher concentrations of CO than HC or NO_X, the CO conversion is the primary source of exotherm in the exhaust system. The EPA's study found that a loading ratio of Pt:Pd:Rh of 1:3:1 had an advantage in reducing the peak temperature due to CO conversion. About one-half of the final prototype exhaust systems used catalysts with a 1:3:1 ratio and the other half of the converters used catalysts with a 3:1:1 ratio.

Small air-cooled engines such as these tend to run with combustion mixtures or air/fuel ratios which are fuel rich. This means that there is more fuel than required for the volume of combustion air drawn into the engine. The excess fuel keeps combustion temperatures low because it acts as a heat sink much like a mist. In the engine, most of the oxygen is consumed through combustion. Without sufficient oxygen in the exhaust, a catalyst cannot completely oxidize hydrocarbons or carbon monoxide. Although reducing the amount of fuel (enleanment) introduced into the engine would free more oxygen, the higher operating temperatures resulting from leaner operation could adversely affect engine durability. Therefore, EPA investigated the use of both passive and active supplemental air systems, which added air to the exhaust before the catalyst. Passive supplemental air systems rely on an integral venturi in the exhaust pipe to drawn in ambient air (Figure A2-4 and A2-8 show ambient air inlets and venturi location). Active systems use a pump to force air into the exhaust system (Figures A2-11 and A2-27 show a supplemental air tube into the muffler). However, as the Table 3 definition of Class II engines shows, supplemental air is not required for Class II catalyst systems.

Supplementing efforts to reduce surface temperatures, EPA also investigated designs to reduce the likelihood of debris, such as grass cuttings, accumulating on or near the prototype exhaust systems. Cooling system air was ducted to flow additional air around the exhaust system, and larger ducting channels were included to reduce plugging of the cooling air flow passages by debris.

EPA investigated exhaust system temperature control using various methods, as follows:

1) Some of the catalytic converters were placed within production mufflers close to the muffler’s inlet to produce a larger cooling volume after the converter.
2) Some of the mufflers had internal baffles added to redirect the exhaust flow along a longer path before exiting the muffler.
3) The catalyst coatings were designed for lower reduction efficiencies that still met the potential emission standards, but did not create an excessive exothermic reaction as often occurs with high CO conversion efficiencies.
4) The catalyst surface area was controlled by using small catalysts (Figure A2-14) or catalysts with low cell density (Figures A2-15, A2-16, and A2-17).
5) Simple shrouds were placed around the muffler similar to production systems (Figure A2-10) or double walls were added around the muffler (Figure A2-28).
6) More elaborate cooling systems were also utilized which ducted engine cooling air around the catalyzed muffler (Figures A2-21 and A2-24, note the non-shrouded equipment in Figure A2-23), or shrouded and ducted cooling air around the whole exhaust system (Figures A2-36 and A2-40, note the non-shrouded equipment in Figure A2-39).
7) An exhaust flow diffuser was incorporated at the muffler outlet to direct hot exhaust (Figures A2-20 and A2-21).
8) EPA mounted an ejector around the exhaust pipe at the muffler exit (Figure A2-12). By placing an open-ended shroud around the exhaust pipe, the ejector utilizes the

exhaust flow within the shroud to draw cooling air from the other end of the ejector. The ejector thus rapidly cools the muffler's surface and its exhaust gases, and shrouds the hot exhaust pipe exit.

EPA installed fuel injection systems on three Class II engines (Figures A2-33, A2-35, and A2-40). The fuel injection systems replaced the carburetors on these engines with a throttle body to control air flow, and a small injector and engine control module (ECM) from an Asian moped. The ECM controls the fuel injector flow by measuring engine speed and the intake manifold pressure, and then looking up the correct fuel flow from an internal data table. The ECM system also has the capability to be operated in closed-loop control by sensing the exhaust oxygen level with an exhaust-gas-oxygen (EGO) sensor in the exhaust pipe (Figure A2-34 at top left). The EGO sensor signals the ECM when the air/fuel mixture is leaner or richer than stoichiometry (exact air-fuel mixture for complete combustion) and the fuel injector flow is adjusted by the ECM to add or subtract fuel accordingly. The use of fuel injection systems was only investigated with larger Class II engines because of higher cost, and because the larger engines have cooling systems which are more effective in controlling the increased combustion temperatures due to enleanment. This analysis does consider carbureted engines, however, prototypes were not available at the time of this report.

C. Definitions and Constraints for this study

The Phase 2, Class I and Class II engines and equipment in this study were defined to be typical of current non-catalyst, production, consumer products. "Typical" in this case means the product has average features and performance. The team used this definition throughout the analysis.

It was useful for the team and the FMEA review process to clearly define the specific characteristics of Class I and Class II product. This was accomplished by listing the major differences between Class I and the Class II products. The differences between small spark ignited, Class II engines (equal to or greater than 225 cubic centimeters displacement and less than 19 kilowatts of rated power) and Class I engines (less than 225 cubic centimeters displacement and less than 19 kilowatts of rated power) include:

1. The Class II engine is larger in physical size.
2. The Class II engine has higher power.
3. The Class II engine has a wider range of quality in design, materials, fuel lines, fuel tanks, location of the fuel tank, engine, and mufflers.
4. The Class II engine intake manifolds are of higher quality and more robust.
5. The Class II engine exhaust system is more robust.
6. The Class II engine cylinder head temperatures are normally lower in general. (exceptions: engines without cylinder head cooling fins)
7. The Class II engine cooling fins are larger and wider apart which reduces the possibility of debris buildup.
8. The Class II engine heat rejection from exhaust is substantial, and may radiate to ground.

9. The Class II engine mufflers are remotely mounted from engine, and closer to the ground than Class I designs.
10. The Class II engine mufflers are often supplied by the equipment (not engine) manufacturer.
11. The Class II engine carburetors are typically of higher quality and have a wider functional range (low idle to rated power).
12. The Class II engine carburetors have idle fuel circuits, and altitude compensation.
13. The Class II engines are typically equipped with fuel cutoff solenoid in float bowl.
14. The Class II engine can have automatic chokes on the carburetors. (Honda has mechanical timer, some use exhaust heat and a bi-metallic choke control)
15. The Class II engine will typically be of an over head valve (OHV) design.
16. Some Class II engines are 2-cylinder designs. This means that the engines can operate on one cylinder and be more prone to backfire.
17. The Class II equipment fuel tanks are often supplied by equipment (not engine) manufacturer.
18. The Class II equipment is more prone to accidental rollover. (Note: this is expected to be true, but intentional tipping of Class I equipment is very high for maintenance activity).
19. The Class II equipment has more fuel capacity and more fuel is resident in the fuel system components.
20. The Class II engines are used on a wider range of equipment.
21. For two-cylinder, Class II engines, a loss of ignition in one cylinder may overheat a catalyst if the engine continues to operate.
22. Class II engine fuel injection systems with a closed-loop control may be employed. (Westerbeke, and Kohler already sell fuel-injected, CL-control generators with catalysts.)
23. Most Class II engines have electric starters and alternators.
24. The Class II engines are more durable and most are designed to be durable in commercial operation.
25. Some Class II engines have high pressure lubrication systems.
26. The Class II equipment, typically locates the operator closer to the engine. (i.e. Riding mowers, and turf equipment).
27. The Class II equipment fuel tank can be remotely mounted from engine.

In addition to the above Class I and Class II information, it was equally important to define the characteristics of Phase 3 products. A list of characteristics was created in co-operation with EPA to more clearly describe the Class I and Class II, Phase 3 products for this study. It is acknowledged that some of the characteristics listed in Table 3 currently appear on Phase 2 products, but it was projected that all Phase 3 engines will have these design, manufacturing and quality improvements. This characterization process was necessary since production Phase 3 engines and equipment are not yet available. The characteristics of Phase 3 products adopted for the purpose of conducting this study are shown in Table 3.

Table 3. Projected Phase 3 Engine Characteristics for the FMEA

Item No.	Class I Lawnmower Engine	Class II Ride-on Mower Engine
1	Application of catalyst (moderate activity 30-50%) designed to minimize CO oxidation, maximize NO_x reduction, with low HC oxidation efficiency at high exhaust-flow-rates and high HC oxidation efficiency at low-exhaust flowrates. This design is expected to minimize catalyst exotherm.	Application of catalyst (moderate activity 30-50%) designed to minimize CO oxidation, maximize NO_X reduction, with low HC oxidation efficiency at high exhaust flowrates and high HC oxidation efficiency at low-exhaust flowrates. This design is expected to minimize catalyst exotherm.
2	Cooling and shrouding of engine and muffler to minimize surface temperatures. Use of heat shielding and/or air-gap insulated exhaust components to minimize surface temperatures.	Cooling and shrouding of engine and muffler to minimize surface temperatures. Use of heat shielding and/or air-gap insulated exhaust components to minimize surface temperatures.
3	Design flow paths/baffles through the mufflers to incorporate flame arresting design features, to improve heat rejection to muffler surfaces and to spread heat rejection over a large surface area of the muffler. This will reduce the incidence of backfire and reduce localized hot spots.	Design flow paths/baffles through the mufflers to incorporate flame arresting design features, to improve heat rejection to muffler surfaces and to spread heat rejection over a large surface area of the muffler. This will reduce the incidence of backfire and reduce localized hot spots.
4	Different catalyst substrates (ceramic, metal monolith, hot tube, metal mesh) can be successfully used.	Different catalyst substrates (ceramic, metal monolith, hot tube, mesh) can be successfully used.
5	The use of air ejectors to cool exhaust gases at the muffler outlet and to improve cooling of heat shielding.	The use of air ejectors to cool exhaust gases at the muffler outlet and to improve cooling of heat shielding.
6	Use of a small amount of passive supplemental air to improve exhaust chemistry at light load, but designed so bulk exhaust remains rich of stoichiometry at all conditions, and flow-limited at high exhaust flowrates. This design minimizes risk of excessive catalyst exotherm.	Use of carburetor recalibration to improve exhaust chemistry at light load conditions.
7	Use of fuel filter and/or improved design needle and seat in carburetor to minimize problems caused by fuel debris.	Improved air/fuel ratio control through tighter manufacturing tolerances to minimize variation.
8	Improved intake manifold design to reduce intake manifold leaks.	No anticipated design changes.
9	Cooling system designed to reduce the accumulation of debris, including the use of a mesh or screen on cooling fan inlet, when lacking in current design.	Cooling system designed to reduce the accumulation of debris.
10	Improved ignition system design to be more reliable and durable than on Phase 2.	Improved ignition system design to be more reliable and durable than on Phase 2.
11	Improved component design and manufacturing processes to reduce air-fuel ratio production variability to stabilize engine performance and emissions.	Component changes are not expected. Improved manufacturing processes to reduce air-fuel ratio production variability to stabilize engine performance and emissions.
12	Locate fuel tanks away from heat sources.	Locate fuel tanks away from heat sources.

13	Use of carburetors with appropriate idle circuits, float-bowl vent, and automatic choke or improved primer bulb. This will improve fuel system reliability.	Use of carburetors with appropriate idle circuits, float-bowl vent, and automatic choke. This will improve fuel system reliability.
14	Locate the exhaust port away from the carburetor/fuel line to minimize carburetor heating.	No anticipated design changes.
15	Improved exhaust system design and materials for better durability and reliability.	No anticipated design changes.
16	Improved muffler/catalyst/equipment design since currently, the muffler designs do not incorporate catalysts.	Improved muffler/catalyst/equipment design since currently, the muffler designs do not incorporate catalysts.
17	Evaporative emission controls: hoses, tank, cap, and evaporative emission control system.	Evaporative emission controls: hoses, tank, cap, and evaporative emission control system.
18	As Needed: non-contact, bi-metal thermal switch to disable ignition system to shut engine down in event of excessive temperature.	As Needed: non-contact, bi-metal thermal switch to disable ignition system to shut engine down in event of excessive temperature. Manufacturers will need to consider the potential trade-off of disengaging engine power on ride-on equipment if were to occur on a slope.

D. Sources of Data and Information

The FMEA study used several sources of information, as outlined below:

SwRI FMEA Team Member Experience:

The team's personal and professional experience with the type of equipment being analyzed was used to conduct the FMEA. This included the creation of the FMEA report formats. SwRI's staff and titles can be found in Section 3-A.

Environmental Protection Agency (EPA) Staff Input

Technical discussions and review of the available OEM and prototype hardware with EPA provided the detailed technical information and insight that was necessary for the review. Thermal test data of OEM and prototype hardware provided a basis for decisions on thermal issues. A sample and a brief discussion of the thermal image data provided by EPA are shown in Attachment 3. EPA staff also acted as a consultation team to the FMEA tables and report.

The EPA NVFEL staff members assisting with the FMEA include: Glenn Passavant – Non-Road Center Director; Joe McDonald – Mechanical Engineer, NVFEL; and Cheryl Caffrey – Mechanical Engineer, NVFEL

Consumer Product Safety Commission (CPSC) Staff Input

CPSC staff provided real-world scenarios of operator burns and fires associated with spark-ignition lawn mowers. Four databases were used to compile the data; the U.S. Consumer

Product Safety Commission's National Electronic Injury Surveillance System (NEISS), Injury and Potential Injury Incidents (IPII), In-Depth Investigations (INDP) and the U.S. Fire Administrator's National Fire Incident Reporting System (NFIRS). Where possible, the data spanned a five-year period, 2000 – 2004. CPSC staff also provided review and input to the FMEA tables and report. The CPSC Directorate for Engineering Sciences staff assisting with the FMEA include –Susan Bathalon, Mechanical Engineer, John Murphy, Mechanical Engineer, and Sarah Brown, Engineering Psychologist in the Human Factors Division.

References:

SwRI performed a literature search to identify documents related to this study. Attachment 4 lists the documents found in the literature search. These documents were reviewed by the team to identify current safety specifications for small off road engines (< 19 kW). The information in these references was used by the team to:

1. Identify the maximum allowable operating temperatures in available standards and guidelines:

    - Consumer Turf Care Equipment:
        - "A guard or shield shall be provided to prevent inadvertent contact with any exposed components that are 'hot' and may cause burns during normal starting and operation of the machine" from ANSI B71.1
        - "All surface which exceed 65.5° C (150° F) at 21° C (70° F) ambient and which might be contacted by the operator during normal starting, mounting, operating or refueling shall be indicated by a safety sign located on or adjacent to the surface." From ASAE S440.3
    - Commercial Turf Care Equipment:
        - "Lawn and garden equipment requires a shield if temperatures exceed 90 °C for non-metallic surfaces and 80° C for metallic surfaces" for ANSI B71.4;
        - "Hot surfaces (engine, hydraulic, transmissions, etc.) that exceed a temperature of 90° C (194° F) for nonmetallic surfaces, or 80° C (176° F) for metallic parts while operating at 21° C (70° F)" for ANSI B71.4;
    - Multi-position Small Engine (handheld engine):
        - "Temperatures shall not exceed 550° F for exposed surfaces and 475° F for exhaust gases" per USDA Forest Service Standard 5100-1 as tested under SAE J335 test procedure).

NOTE: *This search did not locate a mandatory standard which defined temperature limits for surfaces on consumer lawn and garden equipment. The standards listed above are voluntary only. There are regulations/guidelines for spark arresters used in off-highway vehicles (SAE J350, SAE J342), handheld equipment engines (SAE J335) and other small engines.*

2. Identify the control volume used for the Design FMEA studies (see Attachment 7 for this study's Control Volume).

3. Identify how previous equipment safety documents were related to this FMEA study; surface temperatures, debris fires, and safe handling and operation. (See Attachment 4).

4. Identify the current safety concerns of regulatory and standard setting organizations relative to sparks, surface temperatures, fire suppression, noise, operator safety and test procedures.

The literature search information allowed the team to understand the different perspectives that exist when considering product safety. Attachment 13 discusses: (1) auto ignition; (2) what constitutes a fire; (3) what constitutes a burn (temperature, material and exposure.

E. FMEA Process and Documentation Structure

The typical FMEA process is defined in detail in SAE standard 1739. In an effort to help the reader understand the mechanics and structure of the FMEA process, a summary explanation is provided below.

The FMEA process is not rigidly dictated. There is considerable leeway for the FMEA team to deviate from the SAE standard in order to best suit the requirements of a specific review. In the case of this Work Assignment FMEA, the team created a worksheet format structure, and developed a ranking process that was appropriate for the study of Class I and Class II lawn mower engines from a safety perspective.

In Attachment 5, a typical Design FMEA worksheet format is presented. This format is similar to the Design FMEA worksheet format that is shown as an example in the SAE standard 1739. Attachment 6 presents the worksheet format that the FMEA team chose for this study. When comparing the two examples, several differences can be seen, and these are explained below:

Column Positions:

The column positions of the worksheet were modified considerably for this study. The team felt that the resulting format was easier to follow.

Added Columns:

The worksheet (Attachment 6) included a Contributing Cause column to assist the team in the evaluation process. In some cases, a secondary cause was identified, but in other cases a primary cause was felt to be sufficient. The addition of the Contributing Cause information does not alter the fact that the FMEA only addresses single point failures as previously discussed in Section 2 above. Since the study was to evaluate the incremental differences between Phase 2 and Phase 3 equipment, ranking columns were added for both phases. In effect, both a Phase 2 FMEA and a Phase 3 FMEA were performed within each Design FMEA process for both the walk-behind and ride-on mowers.

To classify the Effects of the failure modes, a “Classification of Effect’ column was added to distinguish between (1) Safety, (2) Regulatory, (3) Performance, and (4) Other Effects.

Severity, Occurrence and Risk Priority Number columns were added for Phase 3 engines to provide a side-by-side comparison with Phase 2 engines. Finally, a column was added to show the difference between the Phase 2 and the Phase 3 RPN (RPN Delta).

Deleted Columns

The Detection value column was deleted from the FMEAs. Detection is useful principally in FMEAs where the team that is responsible for the analysis has direct knowledge of their organizations’ ability to detect design problems before the product is released to the market. In the case of this Work Assignment, the team is composed of people that are independent of any specific engine manufacturer. Consequently, direct understanding of the detection process was limited. Detection also can differ considerably among Class I and Class II engine manufacturers and equipment OEM’s. Further, if Detection were to be utilized, the team decided that all detection numbers would have to be the same by default, due to the limited knowledge of and the variance among manufacturers’ processes. Therefore, removing the Detection ranking number from the process had no effect on the relative Risk Priority Number rankings. As a result, it was decided that the ranking parameter of Detection would not be considered, and would not be part of the FMEA analysis or the FMEA worksheet.

To understand the FMEA process, it is important to understand the definitions of the terms used.

1. *Risk Priority Number (RPN)*: This is one of the primary output of the FMEA process. The RPN value is the product of the ranking values. In this study, the RPN is the product of the Severity Ranking and the Occurrence Ranking (S x O = RPN). The RPN is used to classify the failure modes to help identify which modes are likely to be the most serious. In industry the RPN values from the FMEA would be used to direct the efforts to make improvements to the product or process (The corrective action is typically targeted for completion prior to production release of the product in question). A high failure mode RPN does not always suggest a high occurrence. When failure modes are associated with Effects (see item 4 below) that have a high Severity ranking (see 5 below) the RPN suggests that if the failure mode does occur (no matter how remote), a serious consequence potentially could result. Typically, any FMEA line item with a severity ranking of 9 or 10 requires that a study be conducted to assess how the potential failure mode that could result in the serious consequences could be mitigated.

2. *Potential Failure mode*: A means by which a component, subsystem or system could potentially fail. In the typical FMEA process the definition of failure modes is a speculative process and defines a failure that "could" happen.

3. *Potential Cause*: This is the identification of the potential cause of the failure mode. This is often an indication of a potential component or system design flaw or weakness which leads to a failure of the subsystem or system to perform the intended function. The failure could be due to a direct failure of the component or system, or could be caused by external factors. There should be at least one cause identified for each potential failure mode. In some cases, a contributing cause was identified, but in other cases a primary cause was felt to be sufficient.

4. *Potential Effects of Failure*: The potential effects of the failure are the results of the component, subsystem or system failing to perform the intended function. Safety effects should be explicitly identified. EPA field data and CPSC real world incidents were helpful in identifying some potential effects of failure. There is usually the potential of multiple effects associated with each potential failure mode, including "no effect".

5. *Severity*: This is a ranking parameter which is an assessment of the relative seriousness of an effect for any failure mode. Typically, the range of ranking values is between 1 and 10 (never zero). Each effect needs to be ranked for severity. Table 4 presents the definitions used in this analysis for the Severity Ranking. In this study the effect "burn risk" was assigned a severity ranking of 9; the effect: "increased risk of fire or burn" was ranked a severity 9; and "fire" was ranked a severity of 10.

6. *Occurrence*: This is a ranking parameter which is an assessment of the likelihood that the potential failure mode (which is the result of the cause or causes) will happen. Typically, the range of ranking values is between 1 and 10 (never zero). Table 5 presents the definitions used in this analysis for the Occurrence Ranking. Note: *The Occurrence is related to the failure mode, not the Effect of the failure mode.*

The Severity and Occurrence tables were developed by the SwRI team. The Dyadem *FMEA-Pro* software used to manage the FMEA process came with pre-installed Severity, Occurrence, and Detection tables. However, the SwRI team decided that the Dyadem definitions for the Severity and for the Occurrence ranking were more typical of automotive products, and needed revision. The team chose definitions, which better represents Class I and Class II small engines. The ranking values and definitions are shown in Tables 4 and 5 shown below.

Table 4. Severity Ranking Definitions

Ranking	Effect	Severity of Effect - Customer
10	Hazardous	Hazardous effect. Safety Related. Regulatory non-compliant
9	Serious	Potential hazardous effect. Able to stop without mishap. Regulatory compliance in jeopardy.
8	Extreme	Item inoperable, but safe. Customer very dissatisfied
7	Major	Performance severely affected, but functional and safe. Customer dissatisfied
6	Significant	Performance degraded, but operable and safe. Customer experiences discomfort
5	Moderate	Performance moderately affected. Fault on non-vital requires repair. Customer experiences some dissatisfaction
4	Minor	Minor effect on performance. Fault does not require repair. Non-vital fault always noticed. Customer experiences minor nuisance.
3	Slight	Slight effect on performance. Non-vital fault noticed most of the time. Customer slightly annoyed.
2	Very Slight	Very slight effect on performance. Non-vital fault may be noticed. Customer is not annoyed.
1	None	No effect.

Table 5. Occurrence Ranking Definitions

Ranking	Probability	Likely Failure Rates
10	Almost Certain	Greater than / Equal to 1 in 2
9	Very High	1 in 3
8	High	1 in 8
7	Moderately High	1 in 20
6	Medium	1 in 80
5	Low	1 in 400
4	Slight	1 in 2000
3	Very Slight	1 in 10,000
2	Remote	1 in 50,000
1	Almost Impossible	≤1 in 500,000

Note 1: *For the Design FMEA the Occurrence Ranking is related to the design life of the equipment.*
Note 2: *For the Process FMEA the Occurrence Ranking is related to a one-year operation period.*

The Design and Process FMEA methodology for this work consisted of the following steps:

1. Define the system to be studied (ref: Attachment 7)
   - This activity depends on the project scope and relies on the expertise of the team members.

2. List the items in the system
   - This activity is intended to make sure each team member is well versed in the sub elements of the system or component being evaluated.

3. List the major functions of each item or element
   - This activity is intended to make sure that the team has identified all of the main functions of the system or component being studied.

4. Anticipate the possible Failure Modes for each item
   - This activity uses experience and engineering judgment to identify the most likely ways the system or component could fail.

5. Consider possible Causes
   - Determine what could be the cause of the failure mode.

6. Determine the potential effects of each failure mode
   - This activity develops a list of what the team members would expect to be the possible results or effects of the particular failure mode.

7. Rank the Severity of the potential effect of the failure mode
   - This activity is based on experience and judgment. The team defines the severity of the effect and assigns a Severity value.

8. Determine the likelihood that the particular failure mode would occur
   - This activity requires the team estimates or use data to project how often the particular failure would likely occur and assigns an Occurrence value.

9. The Risk Priority Number (RPN)
   - This is calculated by multiplying the Severity ranking value of the potential effect of the failure mode by the Occurrence ranking value. The RPN parameter relates to each failure mode and is a primary output of the FMEA analysis. It is intended to drive focus on the areas needing product improvement. The highest ranked potential failures should get further attention and the lowest ranked items may not be addressed at all.

10. Perform Failure Analysis on Phase 2 and Phase 3 engines
   - Since the study considered incremental changes between Phase 2 and Phase 3 engine; each had to be analyzed and ranked separately.

11. RPN Delta (Phase 2 versus Phase 3)
   - This value is the difference between the Phase 3 RPN and the Phase 2 RPN. A positive number suggests an improvement for Phase 3.

The ranking process for an FMEA is adapted to the particular study being conducted. In the case of this FMEA, the Occurrence of the Failure Mode and the Severity of the Effects were ranked using the list of criteria presented in Tables 4 and 5. The ranking definitions and the specific ranking process were established by consensus of the team. The ranking process is generally unique for each study and team. One exception is that any Effect of a Failure that is defined as hazardous or potentially hazardous is ranked as a 10 or 9, respectively. In addition, in this study parallel Design FMEAs were conducted for Phase 2 and Phase 3 engines in order to identify the expected incremental risk.

4.0 DISCUSSION OF RESULTS

OVERVIEW

This FMEA was conducted to identify and assess potential safety differences between engines/equipment meeting EPA Phase 2 emission standards and engines/equipment meeting potential EPA Phase 3 standards. This analysis covered both equipment using Class I (<225cc) and Class II (≥225cc) engines. For the Class I engines, the equipment identified were a typical walk behind lawnmower. For Class II, the equipment identified was a typical ride on mower.

Two different types of FMEAs were prepared. The first was a Design FMEA. This was prepared for Class I and Class II engines. The second was a Process FMEA. This was prepared for the processes of refueling, maintenance and storage of the aforementioned equipment. The Design FMEAs will be discussed first followed by the Process FMEAs, and then more general conclusions about the work. The complete tables of results for the two Design FMEAs for Class I and Class II engines/equipment can be found in Attachments 8 and 9. The complete tables of results for the three Process FMEAs for refueling, maintenance and storage can be found in Attachments 10, 11, and 12, respectively.

Design FMEA

The Design FMEAs were completed using a systems approach. The system, subsystem and components most likely to be modified for compliance with potential exhaust and evaporative requirements were considered. Twelve systems/subsystems were evaluated. This was deemed an essential part of the process because of the technical interdependency of these systems, and the potential interaction among these systems in potential failure mode situations.

The twelve systems evaluated included those listed in Table 6.

Table 6. FMEA Systems Evaluated

1	Intake air filter	7	Exhaust manifold, muffler, muffler shroud and gasket
2	Carburetor system	8	Supplemental air (Class I only)
3	Governor	9	Catalyst (monolith, matting)
4	Intake manifold, port, valve and seals	10	Cooling system
5	Block	11	Ignition system
6	Exhaust valve and seal	12	Fuel tank and line

The Design FMEAs were structured and conducted in the following manner.

1. The systems and functions were identified.

2. Inputs for the row items of each system/function combination were determined (Potential Cause (Contributing), Potential Cause (Primary), Potential Failure Modes, Potential Effect(s) of Failure).

3. Ranking were established for Severity and Occurrence.

4. Values were assigned for the Phase 2 engine: Occurrence of the Potential Failure Mode and Severity of the Potential Effect(s) of Failure

5. Values were assigned for the Phase 3 engine: Occurrence of the Potential Failure Mode and Severity of the Potential Effect(s) of Failure

6. Calculation of RPN's for Phase 2 and Phase 3 and calculation of difference in RPN (Phase 3-Phase 2)

7. Include notes to describe important items in the decision making for each line item.

8. Classify the Effect (Safety, Regulatory, Performance, Other)

This work leaned heavily on the teams understanding of engines, combustion, fuels and how primary and contributing causes can translate into potential failure modes. Each member of the team was given opportunity to add input and speak to the need for refinement and changes. The reports and data provided by CPSC were important and identified some of the potential failure modes and effects.

Process FMEAs

Input received from various sources and the CPSC reports and data revealed processes which led to potential problems in use. EPA felt that specific analysis of these three areas was important because they represent typical life-cycle use for the product. The Process FMEAs conducted by the team included refueling, maintenance, and storage. While some of the information and results from the Design FMEAs carry across to the Process FMEAs, the difference is in the introduction of the operator to perform these functions. These Process FMEAs were completed with heavy reliance on the technical information, the expertise of the team members and input from the CPSC reports and data.

RESULTS

Complete FMEA summaries are included in the Attachments 8 through 12. A subset of these results that relate only to safety items are presented in Tables 7 through 11. Tables 7 and 8 cover Class I and Class II Design FMEA safety items, and Tables 9 through 11 cover refueling, shutdown and storage, and maintenance Process FMEA safety items, respectively.

Design FMEAs – Discussion of Safety Tables for Class I and Class II

In Table 7, Class I engine FMEA safety items are grouped by systems/subsystems, i.e. intake air filter, carburetor system, governor, and others as presented in Table 6. Intake air filter failures (dirty, missing filters) can cause engine operation to switch either richer or leaner. Richer operation (reference item 1) could cause a backfire, which could result in a fire or burn. Fire or burn is always classified with a severity of 10. The team rated the occurrence of this failure mode to be reduced for the Phase 3 product relative to the Phase 2 product. This difference is based on experience with EPA prototype Phase 3 engines, which showed reduced incidence of backfire with catalyst, principally due to the flame arresting function provided by the catalyst. For intake air failure mode (reference item 2), a leaner mixture can create slightly higher exhaust temperatures. Since baseline (non-failure mode) exhaust temperatures are already high enough to cause burns, this failure mode only incrementally increases severity of the burn. Since catalyst application does not increase the occurrence of the failure mode, the RPN values are the same for Phase 2 and 3 products. This increase could be mitigated by application of a thermal cutoff switch, designed to shut the engine off at a specified temperature.

The next four failure modes (reference items 3 through 6) have to do with the carburetor system. Restrictions in fuel passages (reference item 3) could result in higher engine and/or catalyst temperatures with the resulting potential effect of a fire or touch burn. This effect rates a severity of 10. While the Phase 3 engine's catalyst may increase the thermal load around the engine, the improvements in manifold air cooling will mitigate these effects. The RPN rankings are thus the same for Phase 2 and Phase 3 product. As is the case above, this effect could be mitigated for either Phase 2 or 3 products by application of a thermal cutoff switch.

Carburetor system failure mode (reference item 4), backfire, is caused by a richer mixture which can be caused by float malfunctions, a stuck choke, or other causes. As in the case of the intake air filter associated backfire, (reference item 1) the team felt the incidence of this would be reduced with catalyst application, thus resulting in a reduced RPN for the Phase 3 product.

Carburetor system failure modes (reference item 5 and 6) involve fuel leakage to a surface where it can potentially be ignited, causing a fire or burn (severity 10). The incidence of this occurring was rated the same with or without a catalyst since adequate ignition temperatures are already present in existing Phase 2 product. Also, fuel can be ignited by the ignition system, which is present in both Phase 2 and Phase 3 product.

A governor malfunction, where the governor does not close the throttle can result in an overspeed, which can cause mechanical engine failure where parts fail or come apart due to excessive speed (reference item 7). Occurrence of this type of failure is very low, and is the same with or without a catalyst.

A significant crack or leak in the intake manifold (reference item 8) can result in a leaner mixture which could lead to increased temperatures in the exhaust systems or catalyst. Potential effects are fire or burn (severity 10). The Phase 3 engine has a significantly lower occurrence due to improvement in intake manifold system design, including the use of gaskets. SwRI recently performed a teardown and inspection of 10, field aged, Class I, Phase 2 engines. Eight of the 10 were found to have leaky intake manifolds. This type of problem will need to be addressed on Phase 3 products to assure in-use emissions compliance.

Engine failures can be caused by excessive temperatures (reference 9 and 10). This can result from higher thermal loads due to higher engine loading or a mechanical problem. Sufficiently high temperatures can cause failure or seizure of an internal component, rendering the engine non-functional. A catastrophic engine failure could create a safety hazard from flying debris or an engine fire. In both cases, the occurrence is rated to be the same with or without a catalyst. As discussed above, these failure modes could be mitigated for either Phase 2 or 3 products by application of a thermal cutoff switch.

The next three failure modes (reference items11 through 13) are related to problems with the exhaust manifold. Gasket failures can cause leaks which can cause burns. Occurrence of this failure mode is reduced for Phases 3 product due to the use of improved exhaust system designs and/or improved materials. Debris accumulation around the exhaust manifold can result in a fire (reference item 12). Occurrence of this failure mode is reduced for Phase 3 product due to improved designs of the cooling air ducting systems. Another potential failure mode is the loss of the muffler shroud. This can also result in fire or burn. Occurrence of this failure mode is again reduced due to improvement in the design of the air ducting system. Thus in all three cases, RPN ratings for exhaust manifold related failure modes are reduced with Phase 3 product, principally due to improvements in design. These same improvements could be effected in Phase 2 product, if desired.

The next failure mode is associated with the catalyst system. The RPN value is higher for Phase 2 due to the absence of catalyst on the Phase 2 product. If in manufacturing, the incorrect catalyst were installed on the engine or the catalyst was installed improperly (reference item 14), excessive temperatures could result if the catalyst has higher catalytic activity than the proper catalyst for that engine. It should be noted that the occurrence of this failure mode for Phase 3 product is relatively low. Further, the occurrence of this mode can be reduced by application of a thermal cutoff switch if the design team determined it was needed.

The next two failure modes result from problems with the cooling system (reference items 15 and 16). A failure of the cooling system shroud (reference item 15) that directs cooling air can result in higher temperatures that present a burn risk. Presence of a catalyst has no effect of the occurrence or severity of this failure and thus Phase 2 and Phase 3 products have the same RPN. The pluggage of cooling passages by debris will tend to increase the component temperatures and could result in a burn risk. Due to the expected design improvements in the cooling system features of the Phase 3 product, the Phase 3 RPN is lower than the Phase 2 product. These problems associated with the cooling system could be mitigated, again, by the use of a thermal cutoff switch.

Ignition system problems can cause a variety of failure modes. A bad spark plug or ignition wire or a problem with the ignition module or the magneto can result in a weak or intermittent spark (reference item 17). This can potentially result in higher muffler and catalyst temperatures and an increased burn risk. Ignition system problems can also result in misfire (reference item 18), which can cause a fire of burn. Phase 3 RPN is less than that for Phase 2 product due to the reduced incidence of backfire when a catalyst is applied, as demonstrated by EPA.

Fuel tank problems can present possibilities for fuel leaks which can result in fires or burns. High muffler or catalyst temperatures could melt nearby fuel lines resulting in a fuel leak. For reference items 19, 20, 21, 22 and 23, the application of fuel evaporative emission controls will reduce leak occurrence, resulting in lower RPNs for Phase 3 product. For the other three cases, the presence of a catalyst does not affect the rankings; they are the same with or without a catalyst.

Table 7. Class I Safety FMEA Items

Class I Safety FMEA Items

Ref. Item No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
1	Intake Air Filter	Degradation or tear of filter element, wrong filter or dirty or missing filter. Prefilter not oiled	richer mixture	backfire	fire or burn	1_Safety	10	3	30	20	10	2	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
2	Intake Air Filter	Degradation or tear of filter element, wrong filter or dirty or missing filter. Prefilter not oiled	leaner mixture	hotter exhaust	fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst because there will be no increase in burn risk with the application of a properly designed catalyst. The effect could be mitigated by the presence of a thermal switch.
3	Carburetor System	Restriction in fuel passages, wrong jets in production or production variability	leaner mixture	higher temperature in engine and catalyst	fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst. Any effect that the catalyst might have on temperature level is offset by the expected improvements in air cooling of the manifold system on Phase 3 products. If the change in temperature is significant the effect could be mitigated by the presence of a thermal switch.
4	Carburetor System	Float breaks, debris in float needle, or wrong jets in production, choke stuck closed or production variability	richer mixture	backfire	fire or burn	1_Safety	10	5	50	40	10	4	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
5	Carburetor System	gasket failure, or needle valve stuck open, or cracked primer bulb	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel ignites	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst because exposed muffler temperatures are nominally equivalent. Fuel can be ignited by hot surfaces or the ignition system.

Class I Safety FMEA Items

Ref. Item No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
6	Carburetor System	gasket failure, or needle valve stuck open, or cracked primer bulb	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel puddles	fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst because exposed muffler surfaces have been shown to be nominally equivalent in Phase 2 (no catalyst) and Phase 3 (catalyzed) prototype systems.
7	Governor	None	Malfunction-ing governor	open governor causes engine overspeed	catastrophic failure (potential injury due to flying parts)	1_Safety	9	2	18	18	9	2	0	Engine failure caused by overspeed. The rankings are the same with or without a catalyst.
8	Intake Manifold	Crack or leak in manifold	leaner mixture	engine, exhaust system and catalyst run hotter	fire or burn	1_Safety	10	9	90	40	10	4	50	The lower occurrence for Phase 3 is due to the expected improvement of the manifold system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
9	Block	Higher thermal load	higher engine temperatures	engine failure (internal component seizure, broken valve or spring, excess wear)	catastrophic failure (potential injury due to flying parts)	1_Safety	9	4	36	36	9	4	0	Engine failure caused by excessive temperatures. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
10	Block	Higher thermal load	higher engine temperatures	engine failure (internal component seizure, broken valve or spring, excess wear)	fire or burn	1_Safety	10	4	40	40	10	4	0	Engine failure can result in contact with hot metal or fluids. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
11	Exhaust Manifold	None	loosening of muffler, manifold or failed gasket (gasket is less common on Class I vertical shaft engines)	exhaust leak	fire or burn	1_Safety	10	6	60	40	10	4	20	The lower Phase 3 occurrence is due to the Phase 3 improved exhaust system design.

Class I Safety FMEA Items

Ref. Item No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
12	Exhaust Manifold	Debris accumulation	reduction in engine cooling and increased muffler temperatures	ignition of debris adjacent to muffler	fire	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting for cooling and control of debris accumulation. In addition, fan inlet screens are expected on all Phase 3 engines. The failure mode could be mitigated by the presence of a thermal switch.
13	Exhaust Manifold	None	removal or mechanical failure of the shroud	loss of muffler shroud	fire or burn	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting for cooling and shroud design.
14	Catalyst	Manufacturing, supplier or installation problem	incorrect or improperly installed catalyst	excessive catalyst performance	fire or burn	1_Safety	1	1	1	20	10	2	-19	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential safety impact. The effect could be mitigated by the presence of a thermal switch.
15	Cooling System	None	cooling system shroud failed	loss of cooling to engine block and muffler system	burn risk	1_Safety	9	2	18	18	9	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
16	Cooling System	None	plugging of cooling passages due to debris	reduction of engine cooling	burn risk	1_Safety	9	5	45	36	9	4	9	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
17	Ignition System	None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	weak or intermittent spark (misfire)	excessive muffler or catalyst temperatures and increased burn risk	1_Safety	9	5	45	27	9	3	18	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
18	Ignition System	plug bad, short in plug wire, failed coil, loose flywheel, magneto	loss of spark	backfire (misfire)	fire or burn	1_Safety	10	6	60	40	10	4	20	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.

Class I Safety FMEA Items

Ref. Item No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
19	Fuel Tank	None	leak of tank or line	fuel puddles	fire or burn	1_Safety	10	5	50	40	10	4	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
20	Fuel Tank	None	leak of tank or line	fuel puddles	operator fuel exposure	1_Safety	9	5	45	36	9	4	9	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
21	Fuel Tank	None	leak of tank or line	fuel leaks on hot component	fire or burn	1_Safety	10	4	40	30	10	3	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
22	Fuel Tank	High muffler or catalyst temperatures near fuel lines	fuel tank or line melted	fuel puddles	fire or burn	1_Safety	10	3	30	20	10	2	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
23	Fuel Tank	High muffler or catalyst temperatures near fuel lines	fuel tank or line melted	fuel puddles	operator fuel exposure	1_Safety	9	3	27	18	9	2	9	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
24	Fuel Tank	High muffler or catalyst temperatures near fuel lines	fuel tank or line melted	fuel leaks on hot component	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst. The exposed muffler temperatures are nominally equivalent.

Table 8 presents a summary of Class II engine FMEA safety items. In many cases, Class II engine safety items are similar or identical to those for Class I engines. Discussion will focus or areas with significant differences.

While most Class II engines currently use carburetors, several use fuel injection systems and it is likely more will do so in the future. Carburetor system items (reference items 3 through 7) can be caused by either carburetor or fuel injection system problems. Fuel pump or pressure regulator failures can cause the leaner mixture problem in reference item 3. This can also be caused by fuel filter or injector restrictions, or problems with injection system wiring, or MAP (manifold absolute pressure) sensors, ECMs (engine control modules), or by oxygen (O_2) sensor failures. For backfire failure modes associated with carburetors (reference item 4), the catalyst will reduce incidence of backfire, as demonstrated by EPA, thus producing lower RPN values for the Phase 3 product.

Another type of fuel injection system failure is presented in reference item 7, where an ECM or a solenoid valve return spring failure could allow fuel to flow into a non running engine. This could puddle or leak from the engine, and could ignite causing a fire. This failure mode is unaffected by the presence of a catalyst; thus the RPN values are the same for Phase 2 and 3 engines.

For Class II engines with a MAP sensor, a leak in the intake manifold can cause the MAP to read a higher pressure that would command a richer mixture (reference item 10). This could produce a backfire, potentially causing a fire or burn. RPN values are the same with or without a catalyst.

Another type of failure mode more specific to Class II products is equipment tip-over. This can happen where the operator is mowing on a slope, for example, and reaches an angle where the equipment rolls over (reference item 23). In such cases, fuel can leak from the fuel tank and potentially catch fire. The evaporative emission controls expected for Phase 3 will reduce the leak occurrence, and thus the Phase 3 RPN is also lower. Available data suggests the Phase 3 product could have directionally cooler exhaust system temperatures as demonstrated by EPA. Cooler exhaust temperature will improve the risk of fire due to equipment tip over further.

Table 8. Class II Safety FMEA Items

Class II Safety FMEA Items

Ref. No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
1	Intake Air Filter	Degradation or tear of filter element, wrong filter or dirty or missing filter.	richer mixture	backfire	fire or burn	1_Safety	10	2	20	20	10	2	0	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. The occurrence is held the same for Phase 2 and 3 in this case since Class II, Phase 2 products are already judged to have a relatively low occurrence of backfire due to intake filter issues.
2	Intake Air Filter	Degradation or tear of filter element, wrong filter or dirty or missing filter.	leaner mixture	hotter exhaust	fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst because there will be no increase in fire or burn risk with the application of a properly designed catalyst. The effect could be mitigated by the presence of a thermal switch.
3	Carburetor System	Restriction in fuel passages, wrong jets in production, or choke stuck open, or production variability. Fuel injection system fuel pump or fuel pressure regulator failure. Fuel filter or injector restriction. Injector wiring connection degraded. MAP, ECM, or O2 sensor failure.	leaner mixture	higher temperature in engine and Catalyst	fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst. Any effect that the catalyst might have on temperature level is offset by the expected improvements in air cooling of the manifold system on Phase 3 products. If the change in temperature is significant the effect could be mitigated by the presence of a thermal switch.

Class II Safety FMEA Items

Ref. No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
4	Carburetor System	Float breaks, debris in float needle, or wrong jets in production, choke stuck closed, or production variability. Fuel injection fuel system fuel pressure regulator failure. Fuel injector stuck open. MAP, ECM, O2 sensor failure.	richer mixture	backfire	fire or burn	1_Safety	10	4	40	30	10	3	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
5	Carburetor System	gasket failure, or needle valve stuck open, or fuel pump / regulator leak	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel ignites	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst because exposed muffler temperatures are nominally equivalent. Fuel can be ignited by hot surfaces or the ignition system.
6	Carburetor System	gasket failure, or needle valve stuck open, or fuel pump / regulator leak	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel puddles	fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst because exposed muffler surfaces have been shown to be nominally equivalent in Phase 2 (no catalyst) and Phase 3 (catalyzed) prototype systems.
7	Carburetor System	ECM failure, solenoid return spring breakage causes fuel cutoff solenoid open failure	fuel flow into and from engine	fuel puddles	fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst.

Class II Safety FMEA Items

Ref. No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
8	Governor	None	malfunctioning governor	open governor causes engine overspeed	catastrophic failure (potential injury due to flying parts)	1_Safety	9	2	18	18	9	2	0	Engine failure caused by overspeed. The rankings are the same with or without a catalyst.
9	Intake Manifold	Crack or leak in manifold	leaner mixture	engine, exhaust system and catalyst run hotter	fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
10	Intake Manifold	Intake manifold leak causes MAP to read higher pressure	richer mixture	backfire	fire or burn	1_Safety	10	3	30	30	10	3	0	The failure relates to fuel Injected engines. EPA demonstrated that the backfire impact was reduced with the addition of a properly designed catalyzed muffler system for Class I. However, since the design quality of the Class II equipment mufflers is very good on Phase 2, the impact of adding the catalyst is minimal.
11	Block	Higher thermal load	higher engine temperatures	engine failure (internal component seizure, broken valve or spring, excess wear)	catastrophic failure (potential injury due to flying parts)	1_Safety	9	3	27	27	9	3	0	Engine failure caused by excessive temperatures. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
12	Block	Higher thermal load	higher engine temperatures	engine failure (internal component seizure, broken valve or spring, excess wear)	fire or burn	1_Safety	10	3	30	30	10	3	0	Engine failure can result in contact with hot metal or fluids. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
13	Exhaust Manifold	None	cracked muffler, manifold or failed gasket	exhaust leak	fire or burn	1_Safety	10	4	40	30	10	3	10	The lower Phase 3 occurrence is due to the Phase 3 definition of improved exhaust system design.
14	Exhaust Manifold	Debris accumulation	reduction in engine cooling / increased muffler temperatures	ignition of debris adjacent to muffler	fire	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting for cooling and control of debris accumulation.

Class II Safety FMEA Items

Ref. No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
15	Exhaust Manifold	None	removal or mechanical failure	loss of muffler shroud	fire or burn	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting design for cooling and shroud design.
16	Catalyst	Manufacturing, supplier or installation problem	incorrect or improperly installed catalyst	increased catalyst performance	fire or burn	1_Safety	1	1	1	20	10	2	-19	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential safety impact. The effect could be mitigated by the presence of a thermal switch.
17	Cooling System	None	plugging of cooling passages due to debris	reduction of engine cooling	burn risk	1_Safety	9	4	36	27	9	3	9	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
18	Cooling System	None	cooling system shroud failed	loss of cooling	burn risk	1_Safety	9	2	18	18	9	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
19	Ignition System	None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	weak or intermittent spark, or loss of ignition in one of two cylinders (misfire)	excessive muffler or catalyst temperatures and increased burn risk	1_Safety	9	3	27	27	9	3	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
20	Ignition System	bad plug, short in plug wire, failed coil, loose flywheel, magneto	loss of spark	Backfire (misfire)	fire or burn	1_Safety	10	4	40	30	10	3	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
21	Fuel Tank	None	leak of tank or line	fuel puddles, or sprays	fire or burn	1_Safety	10	3	30	20	10	2	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
22	Fuel Tank	None	leak of tank or line	fuel puddles, or sprays	operator fuel exposure	1_Safety	9	3	27	18	9	2	9	The rankings are the same with or without a catalyst.
23	Fuel Tank	Equipment tip over, material failure, component failure	leak of tank or line	fuel contacts hot component	fire or burn	1_Safety	10	3	30	20	10	2	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence

Class II Safety FMEA Items

Ref. No.	Item	Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
24	Fuel Tank	High muffler or catalyst temperatures near fuel tank	fuel tank or line melted	fuel puddles or sprays	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst.
25	Fuel Tank	High muffler or catalyst temperatures near fuel tank	fuel tank or line melted	fuel puddles or sprays	operator fuel exposure	1_Safety	9	2	18	18	9	2	0	The rankings are the same with or without a catalyst.
26	Fuel Tank	High muffler or catalyst temperatures near fuel tank	fuel tank or line melted	fuel contacts hot component	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst.

Process FMEAs – Discussion of Safety Tables

Tables 9 – 11 summarize safety related failure modes and effects for Class I and Class II engines. These tables are for Process FMEAs, which consider failure modes which can occur in the course of a process or an operation. Table 9 considers engine refueling. Table 10 addresses the process of engine shutdown and storage; and Table 11 is for maintenance processes.

Safety issues associated with refueling principally involve fuel spillage which can result in a fire. Refueling failure mode, reference item 1, involves a scenario where the operator has not shut off the engine before refueling (Table 9). The potential effect of this failure mode is the risk of refueling while the engine is still running. Thermal images taken by EPA of current Phase 2 product and prototype Phase 3 product indicate that exhaust surface temperatures at idle are similar. In addition, EPA is not expected to propose measures to reduce spillages related to the refueling process as part of its Phase 3 rulemaking. Since the thermal characteristics between Phase 2 and Phase 3 products are expected to be similar and the human factors associated with the refueling process are the same in each case, the RPN values are ranked equally for the Phase 2 and Phase 3 products for all refueling process scenarios.

Table 9. Refueling Process FMEA

Refueling Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
1	Shut off engine	failed to shut engine off	engine running	risk of refueling while engine running and a potential of a fire or burn	1_Safety	9	2	18	No difference between Phase 2 and Phase 3 expected. Thermal images indicate that at idle operation the maximum surface temperatures are comparable for Phase 2 and Phase 3 designs.
2	Open mower cap	overpressure of fuel tank	spillage (hot fuel, full tank, pressurized tank - i.e. vent blocked)	operator contact w/ fuel	1_Safety	9	2	18	A safety concern, but no significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
3	Open mower cap	overpressure of fuel tank		spillage onto hot surfaces and a potential of a fire or burn	1_Safety	9	2	18	A safety concern, but no significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
4	Open mower cap	overpressure of fuel tank		fire	1_Safety	10	2	20	A safety concern, but no significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
5	Remove fuel can cap	operator behavior	Fail to open vent	fuel spillage	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
6	Remove fuel can cap	hot fuel and high pressure(high temperature storage, heating from sunlight)	fuel spray upon opening cap/vent	operator contact w/ fuel	1_Safety	9	2	18	A safety concern, but no difference between Phase 2 and Phase 3 expected.
7	Remove fuel can cap	hot fuel and high pressure(high temperature storage, heating from sunlight)		spillage	1_Safety	9	2	18	A safety concern, but no difference between Phase 2 and Phase 3 expected.
8	Remove fuel can cap	operator behavior		spillage	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
9	Remove fuel can cap	operator behavior		vapor released from can	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.

Refueling Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
10	pick up can and pour	fuel spill	fuel puddle on equipment	fuel fire	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
11	pick up can and pour	fuel spill	fuel spill into fan inlet	fuel fire	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
12	pick up can and pour	fuel spill	fuel over the cowling and makes contact with a hot exhaust system component	fuel fire	1_Safety	10	4	40	A safety concern, but effectively no difference between Phase 2 and Phase 3 expected. Thermal imaging cross-validation studies indicated that "…the application of a catalyst to a small gasoline engine does not increase, and can actually lower, exhaust system surface temperatures…"
13	pick up can and pour	fuel spill	spill on operator and/or bystander	fuel exposure	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
14	pick up can and pour	fuel spill	spill on operator and/or bystander	fuel fire and burn	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
15	pick up can and pour	fuel spill	spillage on surrounding areas	fuel fire and burn	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
16	pick up can and pour	fuel spill	spillage on surrounding areas	creates combustible material	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
17	pick up can and pour	material failure	gas can cracks	fuel spill and potential of fire or burn	1_Safety	9	3	27	A safety concern, but no difference between Phase 2 and Phase 3 expected.
18	pick up can and pour	engine running	refuel while running	spill fuel	1_Safety	9	2	18	A safety concern, but no difference between Phase 2 and Phase 3 expected.
19	pick up can and pour	engine running	refuel while running	fuel vapor ignites	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.

Refueling Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
20	pick up can and pour	static charge	spark	fire or explosion	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
21	pick up can and pour	gas cap on can is not secure	spillage on surrounding areas	fire or burn	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
22	Recap the Mower Tank	failure to recap mower tank	fuel spillage or vapor release onto equipment or operator during operation	fire	1_Safety	10	3	30	A safety concern, but no difference between Phase 2 and Phase 3 expected.
23	Recap the Mower Tank	failure to recap mower tank		fuel exposure	1_Safety	9	3	27	A safety concern, but no difference between Phase 2 and Phase 3 expected.
24	Restart	fuel on the equipment	ignition component failure	fire or burn	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
25	Restart	fuel or debris left on the equipment	hot surfaces ignites	fire or burn	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.

Table 10 presents failure modes that can occur during equipment shutdown and storage. In several cases, failures can result from inability to shut the engine off. The operator can be burned while trying to disconnect the spark plug wire. Another failure mode can occur if the operator covers the equipment with a tarp while it is still hot. The tarp could catch fire and damage the equipment or even cause a structural fire if the equipment had been moved indoors. Fires can also result from storage of hot equipment on or next to combustible materials, such as newspapers. In all cases, there are no differences between RPNs for Phase 2 and Phase 3 equipment.

Table 10. Shutdown and Storage Process FMEA

Shutdown and Storage Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
1	Engine Shut Down	ignition cut off and engine brake fail (and engine does not shut off)	engine left running, and operator may pull plug wire to stop	high surface temperatures, and risk of fuel ignition from high voltage spark and risk of shock	1_Safety	9	2	18	No difference between Phase 2 and Phase 3 expected
2	Engine Shut Down	engine won't stop and operator goes for help	untended operation	bystander gets injured by burn	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
3	Engine Shut Down	engine won't stop and operator goes for help		debris fire	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
4	Engine Shut Down	engine won't stop and operator pulls plug wire	risk of fuel ignition due to high voltage spark	fire or burn	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
5	Engine Shut Down	engine won't stop and operator pulls plug wire	operator contacts hot component	burn	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
6	Equipment Storage	cover with tarp while engine hot (any material)	tarp ignites	fire ignites adjacent materials	1_Safety	10	2	20	Tarp ignites and fire could spread. No impact due to addition of a catalyst.
7	Equipment Storage	cover with tarp while engine hot (any material)		fire damages equipment	1_Safety	10	2	20	Tarp ignites and fire could spread. No impact due to addition of a catalyst.
8	Equipment Storage	store in or near garage or shed when engine hot	equipment ignites combustible material	structural fire	1_Safety	10	1	10	Surrounding material could ignite. No impact due to addition of a catalyst. Data available does not support a higher occurrence ranking.
9	Equipment Storage	store in or near garage or shed when engine hot	water heater pilot light ignites gasoline vapor from leak, spill or refueling	structural fire	1_Safety	10	1	10	Gas vapor could ignite. No impact due to addition of a catalyst. Data available does not support a higher occurrence ranking.
10	Equipment Storage	store in or near garage or shed when engine hot	Spilled fuel or debris on mower deck ignites	Equipment or structural fire	1_Safety	10	1	10	Debris on the mower deck could ignite. No impact due to addition of a catalyst. Data available does not support a higher occurrence ranking.

Shutdown and Storage Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
11	Equipment Storage	store in or near garage or shed when engine hot	operator and/or bystander contacts hot component	burn	1_Safety	10	2	20	No impact due to addition of a catalyst.
12	Equipment Storage	park equipment on combustible debris	debris ignites	debris fire	1_Safety	10	2	20	Surrounding material could ignite. No impact due to addition of a catalyst.
13	Equipment Storage	park equipment on combustible debris	debris ignites	structural fire	1_Safety	10	2	20	Surrounding material could ignite. No impact due to addition of a catalyst.
14	Equipment Storage	park equipment on combustible debris	debris ignites	bystander gets injured by burn	1_Safety	10	2	20	No impact due to addition of a catalyst.
15	Equipment Storage	park equipment on combustible debris	debris ignites	fire damages equipment	1_Safety	10	2	20	Surrounding material could ignite. No impact due to addition of a catalyst.

The Equipment/Engine Maintenance Process FMEA is included in Attachment 12. Table 11 addresses only the maintenance processes with potential safety effects. These include cleaning the equipment, changing the oil and filter, changing the spark plug, sharpening the mower blade, and replacing the drive belt. Possible failure modes and resulting effects can include burns from contact with hot surfaces, fires caused by fuel or oil spillage, or personal injury from equipment tip over. Additionally, if the drive belt is improperly installed, it can slip and get very hot, potentially causing a fire. For the fuel spillage scenarios, vapor control requirements will reduce the occurrence of fuel spillage with Phase 3 product. For all other cases, the presence of a catalyst does not increase the RPN value above that for Phase 2 product.

Although a Process FMEA was not conducted to specifically address lack of maintenance of Class I or Class II engines, the causes, failure modes, and effects due to lack of maintenance are addressed within the Equipment/Engine Maintenance Process FMEA and/or the Design FMEAs. The maintenance processes which are typically performed by the equipment operator which, if neglected, could have incremental effects with operation of Phase 3 engines are as follows:

1. Equipment Cleaning: The Equipment/Engine Maintenance Process FMEA does not address lack of cleaning. However, Sections 10 and 9 “Cooling System” of the Class I and Class II Design FMEAs (Attachments 8 and 9) respectively, do address plugging of cooling passages by debris. The Occurrence and RPN associated with plugging due to lack of cleaning is expected to be reduced with Phase 3 engines.

2. Engine Oil and Oil Filter Maintenance: In Attachment 12, reference number 10 addresses lack of maintenance. In addition, if engine oil was not replaced or kept at an adequate level, the effects due to a higher thermal load is identified in Item 5 “Block, Power Head” in Attachments 8 and 9. No difference between Phase 2 and Phase 3 engines is expected.

3. Air Filter Maintenance: Lack of maintenance is described in references 25 and 26 of Attachment 12. The effects in Attachment 12 are general, however, in the Design FMEAs specific effects due to the two Potential Causes (Primary) are identified in Item 1 “Intake Filter”. For example, a richer or leaner mixture could result if the air filter was not maintained or replaced at regular intervals. A reduction in safety related RPN, and an increased in RPN associated with failing to meet emissions regulations were identified due to filter degradation.

4. Spark Plug Maintenance: The cause, failure, and effect that could be envisaged from lack of maintenance of the spark plug is addressed in reference 28 of Appendix 12, and in Items 11 and 10 “Ignition System” of the Class I and Class II engine Design FMEAs, respectively. No increased safety related RPN was identified, however, there is an incremental RPN associated with failing to meet emissions regulations due to a lack of maintenance.

5. Carburetor Maintenance: Lack of maintenance of the carburetor is not addressed in the Equipment/Engine Maintenance Process FMEA. However, if carburetor

maintenance was not performed causing restricted fuel passages or allowing debris accumulation in the float bowl, these contributing causes are identified in Item 2 "Carburetor or Fuel Injection System" in the Design FMEAs. A reduction in safety related RPN, and an increased RPN associated with failing to meet emissions regulations were identified due to fuel passage restriction or debris accumulation within the fuel system.

Table 11. Maintenance Process FMEA

Maintenance Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
1	Cleaning Equipment	Tip equipment to clean underneath	spill fuel or oil	fire	1_Safety	10	8	80	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 70.
2	Cleaning Equipment	Tip equipment to clean underneath		operator exposure to fuel or oil	1_Safety	9	8	72	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 63.
3	Cleaning Equipment	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected
4	Change Oil / Filter	Improper maintenance	spill oil	operator exposure to oil	1_Safety	9	9	81	No difference between Phase 2 and Phase 3 expected
5	Change Oil / Filter	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected
6	Change Oil / Filter	Tip equipment for maintenance	spill fuel or oil	fire	1_Safety	10	8	80	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 70.
7	Change Oil / Filter	Tip equipment for maintenance		operator exposure to fuel or oil	1_Safety	9	8	72	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 63.
8	Change Air Filter	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected
9	Change Spark Plug	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected
10	Change Spark Plug	testing for spark	spark ignites fuel	fire	1_Safety	10	3	30	No difference between Phase 2 and Phase 3 expected
11	Sharpen Blade	tipping equipment for blade access	equipment falls	personnel injury	1_Safety	10	5	50	No difference between Phase 2 and Phase 3 expected
12	Sharpen Blade	tipping equipment for blade access	spill fuel or oil	fire	1_Safety	10	8	80	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 70.

Maintenance Process FMEA

Ref. Item No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
13	Sharpen Blade	Improper reassembly	spill fuel or oil	personnel injury	1_Safety	10	1	10	No difference between Phase 2 and Phase 3 expected
14	Replace Drive Belt	wrong belt installed	belt slips or does not engage	belt fire / debris fire	1_Safety	10	4	40	No difference between Phase 2 and Phase 3 expected
15	Replace Drive Belt	belt installed incorrectly	belt slips or does not engage	belt fire / debris fire	1_Safety	10	3	30	No difference between Phase 2 and Phase 3 expected
16	Replace Drive Belt	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected

5.0 CONCLUSIONS

Design FMEAs

The safety summary tables for the Design FMEAs for Class I and Class II engines contain 49 potential failure modes. For 28 of these, there was no difference in Risk Priority Number (RPN) between Phase 2 and Phase 3 product designs. There are also 19 potential failure modes for which there is a decreased RPN due to improvements in Phase 3 product design, and two for which there is an increased RPN.

As can be seen in Table 3, EPA's Phase 3 designs improve on Phase 2 designs in several key areas. EPA's Phase 3 design includes features which are key to implementing catalyst-based standards and fuel evaporative emission controls, with overall comparable or lower RPNs, which helps to address safety-related shortcomings in the current Phase 2 engines evaluated. Data supplied by EPA showed comparable or better results in key areas such as exhaust system surface temperatures, backfire/misfire performance, and post use cool down.

Overall, the Design FMEAs indicate that from a safety perspective, Phase 3 designs can be comparable, if not directionally better than Phase 2 for both Class I and Class II products.

This FMEA report relies on laboratory and field data collected by the EPA which shows that the use of catalyst on small SI engines, if properly designed, could result in exhaust system temperatures which are comparable or lower than current product in the marketplace. The main features of EPA's Phase 3 system design include use of cooling air from the fan to flow across the catalyzed muffler and engine block, control of CO emission reductions to reduce the CO oxidation exotherm, and a properly designed and located heat shield. However, as is the case with mufflers on current product, thermal images taken of catalyzed mufflers show that temperatures are still above the second degree burn temperature for skin.

It is the nature of the FMEA process to consider interdependencies and interactions among subsystems. That is, the FMEA looks at how a failure of as subsystem or component to properly perform its intended function can affect other subsystems and components. In this way, potential effects on the catalyzed muffler and changes in catalyst performance affecting safety were considered in every item of the Phase 3 analyses. The same is true for the fuel system and fuel system components impacted by fuel evaporative emission controls.

The potential failure modes that represent the two Class I and Class II negative difference RPNs involved the use of an improper catalyst or a mis-installation of a catalyst.

- The engine manufacturer selected a catalyst with the wrong specification or assembled the wrong catalyst component on the engine and the catalyst converted more CO than expected which resulted in increased catalyst temperatures.

While the probability of this failure was ranked as remote, if this was to occur, the failure has the potential to result in higher temperatures of the catalyst muffler/shroud system with the potential effect of risk or a fire or burn.

With regard to burn, this potential effect of failure is probably better characterized as the potential for a more severe (thermal) burn than an increase in the occurrence of thermal burn since Phase 2 exhaust system temperatures are already high enough to cause a thermal burn. In order to have an increase in the occurrence of thermal burn, the designs would have to create a situation where the operator has more frequent contact with the muffler area. During the use of this equipment with Phase 3 engines, the operator need not access the area of the muffler any more frequently than with the current Phase 2 product.

If temperatures of the catalyst muffler/shroud system were to increase beyond those of current product, the incidence of fires may still be the same. This is based on the fact that in order for a fire to happen, the surface temperatures on current products are often above the ignition temperature for combustibles such as dry debris or fuel. In this study, the catalyst mufflers replace the existing mufflers in current locations, but EPA is projecting improvements in cooling approaches to reduce surface temperatures. If the engine or equipment manufacturer elected, it could reduce burn risk by incorporating a bimetallic thermal cutoff switch which would shut off the engine if temperatures exceeded a selected value. This would result in a decrease in the risk of fire or burn. This approach could be used with current Phase 2 product, as well.

Process FMEAs

Three processes were identified for FMEA analysis: refueling, equipment storage, and maintenance. The Process FMEAs were done to identify if there could be any potential for increased concern of Phase 3 engine systems with catalyst mufflers compared to the current Phase 2 product. Due to the fact that these processes are mostly done with the engine off, the processes were analyzed primarily with respect to worst case outcomes after shut-off. It was concluded that there were no additional areas of concern with Phase 3 prototypes versus Phase 2 engine designs. This was based on EPA's thermal data that showed the muffler's hot soak temperatures were comparable, or potentially reduced, with properly designed Phase 3 catalyst systems. In some cases, there was the potential for improvement due to fuel system modifications and upgrades associated with meeting the fuel evaporative emission control requirements EPA is considering.

ATTACHMENT 1

EPA STATEMENT OF WORK

Work Assignment

United States Environmental Protection Agency
Washington, DC 20460

EPA

Work Assignment

Work Assignment Number: 0-10

[X] Original | Amendment Number: [ ]

Contract Number: EP-C-05-018

Title of Work Assignment/SF Site Name: DESIGN/CONDUCT PMEA FOR SMALL SI ENGINES

Contract Period: X Base Option Period No.

Contractor: Swri

Specify Section and Paragraph of Contract SOW: SECTION II, TASK 13

Purpose:

- [X] Work Assignment Initiation
- [ ] Work Assignment Close-Out
- [ ] Work Assignment Amendment
- [ ] Incremental Funding
- [ ] Work Plan Approval

Period of Performance

From: [redacted] 9/1/05 To: 12/31/05

Comments:

SEE ATTACHED SOW

[ ] Superfund

Accounting and Appropriations Data

[X] Non-Superfund

SFO 22 (Max 2)

Note: To report additional accounting and appropriations data use EPA Form 1900-69A.

Line	DCN (Max 6)	Budget/FYs (Max 4)	Code (Max 6)	Budget Org/Code (Max 7)	Program Element (Max 9)	Object Class (Max 4)	Amount	Site/Project (Max 8)	Cost Org/Code (Max 7)
1									
2									
3									
4									
5									

Authorized Work Assignment Ceiling

Contract Period:	Cost/Fee:	LOE:
Previously Approved		HRS
This Action		550 HRS
Total	$0	550 HRS

Work Plan / Cost Estimate Approvals

Contractor WP Dated:	Cost/Fee:	LOE: HRS
Cumulative approved:	Cost/Fee: $0	LOE: [redacted] HRS

Work Assignment Manager Name: [redacted] CHERYL CAFFREY

(Signature) Cheryl McCaffrey (Date) 8/29/05

Branch/mail code: OMS/ASD
Phone No.: 734-214-4803/4849
Fax No.: 734-214-4050

Project Officer Name: ROBERT J. JOHNSON

(Signature) Robert J Johnson (Date) 8/29/05

Branch/mail code: OMS/ASD
Phone No.: 734-214-4393
Fax No.: 734-214-4816

Other Agency Official Name

(Signature) (Date)

Branch/mail code:
Phone No.:
Fax No.:

Contracting Official Name: SANDRA SAVAGE

(Signature) S. Savage (Date) 9/1/05

Branch/mail code: OPOD
Phone No.: 513-487-2046
Fax No.: 513-487-2109

Contractor Acknowledgement of Receipt and Approval of Workplan (Signature and Title) Date

EPA Form 1900-69 (Rev. 07-95) COPY 1 - CONTRACTING OFFICER

STATEMENT OF WORK

WORK ASSIGNMENT 0-10 — EPA Contract EP-C-05-018

A. [redacted] Office: Environmental Protection Agency
2000 Traverwood Drive
Ann Arbor Michigan 48105

B. Contractor: Southwest Research Institute
6220 Culebra Rd., PO Box 28510
San Antonio, TX 78228-0510

C. Statement of Work: Design/Conduct FMEAs for Small SI Equipment and Engines

BACKGROUND

EPA is analyzing the potential safety impact of new emission standards which may require the use of catalysts on small SI engines (<19kW). There are a variety of types of equipment which use these engines, but the overall population is dominated by walk-behind and ride-on lawn and garden equipment. The objective of this work assignment will be to design and perform Failure Mode and Effects Analyses (FMEAs) on Class 1 and Class 2 engines and equipment (at minimum, a walk-behind lawnmower and garden tractor, respectively).

TASK DESCRIPTION

The purpose of this work is to identify and assess incremental risk between the Phase II (current versions) of a number of small SI equipment/ engines and the same equipment/engines modified to meet more stringent emission standards. As part of our technology assessment work, EPA has modified the above stock engine/equipment configurations in such a manner that they meet the California Tier 3 emission standards. Thus, the contractor will need to do FMEAs on both the existing Phase 2 (current production model) and modified Phase 3 configurations of the same basic equipment/engine model. The modified configurations to be considered are those developed by EPA. The number of configurations to be assessed include up to four lawnmowers and three tractors, for a total of eight lawnmowers and six tractors. The specific models will be identified by EPA when work is begun on this work assignment.

NATURE OF THE WORK ASSIGNMENT

The contractor's work plan shall be submitted in accordance with the provisions of the contract. The workplan shall include a breakdown of costs and work hours by task and configuration, and shall provide a breakdown of costs/ hours for the work that will be performed prior to December 31, 2005 and the work, if any, that will be performed after January 1, 2006. The contractor shall also provide a Quality Assurance Project Plan, as specified in Appendix A.

Task 1: Selection of FMEA Approach and Project Team

Several standardized FMEA techniques exist. The contractor and EPA shall discuss these techniques and agree on which is most appropriate for this effort. The contractor shall propose project team members for EPA concurrence. The contractor's team nominations shall include a minimum two experts on small SI engines and one FMEA expert. EPA will provide up to two experts on small engines. Additional technical experts may be involved, as necessary.

Task 2. Setup for FMEA

The contractor shall present an overall plan describing how they will conduct the FMEA work. EPA has performed many tests examining catalyst equipped prototypes on current engine models, and can provide data, pictures, video tapes, and other information as necessary for use in this work. EPA will also provide engineering expertise as necessary to assist in these analyses. As part of this work, the contractor shall include all normal engine/equipment life-cycle events including normal cutting or other operations, refueling, short and long-term storage, maintenance, transport, disposal and others. EPA may also require that the potential solutions to the failure modes be identified and considered in the analysis, especially for the modified configurations. Any FMEA rankings shall include the impact of the identified solution on the ranking of the failure modes.

Task 3. Conduct of FMEAs

The contractor shall conduct FMEAs on each of the eight engines/pieces of equipment. For this task the contractor shall perform the FMEAs on the Phase 2 and Phase 3 small SI equipment/engines as discussed above. THE EPA WAM will make Phase 2 and Phase 3 hardware configurations available to the contractor at the EPA National Vehicle and Fuel Emissions Laboratory (NVFEL) in Ann Arbor, Michigan. The FMEAs shall follow the approach and format agreed upon in Tasks 1 and 2. To provide access to the equipment /engines, the contractor shall perform the FMEA work at the NVFEL.

Task 4: Contractor Report and Presentations

The contractor shall prepare a draft report describing the project. THE EPA WAM will provide comments on the draft report. The report shall present the results of the FMEAs for each configuration, but shall also focus on changes in incremental risk between the Phase 2 and Phase 3 configurations. The contractor shall prepare a final report incorporating any EPA comments. THE EPA WAM may also ask the contractor to make up to three presentations (possibly public) of the project and the results of the FMEA work.

D. Deliverables and Schedule

<u>Deliverables</u>

Draft and final FMEA reports, including discussion text, FMEA with tables and results format as agreed upon with EPA.

Weekly progress reports shall be made via conference calls and e-mails. The weekly progress reports shall include the percentage of the level of effort expended, percent of the task completed to date and any problems. Reports shall be made to the Project Officer, or alternatively to the Work Assignment Manager.

<u>Schedule</u> (from Work Assignment initiation)

Task 1:	Completion within one week of EPA receipt of contractor work plan. Include within deliverable for Task 2.
Task 2:	Two weeks from completion of Task 1.
Task 3:	Six weeks from EPA approval of contractor work plan. Includes completion of all FMEA analyses and draft report.
Task 4:	Final report one week after EPA/contractor coordinate on EPA comments. Presentations to be determined later, but within six months of work plan approval.

E. Work Assignment Managers

ALT. WAM: Joseph McDonald Phone: (734) 214-4803 Fax: (734) 214-4050
WAM: Cheryl Caffrey Phone: (734) 214-4849 Fax: (734) 214-4050

ATTACHMENT 2

REFERENCE PHOTOGRAPHS OF PHASE 2 AND PROTOTYPE PHASE 3 HARDWARE AT EPA

FIGURE A2-1. STOCK BRIGGS QUANTUM SIDE VALVE COMPLETE ENGINE

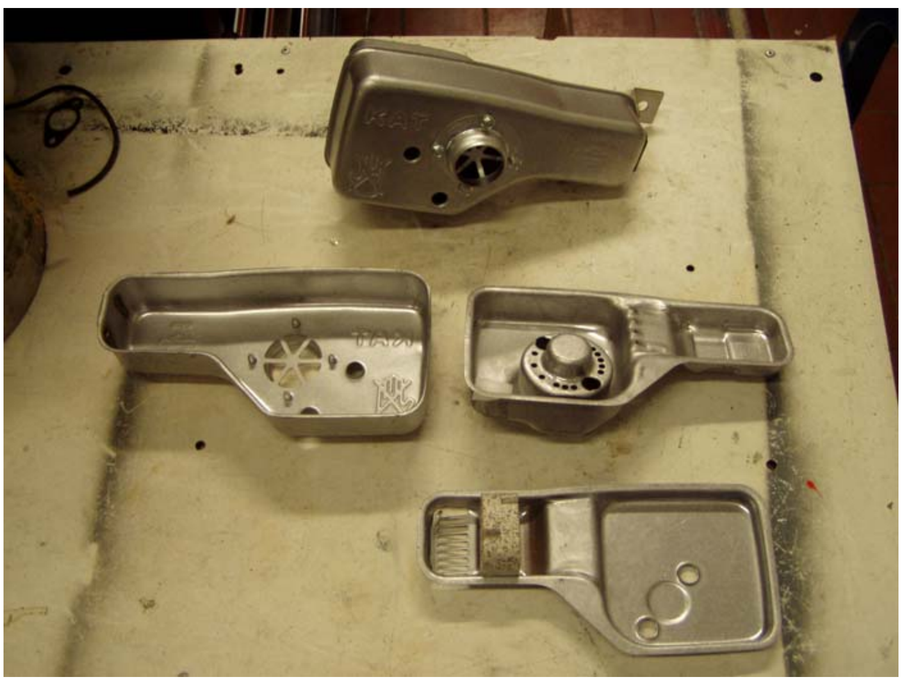


FIGURE A2-2. STOCK BRIGGS QUANTUM EUROPEAN CATALYTIC MUFFLER

FIGURE A2-3. STOCK BRIGGS QUANTUM SV CLOSE UP OF FRONT OF EUROPEAN CATALYTIC MUFFLER

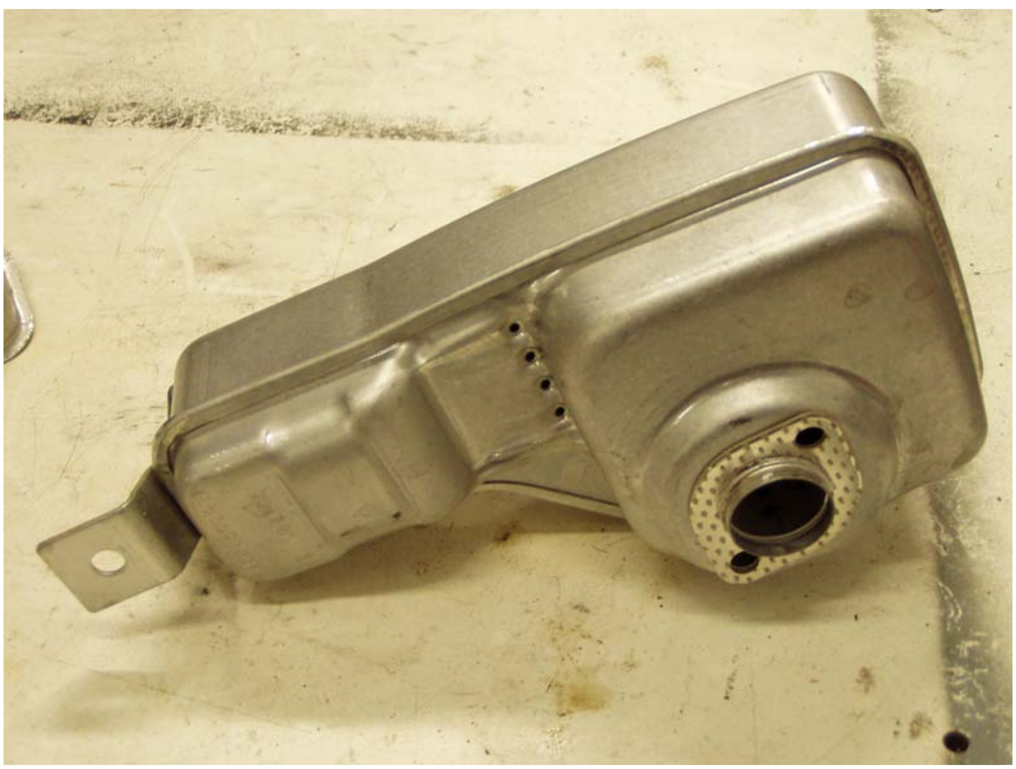


FIGURE A2-4. STOCK BRIGGS QUANTUM SV CLOSE UP OF BACK OF EUROPEAN CATALYTIC MUFFLER

FIGURE A2-5. STOCK BRIGGS QUANTUM SV EUROPEAN CATALYTIC MUFFLER SHROUD

FIGURE A2-6. STOCK BRIGGS QUANTUM SV EUROPEAN CATALYTIC MUFFLER INTERIOR

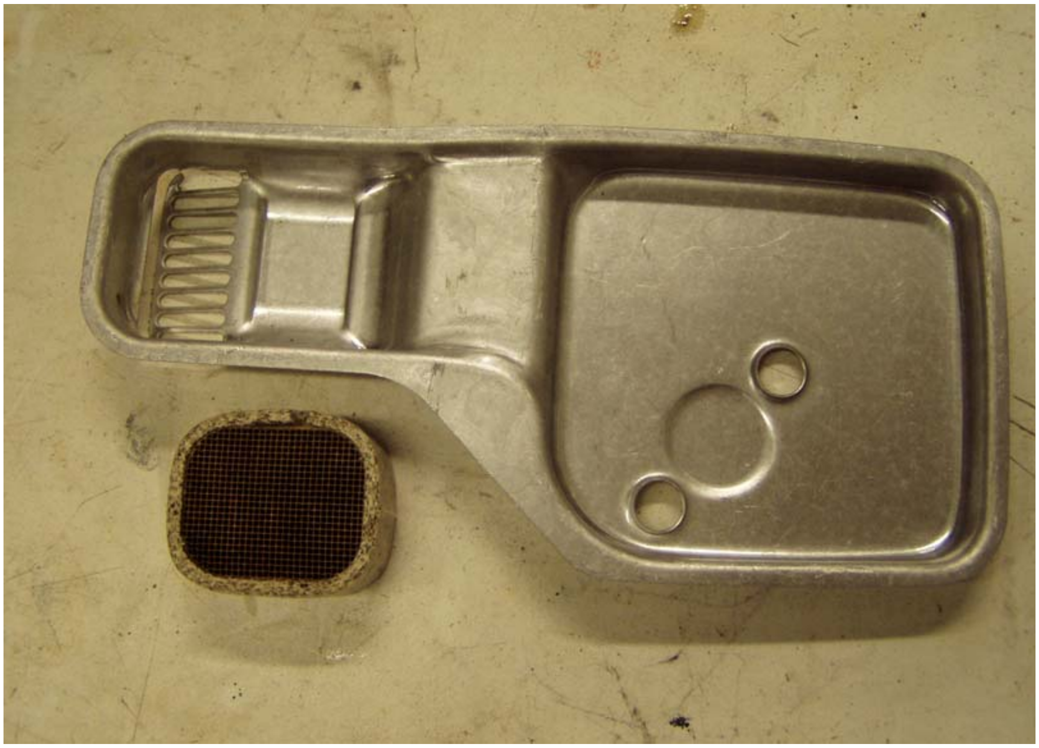


FIGURE A2-7. STOCK BRIGGS QUANTUM SV CENTER EUROPEAN CATALYTIC MUFFLER INTERIOR WITH SUBSTRATE REMOVED

FIGURE A2-8. STOCK BRIGGS QUANTUM SV EUROPEAN CATALYTIC MUFFLER SUPPLEMENTAL AIR VENTURI

FIGURE A2-9. STOCK HONDA GVC 160 WITHOUT MUFFLER

FIGURE A2-10. STOCK HONDA GVC 160 MUFFLER WITH SHROUD

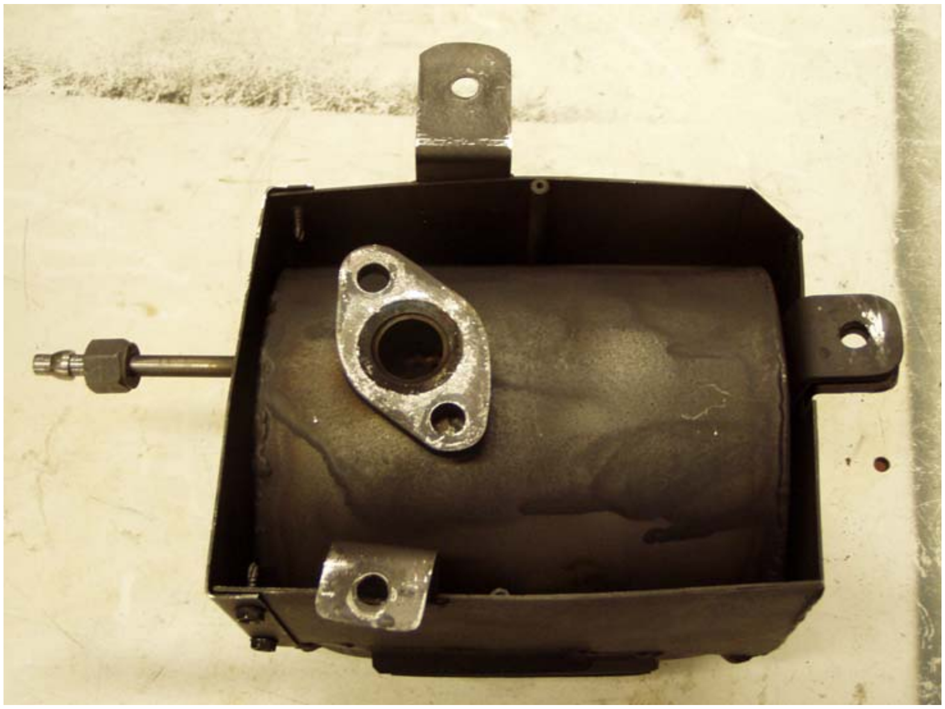


FIGURE A2-11. EPA PROTOTYPE CATALYZED MUFFLER IN SHROUD FOR HONDA GVC 160

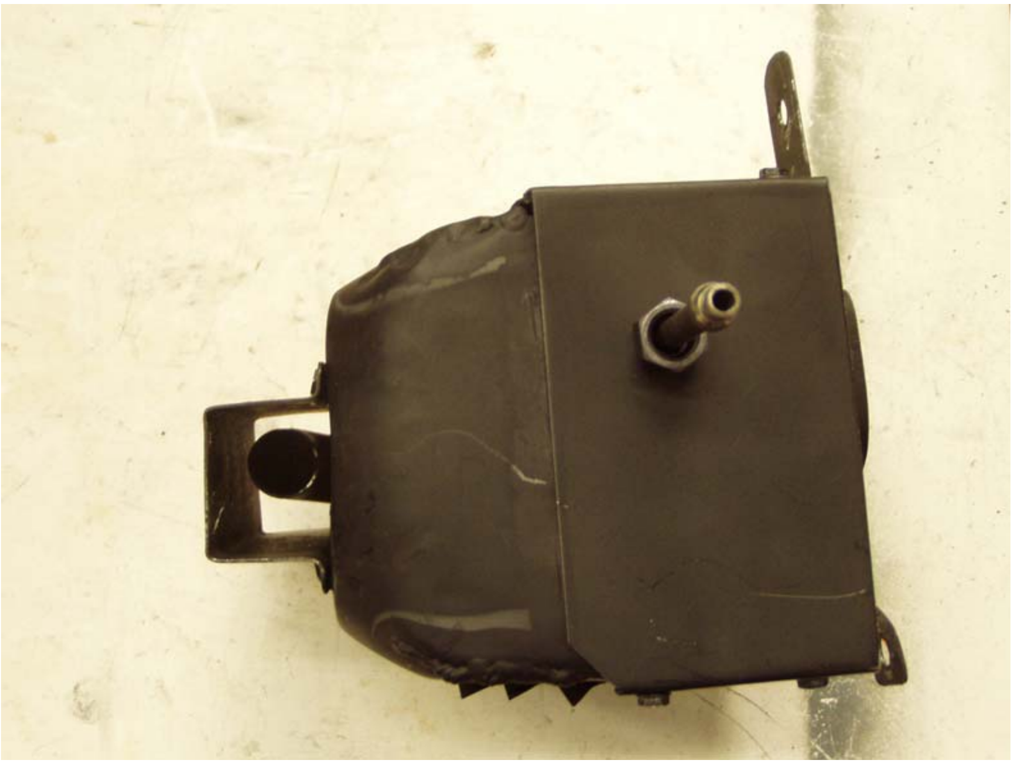


FIGURE A2-12. EPA PROTOTYPE MUFFLER WITH EXHAUST GAS COOLING AIR EJECTOR AROUND EXHAUST FOR HONDA GVC 160

FIGURE A2-13. EPA PROTOTYPE MUFFLER AIR EJECTION TUBE FOR HONDA GVC 160

FIGURE A2-14. EPA PROTOTYPE MUFFLER CERAMIC SUBSTRATE FOR HONDA GVC 160

FIGURE A2-15. TUBE CATALYST FOR INSERTION IN EXHAUST PORT

FIGURE A2-16. PROTOTYPE LOW CELL DENSITY METAL SUBSTRATE CATALYST

FIGURE A2-17. WIRE MESH CATALYST IN MUFFLER

FIGURE A2-18. WIRE MESH CATALYST REMOVED FROM MUFFLER

FIGURE A2-19. STOCK HONDA GVC160 MOWER

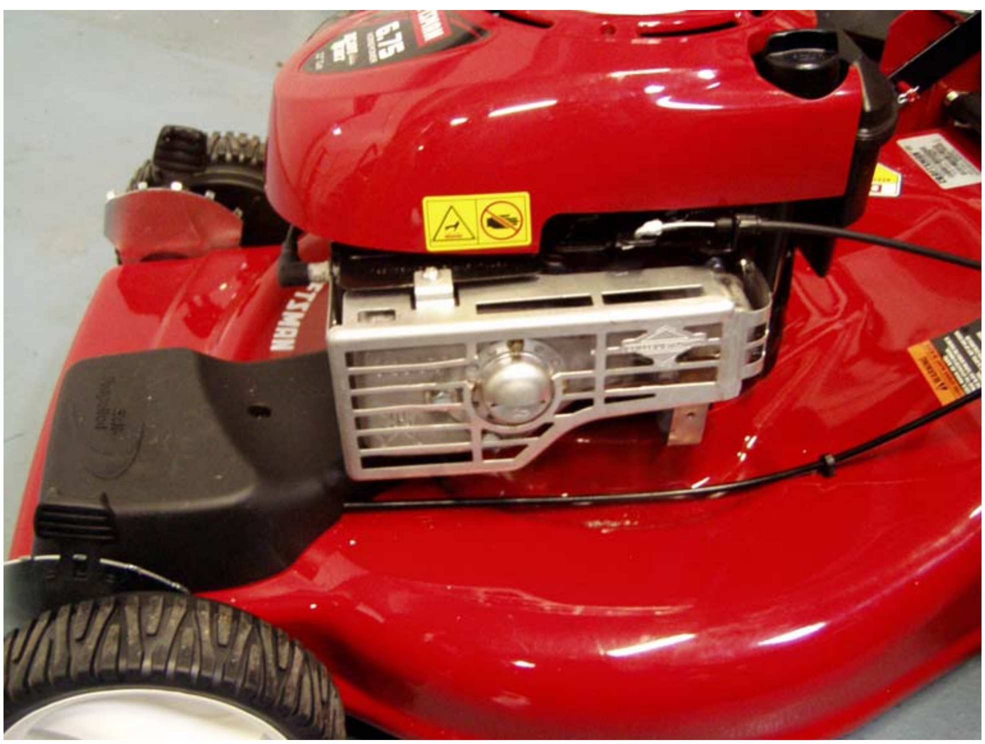


FIGURE A2-20. BRIGGS 6.QUANTUM WITH BRIGGS EUROPEAN CATALYZED MUFFLER

FIGURE A2-21. BRIGGS INTEK ENGINE WITH DUAL SUBSTRATE EUROPEAN MUFFLER AND COOLING AIR DUCT

FIGURE A2-22. STOCK BRIGGS INTEK ENGINE WITH STOCK MUFFLER

FIGURE A2-23. STOCK TECUMSEH LV195BA

FIGURE A2-24. BRIGGS DUAL METALLIC SUBSTRATE EUROPEAN MUFFLER ON TECUMSEH LV195BA

FIGURE A2-25. STOCK KAWASKI FH 601D INTAKE AIR

FIGURE A2-26. STOCK KAWASAKI FH 601D MUFFLER

FIGURE A2-27. KAWASAKI FH 601D MUFFLER WITH AIR INJECTION & CATALYST

FIGURE A2-28. TRIPLE PASS CATALYST WITH DOUBLE WALL

FIGURE A2-29. STOCK MUFFLER WITH INSERTED CATALYST

FIGURE A2-30. STOCK MUFFLER WITH INSERTED CATALYST

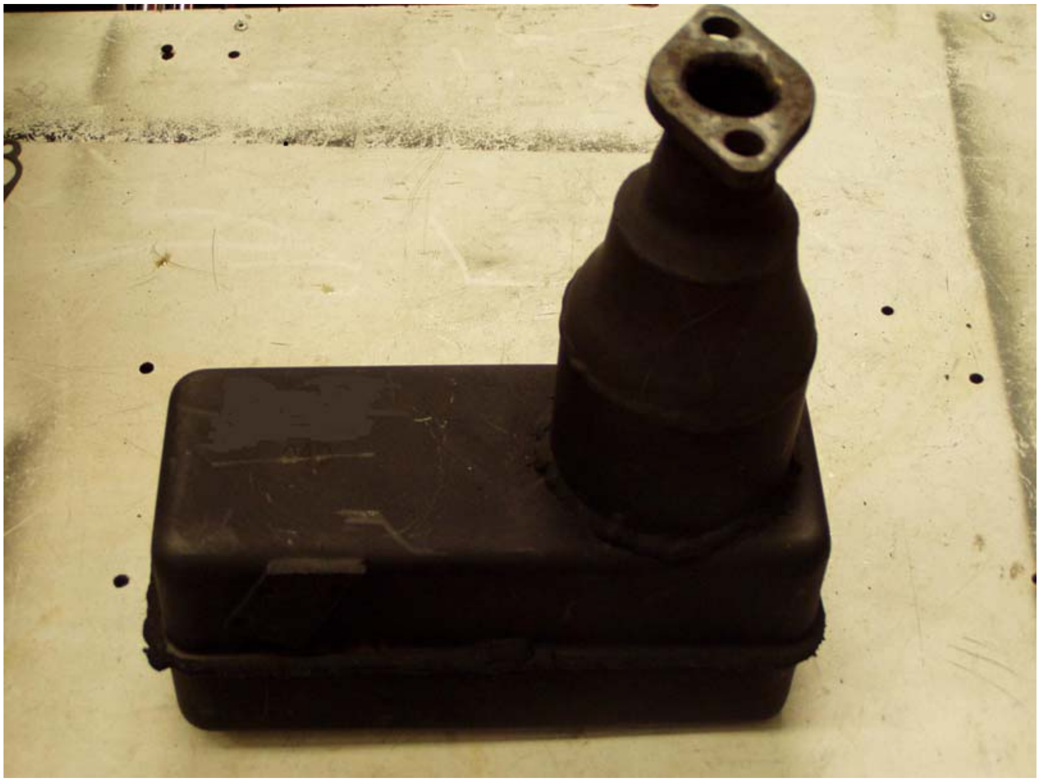


FIGURE A2-31. HIGH EFFICIENCY DUAL CATALYST AHEAD OF MUFFLER

FIGURE A2-32. BRIGGS INTEK 31P777 SHOWING NO HEAD COOLING FINS

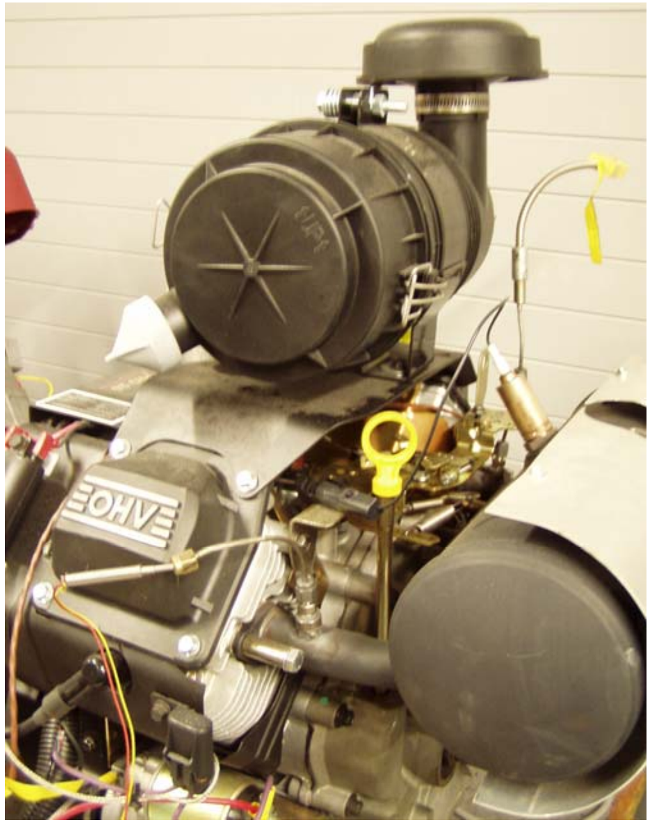


FIGURE A2-33. KOHLER CH26 WITH STOCK MUFFLER WITHOUT CATALYST, WITH EFI WITH EGO SENSOR FEEDBACK

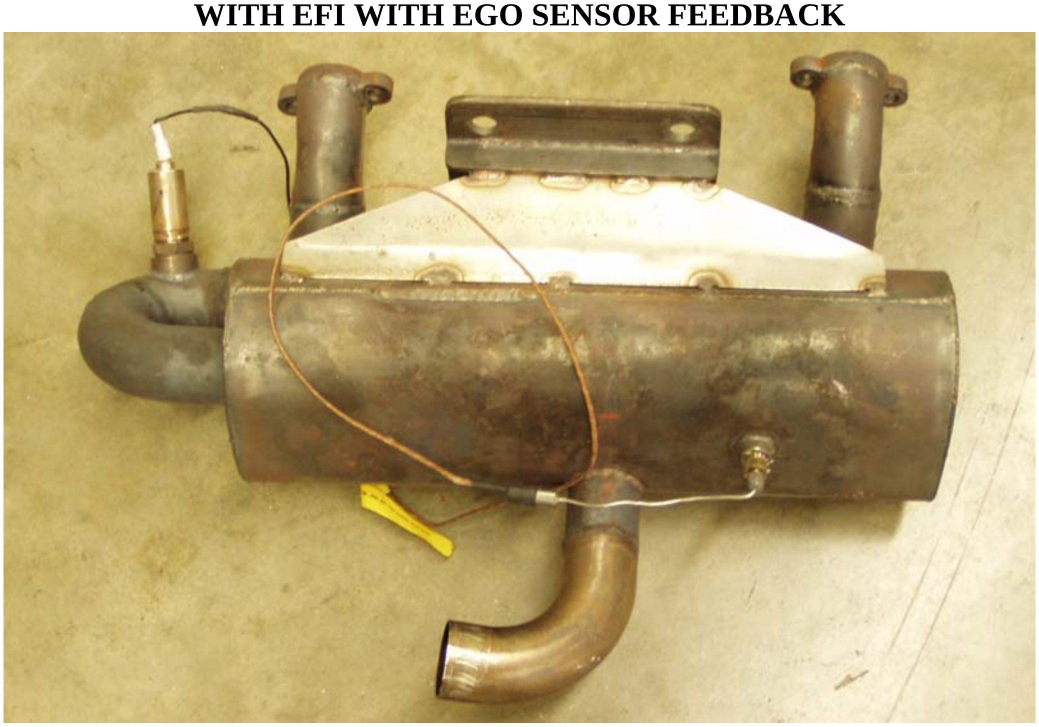


FIGURE A2-34. KOHLER CATALYZED MUFFLER FOR CH26 EFI ENGINE WITH FEEDBACK EGO SENSOR

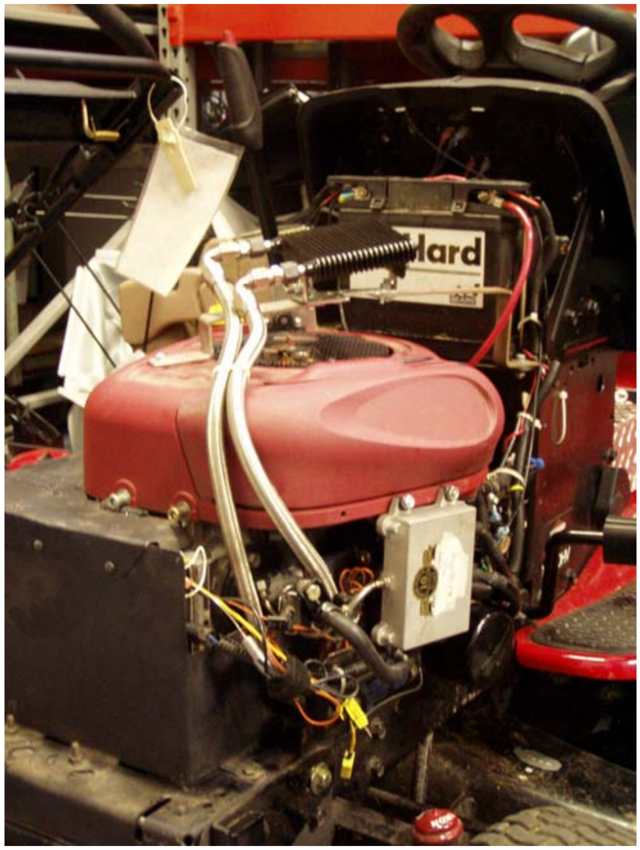


FIGURE A2-35. PROTOTYPE BRIGGS 31P777 INTEK WITH OIL COOLER

FIGURE A2-36. PROTOTYPE BRIGGS 31P777 INTEK WITH AIR DUCTED TO CATALYST MUFFLER

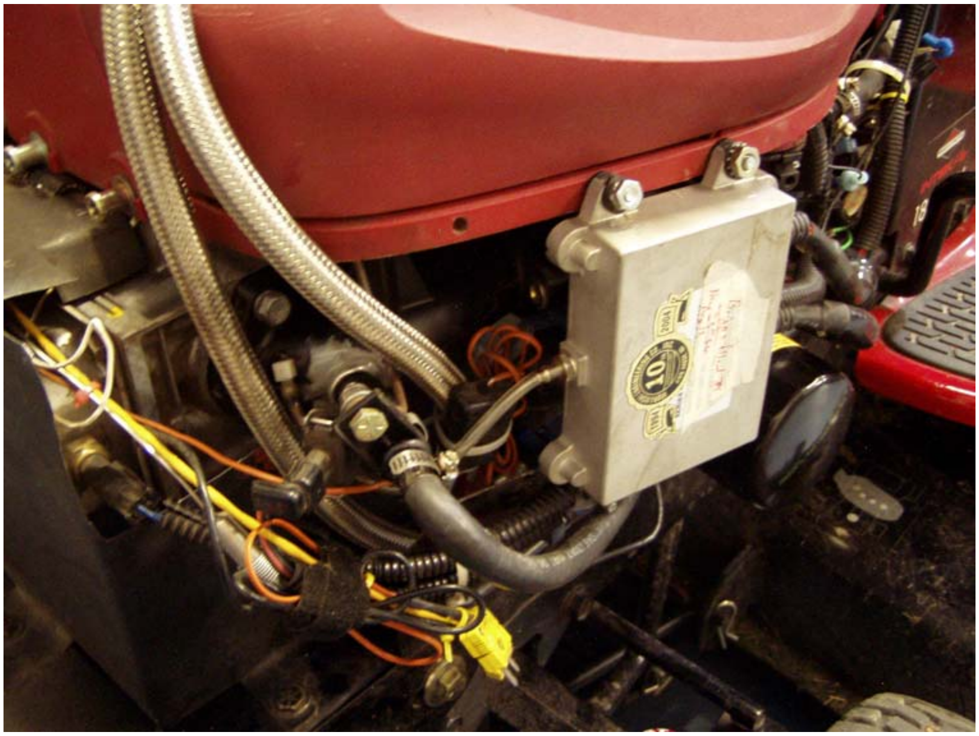


FIGURE A2-37. PROTOTYPE BRIGGS 31P777 INTEK CLOSE-UP OF ECU & FUEL INJECTOR

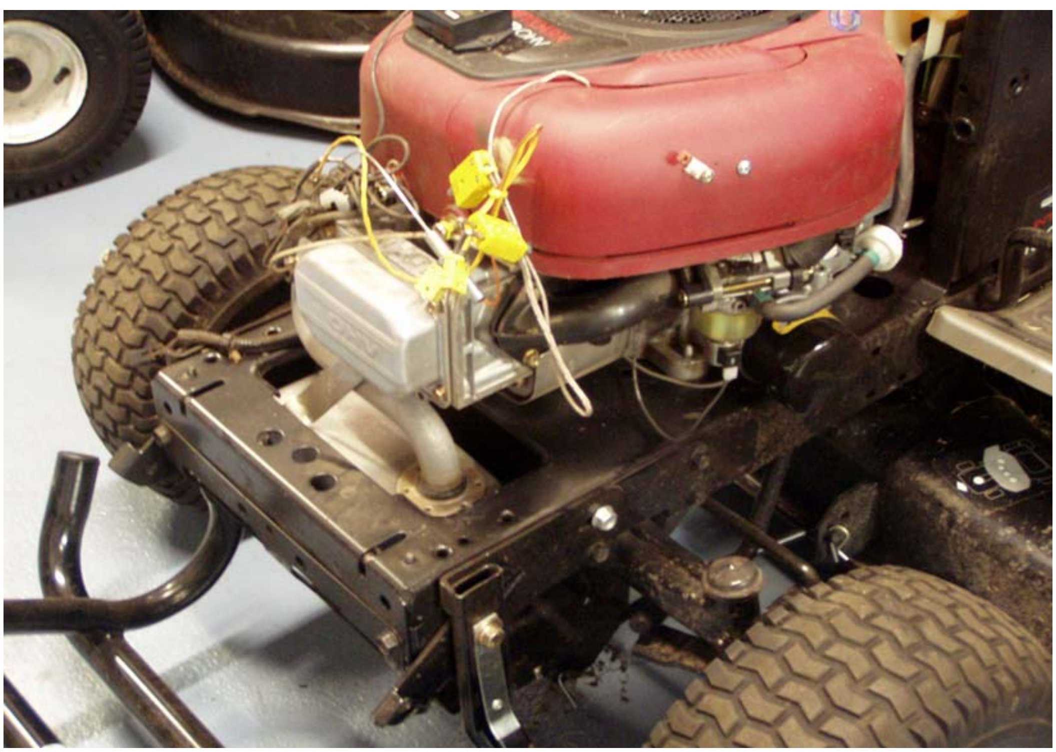


FIGURE A2-38. STOCK BRIGGS 31P777 INTEK ON RIDING MOWER

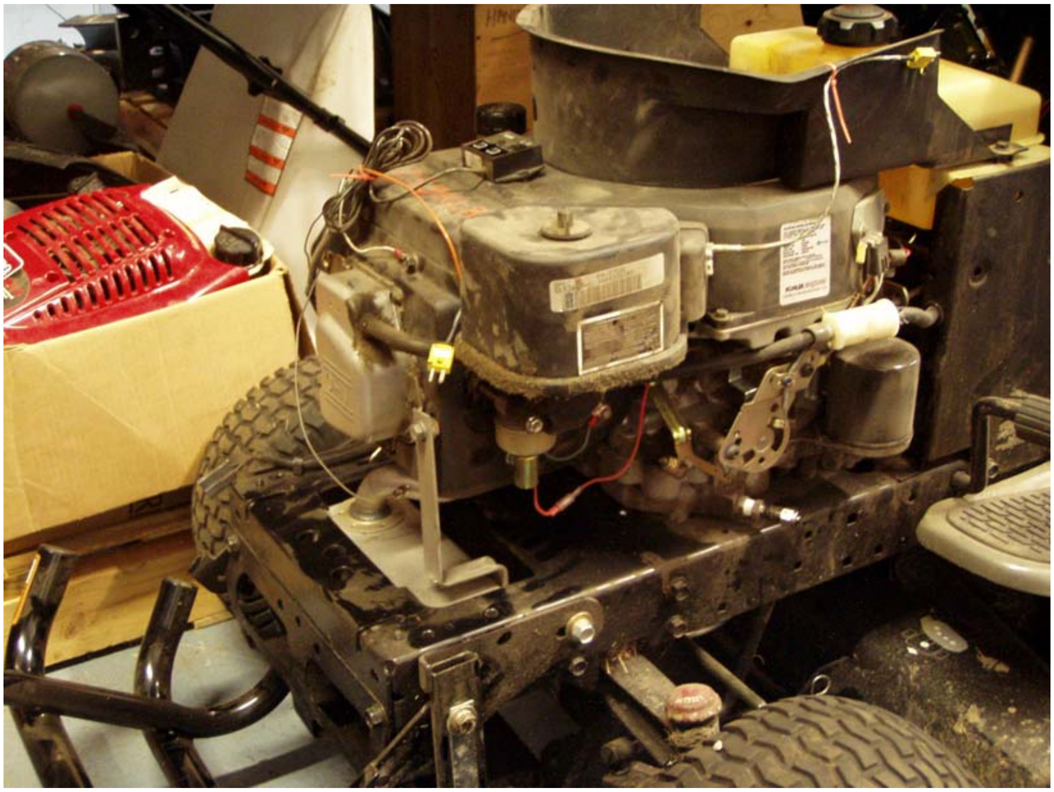


FIGURE A2-39. STOCK KOHLER CV490 RIDING MOWER

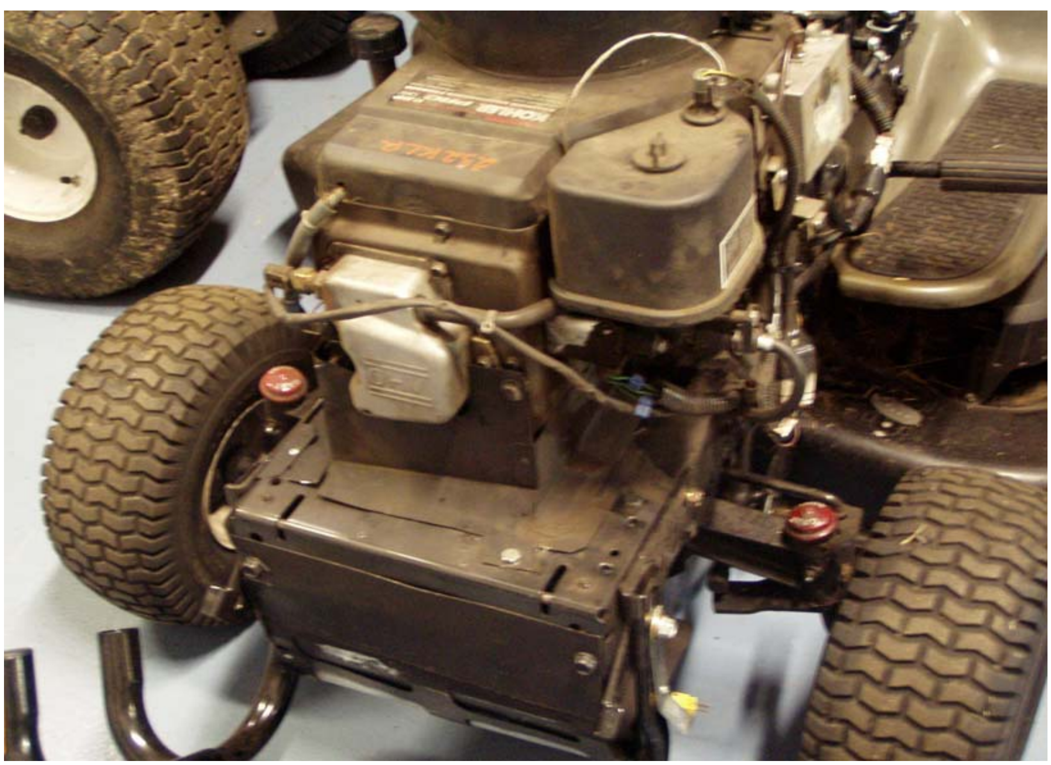


FIGURE A2-40. KOHLER CV490 RIDING MOWER WITH CATALYZED MUFFLER & MODIFIED SHROUD COOLING & EFI

ATTACHMENT 3

NOTES ON CLASS II SOAK DATA FROM EPA

Notes on Class II Soak Data from EPA

Table 3-1 shows muffler surface temperature data taken from thermal images of Class II engines that were brought up to normal operating temperature and then shut down in order to document the temperature over time. All catalysts tested met proposed Class II Phase 3 standards. Data from Table 3-1 and Figure 3-1, show that with proper selection of catalyst and exhaust system engineering, the prototype Briggs & Stratton INTEK engine's maximum muffler surface temperatures do not exceed stock exhaust temperatures. In addition, Figure 3-1 shows that prototype exhaust hot soak temperature profiles can closely match those measured in the stock configuration. The muffler with catalyst D showed the highest surface temperatures; it was the most efficient and produced $HC+NO_X$ emission test results significantly below results from tests using catalysts A and B.

Table A3 - 1. Muffler Temperature Field Soak Data vs. Time

TEST CONFIGURATIONS	MAXIMUM OBSERVED TEMPERATURE, °C						
Time, minutes from shutdown	0	1	2	3	4	5	6
Stock B&S Intek Plus	478	342	221	212	175	145	122
Prototype B&S EFI with Catalyst D	459	425	386	352	321	298	275
Prototype B&S EFI with Catalyst A	460	280	226	183	153	133	118
Prototype B&S EFI with Catalyst B	517	425	332	279	239	212	
Stock Kohler CV490 with muffler	441	351	285	224	187	157	137
Prototype Kohler CV490 EFI with Catalyst F	515	478	405	353	316	286	261
Prototype Kohler CV490 EFI with Catalyst E	610	482	401	356	321	290	268
B&S INTEK Plus Stock Tractor (in-chassis data)	265	221	179	157	94.3	87	
Prototype B&S INTEK Plus EFI Tractor with Catalyst D (in-chassis data)	138	144	149	145	138	135	133

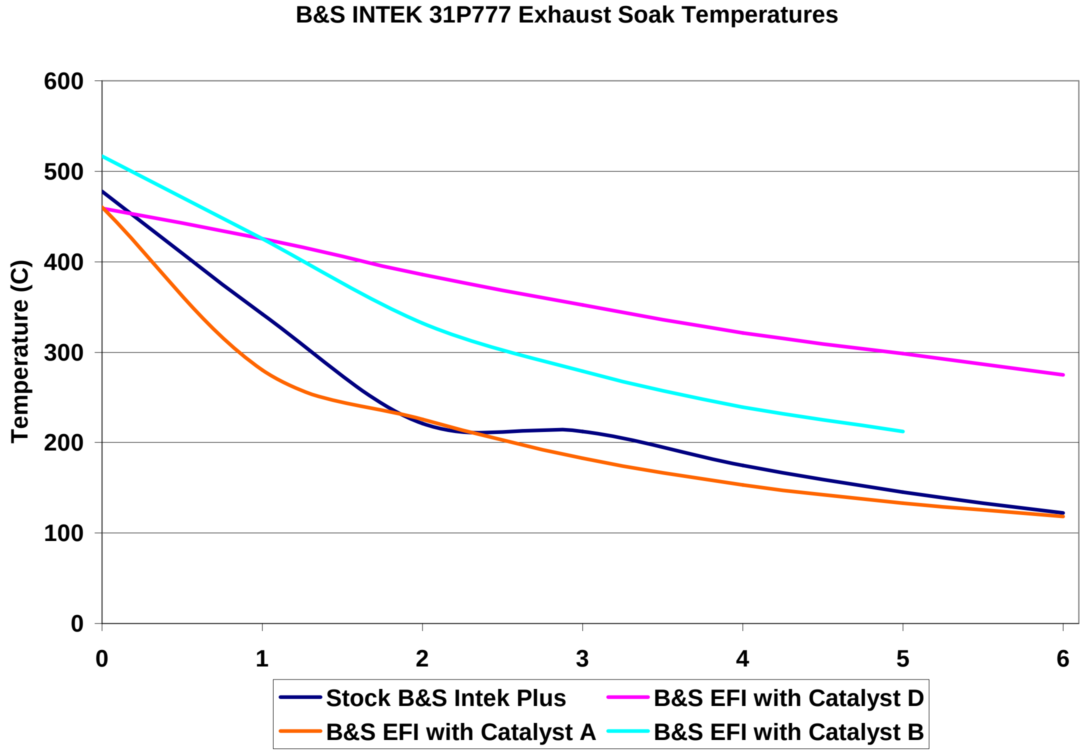


FIGURE A3-1. TIME (MINUTES AFTER SHUTDOWN)

Figure 3-2 shows data from a B&S INTEK equipped tractor with a stock and a modified muffler with catalyst D. Shrouding around the engine and exhaust system was modified in order to control maximum surface temperatures while using catalyst D. Figure 3-2 shows that with proper cooling system design, exposed surface temperatures can be much lower than current non-catalyst designs, and that they remain below grass ignition temperatures (350-400 °C per Attachment 13) during a hot soak.

Figure 3-3 shows surface temperature data from a Kohler CV490 in stock and modified muffler configurations. The line for catalyzed muffler F indicates that maximum temperatures upon shut down were 74 °C higher than the stock muffler, and maintained a ~130 °C higher temperature than stock during the soak. With catalysts F and E, the Kohler engine met the proposed Class II Phase 3 standards.

The catalyst D data shown in Figure 3-2 and the catalyst A data in Figure 3-1 illustrate why many failure modes in the FMEAs have lower probabilities of occurrence for Phase 3 engines than for Phase 2 engines. However, there is also data in Table 3-1 and Figures 3-1 and 3-3 that shows the need for sound engineering of Phase 3 designs.

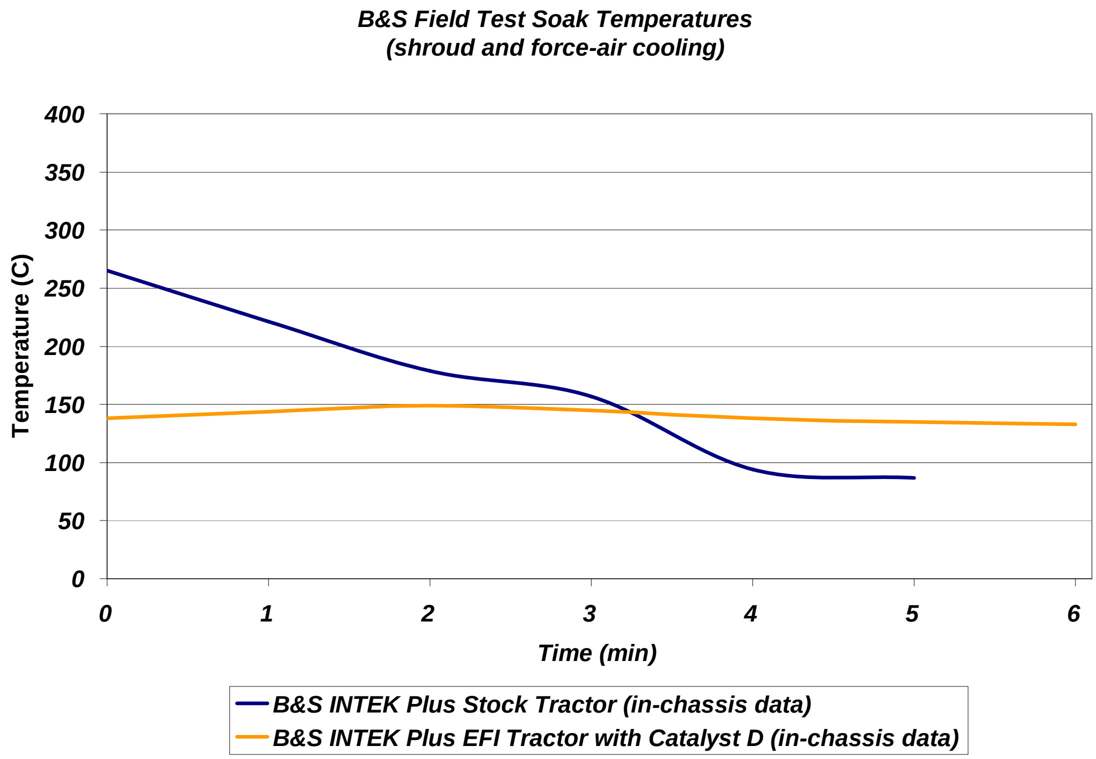


FIGURE A3-2. TIME (MINUTES AFTER SHUTDOWN)

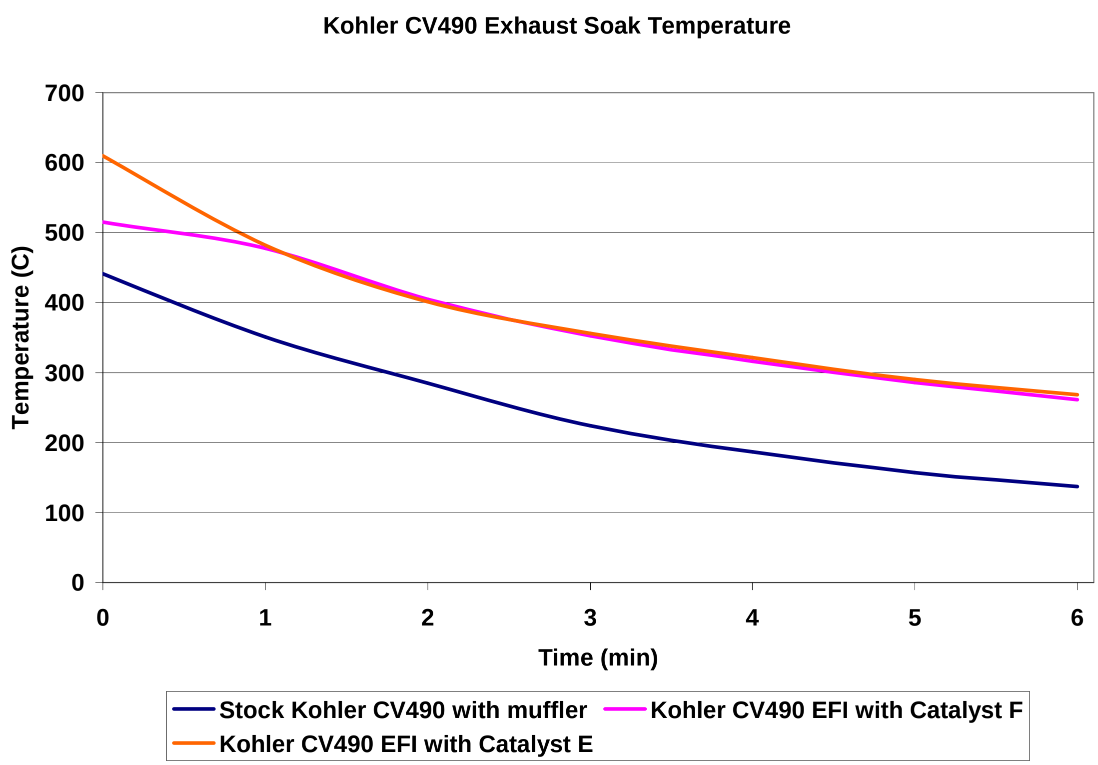


FIGURE A3-3. TIME (MINUTES AFTER SHUTDOWN)

ATTACHMENT 4

LIST OF STANDARDS REVIEWED FOR THE FMEA STUDY

Ref.	Standard Ref.	Date	Title	Group
4-1	ANSI B175.1	January-00	*Power Tools-Gasoline- Powered Chain Saws - Safety Requirements*	ACTV-CURR
4-2	ANSI B175.2	January-00	*Power Tools-Hand-Held and Backpack, Gasoline-Engine-Powered Blowers*	ACTV-CURR
4-3	ANSI B175.3	January-03	*Outdoor Power Equipment-Grass Trimmers and Bushcutters-Safety Requirements*	ACTV-CURR
4-4	ANSI B71.1	September-05	*Consumer Turf Care Equipment Walk-Behind Mowers and Ride-On Machines with Mowers Safety Specifications*	ACTV-CURR
4-5	ANSI B71.3	January-05	*Snow Throwers - Safety Specifications*	ACTV-CURR
4-6	ANSI B71.4	January-04	*Commercial Turf Care Equipment - Safety Specifications*	ACTV-CURR
4-7	ANSI B71.6	February-00	*Powered Shredder/Grinders,Shredder/Baggers,Chippers,and Walk-Behind Chipper/Vacuums-Safety Specifications*	ACTV-CURR
4-8	ANSIB71.7	January-85	*Powered Log Splitters - Safety Specifications*	INAC-WDRN
4-9	ANSIB71.8	January-96	*Outdoor Power Equipment - Walk-Behind Powered Rotary Tillers and Hand Supported Cultivators - Safety Specifications*	ACTV-CURR
4-10	SAE J997		*SAE J997 Spark Arrester Test Carbon (establishes physical properties required of SAE Coarse Test Carbon and SAE Fine Test Carbon)*	SAE
4-11	SAE J350	January-91	*SAE J350 Spark Arrester Test Procedure for Medium Size Engines (motorcycles, highway trucks, agricultural tractors, industrial tractors*	SAE
4-12	SAE J335	June-95	*Multiposition Small Engine Exhaust System Fire Ignition Suppressions*	SAE
4-13	EEC Council Directive	December-78	*EEC Council Directive of 19 Dec 1978 - noise emission of construction plant and equipment*	EEC
4-14	EEC Council Directive	September-84	*EEC Council Directive of 17 Sept 1984 - permissible sound power levels of lawnmowers*	EEC
4-15	EEC Council Directive	April-87	*EEC Council Directive of 7 April 1987 - amendment to 17 Sept 1984 (adapting to technical progress)*	EEC
4-16	ASAE S440.3	March-05	Safety for Powered Lawn and Garden Equipment	ASAE
4-17	16 CFR 1205	January-05	Safety for Walk-behind Power Lawn Mowers	CFR

Ref.	Standard Ref.	Date	Title	Group
4-18	PMS 430-1 NFES #1363	June-02	*Spark Arrester Guide - General Purpose and Locomotive (GP/Loco)*	National Wildfire Coordinating Group
4-19	PMS 430-2 NFES #2363	June-03	*Spark Arrester Guide - Multiposition Small Engines (MSE)*	National Wildfire Coordinating Group
4-20	5100-Fire Management 9151 1801	April-91	*Fire Investigation Procedure For Multipurpose Small Engines &General Purpose Spark Arrester Exhaust Systems*	USDA - Forest Service
4-21	5100-Fire Management 0551 1803-SDTDC	July-05	*Manufacturer Submission Procedure for the Qualification Testing of General-purpose, Screen, and Locomotive Spark Arrester Exhaust Systems*	USDA - Forest Service
4-22	5100-Fire Management 9151 1804	August-91	*Standard Test Procedure for Chain Saw Spark Arrester Exhaust Systems*	USDA - Forest Service
4-23	5100-Fire Management 9951 1805-SDTDC	August-99	*Standard Test Procedure for General Purpose Spark Arresters*	USDA - Forest Service
4-24	5100-Fire Management 9151 1202	January-91	*Spark Arrester Test Carbon Replacement Study -- Final Report*	USDA - Forest Service
4-25	Fire Management Tech Tips 5100 0351 1304-SDTDC	May-03	*An Introduction to Spark Arrestors: Spark Arresters and the Prevention of Wildland Fires*	USDA - Forest Service Technology & Development Program
4-26	Fire Management Tech Tips 5100 0351 1305-SDTDC	May-03	*Multiposition Small-Engine Spark Arresters: Spark Arresters and the Prevention of Wildland Fires*	USDA - Forest Service Technology & Development Program
4-27	Fire Management Tech Tips 5100 0351 1306-SDTDC	May-03	*General-Purpose Spark Arresters: Spark Arresters and the Prevention of Wildland Fires*	USDA - Forest Service Technology & Development Program
4-28	Fire Management Tech Tips 5100 0351 1307-SDTDC	May-03	*Off-Highway Vehicle Spark Arrestors: Spark Arresters and the Prevention of Wildland Fires*	USDA - Forest Service Technology & Development Program
4-29	RFQ-R5-15-03-073	April-91	*Fire Plan for Construction and Service Contracts (Attachment to Contract) (Ref: FSH 6309.32 and 6309.11)*	USDA - Forest Service
A-30	SDTDC		*Fire Investigation Report*	Forest Service
4-31	515-MW-01	December-05	*Specification for Mowers, Power, Rotary, Walk-Behind*	Texas Specification

Ref.	Standard Ref.	Date	Title	Group
4-32	ANSI C 1055-03		*Standard Guide for Heated System Surface Conditions that Produce Contact Burns*	ANSI
4-33	UL 1602		*Gasoline Engine Powered, Rigid Cutting-Member Edgers and Edger Trimmers*	UL
4-34	ISO 5395:1900 (E)		*Powered Lawn-mowers, Lawn Tractors, Lawn and Garden Tractors, Professional Mowers, and Lawn and Garden Tractors with Mowing Attachments – Definitions, Safety Requirements and Test Procedures. Section 2.2.3 Heat Protection*	ISO

ATTACHMENT 5

EXAMPLE: A TYPICAL FMEA REPORT FORMAT

System: Phase 3 (vs. Phase 2), Small Off Road Engines (Class I and II Lawn Mowers) Subsystem: Exhaust, Component: Manifold

Item Selected: gasket

Item Function Selected: 1. seals

Potential Failure Modes	Potential Effect(s) of Failure	Sev	Potential Cause / Mechanism of Failure	Occur	Current Design Control PREVENTIONS	Current Design Control DETECTIONS	Detec	R.P.N.	Recommendations			Action Results						
									Recommendation	Resp	Target Completion Date	Actions Taken	Effect Date	Sev	Occur	Detec	R.P.N.	% Reduction

ATTACHMENT 6

EXAMPLE: THE MODIFIED FMEA REPORT FORMAT USED IN W.A. 1-10

EXAMPLE: Modified DESIGN FMEA Format

Subsystem: Catalyst System Control Volume

Component: Intake, Cooling Air, Power Cylinder, Exhaust, Block, Equipment

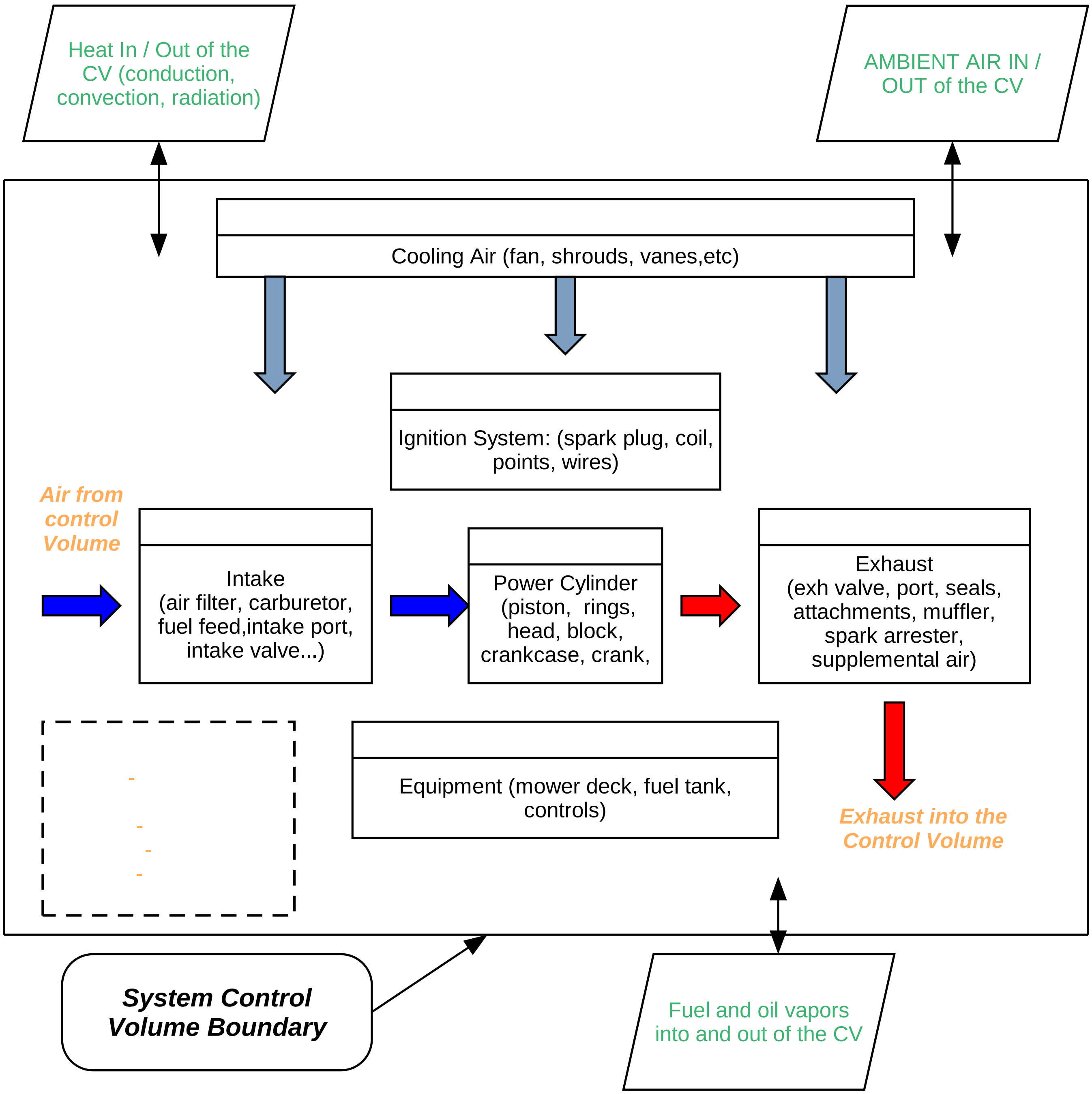
Item Selected: 1. intake air filter

Item Function Selected: 1. filter air

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	Difference in RPN (Phase 3 vs. Phase 2)	Notes
Degradation or tear of filter element, wrong filter or dirty or missing filter. Prefilter not oiled	richer mixture	backfire	noise	4_Other	3	3	9	6	3	2	3	EPA demonstrated that the backfire incidence was significantly reduced with the addition of a catalyst. That fact drives a reduction in the Occurrence ranking.
			flame out of muffler	4_Other	4	3	12	8	4	2	4	In this case it is assumed that a momentary flame does not cause a safety issue. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a catalyst. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	3	30	20	10	2	10	A backfire could cause a fire or burn. However, EPA demonstrated that the backfire incidence was significantly reduced with the addition of a catalyst. That fact drives a reduction in the Occurrence ranking.
Degradation or tear of filter element, wrong filter or dirty or missing filter. Prefilter not oiled	leaner mixture	hotter exhaust	no effect	4_Other	1	3	3	3	1	3	0	The rankings are expected to be the same with or without a catalyst.

ATTACHMENT 7

REPRESENTATION OF THE CATALYST CONTROL VOLUME



Heat In / Out of the CV (conduction, convection, radiation)
AMBIENT AIR IN / OUT of the CV
Cooling Air (fan, shrouds, vanes,etc)
Ignition System: (spark plug, coil, points, wires)
Air from control Volume
Intake (air filter, carburetor, fuel feed,intake port, intake valve...)
Power Cylinder (piston, rings, head, block, crankcase, crank,
Exhaust (exh valve, port, seals, attachments, muffler, spark arrester, supplemental air)
Equipment (mower deck, fuel tank, controls)
Exhaust into the Control Volume
System Control Volume Boundary
Fuel and oil vapors into and out of the CV

ATTACHMENT 8

CLASS I DESIGN FMEA REPORT

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 1. intake air filter

Item Function Selected: 1. filter air

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Degradation or tear of filter element, wrong filter or dirty or missing filter. Prefilter not oiled	richer mixture	backfire	noise	4_Other	3	3	9	6	3	2	3	EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			flame out of muffler	4_Other	4	3	12	8	4	2	4	In this scenario, a momentary flame does not cause a safety issue. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	3	30	20	10	2	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
Degradation or tear of filter element, wrong filter or dirty or missing filter. Prefilter not oiled	leaner mixture	hotter exhaust	no effect	4_Other	1	3	3	3	1	3	0	The rankings are the same with or without a catalyst.
			muffler failure (crack, oxidation, breakage, internal damage)	3_Performance	6	3	18	18	6	3	0	Mechanical failure caused by excessive temperature. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure (internal component seizure, broken valve or spring, excess wear)	3_Performance	8	3	24	24	8	3	0	Engine failure caused by excessive combustion temperatures. This is considered to be a failure of the engine contained to internal components and does not put the user at risk. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst because there will be no increase in burn risk with the application of a properly designed catalyzed muffler system. The effect could be mitigated by the presence of a thermal switch.
			catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines,
Class I, Walk-behind Lawn Mowers

Item Selected: 2. carburetor system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed or production variability	richer mixture	backfire	noise	4_Other	3	5	15	12	3	4	3	EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			flame out of muffler	4_Other	4	5	20	16	4	4	4	In this case it is expected that a momentary flame does not cause a safety issue. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	5	50	40	10	4	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed or production variability	richer mixture	cooler exhaust and catalyst	no effect	4_Other	1	5	5	5	1	5	0	The rankings are the same with or without a catalyst.
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed or production variability	richer mixture	engine power loss	degraded performance	3_Performance	5	5	25	25	5	5	0	The rankings are the same with or without a catalyst.
too many primer bulb pumps	richer mixture	engine stalls	Nuisance to customer.	3_Performance	4	6	24	24	4	6	0	The rankings are the same with or without a catalyst.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines,
Class I, Walk-behind Lawn Mowers

Item Selected: 2. carburetor system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Restriction in fuel passages, wrong jets in production, or choke stuck open, or production variability.	leaner mixture	engine won't start	inoperable and needs repair	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed or production variability	richer mixture	engine won't start	inoperable	3_Performance	8	5	40	40	8	5	0	The rankings are the same with or without a catalyst.
stuck choke (open)	leaner mixture	engine won't start	inoperable	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.
crack primer bulb	leaner mixture	engine won't start	inoperable	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 2. carburetor system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Restriction in fuel passages, wrong jets in production or production variability	leaner mixture	higher temperature in engine and catalyst	no effect	4_Other	1	4	4	4	1	4	0	The rankings are the same with or without a catalyst.
			muffler failure (crack, oxidation, breakage, internal damage)	3_Performance	6	4	24	24	6	4	0	Mechanical failure caused by excessive temperature. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure (internal component seizure, broken valve or spring, excess wear)	3_Performance	8	4	32	32	8	4	0	Engine failure caused by excessive combustion temperatures. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst. Any effect that the catalyst might have on temperature level is offset by the expected improvements in air cooling of the manifold system on Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
			catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 2. carburetor system

Item Function Selected: 2. throttles the air

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Throttle shaft wear	significant air leak around shaft	degraded load control	degraded performance	3_Performance	4	3	12	12	4	3	0	The rankings are the same with or without a catalyst.
Throttle shaft wear	butterfly / linkage failure	lack of load control	engine will only idle	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst.
Throttle shaft wear	slight air leak around shaft	leaner mixture	no effect	4_Other	1	3	3	3	1	3	0	The rankings are the same with or without a catalyst.

Item Selected: 2. carburetor system

Item Function Selected: 3. stores fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
gasket failure, or needle valve stuck open, or cracked primer bulb	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	engine dies due to lack of fuel or excess of fuel	engine inoperable	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.
gasket failure, or needle valve stuck open, or cracked primer bulb	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel ignites	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst because exposed muffler temperatures are nominally equivalent. Fuel can be ignited by hot surfaces or the ignition system.
gasket failure, or needle valve stuck open, or cracked primer bulb	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel puddles	no effect	4_Other	1	4	4	4	1	4	0	The rankings are the same with or without a catalyst.
			needs repair	3_Performance	5	4	20	20	5	4	0	The rankings are the same with or without a catalyst.
			fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst because exposed muffler surfaces have been shown to be nominally equivalent in Phase 2 (no catalyst) and Phase 3 (catalyzed) prototype systems.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 3. governor

Item Function Selected: 1. controls engine speed and load

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	malfunctioning governor	closed governor prevents the engine from making power	equipment inoperable	3_Performance	8	4	32	32	8	4	0	Insufficient power available to perform the job. The rankings are the same with or without a catalyst.
None	malfunctioning governor	open governor causes engine overspeed	higher exhaust temperatures	3_Performance	2	2	4	4	2	2	0	The rankings are the same with or without a catalyst.
			engine failure (internal component seizure, broken valve or spring, excess wear)	3_Performance	9	2	18	18	9	2	0	Engine failure caused by overspeed. The rankings are the same with or without a catalyst.
			catastrophic failure (potential injury due to flying parts)	1_Safety	10	2	20	20	10	2	0	Engine failure caused by overspeed. The rankings are the same with or without a catalyst.
None	malfunctioning governor	poor load control	degraded engine performance	3_Performance	6	5	30	30	6	5	0	The rankings are the same with or without a catalyst.

Item Selected: 4. intake manifold, port, valve and seals

Item Function Selected: 1. Transfer the air / fuel mixture to the intake valve

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Crack or leak in manifold	leaner mixture	catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	loss of emission control	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 4. intake manifold, port, valve and seals

Item Function Selected: 1. Transfer the air / fuel mixture to the intake valve

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Crack or leak in manifold	leaner mixture	change in power	degraded engine performance	3_Performance	4	9	36	20	4	5	16	The lower occurrence for Phase 3 is due to the improvement of the manifold system for Phase 3 products.
Crack or leak in manifold	leaner mixture	engine, exhaust system and catalyst run hotter	no effect	4_Other	1	9	9	4	1	4	5	The lower occurrence for Phase 3 is due to the expected improvement of the manifold system for Phase 3 products.
			muffler failure	3_Performance	6	9	54	24	6	4	30	The lower occurrence for Phase 3 is due to the expected improvement of the manifold system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	8	9	72	32	8	4	40	The lower occurrence for Phase 3 is due to the expected improvement of the manifold system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	9	90	40	10	4	50	The lower occurrence for Phase 3 is due to the expected improvement of the manifold system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
Crack or leak in manifold	leaner mixture	engine failure (internal component seizure, broken valve or spring, excess wear)	inoperable	3_Performance	8	3	24	16	8	2	8	The lower occurrence for the Phase 3 is due to the improvement of the manifold system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
Crack or leak in manifold	leaner mixture	engine stalls	inoperable	3_Performance	8	4	32	24	8	3	8	The lower occurrence for Phase 3 is due to the improvement of the manifold system for Phase 3 products.
None	damaged valve	leaky intake valve	power loss	3_Performance	5	4	20	15	5	3	5	The lower Phase 3 occurrence due to the improved Phase 3 cooling and fuel control, which could reduce cases of excessive temperature that could damage valves.
leaky intake manifold gasket	head gasket failure	loss of compression	degraded engine performance	3_Performance	7	8	56	35	7	5	21	The lower Phase 3 occurrence due to the improved Phase 3 cooling and fuel control, which could reduce cases of excessive temperature that could damage the manifold and head gasket.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 5. block, power head

Item Function Selected: 1. Produces power

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Higher thermal load	higher engine temperatures	engine failure (internal component seizure, broken valve or spring, excess wear)	inoperable	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			catastrophic failure (potential injury due to flying parts)	1_Safety	9	4	36	36	9	4	0	Engine failure caused by excessive temperatures. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	4	40	40	10	4	0	Engine failure can result in contact with hot metal or fluids. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
None	ring, cylinder or valve wear or leakage	increased oil consumption	catalyst poisoning due to lubricant components	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
None	ring, cylinder or valve wear or leakage	increased oil consumption	smoke	3_Performance	3	9	27	27	3	9	0	The rankings are the same with or without a catalyst.
			no effect	4_Other	1	9	9	9	1	9	0	The rankings are the same with or without a catalyst.

Item Selected: 6. exhaust valve and seal

Item Function Selected: 1. seal combustion chamber

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Burn or warped valve	head warpage	engine damage	inoperable	3_Performance	8	3	24	24	8	3	0	The rankings are the same with or without a catalyst.
Excessive engine temperature or wear	burned or warped valve	valve leakage	higher exhaust and catalyst temperature	3_Performance	4	4	16	12	4	3	4	Valve leakage permits hot cylinder gases to escape into exhaust system. The lower Phase 3 occurrence ranking is due to the Phase 3 improved design and/or materials. The effect could be mitigated by the presence of a thermal switch.
			backfire	3_Performance	5	4	20	15	5	3	5	The lower Phase 3 occurrence due to the Phase 3 improved cooling and fuel control which would reduce cases of excessive temperature that would damage valves.
			lower power	3_Performance	5	4	20	15	5	3	5	The lower Phase 3 occurrence due to the Phase 3 improved cooling and fuel control which would reduce cases of excessive temperature that would damage valves.
			allow unburned fuel and oil to reach the catalyst	2_Regulatory	1	1	1	27	9	3	-26	The lower Phase 3 occurrence due to the Phase 3 improved cooling and fuel control which would reduce cases of excessive temperature that would damage valves.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 7. exhaust manifold, muffler, muffler shroud and gasket

Item Function Selected: 1. seals exhaust and directs exhaust and muffles noise

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	loosening of muffler, manifold or failed gasket (gasket is less common on Class I vertical shaft engines)	exhaust leak	increased emissions	2_Regulatory	1	6	6	36	9	4	-30	The RPN difference is due to the regulatory requirement of Phase 3 and the increased severity. Also, the lower occurrence for the Phase 3 is due to the improved exhaust system design.
			increased noise	3_Performance	6	6	36	24	6	4	12	The lower occurrence for the Phase 3 is due to the improved design of the engine.
			fire or burn	1_Safety	10	6	60	40	10	4	20	The lower Phase 3 occurrence is due to the Phase 3 improved exhaust system design.
			heat surrounding components reducing their durability	3_Performance	4	6	24	16	4	4	8	The lower occurrence for the Phase 3 is due to the improved design of the engine.
Debris accumulation	reduction in engine cooling and increased muffler temperatures	ignition of debris adjacent to muffler	fire	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting for cooling and control of debris accumulation. In addition, fan inlet screens are expected on all Phase 3 engines. The failure mode could be mitigated by the presence of a thermal switch.
None	removal or mechanical failure	loss of muffler shroud	fire or burn	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting for cooling and shroud design.

Item Selected: 8. supplemental air (venturi)

Item Function Selected: 1. provides supplemental air to catalyst and leans the mixture

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	cracks in supplemental air system	mechanical failure	reduced supplemental air and catalyst performance	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
None	external debris	system plugs	reduced supplemental air and catalyst performance	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 9. catalyst (monolith, matting)

Item Function Selected: 1. reduce emissions (HC NOx CO)

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Lean mixture or engine overspeed	excessive catalyst temperatures	catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	increased emissions	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
			increased engine back pressure with degraded performance	3_Performance	1	1	1	6	3	2	-5	The performance change is small. The failure mode could be mitigated by the presence of a thermal switch.
Engine wear	release of engine metallic debris	catalyst plugs	increased emissions	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
			increased engine back pressure	3_Performance	1	1	1	6	3	2	-5	The performance change is small.
Rich mixture	soot coats catalyst	deactivates catalyst	increased emissions	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
Manufacturing, supplier or installation problem	incorrect or improperly installed catalyst	excessive catalyst performance	reduced emissions	3_Performance	1	1	1	2	1	2	-1	The performance change is small.
			slightly higher temperatures	3_Performance	1	1	1	2	1	2	-1	The performance change is small.
			fire or burn	1_Safety	1	1	1	20	10	2	-19	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential safety impact. The effect could be mitigated by the presence of a thermal switch.
Manufacturing, material problem or vibration	catalyst mat failure	mechanical failure of ceramic monolith catalyst	increased emissions	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
			change engine back pressure	3_Performance	1	1	1	9	3	3	-8	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks higher due to the catalyst being present.
Engine wear	excessive lubricant consumption	poison deactivation due to lubricant components	increased emissions	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks higher due to the potential regulatory non-compliance. Replicates failure modes from power cylinder rankings.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 9. catalyst (monolith, matting)

Item Function Selected: 1. reduce emissions (HC NOx CO)

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
Manufacturing or supplier problem	defective or wrong catalyst	poor catalyst performance	increased emissions	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
Fuel or ignition system malfunction	increased thermal load from catalyst	potential damage to engine, catalyst or components	poor performance	3_Performance	1	1	1	18	6	3	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks higher due to the catalyst being present. The failure mode could be mitigated by the presence of a thermal switch.
			reduced engine durability	3_Performance	1	1	1	18	6	3	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks higher due to the catalyst being present. The failure mode could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	1	1	1	24	8	3	-23	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks higher due to the catalyst being present. The failure mode could be mitigated by the presence of a thermal switch.

Item Selected: 10. cooling system

Item Function Selected: 1. Provides cooling air to engine and components

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	material failure or loose bolt	fan / flywheel fails	engine stops	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst.
None	cooling system shroud failed	loss of cooling to engine block and muffler system	engine overheats and stalls	3_Performance	7	2	14	14	7	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			burn risk	1_Safety	9	2	18	9	9	1	9	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			hotter engine	3_Performance	1	2	2	2	1	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			higher exhaust surface temperatures	3_Performance	1	2	2	2	1	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 10. cooling system

Item Function Selected: 1. Provides cooling air to engine and components

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	plugging of cooling passages due to debris	reduction of engine cooling	engine overheats and stalls	3_Performance	5	5	25	20	5	4	5	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	8	5	40	32	8	4	8	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			burn risk	1_Safety	9	5	45	36	9	4	9	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			hotter engine	3_Performance	1	5	5	4	1	4	1	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			higher exhaust surface temperatures	3_Performance	1	5	5	4	1	4	1	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.

Item Selected: 11. ignition system

Item Function Selected: 1. provides timed spark

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
plug bad, short in plug wire, failed coil, loose flywheel, magneto	loss of spark	backfire (misfire)	noise	3_Performance	3	6	18	12	3	4	6	EPA demonstrated that the backfire incidence was significantly reduced with the addition of a catalyst. That fact drives a reduction in the Occurrence ranking.
			Flame out of muffler	3_Performance	4	6	24	16	4	4	8	In this scenario, a momentary flame does not cause a safety issue. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	6	60	40	10	4	20	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 11. ignition system

Item Function Selected: 1. provides timed spark

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	weak or intermittent spark	excessive catalyst temperatures	catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.
None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	loss of spark	engine stalls and unburned fuel pumped through engine resulting in high catalyst temperatures	3_Performance	7	5	35	24	8	3	11	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
			engine stalls and won't run	3_Performance	8	5	40	24	8	3	16	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	spark timing changes	engine stalls and won't run	3_Performance	8	4	32	16	8	2	16	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	weak or intermittent spark (misfire)	degraded engine performance	3_Performance	6	5	30	18	6	3	12	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
			potentially higher muffler / catalyst temperatures	3_Performance	2	5	10	9	3	3	1	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.
			engine stalls and won't run	3_Performance	8	5	40	24	8	3	16	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
			excessive muffler or catalyst temperatures and increased burn risk	1_Safety	9	5	45	27	9	3	18	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products. The effect could be mitigated by the presence of a thermal switch.

Class I Design FMEA

Phase 2 versus Phase 3, Small Off-Road Engines, Class I, Walk-behind Lawn Mowers

Item Selected: 12. fuel tank and line

Item Function Selected: 1. Contains fuel and conveys to engine

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph 2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Notes
None	leak of tank or line	fuel leaks on hot component	needs repair	3_Performance	5	4	20	15	5	3	5	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			fire or burn	1_Safety	10	4	40	30	10	3	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
High muffler or catalyst temperatures near fuel lines	Fuel tank or line melted	fuel leaks on hot component	needs repair	3_Performance	5	2	10	10	5	2	0	The rankings are the same with or without a catalyst.
			fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst. The exposed muffler temperatures are nominally equivalent.
None	leak of tank or line	fuel puddles	needs repair	3_Performance	5	5	25	20	5	4	5	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			fire or burn	1_Safety	10	5	50	40	10	4	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			operator fuel exposure	1_Safety	9	5	45	36	9	4	9	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
High muffler or catalyst temperatures near fuel lines	Fuel tank or line melted	fuel puddles	needs repair	3_Performance	5	3	15	10	5	2	5	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			fire or burn	1_Safety	10	3	30	20	10	2	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			operator fuel exposure	1_Safety	9	3	18	18	9	2	9	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence

ATTACHMENT 9

CLASS II DESIGN FMEA REPORT

Item Selected: 1. intake air filter

Item Function Selected: 1. filter air

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Degradation or tear of filter element, wrong filter or dirty or missing filter.	richer mixture	backfire	noise	4_Other	3	2	6	6	3	2	0	The rankings are the same with or without a catalyst.
			Flame out of muffler	4_Other	4	2	8	8	4	2	0	In this scenario, a momentary flame does not cause a safety issue. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	2	20	20	10	2	0	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
Degradation or tear of filter element, wrong filter or dirty or missing filter.	leaner mixture	hotter exhaust	no effect	4_Other	1	3	3	3	1	3	0	The rankings are the same with or without a catalyst.
			muffler failure (crack, oxidation, breakage, internal damage)	3_Performance	6	3	18	18	6	3	0	Mechanical failure caused by excessive temperature. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure (internal component seizure, broken valve or spring, excess wear)	3_Performance	8	3	24	24	8	3	0	Engine failure caused by excessive combustion temperatures. This is considered to be a failure of the engine contained to internal components and does not put the user at risk. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst because there will be no increase in fire or burn risk with the application of a properly designed catalyzed muffler system. The effect could be mitigated by the presence of a thermal switch.
			Catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.

Item Selected: 2. carburetor or fuel injection system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Restriction in fuel passages, wrong jets in production, or choke stuck open, or production variability. Fuel injection system fuel pump or fuel pressure regulator failure. Fuel filter or injector restriction. Injector wiring connection degraded. MAP, ECM, or O2 sensor failure.	leaner mixture	higher temperature in engine and Catalyst	no effect	4_Other	1	3	3	3	1	3	0	The rankings are the same with or without a catalyst.
			muffler failure (crack, oxidation, breakage, internal damage)	3_Performance	6	3	18	18	6	3	0	Mechanical failure caused by excessive temperature. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure (internal component seizure, broken valve or spring, excess wear)	3_Performance	8	3	24	24	8	3	0	Engine failure caused by excessive combustion temperatures. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst. Any effect that the catalyst might have on temperature level is offset by the expected improvements in air cooling of the manifold system on Phase 3 products. If the change in temperature is significant the effect could be mitigated by the presence of a thermal switch.
			Catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.

Item Selected: 2. carburetor or fuel injection system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Restriction in fuel passages, wrong jets in production, or choke stuck open, or production variability. Fuel injection system fuel pump or fuel pressure regulator failure. Fuel filter or injector restriction. Injector wiring connection degraded. MAP, ECM, or O2 sensor failure.	leaner mixture	engine won't start	inoperable and needs repair	3_Performance	8	3	24	24	8	3	0	The rankings are the same with or without a catalyst.
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed, or production variability. Fuel injection fuel system fuel pressure regulator failure. Fuel injector stuck open. MAP, ECM, O2 sensor failure.	richer mixture	backfire	noise	4_Other	3	4	12	9	3	3	3	EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			Flame out of muffler	4_Other	4	4	16	12	4	3	4	In this case it is expected that a momentary flame does not cause a safety issue. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	4	40	30	10	3	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.

Item Selected: 2. carburetor or fuel injection system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed, or production variability. Fuel injection fuel system fuel pressure regulator failure. Fuel injector stuck open. MAP, ECM, O2 sensor failure.	richer mixture	cooler exhaust and catalyst	no effect	4_Other	1	4	4	4	1	4	0	The rankings are the same with or without a catalyst.
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed, or production variability. Fuel injection fuel system fuel pressure regulator failure. Fuel injector stuck open. MAP, ECM, O2 sensor failure.	richer mixture	engine power loss	degraded performance	3_Performance	5	4	20	20	5	4	0	The rankings are the same with or without a catalyst.

Item Selected: 2. carburetor or fuel injection system

Item Function Selected: 1. mixes the air and fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Float breaks, debris in float needle, or wrong jets in production, choke stuck closed, or production variability. Fuel injection fuel system fuel pressure regulator failure. Fuel injector stuck open. MAP, ECM, O2 sensor failure.	richer mixture	engine won't start	inoperable and needs repair	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.
None	wear, wiring short, age of pump	fuel pump failure	inoperable and needs repair	3_Performance	8	3	24	24	8	3	0	The rankings are the same with or without a catalyst.

Item Selected: 2. carburetor or fuel injection system

Item Function Selected: 2. throttles the air

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Throttle shaft wear	butterfly / linkage failure	lack of load control	engine will only idle	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst.
Throttle shaft wear	significant air leak around shaft	degraded load control	degraded performance	3_Performance	4	2	8	8	4	2	0	The rankings are the same with or without a catalyst.
Throttle shaft wear	slight air leak around shaft	leaner mixture	no effect	4_Other	1	2	2	2	1	2	0	The rankings are the same with or without a catalyst.

Item Selected: 2. carburetor or fuel injection system

Item Function Selected: 3. stores fuel

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
gasket failure, or needle valve stuck open, or fuel pump/regulator leak	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	fuel ignites	fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst because exposed muffler temperatures are nominally equivalent. Fuel can be ignited by hot surfaces or the ignition system.
gasket failure, or needle valve stuck open, or fuel pump/regulator leak	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	engine stalls	inoperable	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.
gasket failure, or needle valve stuck open, or fuel pump/regulator leak	leakage of fuel to mower deck, air filter or elsewhere (i.e. out of air filter)	Fuel puddles	no effect	4_Other	1	3	3	3	1	3	0	The rankings are the same with or without a catalyst.
			needs repair	3_Performance	5	3	15	15	5	3	0	The rankings are the same with or without a catalyst.
			fire or burn	1_Safety	10	3	30	30	10	3	0	The rankings are the same with or without a catalyst because exposed muffler surfaces have been shown to be nominally equivalent in Phase 2 (no catalyst) and Phase 3 (catalyzed) prototype systems.
ECM failure, solenoid return spring breakage causes fuel cutoff solenoid open failure	fuel flow into and from engine	fuel puddles	needs repair	3_Performance	5	4	20	20	5	4	0	The rankings are the same with or without a catalyst.
			fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst.
ECM failure, solenoid return spring breakage causes fuel cutoff solenoid open failure	fuel flow into and from engine	floods engine	inoperable/ needs repair	3_Performance	1	4	4	4	1	4	0	The rankings are the same with or without a catalyst.
None	fuel cutoff solenoid fails closed during operation	engine shuts off	inoperable/ needs repair	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.

Item Selected: 3. governor

Item Function Selected: 1. controls engine speed and load

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	malfunctioning governor	open governor causes engine overspeed	higher exhaust temperatures	3_Performance	2	2	4	4	2	2	0	The rankings are the same with or without a catalyst. This is not a significant overspeed condition.
			engine failure (internal component seizure, broken valve or spring, excess wear)	3_Performance	9	2	18	18	9	2	0	Engine failure caused by overspeed. The rankings are the same with or without a catalyst.
			catastrophic failure (potential injury due to flying parts)	1_Safety	10	2	20	20	10	2	0	Engine failure caused by overspeed. The rankings are the same with or without a catalyst.
None	malfunctioning governor	closed governor prevents the engine from making power	equipment inoperable and needs repair	3_Performance	8	3	24	24	8	3	0	Insufficient power available to perform the job. The rankings are the same with or without a catalyst.
None	malfunctioning governor	poor load control	degraded engine performance	3_Performance	6	4	24	24	6	4	0	The rankings are the same with or without a catalyst.

Item Selected: 4. intake manifold, port, valve and seals

Item Function Selected: 1. Transfer the air / fuel mixture to the intake valve

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Crack or leak in manifold	leaner mixture	engine, exhaust system and catalyst run hotter	no effect	4_Other	1	4	4	4	1	4	0	The rankings are the same with or without a catalyst.
			muffler failure	3_Performance	6	4	24	24	6	4	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	4	40	40	10	4	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			Catalyst failure	2_Regulatory	1	1	1	36	9	4	-35	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
Crack or leak in manifold	leaner mixture	change power	degraded engine performance	3_Performance	4	4	16	16	4	4	0	The rankings are the same with or without a catalyst.

Item Selected: 4. intake manifold, port, valve and seals

Item Function Selected: 1. Transfer the air / fuel mixture to the intake valve

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Crack or leak in manifold	leaner mixture	engine stalls	inoperable	3_Performance	8	4	32	32	8	4	0	The rankings are the same with or without a catalyst.
Crack or leak in manifold	leaner mixture	engine failure (internal component seizure, broken valve or spring, excess wear)	inoperable	3_Performance	8	3	24	24	8	3	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
Crack or leak in manifold	leaner mixture	catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	loss of emission control	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
None	damaged valve	leaky intake valve	power loss	3_Performance	5	4	20	15	5	3	5	The lower Phase 3 occurrence due to the Phase 3 definition of improved cooling and fuel control, which could reduce cases of excessive temperature that could damage valves.
leaky intake manifold gasket	head gasket failure	loss of compression	degraded engine performance	3_Performance	7	4	28	28	7	4	0	The rankings are the same with or without a catalyst.
Intake manifold leak causes MAP to read higher pressure	richer mixture	backfire	noise	4_Other	3	3	9	9	3	3	0	The failure relates to fuel Injected engines. EPA demonstrated that the backfire impact was reduced with the addition of a catalyst for Class I. However, since the design quality of the Class II equipment mufflers is very good on Phase 2, the impact of adding the catalyst is minimal.
			Flame out of muffler	3_Performance	4	3	12	12	4	3	0	The failure relates to fuel Injected engines. EPA demonstrated that the backfire impact was reduced with the addition of a catalyst for Class I. However, since the design quality of the Class II equipment mufflers is very good on Phase 2, the impact of adding the catalyst is minimal.
			fire or burn	1_Safety	10	3	30	30	10	3	0	The failure relates to fuel Injected engines. EPA demonstrated that the backfire impact was reduced with the addition of a catalyst for Class I. However, since the quality of the Class II equipment mufflers is very good on Phase 2, the impact of adding the catalyst is minimal.

Item Selected: 4. intake manifold, port, valve and seals

Item Function Selected: 1. Transfer the air / fuel mixture to the intake valve

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Intake manifold leak causes MAP to read higher pressure	richer mixture	cooler exhaust / catalyst	no effect	4_Other	1	4	4	4	1	4	0	The rankings are the same with or without a catalyst.
Intake manifold leak causes MAP to read higher pressure	richer mixture	power loss	degraded performance	3_Performance	5	4	20	20	5	4	0	The rankings are the same with or without a catalyst.
Intake manifold leak causes MAP to read higher pressure	richer mixture	won't start	inoperable	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst.

Item Selected: 5. block, power head

Item Function Selected: 1. Produces power

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Higher thermal load	higher engine temperatures	engine failure (internal component seizure, broken valve or spring, excess wear)	inoperable	3_Performance	8	3	24	24	8	3	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			catastrophic failure (potential injury due to flying parts)	1_Safety	9	3	27	27	9	3	0	Engine failure caused by excessive temperatures. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			fire or burn	1_Safety	10	3	30	30	10	3	0	Engine failure can result in contact with hot metal or fluids. The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
None	ring, cylinder or valve wear or leakage	increased oil consumption	catalyst poisoning	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
None	ring, cylinder or valve wear or leakage	increased oil consumption	smoke	3_Performance	3	6	18	18	3	6	0	The rankings are the same with or without a catalyst.
			no effect	4_Other	1	6	6	6	1	6	0	The rankings are the same with or without a catalyst.

Item Selected: 6. exhaust valve and seal

Item Function Selected: 1. seal combustion chamber

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Excessive engine temperature or wear	burned or warped valve	valve leakage	higher exhaust and catalyst temperature	3_Performance	4	3	12	12	4	3	0	The rankings are the same with or without a catalyst.
			backfire	3_Performance	5	3	15	15	5	3	0	The rankings are the same with or without a catalyst.
			lower power	3_Performance	5	3	15	15	5	3	0	The rankings are the same with or without a catalyst.
			allow unburned fuel and oil to reach the catalyst	2_Regulatory	1	1	1	27	9	3	-26	The lower Phase 3 occurrence due to the Phase 3 improved cooling and fuel control which would reduce cases of excessive temperature that would damage valves.
Burn or warped valve	head warpage	engine damage	inoperable	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst.

Item Selected: 7. exhaust manifold, muffler, muffler shroud and gasket

Item Function Selected: 1. seals exhaust and directs exhaust and muffles noise

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	cracked muffler, manifold or failed gasket	exhaust leak	increased emissions	2_Regulatory	1	4	4	27	9	3	-23	The RPN difference is due to the regulatory requirement of Phase 3 and the increased severity. Also, the lower occurrence for the Phase 3 is due to the Improved exhaust system design.
			noise	3_Performance	6	4	24	18	6	3	6	The lower occurrence for the Phase 3 is due to the improved design of the engine.
			fire or burn	1_Safety	10	4	40	30	10	3	10	The lower Phase 3 occurrence is due to the Phase 3 definition of improved exhaust system design.
			heat surrounding components reducing their durability	3_Performance	4	4	16	12	4	3	4	The lower Phase 3 occurrence is due to the Phase 3 definition of improved exhaust system design.
Debris accumulation	reduction in engine cooling / increased muffler temperatures	ignition of debris adjacent to muffler	Fire	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting for cooling and control of debris accumulation.
None	removal or mechanical failure	loss of muffler shroud	fire or burn	1_Safety	10	3	30	20	10	2	10	The lower occurrence for the Phase 3 is due to the improvement of the air ducting design for cooling and shroud design.

Item Selected: **8. catalyst (monolith, matting)**

Item Function Selected: 1. reduce emissions (HC NOx CO)

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Manufacturing, material problem or vibration	catalyst mat failure	mechanical failure of ceramic monolith catalyst	increased emissions	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
			change engine back pressure	3_Performance	1	1	1	9	3	3	-8	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the catalyst being present.

Item Selected: 8. catalyst (monolith, matting)

Item Function Selected: 1. reduce emissions (HC NOx CO)

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Lean mixture or over speed. one lean cylinder in two cylinder engine.	excessive temperatures	catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	increased emissions	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
			change engine back pressure	3_Performance	1	1	1	6	3	2	-5	The performance change is small. The failure mode could be mitigated by the presence of a thermal switch.
Rich mixture	soot coats catalyst	deactivates catalyst	increased emissions	2_Regulatory	1	1	1	27	9	3	-26	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
Engine wear	excessive lubricant consumption	poison deactivation due to lubricant components	increased emissions	2_Regulatory	1	1	1	36	9	4	-35	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. Replicates failure modes from power cylinder rankings.
Manufacturing or supplier problem	defective / wrong catalyst	poor catalyst performance	increased emissions	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
Manufacturing, supplier or installation problem	incorrect or improperly installed catalyst	increased catalyst performance	reduced emissions	3_Performance	1	1	1	2	1	2	-1	The performance change is small.
			slightly higher temperatures	3_Performance	1	1	1	2	1	2	-1	The performance change is small.
			fire or burn	1_Safety	1	1	1	20	10	2	-19	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential safety impact. The effect could be mitigated by the presence of a thermal switch.
Engine wear	engine debris	catalyst plugs	increased emissions	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance.
			increase engine back pressure	3_Performance	1	1	1	6	3	2	-5	The performance change is small.

Item Selected: 8. catalyst (monolith, matting)

Item Function Selected: 1. reduce emissions (HC NOx CO)

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
Fuel or ignition system malfunction	increased thermal load from catalyst	potential damage to engine, catalyst or components	poor performance	3_Performance	1	1	1	12	6	2	-11	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the catalyst being present. The failure mode could be mitigated by the presence of a thermal switch.
			reduced durability	3_Performance	1	1	1	12	6	2	-11	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the catalyst being present. The failure mode could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	1	1	1	16	8	2	-15	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the catalyst being present. The failure mode could be mitigated by the presence of a thermal switch.

Item Selected: 9. cooling system

Item Function Selected: 1. Provides cooling air to engine and components

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	material failure or loose bolt	fan / flywheel fails	engine stops	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst.
None	cooling system shroud failed	loss of cooling	engine overheats and stalls	3_Performance	7	2	14	14	7	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			burn risk	1_Safety	9	2	18	18	9	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	8	2	16	16	8	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			hotter engine	3_Performance	1	2	2	2	1	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.
			higher muffler and/or converter surface temperatures	3_Performance	1	2	2	2	1	2	0	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch.

Item Selected: 9. cooling system

Item Function Selected: 1. Provides cooling air to engine and components

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	plugging of cooling passages due to debris	reduction of engine cooling	engine overheats and stalls	3_Performance	5	4	20	15	5	3	5	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			engine failure	3_Performance	8	4	32	24	8	3	8	By definition of the Phase 3 product, the improved design features are expected to result in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			hotter engine	3_Performance	1	4	4	3	1	3	1	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			higher muffler and/or converter surface temperatures	3_Performance	1	4	4	3	1	3	1	By definition of the Phase 3 product, the improved design features for Phase 3 results in a slight reduction in Occurrence. The effect could be mitigated by the presence of a thermal switch.
			burn risk	1_Safety	9	4	36	27	9	3	9	The rankings are the same with or without a catalyst. The effect could be mitigated by the presence of a thermal switch,

Item Selected: 10. ignition system

Item Function Selected: 1. provides timed spark

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	loss of spark	engine stalls and unburned fuel pumped through engine resulting in high catalyst temperatures	3_Performance	7	4	28	24	8	3	4	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
			engine stalls and won't run	3_Performance	8	4	32	24	8	3	8	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.

Item Selected: 10. ignition system

Item Function Selected: 1. provides timed spark

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	spark timing changes	engine stalls and won't run	3_Performance	8	3	24	16	8	2	8	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.

Item Selected: 10. ignition system

Item Function Selected: 1. provides timed spark

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	plug bad, short in plug wire, failed coil, loose flywheel, magneto, ignition module failure	weak or intermittent spark, or loss of ignition in one of two cylinders (misfire)	degraded engine performance	3_Performance	6	4	24	18	6	3	6	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
			potentially higher muffler / catalyst temperatures	3_Performance	2	4	8	8	2	4	0	The rankings are the same with or without a catalyst.
			engine stalls and won't run	3_Performance	8	4	32	24	8	3	8	The lower occurrence for the Phase 3 is due to the improved ignition system for Phase 3 products.
			excessive muffler or catalyst temperatures and increased burn risk	1_Safety	9	3	27	27	9	3	0	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential safety impact. Excess air and unburned fuel can cause high catalyst exotherm. The effect could be mitigated by the presence of a thermal switch.
None	weak or intermittent spark	excessive catalyst temperatures	catalyst overheats and fails (substrate cracks, washcoat spalling, noble metal sintering, alumina phase change, crystallite growth)	2_Regulatory	1	1	1	18	9	2	-17	The Phase 2 ranking is low by definition, since Phase 2 does not have a catalyst. For Phase 3, the severity ranks high due to the potential regulatory non-compliance. The effect could be mitigated by the presence of a thermal switch.
bad plug, short in plug wire, failed coil, loose flywheel, magneto	loss of spark	backfire (misfire)	noise	3_Performance	3	4	12	9	3	3	3	EPA demonstrated that the backfire impact was significantly reduced with the addition of a catalyst. That fact drives a reduction in the Occurrence ranking.
			Flame out of muffler	3_Performance	4	4	16	12	4	3	4	In this scenario a momentary flame does not cause a safety issue. EPA demonstrated that the backfire impact was significantly reduced with the addition of a catalyst. That fact drives a reduction in the Occurrence ranking.
			fire or burn	1_Safety	10	4	40	30	10	3	10	In this scenario, the backfire is of such intensity that it can cause a fire or burn. EPA demonstrated that the backfire incidence was significantly reduced with the addition of a properly designed catalyzed muffler system. That fact drives a reduction in the Occurrence ranking.

Item Selected: 11. fuel tank and line

Item Function Selected: 1. Contains fuel and conveys to engine

Potential Cause (Contributing)	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev Ph2	Occur Ph 2	RPN Ph 2	RPN Ph 3	Sev Ph 3	Occur Ph 3	RPN Delta (Ph 2 vs Ph 3)	Note
None	leak of tank or line	fuel puddles, or sprays	needs repair	3_Performance	5	3	15	10	5	2	5	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			fire or burn	1_Safety	10	3	30	20	10	2	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			operator fuel exposure	1_Safety	9	3	27	18	9	2	9	The rankings are the same with or without a catalyst.
Equipment tip over, material failure, component failure	leak of tank or line	fuel contacts hot component	needs repair	3_Performance	5	3	15	10	5	2	5	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
			fire or burn	1_Safety	10	3	30	20	10	2	10	By definition of the Phase 3 product, the improved design features for Phase 3 is expected to result in a slight reduction in Occurrence. The evaporative emission controls will reduce leak occurrence
High muffler or catalyst temperatures near fuel tank	fuel tank or line melted	fuel puddles or sprays	needs repair	3_Performance	5	2	10	10	5	2	0	The rankings are the same with or without a catalyst.
			fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst.
			operator fuel exposure	1_Safety	9	2	18	18	9	2	0	The rankings are the same with or without a catalyst.
High muffler or catalyst temperatures near fuel tank	fuel tank or line melted	fuel contacts hot component	needs repair	3_Performance	5	2	10	10	5	2	0	The rankings are the same with or without a catalyst.
			fire or burn	1_Safety	10	2	20	20	10	2	0	The rankings are the same with or without a catalyst.

ATTACHMENT 10

PROCESS FMEA REPORT – REFUELING PROCESS FOR CLASS I AND CLASS II, PHASE 2 AND PHASE 3 EQUIPMENT

Class I and Class 2 Refueling Process FMEA

Selected Process Function: 1. Shut off engine

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
1	Shut off engine	failed to shut engine off	engine running	risk of refueling while engine running and a potential of a fire or burn	1_Safety	9	2	18	No difference between Phase 2 and Phase 3 expected. Thermal images indicate that at idle operation the maximum surface temperatures are comparable for Phase 2 and Phase 3 designs.

Selected Process Function: 2. Get fuel can

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
2	Get fuel can	no fuel	empty can	no refueling	3_Performance	1	6	6	No difference between Phase 2 and Phase 3 expected
3	Get fuel can	mislabeled gas can, operator behavior	wrong fuel	engine won't run after refueling (E-85)	3_Performance	8	3	24	No difference between Phase 2 and Phase 3 expected
4	Get fuel can	mislabeled gas can, operator behavior		will run, but smoky after refueling (2-cycle fuel)	3_Performance	6	3	18	No difference between Phase 2 and Phase 3 expected

Class I and Class 2 Refueling Process FMEA

Selected Process Function: 3. Open mower cap

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
5	Open mower cap	overpressure of fuel tank	spillage (hot fuel, full tank, pressurized tank - i.e. vent blocked)	operator contact w/ fuel	1_Safety	9	2	18	A safety concern, but no significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
6	Open mower cap	overpressure of fuel tank		spillage onto deck	4_Other	3	2	6	No significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
7	Open mower cap	overpressure of fuel tank		spillage onto ground	4_Other	3	2	6	No significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
8	Open mower cap	overpressure of fuel tank		spillage onto hot surfaces and a potential of a fire or burn	1_Safety	9	2	18	A safety concern, but no significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)
9	Open mower cap	overpressure of fuel tank		fire	1_Safety	10	2	20	A safety concern, but no significant difference between Phase 2 and Phase 3 expected. (Phase 3 tank venting could be a slight improvement)

Selected Process Function: 4. Remove and replace fuel can cap and vent

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
10	Remove fuel can cap	operator behavior	Fail to remove cap and vent	no refueling	3_Performance	1	2	2	No difference between Phase 2 and Phase 3 expected.
11	Remove fuel can cap	operator behavior	Fail to open vent	fuel spillage	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
12	Remove fuel can cap	operator behavior		no effect	4_Other	1	4	4	None

Class I and Class 2 Refueling Process FMEA

Selected Process Function: **4. Remove and replace fuel can cap and vent**

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
13	Remove fuel can cap	hot fuel and high pressure(high temperature storage, heating from sunlight)	fuel spray upon opening cap/vent	operator contact w/ fuel	1_Safety	9	2	18	A safety concern, but no difference between Phase 2 and Phase 3 expected.
14	Remove fuel can cap	hot fuel and high pressure(high temperature storage, heating from sunlight)		spillage	1_Safety	9	2	18	A safety concern, but no difference between Phase 2 and Phase 3 expected.
15	Remove fuel can cap	hot fuel and high pressure(high temperature storage, heating from sunlight)		pressure is relieved	4_Other	1	2	2	None
16	Remove fuel can cap	operator behavior	fail to recap the can	no effect	4_Other	1	4	4	None
17	Remove fuel can cap	operator behavior		spillage	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
18	Remove fuel can cap	operator behavior		vapor released from can	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.

Class I and Class 2 Refueling Process FMEA

Selected Process Function: **5. Pick up can and tilt to pour in to the mower fuel tank fill tube**

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
19	pick up can and pour	fuel spill	fuel puddle on equipment	fuel fire	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
20	pick up can and pour	fuel spill		no effect	4_Other	1	4	4	None
21	pick up can and pour	fuel spill	fuel spill into fan inlet	fuel fire	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
22	pick up can and pour	fuel spill		no effect	4_Other	1	4	4	None
23	pick up can and pour	fuel spill	fuel over the cowling and makes contact with a hot exhaust system component	fuel fire	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
24	pick up can and pour	fuel spill		no effect	4_Other	1	4	4	None
25	pick up can and pour	fuel spill	spill on operator and/or bystander	fuel exposure	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
26	pick up can and pour	fuel spill		fuel fire and burn	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
27	pick up can and pour	fuel spill	spillage on surrounding areas	fuel fire and burn	1_Safety	10	4	40	A safety concern, but no difference between Phase 2 and Phase 3 expected.
28	pick up can and pour	fuel spill		creates combustible material	1_Safety	9	4	36	A safety concern, but no difference between Phase 2 and Phase 3 expected.
29	pick up can and pour	fuel spill		no effect	4_Other	1	4	4	None
30	pick up can and pour	material failure	gas can cracks	fuel spill and potential of fire or burn	1_Safety	9	3	27	A safety concern, but no difference between Phase 2 and Phase 3 expected.
31	pick up can and pour	material failure	debris in fuel tank	fuel control problem	3_Performance	6	3	18	No difference between Phase 2 and Phase 3 expected.

Class I and Class 2 Refueling Process FMEA

Selected Process Function: 5. Pick up can and tilt to pour in to the mower fuel tank fill tube

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
32	pick up can and pour	engine running	refuel while running	spill fuel	1_Safety	9	2	18	A safety concern, but no difference between Phase 2 and Phase 3 expected.
33	pick up can and pour	engine running		fuel vapor ignites	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
34	pick up can and pour	engine running		engine refueled	4_Other	1	2	2	None
35	pick up can and pour	static charge	spark	fire or explosion	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
36	pick up can and pour	static charge		no effect	4_Other	1	2	2	None
37	pick up can and pour	gas cap on can is not secure	spillage on surrounding areas	fire or burn	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
38	pick up can and pour	gas cap on can is not secure		no effects	4_Other	1	2	2	None

Selected Process Function: 6. Recap the Mower Tank

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
39	Recap the Mower Tank	failure to recap mower tank	fuel spillage or vapor release onto equipment or operator during operation	fire	1_Safety	10	3	30	A safety concern, but no difference between Phase 2 and Phase 3 expected.
40	Recap the Mower Tank	failure to recap mower tank		fuel exposure	1_Safety	9	3	27	A safety concern, but no difference between Phase 2 and Phase 3 expected.
42	Recap the Mower Tank	failure to recap mower tank		no effect	4_Other	1	3	3	None

Class I and Class 2 Refueling Process FMEA

Selected Process Function: 7. Restart

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
42	Restart	fuel on the equipment	ignition component failure	fire or burn	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.
43	Restart	fuel or debris left on the equipment	hot surfaces ignites	fire or burn	1_Safety	10	2	20	A safety concern, but no difference between Phase 2 and Phase 3 expected.

ATTACHMENT 11

PROCESS FMEA REPORT – SHUTDOWN AND EQUIPMENT STORAGE PROCESS FOR CLASS I AND CLASS II, PHASE 2 AND PHASE 3 EQUIPMENT

Class I and Class 2 Shutdown and Storage Process FMEA

Selected Process Function: 1. Engine Shut Down

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
1	Engine Shut Down	ignition cut off and engine brake fail (and engine does not shut off)	engine left running, and operator may pull plug wire to stop	high surface temperatures, and risk of fuel ignition from high voltage spark and risk of shock	1_Safety	9	2	18	No difference between Phase 2 and Phase 3 expected
2	Engine Shut Down	engine won't stop and operator goes for help	unattended operation	runs out of fuel	3_Performance	1	2	2	No difference between Phase 2 and Phase 3 expected
3	Engine Shut Down	engine won't stop and operator goes for help		bystander gets injured by burn	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
4	Engine Shut Down	engine won't stop and operator goes for help		debris fire	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
5	Engine Shut Down	engine won't stop and operator pulls plug wire	risk of fuel ignition due to high voltage spark	fire or burn	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected
6	Engine Shut Down	engine won't stop and operator pulls plug wire		engine stops	3_Performance	1	2	2	No difference between Phase 2 and Phase 3 expected
7	Engine Shut Down	engine won't stop and operator pulls plug wire	operator contacts hot component	burn	1_Safety	10	2	20	No difference between Phase 2 and Phase 3 expected

Selected Process Function: 2. Equipment Storage

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
8	Equipment Storage	cover with plastic tarp while engine hot	plastic tarp melts	equipment mess	3_Performance	4	2	8	Tarp melts, but no resultant fire. No impact due to addition of a catalyst.
9	Equipment Storage	cover with tarp while engine hot (any material)	tarp ignites	fire ignites adjacent materials	1_Safety	10	2	20	Tarp ignites and fire could spread. No impact due to addition of a catalyst.
10	Equipment Storage	cover with tarp while engine hot (any material)		fire damages equipment	1_Safety	10	2	20	Tarp ignites and fire could spread. No impact due to addition of a catalyst.
11	Equipment Storage	cover with tarp while engine hot (any material)	tarp gets hot	no effect	4_Other	1	2	2	No impact due to addition of a catalyst.

Class I and Class 2 Shutdown and Storage Process FMEA

Selected Process Function: 2. Equipment Storage

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
12	Equipment Storage	store in or near garage or shed when engine hot	equipment ignites combustible material	structural fire	1_Safety	10	1	10	Surrounding material could ignite. No impact due to addition of a catalyst. Data available does not support a higher occurrence ranking.
13	Equipment Storage	store in or near garage or shed when engine hot	water heater pilot light ignites gas vapor	structural fire	1_Safety	10	1	10	Gas vapor could ignite. No impact due to addition of a catalyst. Data available does not support a higher occurrence ranking.
14	Equipment Storage	store in or near garage or shed when engine hot	debris on mower deck ignites	structural fire	1_Safety	10	1	10	Debris on the mower deck could ignite. No impact due to addition of a catalyst. Data available does not support a higher occurrence ranking.
15	Equipment Storage	store in or near garage or shed when engine hot	operator and/or bystander contacts hot component	burn	1_Safety	10	2	20	No impact due to addition of a catalyst.
16	Equipment Storage	park equipment on combustible debris	debris ignites	debris fire	1_Safety	10	2	20	Surrounding material could ignite. No impact due to addition of a catalyst.
17	Equipment Storage	park equipment on combustible debris		structural fire	1_Safety	10	2	20	Surrounding material could ignite. No impact due to addition of a catalyst.
18	Equipment Storage	park equipment on combustible debris		bystander gets injured by burn	1_Safety	10	2	20	No impact due to addition of a catalyst.
19	Equipment Storage	park equipment on combustible debris		fire damages equipment	1_Safety	10	2	20	Surrounding material could ignite. No impact due to addition of a catalyst.

ATTACHMENT 12

PROCESS FMEA REPORT – EQUIPMENT AND ENGINE MAINTENANCE FOR CLASS I AND CLASS II, PHASE 2 AND PHASE 3 EQUIPMENT

Class I and Class 2 Equipment/Engine Maintenance Process FMEA

Selected Process Function: 1. Cleaning equipment

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
1	Cleaning Equipment	Spray water into fuel tank while cleaning	Engine will not run	Engine inoperable	3_Performance	8	3	24	No difference between Phase 2 and Phase 3 expected
2	Cleaning Equipment	Spray water into engine intake	Engine will not run	Engine inoperable	3_Performance	8	3	24	No difference between Phase 2 and Phase 3 expected
3	Cleaning Equipment	Tip equipment to clean underneath	spill fuel or oil	Fuel or oil spill	4_Other	4	8	32	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 28.
4	Cleaning Equipment	Tip equipment to clean underneath		fire	1_Safety	10	8	80	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 70.
5	Cleaning Equipment	Tip equipment to clean underneath		operator exposure to fuel or oil	1_Safety	9	8	72	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 63.
6	Cleaning Equipment	Tip equipment to clean underneath		damage engine or equipment	3_Performance	7	8	56	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 49.
7	Cleaning Equipment	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected

Selected Process Function: 2. Change oil and filter

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
8	Change Oil / Filter	Improper maintenance	wrong fluid fill	can't start	3_Performance	8	5	40	No difference between Phase 2 and Phase 3 expected
9	Change Oil / Filter	Improper maintenance		premature wear	3_Performance	6	5	30	No difference between Phase 2 and Phase 3 expected
10	Change Oil / Filter	Improper maintenance	no oil	engine failure	3_Performance	9	4	36	No difference between Phase 2 and Phase 3 expected
11	Change Oil / Filter	Improper maintenance	left drain plug or filter off	spilled on oil on ground	4_Other	4	5	20	No difference between Phase 2 and Phase 3 expected
12	Change Oil / Filter	Improper maintenance	over fill	loss of power	3_Performance	6	6	36	No difference between Phase 2 and Phase 3 expected

Class I and Class 2 Equipment/Engine Maintenance Process FMEA

Selected Process Function: 2. Change oil and filter

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
13	Change Oil / Filter	Improper maintenance		spill	4_Other	4	6	24	No difference between Phase 2 and Phase 3 expected
14	Change Oil / Filter	Improper maintenance		blow out seals	3_Performance	7	6	42	No difference between Phase 2 and Phase 3 expected
15	Change Oil / Filter	Improper maintenance	spill oil	pollution	2_Regulatory	4	9	36	No difference between Phase 2 and Phase 3 expected
16	Change Oil / Filter	Improper maintenance		operator exposure to oil	1_Safety	9	9	81	No difference between Phase 2 and Phase 3 expected
17	Change Oil / Filter	Improper maintenance	wrong filter (Class II only)	leak	3_Performance	4	5	20	No difference between Phase 2 and Phase 3 expected
18	Change Oil / Filter	Improper maintenance		engine damage	3_Performance	7	5	35	No difference between Phase 2 and Phase 3 expected
19	Change Oil / Filter	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected
20	Change Oil / Filter	Tip equipment for maintenance	spill fuel or oil	Fuel or oil spill	4_Other	4	8	32	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 28.
21	Change Oil / Filter	Tip equipment for maintenance		fire	1_Safety	10	8	80	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 70.
22	Change Oil / Filter	Tip equipment for maintenance		operator exposure to fuel or oil	1_Safety	9	8	72	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 63.
23	Change Oil / Filter	Tip equipment for maintenance		damage engine or equipment	3_Performance	7	8	56	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 49.

Class I and Class 2 Equipment/Engine Maintenance Process FMEA

Selected Process Function: 3. Change air filter

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
24	Change Air Filter	improper maintenance	installed wrong or incorrectly prepared pre-oiled filter	may affect engine operation	3_Performance	3	5	15	No difference between Phase 2 and Phase 3 expected. These failure modes were also addressed in the design FMEAs.
25	Change Air Filter	improper maintenance	failed to change or clean filter	may affect engine operation	3_Performance	3	7	21	No difference between Phase 2 and Phase 3 expected
26	Change Air Filter	improper maintenance	failure to reinstall filter	may affect engine operation	3_Performance	3	5	15	No difference between Phase 2 and Phase 3 expected
27	Change Air Filter	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected

Selected Process Function: 4. Change spark plug

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
28	Change Spark Plug	improper maintenance	failure to change spark plug	may affect engine operation	3_Performance	4	7	28	No difference between Phase 2 and Phase 3 expected
29	Change Spark Plug	improper maintenance	installed wrong / defective / improperly gapped spark plug	may affect engine operation	3_Performance	4	6	24	No difference between Phase 2 and Phase 3 expected
30	Change Spark Plug	improper maintenance	failed to tighten spark plug	may affect engine operation	3_Performance	4	6	24	No difference between Phase 2 and Phase 3 expected
31	Change Spark Plug	improper maintenance	failed to connect plug wire	engine won't run	3_Performance	8	6	48	No difference between Phase 2 and Phase 3 expected
32	Change Spark Plug	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected
33	Change Spark Plug	testing for spark	spark ignites fuel	fire	1_Safety	10	3	30	No difference between Phase 2 and Phase 3 expected
34	Change Spark Plug	testing for spark		flash flame	3_Performance	5	3	15	In this case, a momentary flame does not cause a safety issue. No impact due to addition of a catalyst.

Class I and Class 2 Equipment/Engine Maintenance Process FMEA

Selected Process Function: 5. Sharpen blade

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
35	Sharpen Blade	improper maintenance	improper sharpening	blade fails	3_Performance	9	7	63	No difference between Phase 2 and Phase 3 expected
36	Sharpen Blade	improper maintenance		poor cutting performance	3_Performance	5	7	35	No difference between Phase 2 and Phase 3 expected
37	Sharpen Blade	improper maintenance		imbalance	3_Performance	7	7	49	No difference between Phase 2 and Phase 3 expected
38	Sharpen Blade	tipping equipment for blade access	equipment falls	personnel injury	1_Safety	10	5	50	No difference between Phase 2 and Phase 3 expected
39	Sharpen Blade	tipping equipment for blade access		no effect	4_Other	1	5	5	No difference between Phase 2 and Phase 3 expected
40	Sharpen Blade	tipping equipment for blade access	spill fuel or oil	fire	1_Safety	10	8	80	Vapor control requirements will reduce occurrence with Phase 3 product to 7 and the RPN to 70.
41	Sharpen Blade	tipping equipment for blade access		no effect	4_Other	1	8	8	No difference between Phase 2 and Phase 3 expected
42	Sharpen Blade	Improper reassembly	blade imbalance, failure or separation	no effect	4_Other	1	1	1	No difference between Phase 2 and Phase 3 expected
43	Sharpen Blade	Improper reassembly		personnel injury	1_Safety	10	1	10	No difference between Phase 2 and Phase 3 expected
44	Sharpen Blade	Improper reassembly		engine damage	3_Performance	6	1	6	No difference between Phase 2 and Phase 3 expected

Selected Process Function: 6. Replace drive belt

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
45	Replace Drive Belt	wrong belt installed	belt slips or does not engage	poor or no performance	3_Performance	7	4	28	No difference between Phase 2 and Phase 3 expected
46	Replace Drive Belt	wrong belt installed		belt fire / debris fire	1_Safety	10	4	40	No difference between Phase 2 and Phase 3 expected
46	Replace Drive Belt	belt installed incorrectly	belt slips or does not engage	poor or no performance	3_Performance	7	3	21	No difference between Phase 2 and Phase 3 expected

Class I and Class 2 Equipment/Engine Maintenance Process FMEA

Selected Process Function: 6. Replace drive belt

Ref. No.	Process Function	Potential Cause (Primary)	Potential Failure Modes	Potential Effect(s) of Failure	Classification of Effect	Sev	Occur	R.P.N.	Notes
41	Replace Drive Belt	belt installed incorrectly		belt fire / debris fire	1_Safety	10	3	30	No difference between Phase 2 and Phase 3 expected
42	Replace Drive Belt	maintenance or cleaning while the equipment is hot	contact with hot part	burn	1_Safety	10	6	60	No difference between Phase 2 and Phase 3 expected

ATTACHMENT 13

IGNITION PROPERTY DATA OF VARIOUS MATERIALS AND HUMAN SKIN DAMAGE AT ELEVATED TEMPERATURE/RADIANT HEAT EXPOSURE DATA

Ignition Property Data of Various Materials and Human Skin Damage at Elevated Temperature/Radiant Heat Exposure Data

Tables 13-1 through 13-9 provides ignition data for various materials that are reasonably expected to be in areas a lawn mower or other small residential application motor with hot surfaces would be stored. Also provided are data related to contact burn temperatures and thermal radiation exposure effects on human skin.

The types of materials considered are both solids and liquids. Ignition can occur in the solid phase, known as smoldering ignition, and the gas phase, known as flaming ignition. For flaming combustion to occur the solid or liquid must gasify. Liquids, such as gasoline, can exert a vapor pressure at ambient conditions producing a flammable mixture. Unlike liquids, solid combustibles do not exert a significant vapor pressure under ambient conditions and have to be heated to gasify. The gasification of solids is a thermally induced decomposition of complex molecules in a process known as pyrolysis. A solid can be heated to pyrolysis when exposed to a heat flux source that is radiative, convective, conductive, or a combination. Whether or not a solid material will reach a temperature sufficient to cause pyrolysis and how quickly it can reach that temperature depends on factors such as the intensity of heat flux; material properties such as thickness, density, specific heat, thermal conductivity, and emissivity.

Once a solid or liquid produces a combustible mixture of gases, flaming ignition can occur as piloted ignition or unpiloted ignition. Unpiloted ignition is also known as auto-ignition. A piloted ignition initiates from a small flame or a hot spark located in the combustible gases. Auto-ignition initiates from a hot surface that heats the combustible gases to the auto-ignition temperature.

Smoldering ignition occurs in the solid phase and is observed more frequently with porous and cellulosic materials. Smoldering ignition occurs when a material is heated for long durations under low heat flux conditions. The heat flux is not sufficient to produce adequate pyrolysis for flaming combustion, but a high enough heat flux applied for a sufficient duration causes an exothermic reaction at the surface that can become self-accelerating. This type of ignition is observed as a glowing on the surface of the solid and can lead to flaming ignition if the heat losses are low and the exothermic reaction is allowed to accelerate.

In addition to ignition of materials reasonably expected to be in areas of motor storage, ignition of materials expected in areas of use, specifically vegetation, is also a concern. Ignition temperatures of vegetation have been measured by numerous researchers with widely varying values. The ignition temperature of vegetation varies based on moisture content, density, thickness, species, etc. Ignition of vegetation by motors can occur by heat flux from hot surfaces and ejection of hot material from the exhaust. Ignitability tests [1] of forest fuels showed that dry vegetation ignites within a few seconds at 550°C and for long durations of exposure ignites at 350-400°C. However, due to the variability of vegetation ignition properties, Babrauskas [1] recommends using ignition temperatures of solid wood.

The data provided in Table A13-10 is for the effects of thermal radiation levels on human skin. Figure A13-1 provides data on reversible human skin injury and cell death as a function of contact skin temperature versus exposure time. From Figure A13-1, a contact temperature of approximately 70 °C for less than 1 second will cause cell death. Reversible injury, as defined in ASTM C 1055 [2], occurs for an exposure time of less than 1 second at a temperature of approximately 64 °C. As the exposure time increases, the temperature to cause cell injury and the temperature to cause reversible injury approach each other.

For a more detailed discussion on ignition, material properties, and human burn hazards, please refer to the references provided.

TABLE A13-1. IGNITION TEMPERATURES OF VARIOUS MATERIALS [3]

Material	T_{ig} (°C)
Aircraft panel epoxy Fiberite	505
Asphalt shingle	378
Carpet #2 (wool, stock)	465
Carpet #2 (wool, treated)	455
Carpet #2 (wool, untreated)	435
Carpet (acrylic)	300
Carpet (nylon wool blend)	412
Chipboard (S118M)	390
Douglas fir particle board (1.27 cm)	382
Fiber insulation board	355
Fiberboard, low density (S119M)	330
Fiberglass shingle	445
Foam, flexible (2.54 cm)	390
Foam, rigid (2.54 cm)	435
Glass reinforced plastic (1.14 mm)	400
Glass reinforced plastic (2.24 mm)	390
Gypsum board, (common) (1.27 mm)	565
Gypsum board, fire retardant (1.27 cm)	510
Gypsum board, Wallpaper (S142M)	412
Hardboard (3.175 mm)	365
Hardboard (6.35 mm)	298
Hardboard (gloss paint) (3.4 mm)	400
Hardboard (nitrocellulose paint)	400
Hardboard (S159M)	372
Mineral wool, textile paper (S160M)	400
Particle board (1.27 cm stock)	412
Plywood, fire retardant (1.27 mm)	620
Plywood, plain (0.635 cm)	390
Plywood, plain (1.27 cm)	390
Polycarbonate (1.52 mm)	528

Polyisocyanurate (5.08 cm)	445
Polymethylmethacrylate polycast (1.59 mm)	278
Polymethylmethacrylate type g (1.27 cm)	378
Polystyrene (5.08 cm)	630
Polyurethane (S353M)	280
Wood panel (S178M)	385

TABLE A13-2. TYPICAL VALUES OF THE MINIMUM AUTO-IGNITION TEMPERATURE FOR FLAMMABLE GASES AND VAPORS [4]

Material	Minimum auto-ignition temperature (°C)
Hydrogen	400
Carbon disulphide	90
Carbon monoxide	609
Methane	601
Propane	450
n-Butane	288[a]
iso-Butane	460[a]
n-Octane	206[a]
iso-Octane (2,2,4-trimethylpentane)	415[a]
Ethene	450
Acetylene (ethyne)	305
Methanol	385
Ethanol	363
Acetone	465
Benzene	560

[a] Note that branched alkanes have much higher auto-ignition temperatures than their straight-chain isomers.

TABLE A13-3. PILOTED IGNITION TEMPERATURES OF VARIOUS WOODS [1]

Wood species	Heat flux (kW/m^2)	T_{ig} (°C)	Plateau temp. (°C)	t_{ig} (s)
Western red cedar (280 kg/m^3)	15.4	450	366	583
	19.7	431	379	216
	24.0	365	-	57
	28.7	346	-	30

	31.7	354	-	23
obeche (350 kg/m^3)	15.4	497	359	684
	19.7	442	361	176
	24.0	364	-	60
	28.7	344	-	39
	31.7	340	-	29
white pine (360 kg/m^3)	15.4	446	354	1094
	19.7	411	380	257
	24.0	397	-	95
	28.7	387	-	48
	31.7	375	-	32
mahogany (540 kg/m^3)	15.4	465	365	850
	19.7	427	385	324
	24.0	364	-	90
	28.7	360	-	60
	31.7	353	-	38

TABLE A13-4. TUBE FURNACE TESTS FOR THE AUTO-IGNITION TEMPERATURE OF CELLULOSE FILTER PAPER [5]

Furnace temperature (°C)	Heating time (h)	Ignition
228	70	no
230	45	no
232	7-9	yes
246	3	yes
253	2	yes
280	0.5	yes

TABLE A13-5. AUTO-IGNITION OF FILTER PAPER FROM HOT-AIR BLOWER [5]

Distance from outlet (mm)	Hot air temp. (°C)	Ignition time (s)
25	876	3.8
51	849	3.7
76	705	5.3
102	545	10.5
127	413	N.I.

TABLE A13-6. HOTPLATE IGNITION TEMPERATURE OF SOME FABRICS [5]

Fabric	Ignition temperature (°C)
cotton	400
acetate	525
nylon 6	530
triacetate	540
acrylic	560
polypropylene	570
wool	600
modacrylic (Teklan - polyacrylonitrile / polyvinylidene chloride, 50/50)	690

TABLE A13-7. AUTO-IGNITION OF COTTON FABRIC FROM A HOT-AIR BLOWER [5]

Distance from outlet (mm)	Hot air temp. (°C)	Ignition time (s)
25	876	3.1
51	849	3.5
76	705	5.0
102	545	17.0
114	470	N.I.

TABLE A13-8. HOT SURFACE IGNITION TEMPERATURES FOR CARPETS [5]

Material	Ignition temperature (°C)
acrylic	710
nylon 6	660
polypropylene	735
viscose rayon	660
wool	760

TABLE A13-9. FLAMMABILITY LIMITS, QUENCHING DISTANCES, AND MINIMUM IGNITION ENERGIES FOR VARIOUS FUELS [3, 5]

Fuel	T_{Boil} (°C)	Spontaneous Ignition Temperature (°C)	Flammability Limits: Equivalence Ratio Φ_{min} (Lean or Lower Limit)	Flammability Limits: Equivalence Ratio Φ_{max} (Rich or Upper Limit)	Flammability Limits: Stoichiometric Mass Air-Fuel Ration
Acetylene	-83.9	305	0.19	∞	13.3
Carbon monoxide	-190.0	608.9	0.34	6.76	2.5
n-Decane	174.0	231.7	0.36	3.92	15.0
Ethane	-88.9	472.2	0.5	2.72	16.0
Ethylene	10.6	428.9	0.41	>6.1	14.8
Gasoline	155.0	298.9	-	-	-
Hydrogen	-252.7	571.1	0.14	2.54	34.5
Methane	-161.7	632.2	0.46	1.64	17.2
Methanol	64.5	470	0.48	4.08	6.5
n-Octane	125.6	240	0.51	4.25	15.1
Propane	-42.2	504.4	0.51	2.83	15.6

TABLE A13-10. EFFECTS OF THERMAL RADIATION [4]

Radiant heat flux (kW/m^2)	Observed effect
0.67	Summer sunshine
1.0	Maximum for indefinite skin exposure
6.4	Pain after 8-s skin exposure
10.4	Pain after 3-s skin exposure
16.0	Blistering of skin after a 5-s exposure

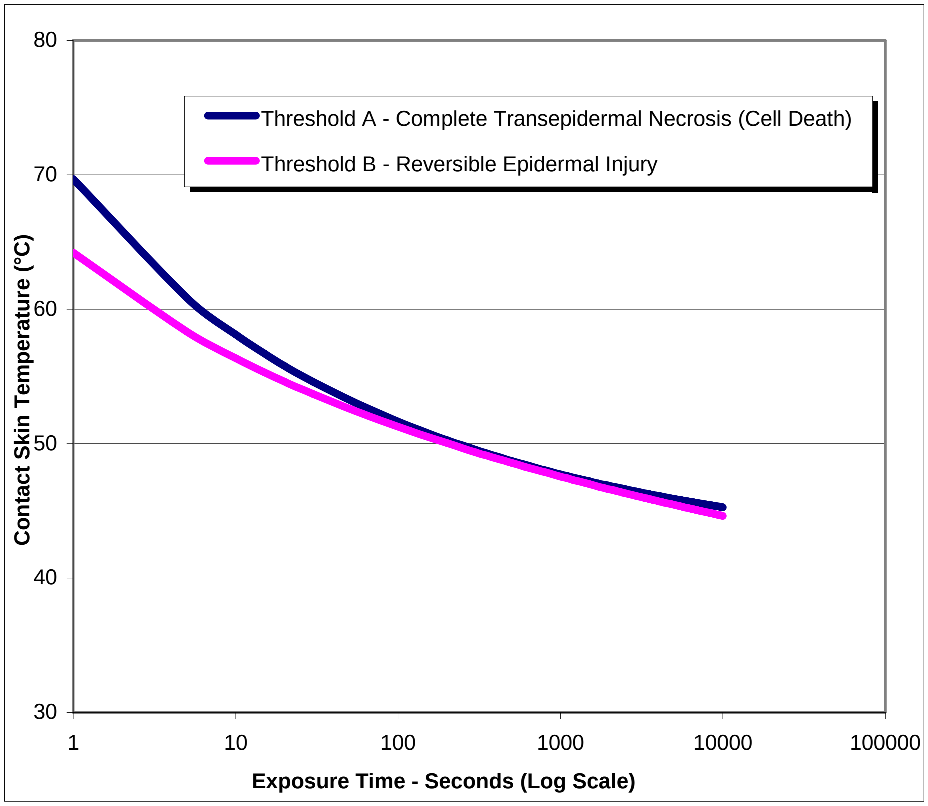


FIGURE A13-1. TEMPERATURE-TIME RELATIONSHIP FOR BURNS [2]

References:

1. Babrauskas, V., *Ignition Handbook*. 2003, Issaquah, WA: Fire Science Publishers.
2. ASTM C 1055-03 *Standard Guide for Heated System Surface Conditions that Produce Contact Burn Injuries*. 2003, ASTM International: West Conshohocken, PA.
3. *The SFPE Handbook of Fire Protection Engineering*. 3rd ed, ed. P. DiNenno, et al. 2002, Quincy, Massachusetts: National Fire Protection Association.
4. Drysdale, D., *An Introduction to Fire Dynamics*. Second Edition ed. 1998, Southern Gate, Chichester, West Sussex, England: John Wiley & Sons, Ltd.
5. Turns, S., *An Introduction to Combustion: Concepts and Applications*. 2nd ed. 2000: McGraw-Hill Higher Education.