SAMUEL W COATES
Small Engines Consulting
51683 Paradise Lane, Lake Linden, MI 49945-6940
Tel: (906) 296-9561
e-mail: swcoates@mtu.edu

Mr Alan Stout
Assessment and Standards Division
U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

March 7, 2006

Dear Alan:

Enclosed you will find my review of the study, " EPA Technical Study on the Safety of Emission Controls for Non-Road Spark Ignition Engines Less Than 50 Horsepower".

The time spent on the review was approximately15 hours.

If you have any questions concerning the review, please do not hesitate to contact me.

Sincerely,

Sam W. Coates, PhD

Enc: EPA Safety Study Review

"EPA Technical Study on the Safety of Emission Controls for Non-Road Spark-Ignition Engines Less Than 50 Horsepower"

NAME AND ADDRESS OF REVIEWER

Samuel W. Coates
51683 Paradise Lane
Lake Linden, MI 49945-9640

QUALIFICATIONS AND EXPERTISE

The reviewer has broad experience in the small engine field, having been involved in research and development of two-stroke direct injection engines, along with exhaust gas after-treatment and noise reduction systems, for over 20 years.

He was closely involved in the development of the ICOMIA and SAE test standards for marine emissions (*Ref: Coates and Lassanske, SAE 901597).

After taking early retirement from industry, he is currently teaching undergraduate engineering technology courses, and maintains a strong interest in small engine development issues.

Education
The Queen's of University, Belfast, Northern Ireland
1974 – Ph.D., Mechanical Engineering
1970 – B.Sc. (First Class Honors), Mechanical Engineering

Employment
Michigan Technological University, Houghton, MI.
8/98 to present – Associate Professor, School of Technology
Mercury Marine Division, Brunswick Corporation, Fond du Lac, WI.
6/95 to 1/98 – Director of Advanced Engine Systems
8/85 to 6/95 – Manager of Computational Engineering
Lockheed Missiles and Space Company, Austin, TX.
5/83 to 8/85 – Senior Research Engineer,
Mercury Marine Division, Brunswick Corporation, Fond du Lac, WI.
9/77 to 5/83 – Manager of Advanced Research
5/74 to 9/77 – Research Engineer
Short Brothers Aircraft Company, Belfast, Northern Ireland.
6/68 to 9/70 – Aeronautical Engineer
9/64 to 6/68 – Aeronautical Engineering Apprentice

Related Affiliations

Society of Automotive Engineers

1974 to present – Member (Served as Reviewer, Technical Session Organizer and Chairperson)

Wisconsin Small Engine Consortium

1994 to 1998 – Mercury Marine Technical Representative

1998 – Chairman, Technical Committee

Related Publications

S.W.Coates, L.W.Evers, C.F.Zellner, M.A.Pruski, J.P.Bogema, "Low Speed Running Characteristics of a Small Two-Stroke Engine with Auxiliary Exhaust Ports," SAE/JSAE Paper 2003-32-0019, Small Engine Technology Conference, Madison, WI, September 2003.

J.A.Hoffman, F.Khatri, J.K.Martin and S.W.Coates, "Mass-Related Properties for Direct Injection SI Engines," SAE Paper 980500.

J.A.Hoffman, J.K.Martin and S.W.Coates, " A Technique for Obtaining Spatial and Temporal Mass Flux Measurements of a Pulsed Spray – a Description of the Hardware and Methodology," Review of Scientific Instruments, November 1997.

M.V.Casarella, M.L.Syvertsen, J.K.Martin, J.A.Hoffmann, J.B.Ghandi, S.W.Coates and F.A.McGinnity, " Spray Combustion and Emissions in a Direct-Injection Two-Stroke Engine with Wall Stabilization of an Air-Assisted Spray," SAE 970360.

J.A.Hoffmann, J.K.Martin and S.W.Coates, " Spray Photographs and Preliminary Spray Mass Flux Distribution Measurements of a Pulsed Pressure Atomizer," ILASS-Americas 9th Annual Conference on Liquid Atomization and Spray Systems, 1996.

M.L.Syvertsen, J.K.Martin, J.A.Hoffmann, S.W.Coates and F.A.McGinnity, " Injection and Ignition Effects on Two-Stroke Direct Injection Emissions and Efficiency," SAE 961803.

**S.W.Coates and G.G.Lassanske*, " Measurement and Analysis of Gaseous Exhaust Emissions from Recreational and Small Commercial Marine Craft," SAE 901597.

CONFLICT OF INTEREST STATEMENT

I have no current involvement in any activities or programs which would disqualify me from being a reviewer of the present EPA study.

REPORT MATERIAL REVIEWED

All written report materials supplied to me by the EPA relating to this study have been reviewed.

REVIEWER COMMENTS

This study addresses the incremental impact on safety, from the use of advanced technology emissions controls, designed to meet new emissions standards being considered by the EPA for certain classes of non-road engines and related equipment.

In particular, the study evaluates safety issues related to catalyst-based emissions controls for Class I and Class II, NHH engines, and evaporative emissions controls for HH, NHH, marine outboards and personal watercraft, and marine generators, all having engines under 50 horsepower.

In support of the study, extensive laboratory and field testing was carried out by the EPA. In addition, design and process FMEA analyses were carried out by Southwest Research Institute.

Dynamometer-based evaluations of Class I and Class II engine systems were carried out by EPA under controlled laboratory conditions using the Federal Phase 2 Test Cycle.

Field-tests of walk-behind and ride-on lawnmowers using Class I and Class II engines were carried out over an extended period of time at several locations, in realistic operating environments.

Nineteen engines in the NHH category were selected for dynamometer testing, consisting of eleven Class I and eight Class II engines. The Class I engines were a mix of side-valve and overhead valve configurations, giving a representative sample of engines found currently in actual consumer use.

State-of the-art infra-red thermal imaging techniques were used for laboratory dynamometer testing, and field testing, to compare component surface temperatures for current product, and advanced technology catalyst-based systems. These techniques gave an extensive amount of thermal data, which appears to be accurate, and the conclusions drawn from the data are reasonable and logical.

The report highlights the important differences between the operating characteristics of catalyst-based systems for non-road applications, compared to light duty automotive applications.

The impact on operational safety with non-road engines, stemming from the need to control of exhaust exotherms is discussed in detail. The importance of the proper selection of catalyst volume, cell density, precious metal mix and loading, air-fuel stoichiometry, secondary air, and cooling air is clearly explained.

The EPA dynamometer testing program evaluated thermal response to hot soak, after-fire, misfire, and rich running conditions. The results indicate that misfire produced the most severe conditions, and was of greatest concern from a safety standpoint using a catalyst-based system. This is a reasonable and valid concern.

In the field-testing program, blockage of cooling air flow was identified as a contributor to thermal safety issues for both conventional and catalyst-based systems. As correctly concluded in the report, proper design of the cooling system alleviates the safety risk.

In all cases where excessive engine temperatures might be encountered, the report suggests that a re-setting thermal switch be used to temporarily shut off the engine's ignition system. In the opinion of the reviewer this would be an excellent solution to a broad range of thermal safety risk issues.

It was noted in the report that a mix of metal and ceramic substrates were used during the study, however there is no mention of any safety related concerns relating specifically to the use of the ceramic material.

The reviewer considers this to be an important issue, and can relate a personal experience involving the use of ceramic substrates in a small engine research and development program. In this particular case, the ceramic substrate suffered extensive mechanical failure. The operating environment involved high levels of vibration, and despite having taken special care to design an appropriate catalyst and canister mounting system, the failure resulted in disintegration of the ceramic after only a few hours of running. The disintegration produced small fragments of the substrate that were expelled from exit pipe of the canister. No such problems were encountered with the use of various metal substrates in the same operating environment.

While this might have been an isolated incident, it did raise serious concerns about the suitability of ceramic substrates from the standpoints of both durability and safety.

It was also noted in the report that the European OEM catalyst muffler (KAT) was used in the testing program, both in original and modified forms. A question therefore arises as to whether there is documented data available from Europe, or elsewhere, which describes laboratory or in-use field experience using the KAT, or other similar OEM or after-market catalyst muffler systems.

The conclusions drawn in the report regarding the use of catalyst-based systems, as a means of meeting Phase 3 emissions control standards, appear to be sound. The testing carried out was very comprehensive and the quality and accuracy of the data appears to be very high. Interpretation of the data and conclusions drawn are reasonable and logical.

It is the opinion of the reviewer that the laboratory and field test program carried out by EPA stands by itself in showing that the safety risk is not incrementally increased by the use of advanced technology systems.

The conclusions reached by EPA, based on the test program, are supported by the results of the FMEA analyses. The outcome of any FMEA analysis relies on the experience and knowledge of the FMEA team members. In this case the team consisted of very qualified individuals, and the formulation of their analyses are realistic. The outcomes and conclusions appear to be reasonable and sound.

The report discusses in depth the proposed EPA standards for evaporative emissions controls. Many safety standards already exist, and in general the small engine industry has been diligent in applying upgraded materials and testing methods to ensure enhanced product safety.

Compared to the challenges of changing to catalyst-based exhaust systems, the requirements of evaporative emissions controls are more straightforward. The discussion and conclusions drawn in the report relative to safety issues concerning evaporative emissions controls are reasonable and valid.

The particular case of marine outboard and personal watercraft is one that is very familiar to the reviewer. The recreational marine industry is keenly aware of the safety issues involved with the operation of their product. Great strides have been made over the past two decades to address the issues of emissions controls, and fire and burn safety.

Marine products, especially outboards, exhibit some unique characteristics in terms of their compact packaging, high vibration levels during operation, and being immersed in a water environment. The analysis and conclusions in the report regarding safety of marine products are well balanced. They recognize the ongoing strides that are being made to employ advanced technology to meet the challenges of emissions and safe operation

In conclusion, it is the opinion of the reviewer that the safety study was conducted in a very professional and excellent manner. The test procedures, analyses and conclusions have been carefully thought through, and there is clear evidence that the issues relating to operational safety with advanced technology systems are well understood. Overall, the accuracy of assumptions and methods used, and the conclusions derived in the report are reasonable and sound.

REVIEWER SIGNATURE AND DATE

____

Samuel W. Coates, Ph.D.
March 7, 2006

RMH Consulting

Alan Stout
Assessment and Standards Division
U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

March 7, 2006

Dear Alan,

The draft report titled "EPA Safety Study of Nonroad SI Emission Controls" was received Tuesday, February 28, 2006. Subsequently, the report was also submitted as PDF files on Thursday, March 2, 2006. I was asked to do a peer review looking at the scope of the work and methodology used by the EPA in addressing the issues and subsequent analysis, concentrating on the increase safety risk of the new emission controls.

The peer reviewer is now retired from Engelhard Corporation and is presently an independent consultant in catalytic emissions controls for his company RMH Consulting. A short description of my career follows which show my qualifications to perform this peer review.

Dr. Ron Heck is president of RMH Consulting where he specializes in consultation on environmental catalysis for auto, diesel and stationary source, general catalysis, fuel cells, reaction engineering, combustion technology, chemical engineering and expert witness. Ron was previously a Research Manager responsible for developing new catalyst technology for Engelhard Corporation's worldwide customers in environmental catalysis. He retired from Engelhard after 31 years working in R&D. where he worked on development of catalytic processes for Engelhard in SCR NOx, NSCR NOx, automotive catalyst, diesel catalyst, PremAir® catalyst systems, hydrogenation technology, ozone abatement, volatile organic compound abatement, ammonia oxidation, chemical feedstock purification and chemical synthesis. Ron is a member of American Men and Women of Science and Who's Who in Technology Today. He is a recipient of the Forest R. McFarland award from the Society of Automotive Engineers for outstanding contributions to this professional society. Ron is an SAE Fellow in recognition of engineering creativity and contributions to the profession and the public at large. He is co-instructor for courses for the SAE in automotive emission control catalysis and diesel emission control catalysis. He is a member of the Scientific Advisory Board of the Strategic Environmental Research and Development Program for environmental studies in the Department of Defense. Ron has been involved in over 80 publications in commercial applications of catalysts and holds 28 U.S. patents on catalytic processes. He is the co-author of the book entitled "Catalytic Air Pollution Control: Commercial Technology" (1^{st} and 2^{nd} edition) and is the co-editor of the *NewsBrief* section of Applied Catalysis B: Environmental. Ron and his former research team from Engelhard received the 2004 Thomas Alva Edison Patent Award from R&D Council of New Jersey for the invention of close coupled catalyst technology for ultra low emission gasoline vehicles. Ron received his B.S. in Chemical Engineering and his Ph.D. from the University of Maryland, and a M.A. in Theology from the College of St. Elizabeth.

My present consulting business and clients would in no way compromise my integrity as a peer reviewer of this draft document and no real or perceived conflicts of interest exist.

The total review took about 13 hours including reporting. The written summary report is enclosed with this note and in addition a CD was mailed on March 7, 2006 containing the PDF files with specific embedded comments to aide the process since the report was so large. This will be much easier to follow since on the draft many pages weren't numbered.

The following lists comments regarding the Report Structure and the Technical Approach. The items listed under Technical Approach have to be answered since they directly impact the test methodology, test results and test conclusions. The report shouldn't be issued without these issues being addressed and in some cases more experiments may be required to answer the questions raised.

Report Structure:

1. The reference and the way you handle them throughout the report is different from the sections in the beginning and end. How does the reader obtain the references cited in section 4?
2. Many paragraphs are very long and difficult to follow the trend of the thought. Consider using shorter paragraphs.
3. In most cases acronyms are explained before they are used but not in all cases.
4. The report needs a transition into the SwRI study.

Technical Approach:

1. The report never mentions issues like pressure and possible de-rating of the equipment.
2. The report does not indicate any statistics regarding the tests such as test repeatability,
   testing error analysis, etc. This needs to be addressed.
3. No mention of types of oil to use, not to use or fuel additives and the consequences on safety with a catalyst.

4. In section 5 on NHH Test Program, a table showing the equipment as received and modified with details of modification would be beneficial.
5. There is no explanation or justification of why you use ceramic monoliths in some cases and metal monoliths in other. Similarly for the wire mesh support. Need some text addressing this.
5. There are no background references for the IR techniques used in 5C. Need something here for referee.
6. In the Hot Soak Testing in section 5D, the term is used…following sustained operation…. What is meant by sustained operation: hours, etc?
7. Section 5E talks about Field Operation. No comments were made in the report comparing the results from Field Operation and Dynamometer? Can something be said here to correlate the two test procedures?
8. In the section about Field Operation, it would be good to describe the characteristics of the test conditions at Southwest Tennessee, etc. That is average grass height, time of cutting, dampness, etc. so the reader has an idea of differences.
9. In section 5E, there is an explanation of the test procedure of Field Operation. Why did you use this break-in procedure? Why was it needed? Does the early stage of operation affect the safety conclusions? This is not discussed in the SwRI FMEA or anywhere.
10. Why don't you put in Appendix the emission results from the initial stages of field operation? Also why don't you describe these results anywhere? This is in section 5E. Do they anyway impact the safety analysis?
11. In 5E, for acquisition of IR thermal data in field, how is IR referenced or calibrated? In 5C this is discussed for the lab tests but no mention of Field Tests.
12. In section 6B, the "degreening" is mentioned but not explained. How was it done? Why was this done? What will be expected with commercial catalyst? How does this "degreening" step affect safety if it won't happen in commercial installations?
13. In section 6B, Infrared thermal aging-Class I OHV Engines, for engine 241, it is stated that tests were done after 110 hours of dyno aging. Why was this done? What were results at zero hours versus 110 hours? How does this affect safety conclusions? Is the engine as safe at zero hours?
14. Engine 231 and Figure 231 with and without catalyst shows that Class II engines really run hot! Not sure what to say here except that they are very hot and appear to have safety issues as a class of engines with and without controls.
15. In section 6B, for Run-on after-fire testing, this phenomena needs to be defined. Also information missing in first paragraph. In the second paragraph, which does it mean…four sequential repeats of the high-inertia shut-down conditions tested…Please define these test conditions.
16. Rich Operation and figure 6-36 don't look right. For richer operation of the OEM, the excess fuel should cool the exhaust. With a catalyst and venture air, the exotherm should raise the temperatures. Why does the opposite occur?
17. In section 6C, for Field Test Results second paragraph, will the grass conditions in Tennessee contribute to debris accumulation?
18. In section 7, Table 7-1 is not explained or mentioned in the text.

19. In section 8, scenario 1, c, there is a paragraph that starts with….In the event of an induction system failure…. It mentions the self-limited by catalyst deactivation. What is this? Any evidence that it will happen? How reliable is this phenomena? This paragraph in general looks too much like conjecture and problematic.

I hope these comments have been useful. If you need to set up a conference call the week of 3/6/2006, I am available. The following week I will be traveling.

Sincerely,

Ronald M. Heck

James F. Hoebel
13506 Star Flower Court
Chantilly, Virginia 20151
March 6, 2006

Alan Stout
Assessment and Standards Division
U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

Dear Mr. Stout:

I am pleased to transmit, both electronically and by mail, my peer review report of the "EPA Technical Study on the Safety of Emissions Controls for Nonroad Spark-Ignition Engines <50 Horsepower."

For your information, I spent approximately 20 hours in preparing this review.

I will submit a copy of my review along with an invoice to RTP Finance soon.

I hope that you find this review useful. I have enjoyed working with EPA.

Sincerely,

Peer Review

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

Prepared by James F. Hoebel

March 6, 2006

I. Introduction

The subject study report concerns an EPA analysis of the safety implications of adopting new exhaust and evaporative emission standards for nonroad spark-ignition engines. The study examines the potential fire and burn safety effects of the anticipated new standards upon consumers. My review is based on my experience with the development of consumer product fire safety standards while serving as Program Manager and Chief Engineer for Fire Safety for the U.S. Consumer Product Safety Commission. My report includes a brief summary, some specific and general comments, and additional required information.

II. Summary

The study evaluates the incremental change to safety of proceeding from the current "Phase 2" emissions requirements to the new "Phase 3". This study takes a reasonable and prudent approach by analyzing the most significant potential adverse fire and burn safety effects of adopting new exhaust and emission standards. The study concentrates on exhaust emission standards for non hand held engines (NHH). Major hazardous situations are first identified and evaluated using appropriate existing databases. Seven scenarios are selected forming the basis for laboratory and field tests using state-of-the-art engines and similar engines modified with advanced catalytic mufflers capable of meeting the Phase 3 standard's requirements. Failure Mode and Effects Analyses (FMEA) are conducted by a contractor to evaluate incremental changes in risk probability of going from Phase 2 to Phase 3 emissions standards. These studies are appropriate in scope, extensive, properly focused, and complete, given the stage of development of engines using advanced technology to meet the new standards requirements. Conclusions reached are reasonable and supported by the results of the tests and analyses. These conclusions support proceeding ahead with Phase 3 exhaust emissions standards for NHH engines.

Additional studies address the incremental effects on fire safety of new evaporative emission standards for both NHH and hand held engines (HH) and new exhaust and evaporative standards for certain marine spark-ignition engines. These studies are limited, since it is believed that these new standards would not require the application of advanced technology in order to achieve compliance. These additional studies conclude that the technology to meet new standards would not result in an increase in the risk of fires and burns to consumers.

Specific and general comments are offered in my review for EPA's consideration.

III. Comments

- A footnote at the beginning of the study would be helpful to explain the regulatory context of the safety study. When I began my review, I was unfamiliar with the EPA emissions standards process. A short description of the scope of the activity, the purpose and status of the various phases, schedules, etc. would have expedited the review.

- New exhaust emission standards for HH engines are not being considered because, I assume, the phase-in for such standards are on schedule for 2010. However, a safety study addressing this subject would be useful and might be considered by EPA at this time.

- While I agree with the approach to limit the evaluation of fire and burn safety associated with new exhaust emission standards for NHH engines to lawn mowers, the new standards will apply to other products. Even though my personal experience related to SI engines is limited, I would assume that the manufacturers of such other products will look to the exhaust catalyst technology to develop complying products. Recognizing that the primary responsibility to manufacture safe products rests with the individual manufacturer, EPA should have a concern that such transfer of technology doesn't create some level of risk of fire and burn.

- In Chapter 4, Scenario 3 describes fires due to fuel leaks on hot surfaces. Was hot surfaces the only potential ignition source considered? Could a spark from an electronic ignition system ignite a fuel leak?

- In Chapter 4, Scenario 4 describes equipment or structural fires when equipment unattended. Was appliance pilot lights the only potential ignition source considered? Could an open flame, a cigarette, or arcing from electric wiring ignite fuel vapors?

- It is noted in Chapter 3 under "Class 1 engines" that Class 1 NHH engines typically run rich, and can result in exothermic exhaust reactions. Is this a factor considered in developing the scenarios? While I have limited experience with SI engines, I wonder if this event is covered by Scenario 7. I note that after-fire in the muffler caused by extremely rich air-to-fuel ratios was not observed in EPA testing for either the OEM muffler or the catalyst-muffler (Chapter 8).

- The source of the engines tested is unclear. It appears that EPA procured certified Phase 2 engines which were modified by EPA to replace existing mufflers with advanced catalyst mufflers capable of reduced exhaust emissions. The question arises to how representative these modified engines were of anticipated production engines compliant with Phase 3 requirements. It is recognized that there may no answer to this question. However, the issue could be noted in the report.

• The incident with run-on after-fire testing of engine 241, described in Chapter 6, seems dramatic. I understand that this happened with the OEM muffler but not with the advanced catalyst muffler. Is this of concern and is any further follow-up planned? I realize that this was a limited observation.

• In preparing for the FMEA (Chapter 7), a list of 18 characteristics of “properly designed” Phase 3 engines is developed. Do the Phase 2 typical production engines contain corresponding “non-catalytic” design characteristics? Or are the listed characteristics appropriate only to engines with advanced catalytic mufflers? For instance, items 7, 8, 9, and 10 could be common to both. The question arises: do these characteristics impose a level of quality that is higher than the usual Phase 2 quality level? Are we comparing an ideal to a real situation?

• In Chapter 9 discussing small SI evaporative emissions, EPA is considering permeation standards, diffusion, and running loss controls for NHH equipment. Yet, running loss controls are not being considered for HH equipment. Is this not a problem?

• The section on HH equipment goes on to state that typical materials used for HH equipment fuel hose are nitrile rubber and fluoroelastomers. However, on the next page, the report lists polyurethane, nitrile rubber, and polyvinyl chloride as common fuel hose materials.

• The conclusions of this study strongly support proceeding with Phase 3 exhaust emission standards for NHH engines. As EPA proceeds through this process, are there any plans or recommendations for further fire and burn safety tasks? For instance, as manufacturers proceed with the development of new technology NHH engines, will there be future tests or analyses of prototype or production models? Or will this responsibility be left to the manufacturer? I understand that new evaporative emission standards will not likely require application of advanced technology. But, are there future plans/concerns relating to marine engines? In any case, I would recommend continued EPA attention to the fire/burn safety implications of new standards as they are developed.

IV Name & Address

James F. Hoebel, Consultant
13506 Star Flower Court
Chantilly, Virginia 20151
703 818-2639

V Material Reviewed

Draft Report, EPA420-R-06-XXX, March xx, 2006, “EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines <50 Horsepower”, Ten Chapters, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency.

Draft Report, "Failure Mode and Effects Analyses for Small SI Equipment and Engines". Southwest Research Institute, was provided but not reviewed.

VI. Summary of Expertise and Qualifications

Retired 1999 after 28 years with U.S. Consumer Product Safety Commission. Served as Chief Engineer for Fire Safety, the agency's primary internal consultant on fire safety associated with consumer products. Products included home furnishings, ignition sources, apparel, and protective devices. Functioned concurrently as Acting Director of Mechanical Engineering Division for over a year. Previously, Program Manager for Fire and Thermal Burn Hazards. Oversaw applied research on flammability and toxicity, injury/death data analysis, development of mandatory and voluntary product safety standards, consumer information projects, and enforcement of existing standards. Projects included cigarette lighters, cigarette fire safety, apparel, space heating systems, upholstered furniture, and smoke detectors. Graduate of Columbia University with an AB and a BS degree in Chemical Engineering..

VII. Real or Perceived Conflicts of Interest

None.

I am a member of the National Association of State Fire Marshals (NASFM) Science Advisory Committee. I understand that NASFM is associated with the International Consortium for Fire Safety, Health & the Environment, and I am aware that the Consortium is involved in a project on the fire safety of measures being considered to reduce emissions of small engines in outdoor power equipment. I am not personally involved with either the Consortium or their project.

SAMUEL W COATES
Small Engines Consulting
51683 Paradise Lane, Lake Linden, MI 49945-6940
Tel: (906) 296-9561
e-mail: swcoates@mtu.edu

Mr Alan Stout
Assessment and Standards Division
U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

March 7, 2006

Dear Alan:

Enclosed you will find my review of the study, " EPA Technical Study on the Safety of Emission Controls for Non-Road Spark Ignition Engines Less Than 50 Horsepower".

The time spent on the review was approximately15 hours.

If you have any questions concerning the review, please do not hesitate to contact me.

Sincerely,

Sam W. Coates, PhD

Enc: EPA Safety Study Review

“EPA Technical Study on the Safety of Emission Controls for Non-Road Spark-Ignition Engines Less Than 50 Horsepower”

NAME AND ADDRESS OF REVIEWER

Samuel W. Coates
51683 Paradise Lane
Lake Linden, MI 49945-9640

QUALIFICATIONS AND EXPERTISE

The reviewer has broad experience in the small engine field, having been involved in research and development of two-stroke direct injection engines, along with exhaust gas after-treatment and noise reduction systems, for over 20 years.

He was closely involved in the development of the ICOMIA and SAE test standards for marine emissions (*Ref: Coates and Lassanske, SAE 901597).

After taking early retirement from industry, he is currently teaching undergraduate engineering technology courses, and maintains a strong interest in small engine development issues.

Education
The Queen’s of University, Belfast, Northern Ireland
    1974 – Ph.D., Mechanical Engineering
    1970 – B.Sc. (First Class Honors), Mechanical Engineering

Employment
Michigan Technological University, Houghton, MI.
    8/98 to present – Associate Professor, School of Technology
Mercury Marine Division, Brunswick Corporation, Fond du Lac, WI.
    6/95 to 1/98 – Director of Advanced Engine Systems
    8/85 to 6/95 – Manager of Computational Engineering
Lockheed Missiles and Space Company, Austin, TX.
    5/83 to 8/85 – Senior Research Engineer,
Mercury Marine Division, Brunswick Corporation, Fond du Lac, WI.
    9/77 to 5/83 – Manager of Advanced Research
    5/74 to 9/77 – Research Engineer
Short Brothers Aircraft Company, Belfast, Northern Ireland.
    6/68 to 9/70 – Aeronautical Engineer
    9/64 to 6/68 – Aeronautical Engineering Apprentice

Related Affiliations

Society of Automotive Engineers

1974 to present – Member (Served as Reviewer, Technical Session Organizer and Chairperson)

Wisconsin Small Engine Consortium

1994 to 1998 – Mercury Marine Technical Representative

1998 – Chairman, Technical Committee

Related Publications

S.W.Coates, L.W.Evers, C.F.Zellner, M.A.Pruski, J.P.Bogema, "Low Speed Running Characteristics of a Small Two-Stroke Engine with Auxiliary Exhaust Ports," SAE/JSAE Paper 2003-32-0019, Small Engine Technology Conference, Madison, WI, September 2003.

J.A.Hoffman, F.Khatri, J.K.Martin and S.W.Coates, "Mass-Related Properties for Direct Injection SI Engines," SAE Paper 980500.

J.A.Hoffman, J.K.Martin and S.W.Coates, " A Technique for Obtaining Spatial and Temporal Mass Flux Measurements of a Pulsed Spray – a Description of the Hardware and Methodology," Review of Scientific Instruments, November 1997.

M.V.Casarella, M.L.Syvertsen, J.K.Martin, J.A.Hoffmann, J.B.Ghandi, S.W.Coates and F.A.McGinnity, " Spray Combustion and Emissions in a Direct-Injection Two-Stroke Engine with Wall Stabilization of an Air-Assisted Spray," SAE 970360.

J.A.Hoffmann, J.K.Martin and S.W.Coates, " Spray Photographs and Preliminary Spray Mass Flux Distribution Measurements of a Pulsed Pressure Atomizer," ILASS-Americas 9th Annual Conference on Liquid Atomization and Spray Systems, 1996.

M.L.Syvertsen, J.K.Martin, J.A.Hoffmann, S.W.Coates and F.A.McGinnity, " Injection and Ignition Effects on Two-Stroke Direct Injection Emissions and Efficiency," SAE 961803.

**S.W.Coates and G.G.Lassanske*, " Measurement and Analysis of Gaseous Exhaust Emissions from Recreational and Small Commercial Marine Craft," SAE 901597.

CONFLICT OF INTEREST STATEMENT

I have no current involvement in any activities or programs which would disqualify me from being a reviewer of the present EPA study.

REPORT MATERIAL REVIEWED

All written report materials supplied to me by the EPA relating to this study have been reviewed.

REVIEWER COMMENTS

This study addresses the incremental impact on safety, from the use of advanced technology emissions controls, designed to meet new emissions standards being considered by the EPA for certain classes of non-road engines and related equipment.

In particular, the study evaluates safety issues related to catalyst-based emissions controls for Class I and Class II, NHH engines, and evaporative emissions controls for HH, NHH, marine outboards and personal watercraft, and marine generators, all having engines under 50 horsepower.

In support of the study, extensive laboratory and field testing was carried out by the EPA. In addition, design and process FMEA analyses were carried out by Southwest Research Institute.

Dynamometer-based evaluations of Class I and Class II engine systems were carried out by EPA under controlled laboratory conditions using the Federal Phase 2 Test Cycle.

Field-tests of walk-behind and ride-on lawnmowers using Class I and Class II engines were carried out over an extended period of time at several locations, in realistic operating environments.

Nineteen engines in the NHH category were selected for dynamometer testing, consisting of eleven Class I and eight Class II engines. The Class I engines were a mix of side-valve and overhead valve configurations, giving a representative sample of engines found currently in actual consumer use.

State-of the-art infra-red thermal imaging techniques were used for laboratory dynamometer testing, and field testing, to compare component surface temperatures for current product, and advanced technology catalyst-based systems. These techniques gave an extensive amount of thermal data, which appears to be accurate, and the conclusions drawn from the data are reasonable and logical.

The report highlights the important differences between the operating characteristics of catalyst-based systems for non-road applications, compared to light duty automotive applications.

The impact on operational safety with non-road engines, stemming from the need to control of exhaust exotherms is discussed in detail. The importance of the proper selection of catalyst volume, cell density, precious metal mix and loading, air-fuel stoichiometry, secondary air, and cooling air is clearly explained.

The EPA dynamometer testing program evaluated thermal response to hot soak, after-fire, misfire, and rich running conditions. The results indicate that misfire produced the most severe conditions, and was of greatest concern from a safety standpoint using a catalyst-based system. This is a reasonable and valid concern.

In the field-testing program, blockage of cooling air flow was identified as a contributor to thermal safety issues for both conventional and catalyst-based systems. As correctly concluded in the report, proper design of the cooling system alleviates the safety risk.

In all cases where excessive engine temperatures might be encountered, the report suggests that a re-setting thermal switch be used to temporarily shut off the engine's ignition system. In the opinion of the reviewer this would be an excellent solution to a broad range of thermal safety risk issues.

It was noted in the report that a mix of metal and ceramic substrates were used during the study, however there is no mention of any safety related concerns relating specifically to the use of the ceramic material.

Response: We expected significantly longer hot-soak time-to-temperature with the ceramic material versus metal monoliths due to the higher mass of ceramic monoliths, but this was not supported by the data. Ceramics are highly durable in land-based environments, even in environments with high shock and vibration.

The reviewer considers this to be an important issue, and can relate a personal experience involving the use of ceramic substrates in a small engine research and development program. In this particular case, the ceramic substrate suffered extensive mechanical failure. The operating environment involved high levels of vibration, and despite having taken special care to design an appropriate catalyst and canister mounting system, the failure resulted in disintegration of the ceramic after only a few hours of running. The disintegration produced small fragments of the substrate that were expelled from exit pipe of the canister. No such problems were encountered with the use of various metal substrates in the same operating environment.

Response: We were also concerned about this, but at least one of our suppliers insisted that this was a matter of proper catalyst canning and matting, and that they could supply suitably durable catalyst configurations. This appears to be the case with the field-tested ceramic monoliths that we have tested. To date, we have not had any substrate failures in the field, and we have run three configurations to the end of useful life on walk-behind mowers. We are just now approaching 100 hours on a ceramic monolith on a lawn tractor without any issues so far. The OEM production European catalyst muffler shown in the study uses a ceramic monolith. I think that metal monoliths may very well be easier to package and handle on an assembly line, but we expect to see a mix of all of the substrate types (ceramic monolith, metal monolith, wire mesh, and catalyzed surfaces like the tubular catalyst), and each has their advantages and disadvantages.

While this might have been an isolated incident, it did raise serious concerns about the suitability of ceramic substrates from the standpoints of both durability and safety.

It was also noted in the report that the European OEM catalyst muffler (KAT) was used in the testing program, both in original and modified forms. A question therefore arises as to whether there is documented data available from Europe, or elsewhere, which describes laboratory or in-use field experience using the KAT, or other similar OEM or after-market catalyst muffler systems.

Response: We have not been successful in obtaining much information from the engine manufacturer. We have extensive experience with our modified versions of this unit, as reported in the safety study.

The conclusions drawn in the report regarding the use of catalyst-based systems, as a means of meeting Phase 3 emissions control standards, appear to be sound. The testing carried out was very comprehensive and the quality and accuracy of the data appears to be very high. Interpretation of the data and conclusions drawn are reasonable and logical.

It is the opinion of the reviewer that the laboratory and field test program carried out by EPA stands by itself in showing that the safety risk is not incrementally increased by the use of advanced technology systems.

The conclusions reached by EPA, based on the test program, are supported by the results of the FMEA analyses. The outcome of any FMEA analysis relies on the experience and knowledge of the FMEA team members. In this case the team consisted of very qualified individuals, and the formulation of their analyses are realistic. The outcomes and conclusions appear to be reasonable and sound.

The report discusses in depth the proposed EPA standards for evaporative emissions controls. Many safety standards already exist, and in general the small engine industry has been diligent in applying upgraded materials and testing methods to ensure enhanced product safety.

Compared to the challenges of changing to catalyst-based exhaust systems, the requirements of evaporative emissions controls are more straightforward. The discussion and conclusions drawn in the report relative to safety issues concerning evaporative emissions controls are reasonable and valid.

The particular case of marine outboard and personal watercraft is one that is very familiar to the reviewer. The recreational marine industry is keenly aware of the safety issues involved with the operation of their product. Great strides have been made over the past two decades to address the issues of emissions controls, and fire and burn safety.

Marine products, especially outboards, exhibit some unique characteristics in terms of their compact packaging, high vibration levels during operation, and being immersed in a water environment. The analysis and conclusions in the report regarding safety of marine products are well balanced. They recognize the ongoing strides that are being made to employ advanced technology to meet the challenges of emissions and safe operation

In conclusion, it is the opinion of the reviewer that the safety study was conducted in a very professional and excellent manner. The test procedures, analyses and conclusions have been carefully thought through, and there is clear evidence that the issues relating to operational safety with advanced technology systems are well understood. Overall, the accuracy of assumptions and methods used, and the conclusions derived in the report are reasonable and sound.

REVIEWER SIGNATURE AND DATE

____

Samuel W. Coates, Ph.D.
March 7, 2006

RMH Consulting

Alan Stout
Assessment and Standards
Division U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

March 5, 2006

Dr. Heck provided two sets of peer review comments. Please look at each.

Dear Alan,

I received the full report last Tuesday, February 28, 2006 and completed my review this morning. All told it took about 9 hours including this memo. As I promised, I will also send the PDF files with embedded comments so it will be easier to follow since on the draft many pages weren't numbered. You should receive the files Tuesday or Wednesday. I wanted you to get these comments sooner since there are some critical issues that need to be addressed.

The following list comments regarding the Report Structure and the Technical Approach. The items listed under Technical Approach have to be answered since they directly impact the test methodology, test results and test conclusions. The report shouldn't be issued without these issues being addressed and in some cases more experiments may be required to answer the questions raised.

Report Structure:

20. The reference and the way you handle them throughout the report is different from the sections in the beginning and end. How does the reader obtain the references cited in section 4?

    RESPONSE: They are available in the public docket

21. Many paragraphs are very long and difficult to follow the trend of the thought. Consider using shorter paragraphs.

    RESPONSE: Modifications incorporated as possible throughout the report

22. In most cases acronyms are explained before they are used but not in all cases.

RESPONSE: Reviewed the study for missing explanatory terms

23. The report needs a transition into the SwRI study.

    RESPONSE: The SwRI study is discussed in detail in Chapter 7.

Technical Approach:

6. The report never mentions issues like pressure and possible de-rating of the equipment.

   RESPONSE: A sentence regarding back-pressure and power output of the engines has been added to Chapter 6, section A. Back-pressure did not change enough to cause any measurable change in power output. In the case of the air-cooled side-valve engines, the primary exhaust restriction is probably the poor exhaust port design, not the small catalyst substrate.

7. The report does not indicate any statistics regarding the tests such as test repeatability,
   testing error analysis, etc. This needs to be addressed.

   RESPONSE: Repeat testing was conducted for emissions tests. Repeat measurements were not conducted for the IR thermal imaging during dynamometer testing. The accuracy of the instrument was the limiting factor, not test-to-test variability. Although the exhaust emissions for these air-cooled engines tended to have a relatively high coefficient of variation (COV), the exhaust gas temperatures at the exhaust port were extremely repeatable from day to day (to within 5-10 °C). This is largely a function of dynamometer torque and air inlet temperature control, which were held very constant (ambient was 25 °C ± 1 °C for all testing, with the test cell at 75 gr/lbm-air humidity ± 5 gr). Torque control at rated gave 1% COV or less, and improved at lighter loads. See Chapter 5, section D.

8. No mention of types of oil to use, not to use or fuel additives and the consequences on safety with a catalyst.

   RESPONSE: API and SAE specifications were added. There was no effort to specifically test with low-ash oil. We used the best quality oil readily available to the test site, which was typically API SL or SM.

9. In section 5 on NHH Test Program, a table showing the equipment as received and modified with details of modification would be beneficial.

   RESPONSE: We found this easier to just show in the figures. We could not find a good way to tabulate this. Some of the changes are actually to the equipment chassis rather than to the engine (e.g., the exhaust ejectors on the lawn tractors). At least one example of each basic engine/emission control system configuration is shown within the figures. There is also a brief summary of engine configuration versus engine number included with the tabulated emissions data in Appendix C (I added a reference to these tables in the introductory paragraph of section C).

10. There is no explanation or justification of why you use ceramic monoliths in some cases and metal monoliths in other. Similarly for the wire mesh support. Need some text addressing this.

    RESPONSE: Both metal foil and ceramic monoliths were tested. The primary deciding factor was availability of substrates. For applications requiring very high shock resistance or faster heat rejection following shutdown, 100 cpsi or 200 cpsi metal foil may be slightly more appropriate. Still, we have had acceptable hot-soak performance from ceramic monoliths. We have not had any problems with ceramic monoliths in either lawn tractor or lawn mower applications as long as the appropriate matting and canning techniques are applied. Text has been corrected.

11. There are no background references for the IR techniques used in 5C. Need something here for reference.

    RESPONSE: citation added

12. In the Hot Soak Testing in section 5D, the term is used…following sustained operation…. What is meant by sustained operation: hours, etc?

    RESPONSE: change made in text

13. Section 5E talks about Field Operation. No comments were made in the report comparing the results from Field Operation and Dynamometer? Can something be said here to correlate the two test procedures?

    RESPONSE: some further text has been added, but results are presented in Chapter 6

14. In the section about Field Operation, it would be good to describe the characteristics of the test conditions at Southwest, Tennessee, etc. That is average grass height, time of cutting, dampness, etc. so the reader has an idea of differences.

    RESPONSE: grass cutting height and mowing deck settings added to captions for the figures showing the test sites. Duration of cutting was added to the text. Specific weather conditions are described in Chapter 6.

15. In section 5E, there is an explanation of the test procedure of Field Operation. Why did you use this break-in procedure? Why was it needed? Does the early

stage of operation affect the safety conclusions? This is not discussed in the SwRI FMEA or anywhere.

RESPONSE: Engine break-in and catalyst degreening procedures were identical. For catalyst-equipped engines, the procedures were also concurrent. Please refer to the response given for p1 of Chapter 6 regarding catalyst degreening.

16. Why don't you put in Appendix the emission results from the initial stages of field operation? Also why don't you describe these results anywhere? This is in section 5E. Do they anyway impact the safety analysis?

    RESPONSE: A citation was added for the emission results.

17. In 5E, for acquisition of IR thermal data in field, how is IR referenced or calibrated? In 5C this is discussed for the lab tests but no mention of Field Tests.

    Response: Citations added. The instrument did not require recalibration for either the field or the laboratory. This is a noncontact microbolometer instrument that does not require calibration more than yearly. Our calibrations span the laboratory and field test dates, and no adjustment was necessary to the calibration to remain within the manufacturer's ±2 % of point accuracy specification. A calibration table was added to Appendix A.

18. In section 6B, the "degreening" is mentioned but not explained. How was it done? Why was this done? What will be expected with commercial catalyst? How does this "degreening" step affect safety if it won't happen in commercial installations?

    RESPONSE: The procedure is described. It is basically engine operation for up to 10 hours. This was done to allow for stable emissions measurements following ring seating and the initial thermal sintering of the catalyst. The actual end user will experience the first 10 hours of operation of the equipment. Catalysts will never go through this prior to installation. An initial point of operation needs to be chosen for when to make the first measurements. Measurements, either of emissions or of IR, conducted during initial engine ring-seating are not representative of engine operation during most of it's first year of service, and are not stable between measurements. 10 hours is approximately halfway through the first year of equipment life, with life expectancy of 5 to 10 years.

19. In section 6B, Infrared thermal aging-Class I OHV Engines, for engine 241, it is stated that tests were done after 110 hours of dyno aging. Why was this done? What were results at zero hours versus 110 hours? How does this affect safety conclusions? Is the engine as safe at zero hours?

RESPONSE: Because of the timing of when we acquired the instrumentation relative to when aging occurred, we have a mix of low and high-hour infrared results. Some results do span identical engine families and similar configurations at high and low hours. We were surprised at how little difference there was between high and low hour configurations. As long as the engine-out emissions are similar, and as long as the catalyst is active, the IR thermal images are fairly comparable at low and high hours.

20. Engine 231 and Figure 231 with and without catalyst shows that Class II engines really run hot! Not sure what to say here except that they are very hot and appear to have safety issues as a class of engines with and without controls.

    RESPONSE: This is beyond the scope of the study, which is focused on the incremental change due to the introduction of Phase 3 emission standards. There appears to be room for improvement with respect to the temperatures encountered with existing equipment. Some of the design elements applied to the catalyst-mufflers on the lawn tractors (management of cooling air-flow, shielding/shrouding, use of exhaust ejectors) are equally applicable to current equipment designs.

21. In section 6B, for Run-on after-fire testing, this phenomena needs to be defined. Also information missing in first paragraph. In the second paragraph, which does it mean…four sequential repeats of the high-inertia shut-down conditions tested…Please define these test conditions.

    RESPONSE: Defined in Chapter 5. Missing information and clarification added.

22. Rich Operation and figure 6-36 don't look right. For richer operation of the OEM, the excess fuel should cool the exhaust. With a catalyst and venture air, the exotherm should raise the temperatures. Why does the opposite occur?

    RESPONSE: This is not the case because the amount of air added is very small. The engine, even at it's normal Phase 2 A/F calibration, is well rich of stoichiometry even after the addition of secondary air. The passive secondary air system only provides enough air for a 0.04 to 0.1 λ change in the exhaust, depending on the engine operating condition. So the exhaust downstream of air entrainment is normally ~0.89 at high load, about 0.92 at moderate load and about 0.95 at light load. Shifting the A/F of the carburetor calibration significantly richer provided too much HC reactant for the available oxygen in the exhaust. A significant exotherm can only occur if there is sufficient oxygen in the exhaust to react with the excess fuel. The surface temperatures stayed about the same for the catalyst-muffler at the rich conditions. The exhaust gas temperatures at the catalyst-muffler inlet actually dropped due to the rich operation, but some of the additional fuel reacted over the catalyst to bring the surface temperatures back up to about where they were with the standard Phase 2 carburetor calibration. The OEM muffler configuration surface temperatures just cooled off at richer operation. In either case, nothing terribly interesting happened.

23. In section 6C, for Field Test Results second paragraph, will the grass conditions in Tennessee contribute to debris accumulation?

    RESPONSE: No, this appears to have been partly due to the length of the grass and the use of mulching instead of side or bag discharge for the lawn mowers. The lawn tractors used side-discharge and had much less debris accumulation. The debris accumulation problem appeared to be a design issue and only affected this one engine type. We saw similar debris build-up when operating engines from this engine family in SE Michigan the previous year. Proper screening of the air-inlet to the cooling system is really essential.

24. In section 7, Table 7-1 is not explained or mentioned in the text.

    RESPONSE: A transitional sentence mentioning the Table was added

25. In section 8, scenario 1, c, there is a paragraph that starts with….In the event of an induction system failure…. It mentions the self-limited by catalyst deactivation. What is this? Any evidence that it will happen? How reliable is this phenomena? This paragraph in general looks too much like conjecture and problematic.

    RESPONSE: This is true, but engine-out exhaust temperatures for air-cooled small engines are about 100 °C higher than for liquid-cooled automotive engines. EPA’s experience during lean-burn NOx adsorption catalyst development is that we had to be very careful during development of our sulfur regeneration strategy to transition rich before increasing catalyst temperature. If we increased the temperature with a fuel exotherm while net lean, we would rapidly take out the catalyst’s activity with thermal sintering.

I hope these comments have been useful. If you need to set up a conference call the week of 3/6/2006, I am available. The following week I will be traveling.

Sincerely,

Ronald M. Heck

Response to Comments from Dr. R. Heck on Chapters ES, 3, 4, 5, 6, 7, 8, and 9

Executive Summary

Editorial comments

Response: no changes made

Chapter 3

p3

Why isn't pressure drop mention here as design elements specific....
If this result in a derating of the engine or affects safety, it should be considered. At least mention why not considered.

p5

Same comment regarding pressure drop.

Response: A sentence regarding back-pressure and power output of the engines has been added to Chapter 6, section A. Back-pressure did not change enough to cause any measurable change in power output. In the case of the air-cooled side-valve engines, the primary exhaust restriction is probably the poor exhaust port design, not the small catalyst substrate.

p7.

Punctuation error

Response: , changed to . after standards

Chapter 4

p1

Started having an issue here with reference material. Many studies are cited and not sure how reader can get the studies cited and if enough information is given to get the citation.

Response: citations added and placed in public docket

Chapter 5

Table 5-1
What does transcribed from emission tag mean? Explain in text.

Response: changed

p3

Where do I find this reference or any references for that matter?

Response: reference citation coding fixed

p5

Okay this is a major change and no mention of effect of pressure, power rating, etc.

Response: The change is minor, going from only 10% of the engine displacement in catalyst volume to 20% on an isochronous governed engine governed to ~3000 rpm. Obviously the increase in catalyst volume increases backpressure, but the resulting impact on power output was not measurable during dynamometer testing. The geometry of the substrates is different than what is used for automotive applications (i.e., short and fat – the diameter is similar to the length). Some of the OEM exhaust port and muffler designs were also relatively restrictive, so in some cases the catalyst substrate may not have been the primary source of restriction within the exhaust system. In the case of this particular engine family, maximum power at WOT was identical (2.14 kW, identical to 3-significant figures) for the 2-substrate catalyst-muffler relative to the OEM muffler. I added a brief reference to this in this section of Chapter 5. It should also be noted that for side-valve engines, volumetric efficiency is very poor (i.e., the primary exhaust restriction is the exhaust port itself), and that air-cooled OHV engines generally have reduced volumetric efficiency relative to modern liquid-cooled OHV engine designs.

Is this tubular pre catalyst a metal monolith? Tell us more info.

Response: I started out referring the reader to figure 5-3 in part because this one is difficult to describe. This is really just a tube with a perforated channel within this. It's not quite a monolith (1 cpsi?). It's just a channel within a tube, with the internal surfaces washcoated. These are not used at all in automotive applications, but show up in motorcycle and small engine applications, as do catalyzed screens and other types of washcoated surfaces. I added a footnote, but without looking at the picture, I'm not sure how else to describe the substrate.

The first time need to say Pt:Pd:Rh.

Response: Change made

What is ETC?

Response: Electronic throttle control. Change made.

OK at this point I was getting lost and wanted to look at an overall table of Engine as is and Engine modified and how modified. Such a table would be very useful throughout this document section.

Response: We found this easier to just show in the figures. We could not find a good way to tabulate this. Some of the changes are actually to the equipment chassis rather than to the engine (e.g., the exhaust ejectors on the lawn tractors). At least one example of each basic engine/emission control system configuration is shown within the figures. There is also a brief summary of engine configuration versus engine number included with the tabulated emissions data in Appendix C (I added a reference to these tables in the introductory paragraph of section C).

p11
Why no ceramic monoliths? Need some explanation of why metallic chosen.
Here you say ceramic while in text above you say metallic foil. Which is it?

Response: Both metal foil and ceramic monoliths were tested. The primary deciding factor was availability of substrates. For applications requiring very high shock resistance or faster heat rejection following shutdown, 100 cpsi or 200 cpsi metal foil may be slightly more appropriate. Still, we have had acceptable hot-soak performance from ceramic monoliths. We have not had any problems with ceramic monoliths in either lawn tractor or lawn mower applications as long as the appropriate matting and canning techniques are applied. Text has been corrected.

p13
Need a reference citation for the IR methodology for others to inquire about the technique.

Response: Citations added

p14
Define
where delta T is ....
delta t is .....

Response: Change made

Need to define "sustained". How long, how measured, etc.?

Response: Change made

p15
After fire is defined as ....

Response: Definition added

Define CAD?

Response: Text changed.

One question that comes to mind is how do dyno results compare with field operation? Need some kind of analysis or link between the two test methods.

Response: some further description has been added, but results are presented in chapter 6.

p17

This seems like a long time. Any comment here why so long?

Response: This is the typical amount of operation used by the engine manufacturers to achieve stable emissions.

Can you make a diagram here to explain test procedure?

Response: A diagram wasn't necessary to make the point. Engine testing is often preceded by a basic break-in period, followed by initial measurements.

Why not attach in Appendix so reader can easily find and compare? Also, why don't you comment on these tests? Anything interesting here? Is safety analysis different?

Response: It is beyond the scope of this study. The primary point of the study is safety, not emissions. EPA will be publishing additional information on emissions and emission control technology as part of the Regulatory Impact Analysis for the Phase 3 Notice of Proposed Rulemaking. It was included in the appendix solely to provide data on the level of emissions control provided to the engines used within the safety study.

More detail on test site conditions: average grass height, duration of cutting, condition of grass (wet, etc.), wind conditions, etc.

Response: Grass cutting height and mowing deck settings added to captions for the figures showing the test sites. Duration of cutting was added to the text. Specific weather conditions are described in Chapter 6.

p21

What were specifications for oil? Ash content, etc.?

Response: API and SAE specifications were added. There was no effort to specifically test with low-ash oil. We used the best quality oil readily available to the test site, which was typically API SL or SM.

How was IR calibrated in field? In the lab there is emphasis on this calibration but no mention of in field calibration?

Response: The instrument did not require recalibration for either the field or the laboratory. This is a noncontact microbolometer instrument that does not require calibration more than yearly. Our calibrations span the laboratory and field test dates, and no adjustment was necessary to the calibration to remain within the manufacturer's ±2 % of point accuracy specification. A calibration table was added to Appendix A.

Chapter 6

p1

What is missing is any statistics on tests? What was test repeatability? If IR measurements done two days in row any difference? Does wind effect the IR results and test repeatability? Need some details on this topic.

Response: Repeat testing was conducted for emissions tests. Repeat measurements were not conducted for the IR thermal imaging during dynamometer testing. The accuracy of the instrument was the limiting factor, not test-to-test variability. Although the exhaust emissions for these air-cooled engines tended to have a relatively high coefficient of variation (COV), the exhaust gas temperatures at the exhaust port were extremely repeatable from day to day (to within 5-10 °C). This is largely a function of dynamometer torque and air inlet temperature control, which were held very constant (ambient was 25 °C ± 1 °C for all testing, with the test cell at 75 gr/lbm-air humidity ± 5 gr). Torque control at rated gave 1% COV or less, and improved at lighter loads. See Chapter 5, section D.

For what tests?

Response: For the tested configurations over the A-cycle.

How done? Why this way selected? Why did you decide to do this? What will be actual end user experience? Will commercial catalyst be installed "degreened"? Need much more on this issue and how it may affect outcome of this study.

Response: The procedure is described. It is basically engine operation for up to 10 hours. This was done to allow for stable emissions measurements following ring seating and the initial thermal sintering of the catalyst. The actual end user will experience the first 10 hours of operation of the equipment. Catalysts will never go through this prior to installation. An initial point of operation needs to be chosen for when to make the first measurements. Measurements, either of emissions or of IR, conducted during initial engine ring-seating are not representative of engine operation during most of it's first year of service, and are not stable between measurements. 10 hours is approximately halfway through the first year of equipment life, with life expectancy of 5 to 10 years.

p2

A very long paragraph.

Response: This was edited into 3 paragraphs.

p5

Why? Don't leave the reader hanging. Is it because of high temperature and mechanical designs?

Response: The reason isn't entirely clear since BSFC is also improved for OHV. It is probably due in part to the higher compression ratio possible with the OHV design, but further analysis was beyond the scope of this study.

Here is where I am really curious. What was the data like at the beginning of life as compared to 110 hours dyno aging?

Response: Because of the timing of when we acquired the instrumentation relative to when aging occurred, we have a mix of low and high-hour infrared results. Some results do span identical engine families and similar configurations at high and low hours. We were surprised at how little difference there was between high and low hour configurations. As long as the engine-out emissions are similar, and as long as the catalyst is active, the IR thermal images are fairly comparable at low and high hours.

p6
Again the "degreening" question?

Response: see above explanation.

p24
These exhaust run very hot. Is there a safety issue with the as is equipment?

Response: This is beyond the scope of the study, which is focused on the incremental change due to the introduction of Phase 3 emission standards. There appears to be room for improvement with respect to the temperatures encountered with existing equipment. Some of the design elements applied to the catalyst-mufflers on the lawn tractors (management of cooling air-flow, shielding/shrouding, use of exhaust ejectors) are equally applicable to current equipment designs.

p37
Again refresh the reader the definition of after fire.

Response: Our opinion was that the definition added to Chapter 5 would suffice.

Missing information.

Response: citation added.

Define what is meant by high-inertia shutdown.

Response: Definition added to Chapter 5 procedures.

Should be.....In

Response: Typo corrected.

p40
& Air Shroud

Response: This configuration in this figure does not have an air-shroud. The shrouded configuration is in the following figure.

p43

Don't understand this result? If engine running rich, HCs left to go into exhaust. Air added and exotherm occurs causing higher temperatures. Rich engine, excess fuel cools exhaust temperature. So I would guess a higher temperature for rich + venturi + catalyst but you see opposite.

Response: This is not the case because the amount of air added is very small. The engine, even at it's normal Phase 2 A/F calibration, is well rich of stoichiometry even after the addition of secondary air. The passive secondary air system only provides enough air for a 0.04 to 0.1 λ change in the exhaust, depending on the engine operating condition. So the exhaust downstream of air entrainment is normally ~0.89 at high load, about 0.92 at moderate load and about 0.95 at light load. Shifting the A/F of the carburetor calibration significantly richer provided too much HC reactant for the available oxygen in the exhaust. A significant exotherm can only occur if there is sufficient oxygen in the exhaust to react with the excess fuel. The surface temperatures stayed about the same for the catalyst-muffler at the rich conditions. The exhaust gas temperatures at the catalyst-muffler inlet actually dropped due to the rich operation, but some of the additional fuel reacted over the catalyst to bring the surface temperatures back up to about where they were with the standard Phase 2 carburetor calibration. The OEM muffler configuration surface temperatures just cooled off at richer operation. In either case, nothing terribly interesting happened.

p44

Is this partly due to grass conditions: high and wet??

Response: No, this appears to have been partly due to the length of the grass and the use of mulching instead of side or bag discharge for the lawn mowers. The lawn tractors used side-discharge and had much less debris accumulation. The debris accumulation problem appeared to be a design issue and only affected this one engine type. We saw similar debris build-up when operating engines from this engine family in SE Michigan the previous year. Proper screening of the air-inlet to the cooling system is really essential.

p45

Missing info.

Response: Added

Chapter 7

p1

Long paragraph

Response: Paragraph kept in tact, as text was important to keep together

p2

Missing reference to Table 7-1

Response: Reference added in text

p8
Change need to needed

Response: Change made

Chapter 8

p2
Long paragraph.
Response: Paragraph split.

Not sure of logic here. This seems like wish more than a fact since today's catalyst technologies are very robust and this may not occur. I would want to check this out carefully with the catalyst manufacturers. Sintering is time, temperature, stoichiometry, precious metal, impurities, etc. dependent and a very complex phenomena.

Response: This is true, but engine-out exhaust temperatures for air-cooled small engines are about 100 °C higher than for liquid-cooled automotive engines. EPA's experience during lean-burn NOx adsorption catalyst development is that we had to be very careful during development of our sulfur regeneration strategy to transition rich before increasing catalyst temperature. If we increased the temperature with a fuel exotherm while net lean, we would rapidly take out the catalyst's activity with thermal sintering.

Don't understand this   What temperatures are you citing? Also do you have a reference for this phenomena?

Response: I removed this language and reworded the section. We have observed the phenomena during catalyst development

.
p3
Long paragraph.

Response: Paragraph split.

Chapter 9

p1
Change capitalization on spillage

Response: Changed

p5
Explain XLPE

Response: Sentence added

p9
Standardize footnotes

Response: Done in final document

James F. Hoebel
13506 Star Flower Court
Chantilly, Virginia 20151
March 6, 2006

Alan Stout
Assessment and Standards Division
U.S. EPA
2000 Traverwood Drive
Ann Arbor, MI 48105

Dear Mr. Stout:

I am pleased to transmit, both electronically and by mail, my peer review report of the “EPA Technical Study on the Safety of Emissions Controls for Nonroad Spark-Ignition Engines <50 Horsepower.”

For your information, I spent approximately 20 hours in preparing this review.

I will submit a copy of my review along with an invoice to RTP Finance soon.

I hope that you find this review useful. I have enjoyed working with EPA.

Sincerely,

Peer Review

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

Prepared by James F. Hoebel

March 6, 2006

IV. Introduction

The subject study report concerns an EPA analysis of the safety implications of adopting new exhaust and evaporative emission standards for nonroad spark-ignition engines. The study examines the potential fire and burn safety effects of the anticipated new standards upon consumers. My review is based on my experience with the development of consumer product fire safety standards while serving as Program Manager and Chief Engineer for Fire Safety for the U.S. Consumer Product Safety Commission. My report includes a brief summary, some specific and general comments, and additional required information.

V. Summary

The study evaluates the incremental change to safety of proceeding from the current “Phase 2” emissions requirements to the new “Phase 3”. This study takes a reasonable and prudent approach by analyzing the most significant potential adverse fire and burn safety effects of adopting new exhaust and emission standards. The study concentrates on exhaust emission standards for non hand held engines (NHH). Major hazardous situations are first identified and evaluated using appropriate existing databases. Seven scenarios are selected forming the basis for laboratory and field tests using state-of-the-art engines and similar engines modified with advanced catalytic mufflers capable of meeting the Phase 3 standard’s requirements. Failure Mode and Effects Analyses (FMEA) are conducted by a contractor to evaluate incremental changes in risk probability of going from Phase 2 to Phase 3 emissions standards. These studies are appropriate in scope, extensive, properly focused, and complete, given the stage of development of engines using advanced technology to meet the new standards requirements. Conclusions reached are reasonable and supported by the results of the tests and analyses. These conclusions support proceeding ahead with Phase 3 exhaust emissions standards for NHH engines.

Additional studies address the incremental effects on fire safety of new evaporative emission standards for both NHH and hand held engines (HH) and new exhaust and evaporative standards for certain marine spark-ignition engines. These studies are limited, since it is believed that these new standards would not require the application of advanced technology in order to achieve compliance. These additional studies conclude that the technology to meet new standards would not result in an increase in the risk of fires and burns to consumers.

Specific and general comments are offered in my review for EPA's consideration.

VI. Comments

- A footnote at the beginning of the study would be helpful to explain the regulatory context of the safety study. When I began my review, I was unfamiliar with the EPA emissions standards process. A short description of the scope of the activity, the purpose and status of the various phases, schedules, etc. would have expedited the review.

Response: Such information is contained in detail in section A of Chapter 1 which follows the Executive Summary

- New exhaust emission standards for HH engines are not being considered because, I assume, the phase-in for such standards are on schedule for 2010. However, a safety study addressing this subject would be useful and might be considered by EPA at this time.

Response: HH engine standards were promulgated in April 2000 to be phased-in between 2002 and 2007. In January 2004, EPA promulgated revised implementation regulations to better align the phase-in requirements with the staged development of technology. Safety was addressed in the original rule and we are now four model years into implementation. Under 40CFR 90.110(a), manufacturers may not introduce equip an engine with emission control technology if such technology"…will cause or contribute to an unreasonable risk to public health, welfare, or safety in its operation or function." With over three years of in-use experience, we see no need for further safety assessment.

- While I agree with the approach to limit the evaluation of fire and burn safety associated with new exhaust emission standards for NHH engines to lawn mowers, the new standards will apply to other products. Even though my personal experience related to SI engines is limited, I would assume that the manufacturers of such other products will look to the exhaust catalyst technology to develop complying products. Recognizing that the primary responsibility to manufacture safe products rests with the individual manufacturer, EPA should have a concern that such transfer of technology doesn't create some level of risk of fire and burn.

Response: We agree. However, as discussed in Chapter 3 of the report, we focused on residential lawn care equipment because the evidence indicated that this application was essentially the near worst case application and that technology demonstrated here could be extrapolated to other applications as well.

- In Chapter 4, Scenario 3 describes fires due to fuel leaks on hot surfaces. Was hot surfaces the only potential ignition source considered? Could a spark from an electronic ignition system ignite a fuel leak?

Response: By far, hot surfaces were the predominant ignition source of concern. However, the FMEA did assess risk related to static charge, backfire, and user induced spark plug firing outside the cylinder during maintenance.

- In Chapter 4, Scenario 4 describes equipment or structural fires when equipment unattended. Was appliance pilot lights the only potential ignition source considered? Could an open flame, a cigarette, or arcing from electric wiring ignite fuel vapors?

Response: Within the databases provided by CPSC pilot lights were the only source identified. Obviously, other sources providing adequate ignition energy to a flammable mixture could also ignite vapor.

- It is noted in Chapter 3 under "Class 1 engines" that Class 1 NHH engines typically run rich, and can result in exothermic exhaust reactions. Is this a factor considered in developing the scenarios? While I have limited experience with SI engines, I wonder if this event is covered by Scenario 7. I note that after-fire in the muffler caused by extremely rich air-to-fuel ratios was not observed in EPA testing for either the OEM muffler or the catalyst-muffler (Chapter 8).

Response: Rich operation by itself does not lead to a large exotherm unless there is sufficient oxygen available in the exhaust to react with the CO and HC that is present. Part of the strategy is to get meaningful emission reductions, but with the limitation that significant CO oxidation must be avoided and that HC oxidation must be done rich of the stoichiometric point. This has driven all of the designs, resulting in very limited amounts of secondary air entrainment in Class I, no secondary air entrainment in Class II, use of small, space-velocity limited catalysts with very light precious metal loadings, etc. This prevents an exotherm that is to large to deal with via the routes of heat rejection designed into the equipment.

- The source of the engines tested is unclear. It appears that EPA procured certified Phase 2 engines which were modified by EPA to replace existing mufflers with advanced catalyst mufflers capable of reduced exhaust emissions. The question arises to how representative these modified engines were of anticipated production engines compliant with Phase 3 requirements. It is recognized that there may no answer to this question. However, the issue could be noted in the report.

Response: The engines were all purchased on equipment at local retailers. I will add some descriptive text to Chapter 5.

- The incident with run-on after-fire testing of engine 241, described in Chapter 6, seems dramatic. I understand that this happened with the OEM muffler but not with the advanced catalyst muffler. Is this of concern and is any further follow-up planned? I realize that this was a limited observation.

Response: This is really beyond the scope of our study, and is outside of our regulatory authority. The condition is also very unlikely to occur in any case. The scenario was analyzed because of it's identification by stakeholders.

• In preparing for the FMEA (Chapter 7), a list of 18 characteristics of "properly designed" Phase 3 engines is developed. Do the Phase 2 typical production engines contain corresponding "non-catalytic" design characteristics? Or are the listed characteristics appropriate only to engines with advanced catalytic mufflers? For instance, items 7, 8, 9, and 10 could be common to both. The question arises: do these characteristics impose a level of quality that is higher than the usual Phase 2 quality level? Are we comparing an ideal to a real situation?

Response: All of our testing was conducted with modified Phase 2 equipment. Some of these items are not yet part of Phase 2 design for some manufacturers but some are. It varies both by manufacturer and engine/equipment model. We believe that in many cases the inclusion of design elements of these types will be needed to meet the Phase 3 emission standards over the useful life of the engine..

• In Chapter 9 discussing small SI evaporative emissions, EPA is considering permeation standards, diffusion, and running loss controls for NHH equipment. Yet, running loss controls are not being considered for HH equipment. Is this not a problem?

Response: Running loss emissions are primarily a function of fuel tank temperature and tank design. These in turn depend on parameters such as tank material, tank location, and tank volume. The total emissions per piece of equipment depend on annual hours of operation. Our assessment indicated that control of running losses from HH engines was not attractive because the average hours of use is low and tank volumes are very small.

• The section on HH equipment goes on to state that typical materials used for HH equipment fuel hose are nitrile rubber and fluoroelastomers. However, on the next page, the report lists polyurethane, nitrile rubber, and polyvinyl chloride as common fuel hose materials.

Response: Corrected to insure consistency.

• The conclusions of this study strongly support proceeding with Phase 3 exhaust emission standards for NHH engines. As EPA proceeds through this process, are there any plans or recommendations for further fire and burn safety tasks? For instance, as manufacturers proceed with the development of new technology NHH engines, will there be future tests or analyses of prototype or production models? Or will this responsibility be left to the manufacturer? I understand that new evaporative emission standards will not likely require application of advanced technology. But, are there future plans/concerns relating to marine engines? In any case, I would recommend continued EPA attention to the fire/burn safety implications of new standards as they are developed.

Response: EPA is concerned about safety for both the small SI and marine sectors and will continue to work these issues throughout the rulemaking and into the implementation phase as needed. As mentioned above, 40CFR90.110 prohibits the use of designs which present an unreasonable increase in safety risk.

IV Name & Address

James F. Hoebel, Consultant
13506 Star Flower Court
Chantilly, Virginia 20151
703 818-2639

V Material Reviewed

Draft Report, EPA420-R-06-XXX, March xx, 2006, "EPA Technical Study on the Safety of Emission Controls for Nonroad Spark-Ignition Engines <50 Horsepower", Ten Chapters, Assessment and Standards Division, Office of Transportation and Air Quality, U.S. Environmental Protection Agency.

Draft Report, "Failure Mode and Effects Analyses for Small SI Equipment and Engines". Southwest Research Institute, was provided but not reviewed.

VIII. Summary of Expertise and Qualifications

Retired 1999 after 28 years with U.S. Consumer Product Safety Commission. Served as Chief Engineer for Fire Safety, the agency's primary internal consultant on fire safety associated with consumer products. Products included home furnishings, ignition sources, apparel, and protective devices. Functioned concurrently as Acting Director of Mechanical Engineering Division for over a year. Previously, Program Manager for Fire and Thermal Burn Hazards. Oversaw applied research on flammability and toxicity, injury/death data analysis, development of mandatory and voluntary product safety standards, consumer information projects, and enforcement of existing standards. Projects included cigarette lighters, cigarette fire safety, apparel, space heating systems, upholstered furniture, and smoke detectors. Graduate of Columbia University with an AB and a BS degree in Chemical Engineering..

IX. Real or Perceived Conflicts of Interest

None.

I am a member of the National Association of State Fire Marshals (NASFM) Science Advisory Committee. I understand that NASFM is associated with the International Consortium for Fire Safety, Health & the Environment, and I am aware that the Consortium is involved in a project on the fire safety of measures being considered to reduce emissions of small engines in outdoor power equipment. I am not personally involved with either the Consortium or their project.