17th ANNUAL MDEC CONFERENCE
Toronto Airport Marriott Hotel, Canada
October 4 – 7, 2011

MDEC DIESEL WORKSHOP
HEALTH EFFECTS AND DIESEL ENGINES

PRESENTED BY: Dr. Sandra Dorman of Laurentian University
Dr. Renaud Vincent of Health Canada
Steve "Skiner" Forbush of Arch Coal
Troy Terrillion of Newmont Mining
Brent Rubeli of Natural Resources of Canada

COORDINATED BY: Mahe Gangal and David Young of NRCan

OCTOBER 4, 2011

MDEC Diesel Workshop

Health Effects and Diesel Engines

Toronto Airport Marriott Hotel
Ontario, Canada

Tuesday, October 4, 2011

07:30 – 08:30 Breakfast and registration

08:30 – 12:00 Welcome – Mahe Gangal, Co-chair MDEC Conference
Introduction of speakers – JP Ouellette, Co-chair MDEC Conference

Health Effects of Diesel Exhaust

- Structure of the respiratory tract, and introduction to cancer, Dr. Sandra Dorman, Laurentian University
- Toxicity of diesel exhaust, Dr. Renaud Vincent, Health Canada

08:30 – 12:00 Lunch

13:00 – 16:30 **New Technology Diesel Engines**

- Advanced diesel engines for mines, Steve "Skinner" Forbush, Arch Coal, and Troy Terrillion, Newmont Mining
- Field emissions testing: Best practices, test and maintenance, Brent Rubeli, Natural Resources Canada
- Discussion and Conclusion, David Young, Secretary and Treasurer MDEC

MDEC Diesel Workshop

Health Effects and Diesel Engines

Toronto Airport Marriott Hotel
Ontario, Canada

Tuesday, October 4, 2011

Contents

MDEC - 2011

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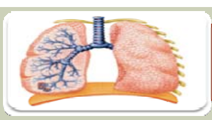
THE AIR WE BREATHE…

Dr. Sandra Dorman, PhD

LaurentianUniversity
UniversitéLaurentienne

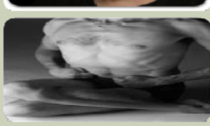
Diesel particle deposition in the airways.

OUTLINE



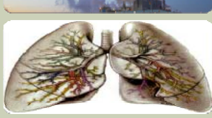
Airway Anatomy

Particle Deposition



Particle Clearance

Ambient vs. Mine Exposure



Cancer Risk

AIRWAY ANATOMY

THE NOSE

Filter

Exercise

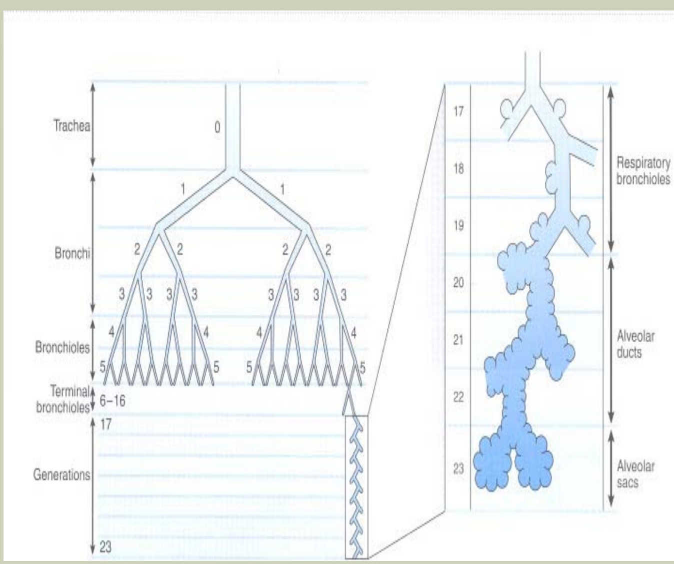
THE LUNGS

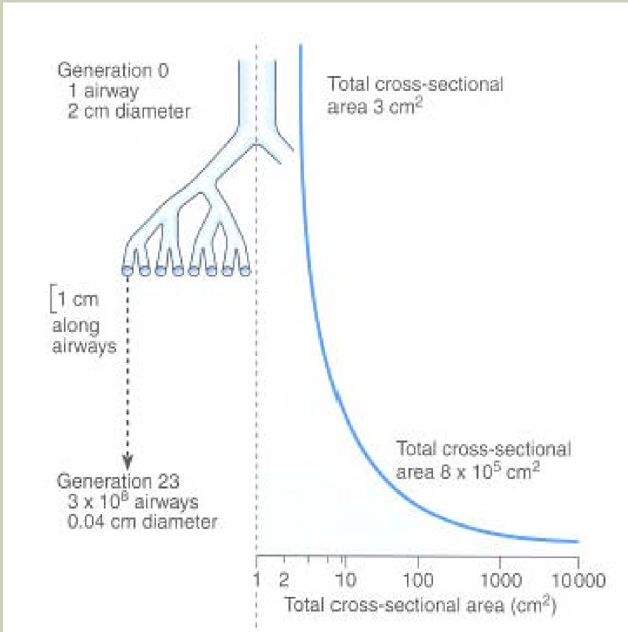
23 branching generations

0-8 trachea and bronchi
Conduction

9-16 bronchioles
Conduction & Diffusion

16-23
Alveolar region
diffusion





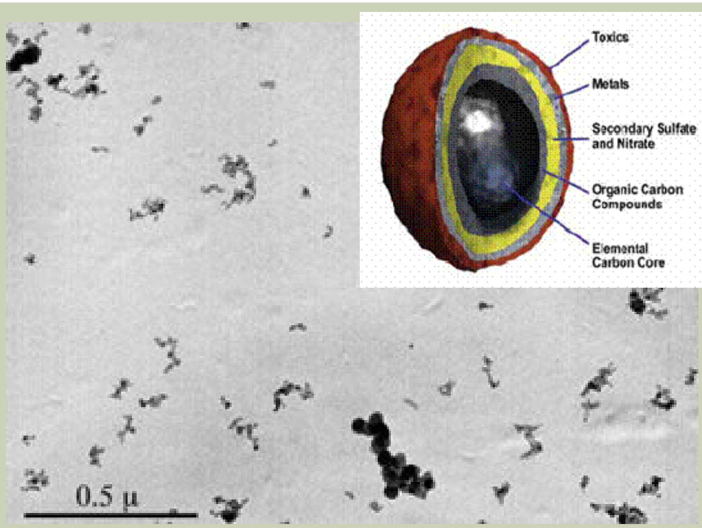
PARTICLE DEPOSITION

MECHANISMS OF DEPOSITION

- Physical and chemical characteristics of the particle
- Properties of the particle kinetics in air
- Biological factors

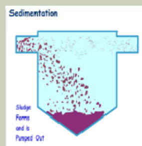
PHYSICAL/CHEMICAL PROPERTIES

- Shape
- Size
- Contents

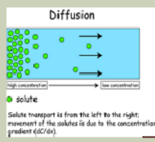


PARTICLE KINETICS & DEPOSITION

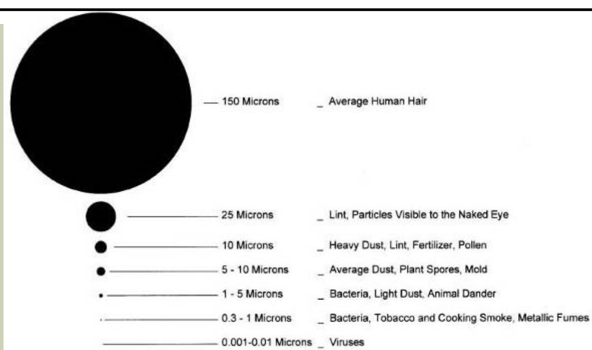
Impact

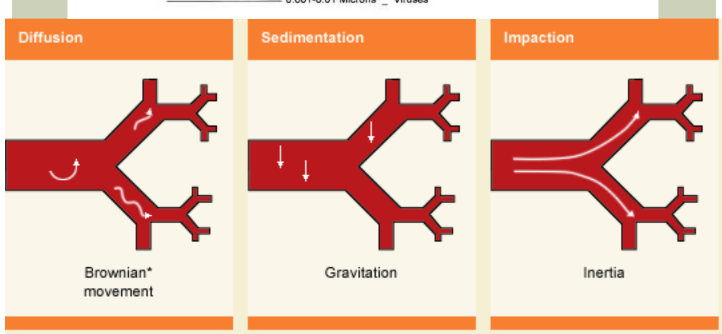


Sedimentation



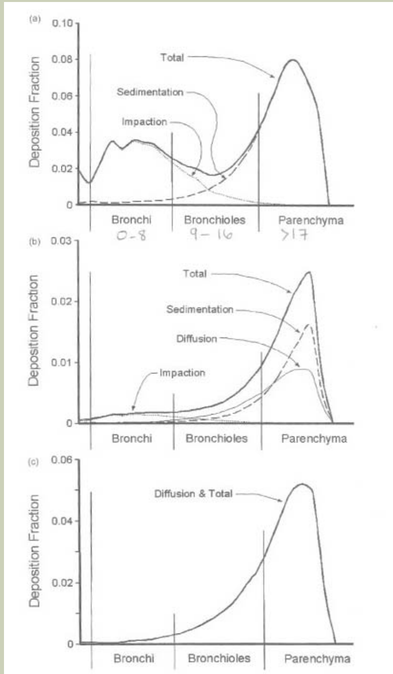
Diffusion





Adapted from:
Voshaar T. Therapie mit Aerosolen • 2005 • Uni- Med: Bremen

PARTICLE SIZE



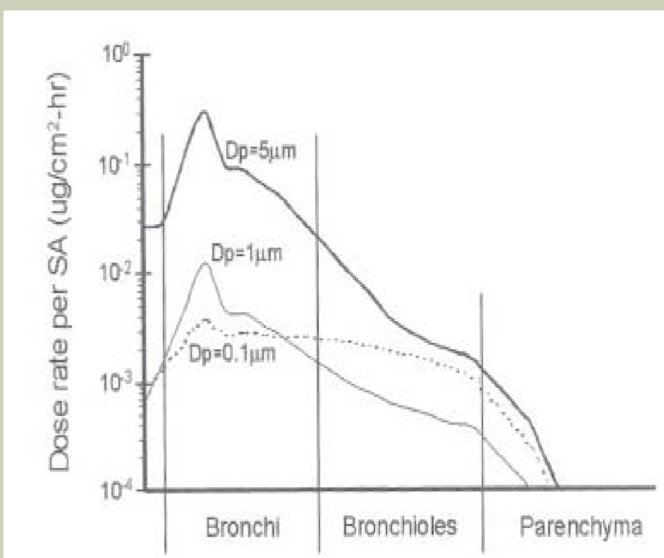
5µm

1µm

0.1µm

PREDICTED LUNG DEPOSITION BY SIZE

Foster & Costa. Lung Biology in Health and Disease. 2005



DEPOSITION BY SIZE AND SURFACE AREA

Foster & Costa. Lung Biology in Health and Disease. 2005

BIOLOGY OF INDIVIDUAL

Different people have different tidal volumes, lung volumes & breathing rates

EXPOSURE → DOSE → RESPONSE

Deposition increases with increasing tidal volume, increased rate of breathing and mouth versus nose breathing

EFFECT OF PHYSICAL ACTIVITY

Total deposition will generally increase in proportion to increases in minute ventilation.

Generally, we see an increase in upper airway deposition with increased airway velocity

Nose to mouth breathing is an important aspect

GENDER

- Women have higher depositions per unit in the upper airways
- Men have higher deposition in their lower airways

AGE

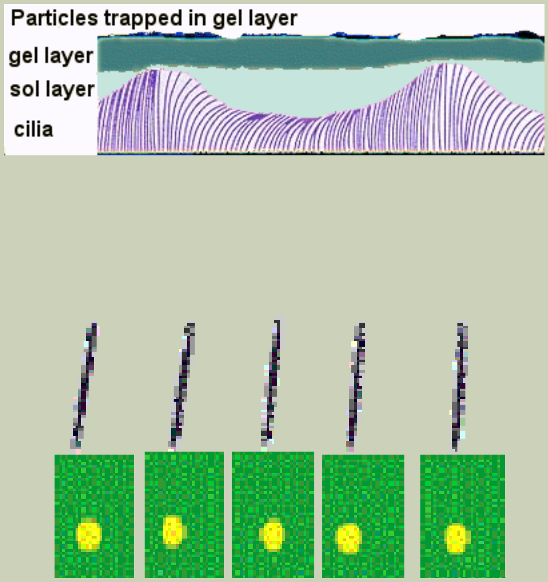
- Similar to gender, children will have higher upper airway deposition due to anatomical size
- Older adults with normal lung function should have minimal changes in tidal volume and minute ventilation and so should not have altered deposition patterns

LUNG DISEASE

- Breathing patterns are changed with lung disease
- These changes effect total deposition
- COPD – higher minute ventilation (103%)
- Bronchitis – increased deposition (narrowed airspaces)
- Asthma – increased deposition (59%)
- Smokers – increased deposition (16%)
- Smokers with small airways disease (49%)

Kin and Kang AJRCCM 1997

PARTICLE CLEARANCE



TWO MAIN METHODS:

1.PHYSICAL REMOVAL

CLEARANCE ~ 2-24 HOURS

2.ABSORPTION

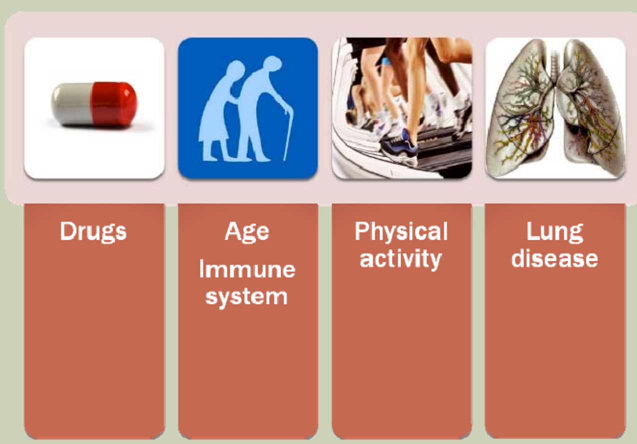
DIRECT OR VIA CELL UPTAKE

CLEARANCE > 24 HOURS

CLEARANCE RATES

- Location matters
- Size matters
- Total number matters

BIOLOGIC ALTERATIONS IN CLEARANCE



OTHER

Smoking

Air pollution

AMBIENT EXPOSURE

Health effects of different Air Quality Index (AQI) levels caused by fine particulate matter

Category	AQI	Pollutant Concentration Breakpoints (µg/m^3)	Fine Particulate Matter ($PM_{2.5}$)
Very Good	0 - 15	0 - 11	Sensitive populations may want to exercise caution.
Good	16 - 31	12 - 22	Sensitive populations may want to exercise caution.
Moderate	32 - 49	23 - 45	People with respiratory disease at some risk.
Poor	50 - 99	46 - 90	People with respiratory disease should limit prolonged exertion; general population at some risk.
Very Poor	100 or over	91 or over	Serious respiratory effects even during light physical activity; people with heart disease, the elderly and children at high risk; increased risk for general population.

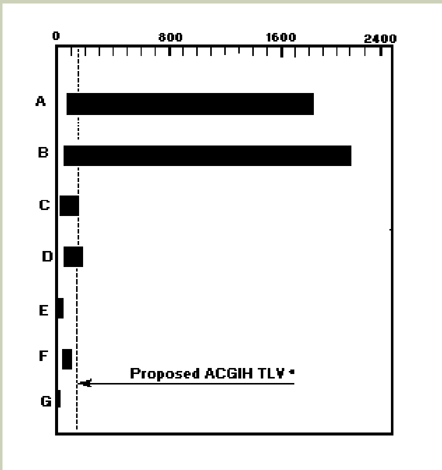
MINING

- Canada: 400ug/m^3
- USA: 160ug/m^3
- Where do these numbers come from?
- What is an actual safe level from a health perspective?

- No Safe level of DPM exposure exists
- How can I say this?

DIESEL PARTICULATE EXPOSURES IN SEVERAL INDUSTRY SEGMENTS

Range of Average DPM Exposures, ug/m^3.



A=Underground Metal and Nonmetal Mine

B=Underground Coal Miners

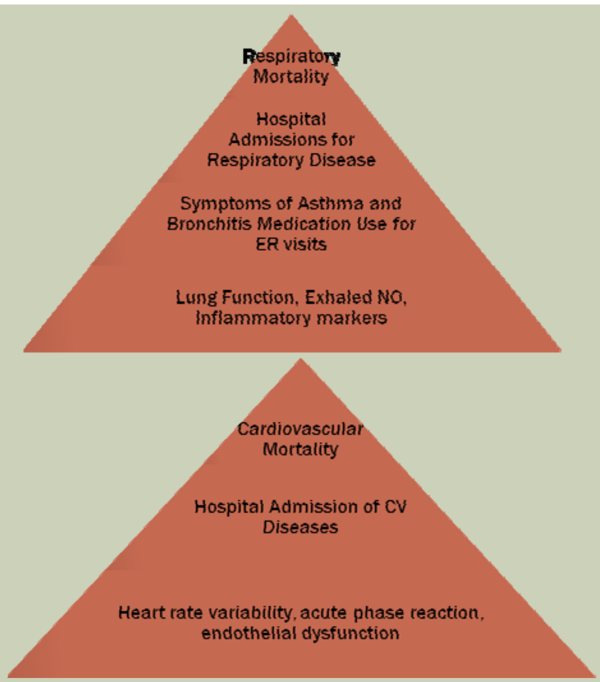
C=Surface Miners

D=Railroad Workers

E=Truck Drivers

F=Dock Workers

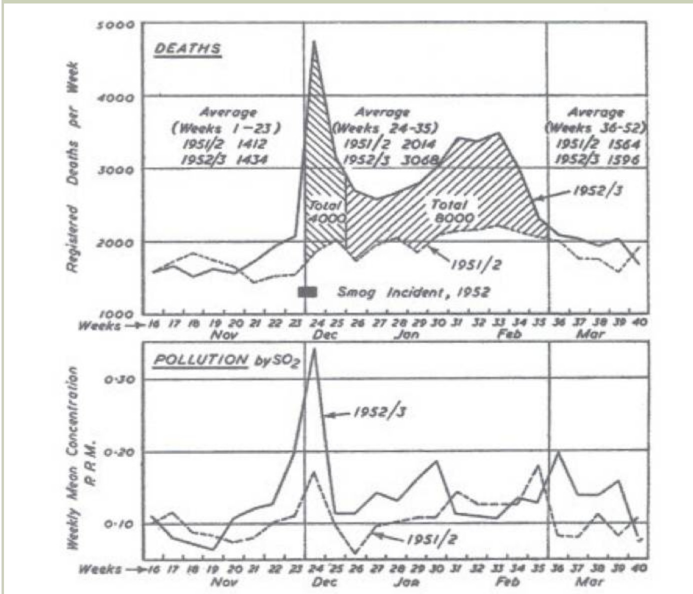
G=Ambient Air (Urban)



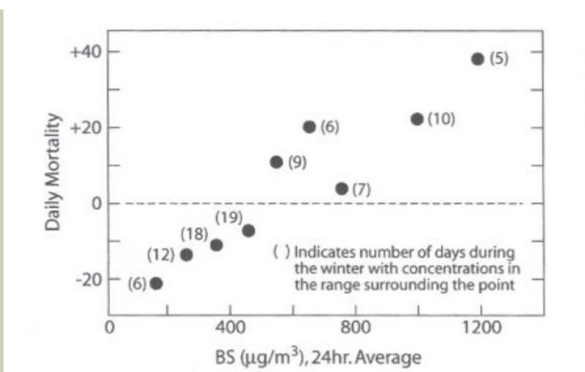
SUMMARY OF EVIDENCE

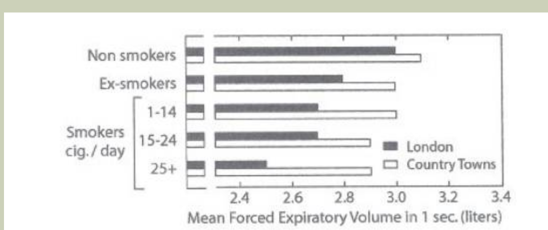
Respiratory

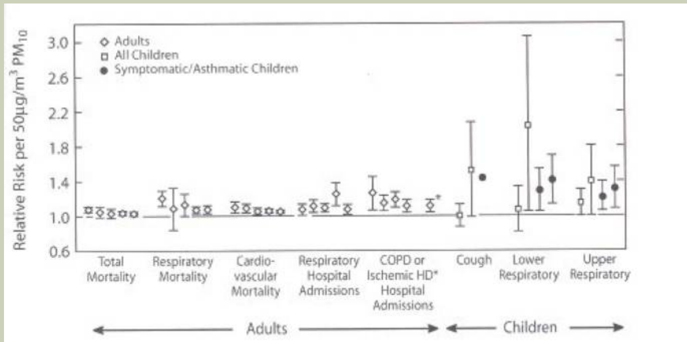
Cardiovascular

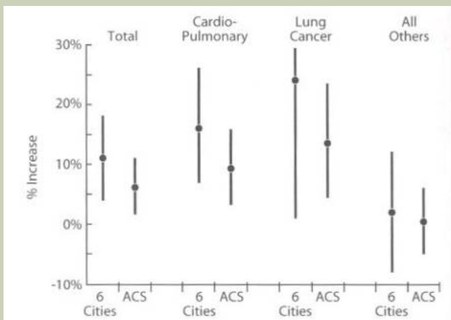

DEATHS
Registered Deaths per Week
Average (Weeks 1–23) 1951/2 1412 1952/3 1434
Average (Weeks 24-35) 1951/2 2014 1952/3 3068
Average (Weeks 36-52) 1951/2 1564 1952/3 1596
Total 4000
Total 8000
1952/3
1951/2
Smog Incident, 1952
POLLUTION by SO2
Weekly Mean Concentration P.P.M.
1952/3
1951/2
Weeks
Nov
Dec
Jan
Feb
Mar

LONDON SMOG


Daily Mortality
( ) Indicates number of days during the winter with concentrations in the range surrounding the point
BS (µg/m3), 24hr. Average


Non smokers
Ex-smokers
Smokers cig./day
1-14
15-24
25+
London
Country Towns
Mean Forced Expiratory Volume in 1 sec. (liters)


Relative Risk per 50µg/m³ PM10
3.0
2.6
2.2
1.8
1.4
1.0
0.6
Adults
All Children
Symptomatic/Asthmatic Children
Total Mortality
Respiratory Mortality
Cardio-vascular Mortality
Respiratory Hospital Admissions
COPD or Ischemic HD* Hospital Admissions
Cough
Lower Respiratory
Upper Respiratory
Adults
Children


% Increase
30%
20%
10%
0%
-10%
Total
Cardio-Pulmonary
Lung Cancer
All Others
6 Cities
ACS

CANCER RISK

Organization & year	Animal Data	Human Data	Overall evaluation
NIOSH '88	Confirmatory	Limited	Potential Occupational carcinogen
IARC '89	Sufficient	Limited	Probably carcinogenic to Humans
IPCD '96	Not evaluated	Not evaluated	Probably carcinogenic to humans
EPA '98	Demonstrated carcinogenicity	Consistent evidence for a causal association	DPM classified as a toxic air contaminant
NTP '00	Supporting animal & mechanistic data	Elevated lung cancer in occupationally exposed groups	DPM-reasonable anticipated to be a carcinogen
EPA '02	Adequate evidence for carcinogenicity	Probable human carcinogen	Probably human carcinogen (Group B1) "Likely to be carcinogenic to humans by inhalation" and this evaluation applies to environmental exposures."

Adapted from: Foster & Costa: Lung Biology in Health and Disease; Vol 204

NOMENCLATURE - MALIGNANT

- There are three groups:
- 1 – carcinomas
- 2 – sarcomas
- 3 – leukemias

- Cancer is a word indicating any type of malignant tumor

METASTASIS

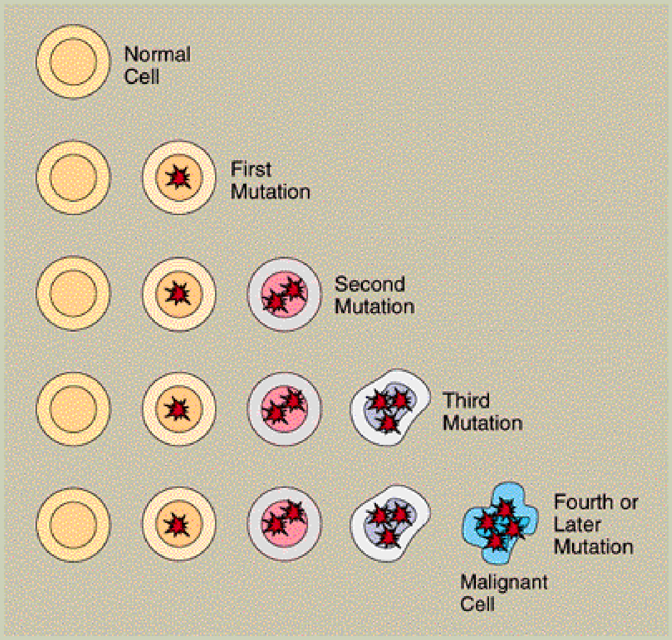
- The process by which a tumor spreads some distance from the primary site of growth.
- Secondary tumors caused in this manner are called metastastic tumors

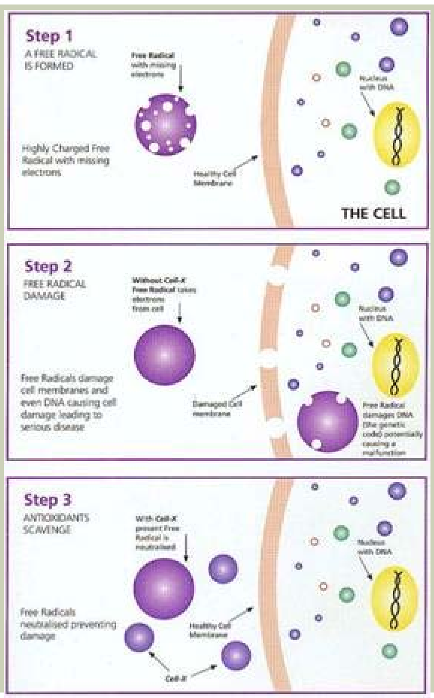
PHED 4717: Current Issues in Physical Education II

CANCER – PROPERTIES OF CELLS

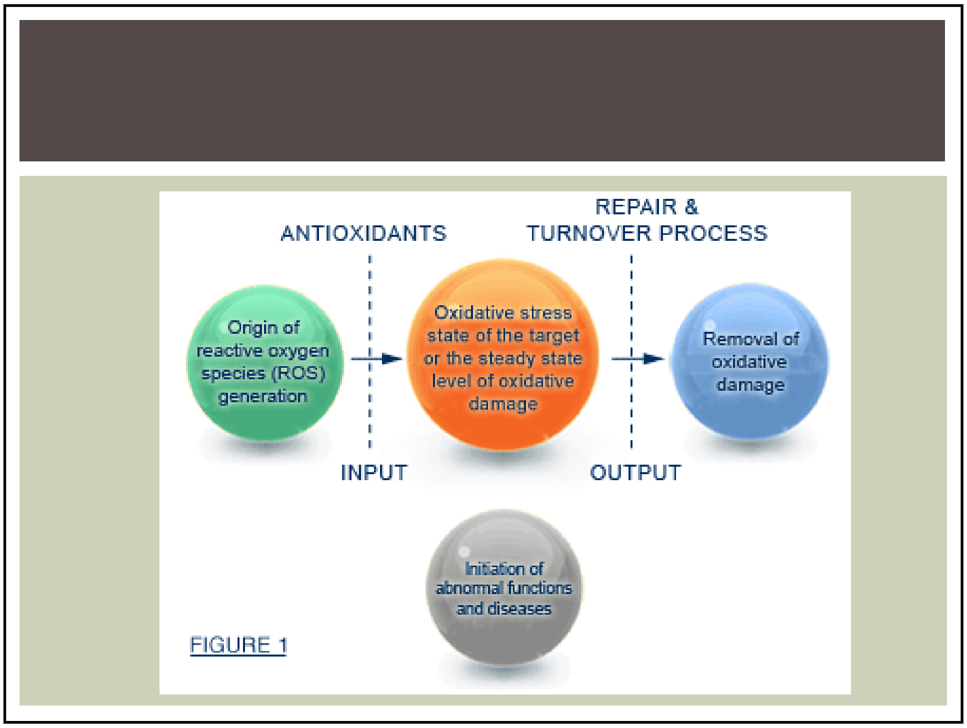
- Malignant tumors start from a single cell that has sustained some type of damage to its genome
- Causing it to proliferate abnormally
- Cancer cells do not respond to normal growth regulatory signals, from other cells
- As they grow they acquire properties that allow them to flourish at the expense of surrounding cells

PHED 4717: Current Issues in Physical Education II





OXIDATIVE STRESS


ANTIOXIDANTS
REPAIR & TURNOVER PROCESS
Origin of reactive oxygen species (ROS) generation
Oxidative stress state of the target or the steady state level of oxidative damage
Removal of oxidative damage
INPUT
OUTPUT
Initiation of abnormal functions and diseases
FIGURE 1

TOXICOLOGICAL TOOLS FOR INVESTIGATING THE TOXICITY OF DIESEL COMBUSTION EMISSIONS

Renaud Vincent PhD

Inhalation Toxicology Laboratory
Hazard Identification Division
Environmental Health Science and Research Bureau
Radiation and Environmental Health Directorate

MDEC Diesel Workshop
Health Effects and Diesel Engines

Toronto, 4 October 2011

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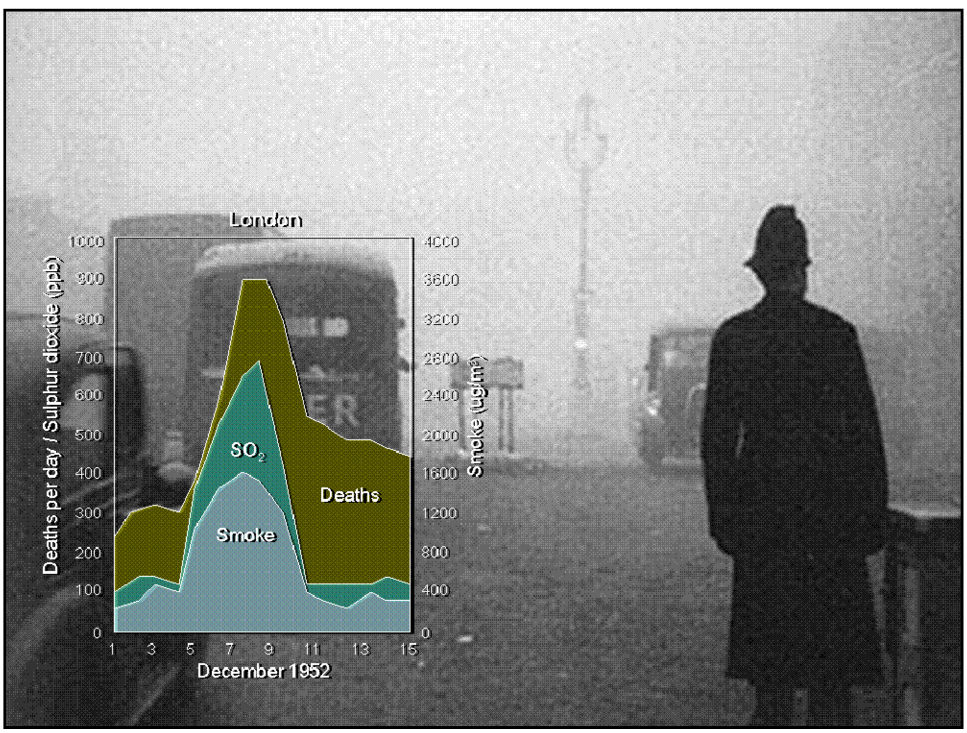

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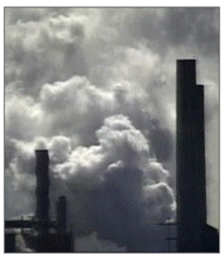
Air pollution kills thousands each year: Health Canada

Last Updated: Monday, May 2, 2005 | 7:51 PM ET
CBC News

It's estimated 5,900 Canadian deaths each year can be attributed to air pollution, a new report from Health Canada says.

The department revised its previous estimate of 5,000 deaths per year from 2002, using data from eight Canadian cities.

- INDEPTH: The Health Effects of Smog



Damaging fine particles of smog can be

Researchers at Health Canada and Johns Hopkins University in Baltimore said they calculated the higher figure after correcting a statistical glitch in a previous model.

Air pollution and mortality data were collected in Quebec City, Montreal, Ottawa, Toronto, Hamilton, Windsor, Ont., Calgary and Vancouver.

Smog alerts are issued in part because air pollutants are known to cause breathing problems and aggravate respiratory and cardiac conditions, which are leading causes of hospitalizations and death in Canada.

Related

External Links

Health and Air Quality, Health Canada

Gov't of Canada's Clean Air Agenda

(Note: CBC does not endorse and is not responsible for the content of external sites - links will open in new window)

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Health Features

YOUR INTERVIEW
Ask an expert
Diet and nutrition tips

Ontario Medical Association 2000

Attributable to air pollution

	2000	2015
premature deaths	1,900	2,600
hospital admissions	9,800	13,000
emergency room visits	13,000	18,000
minor illness-day	47 million	53 million

Health Direct Costs

Health care system	$600 million
Direct losses to employers and employees	$560 million

Indirect Costs

Pain and suffering	$5 billion
Loss of life	$4 billion

Annual economic loss

2000	$10 billion
2015	$15 billion

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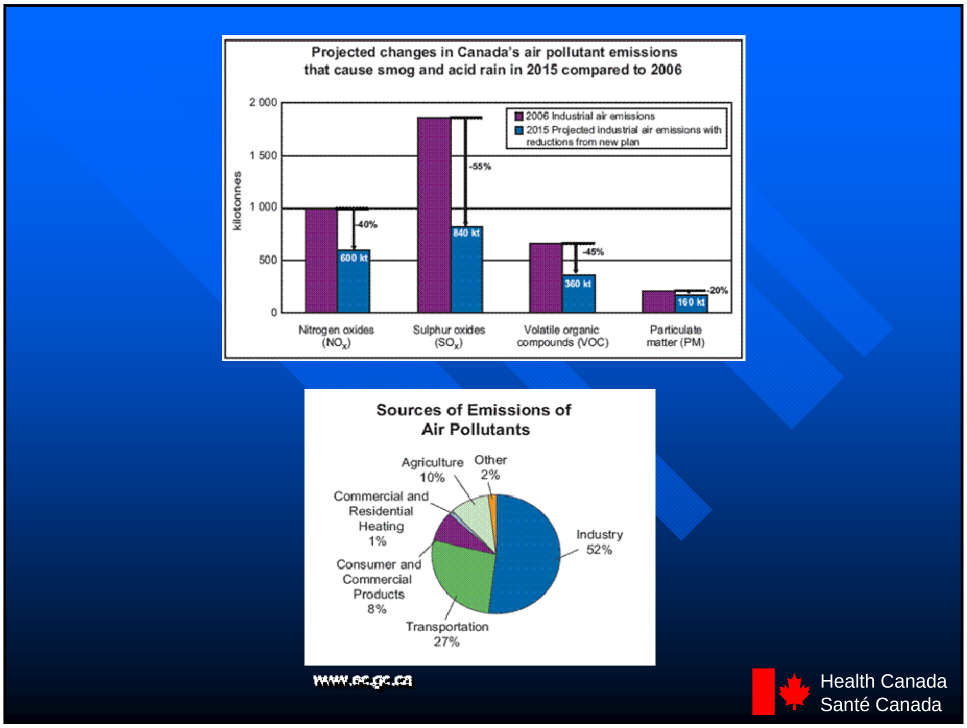
Projected changes in Canada's air pollutant emissions
that cause smog and acid rain in 2015 compared to 2006
kilotonnes
2 000
1 500
1 000
500
0
2006 Industrial air emissions
2015 Projected industrial air emissions with reductions from new plan
-40%
600 kt
-55%
840 kt
-45%
380 kt
-20%
160 kt
Nitrogen oxides (NOx)
Sulphur oxides (SOx)
Volatile organic compounds (VOC)
Particulate matter (PM)
Sources of Emissions of
Air Pollutants
Agriculture 10%
Other 2%
Commercial and Residential Heating 1%
Industry 52%
Consumer and Commercial Products 8%
Transportation 27%
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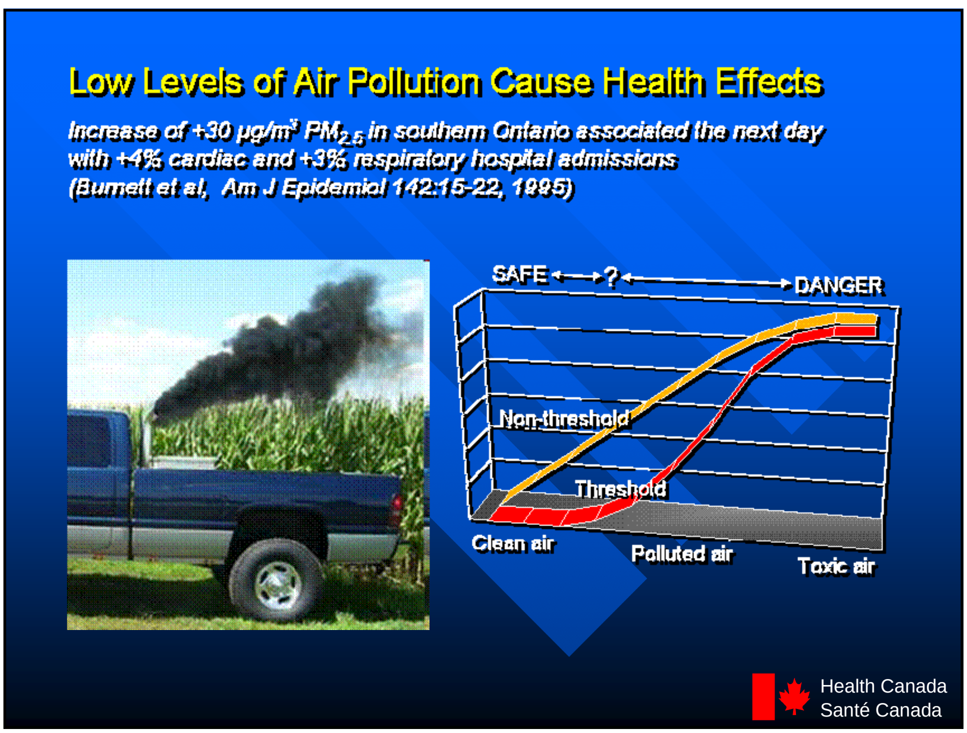
Low Levels of Air Pollution Cause Health Effects
Increase of +30 µg/m³ PM2.5 in southern Ontario associated the next day
with +4% cardiac and +3% respiratory hospital admissions
(Burnett et al, Am J Epidemiol 142:15-22, 1995)
SAFE ? DANGER
Non-threshold
Threshold
Clean air
Polluted air
Toxic air
Health Canada
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TOXICITY = DOSE X POTENCY

Potency is a function of physicochemical characteristics of the particles

Determined by size and chemical composition

Vary with sources

Can be modified by co-pollutants

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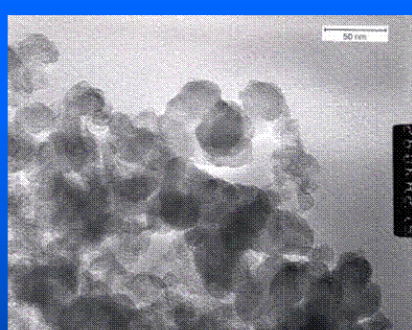

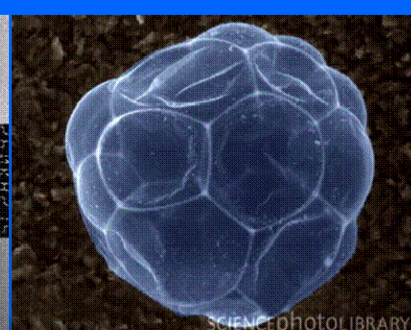

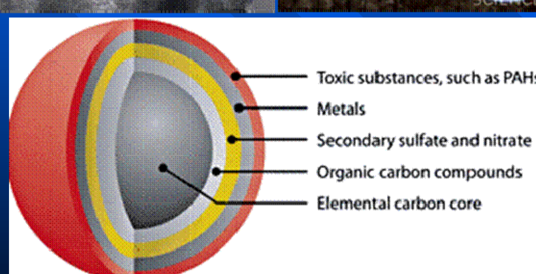

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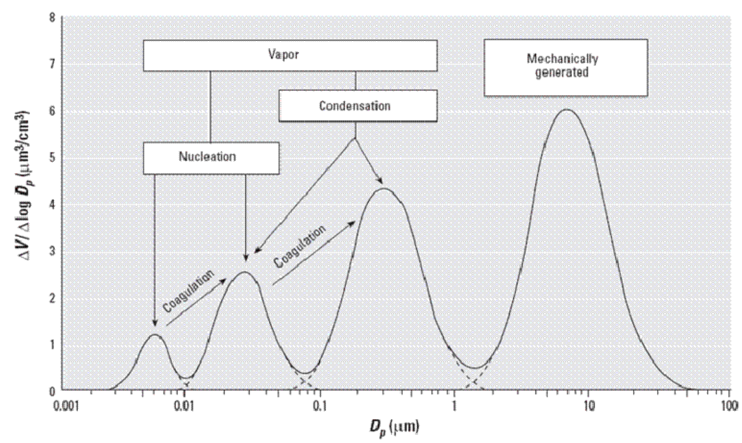

Figure 1. Idealized size distribution of traffic-related particulate matter (U.S. EPA 2004). D_p, particle diameter. The four polydisperse modes of traffic-related ambient particulate matter span approximately four orders of magnitude from < 1 nm to > 10 μm. Nucleation- and Aitken-mode particles are defined as UFPs (< approximately 100 nm). Source-dependent chemical composition is not well controlled and varies considerably. In contrast, NPs (1–100 nm) have well-controlled chemistry and are generally monodispersed.

Oberdorster et al Environ Health Perspect 113:823–839 (2005)

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Ultrafine Particles – Incidental Nanoparticles

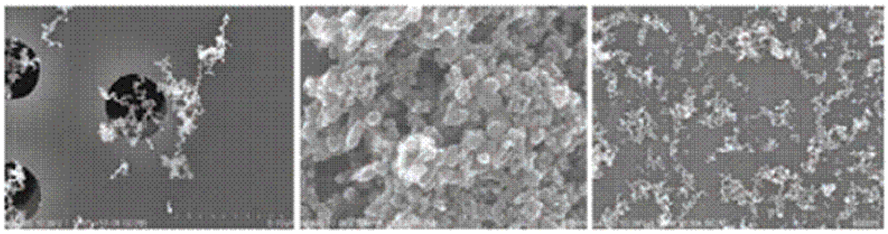

Figure 4-1. Photomicrographs of airborne exposure to ultrafine (nanoscale) particles of welding fumes, diesel exhaust, and cerium oxide

NIOSH Publication No. 2009-125
Approaches to Safe Nanotechnology - Managing the Health and Safety Concerns Associated with Engineered Nanomaterials
http://www.cdc.gov/niosh/docs/2009-125/

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Table 2. Particle number and particle surface area per 10 μg/m³ airborne particles.

Particle diameter (μm)	Particle no. (cm^{-3})	Particle surface area ($\mu m^2/cm^3$)
5	153,000,000	12,000
20	2,400,000	3,016
250	1,200	240
5,000	0.15	12

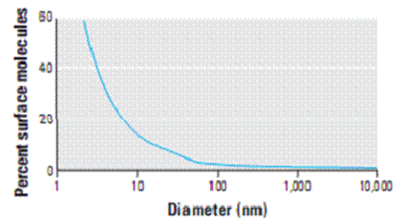

Figure 2. Surface molecules as a function of particle size. Surface molecules increase exponentially when particle size decreases < 100 nm, reflecting the importance of surface area for increased chemical and biologic activity of NSPs. The increased biologic activity can be positive and desirable (e.g., antioxidant activity, carrier capacity for therapeutics, penetration of cellular barriers), negative and undesirable (e.g., toxicity, induction of oxidative stress or of cellular dysfunction), or a mix of both. Figure courtesy of H. Fissan (personal communication).

Günter Oberdörster, Eva Oberdörster, Jan Oberdörster. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect 113:823–839 (2005).

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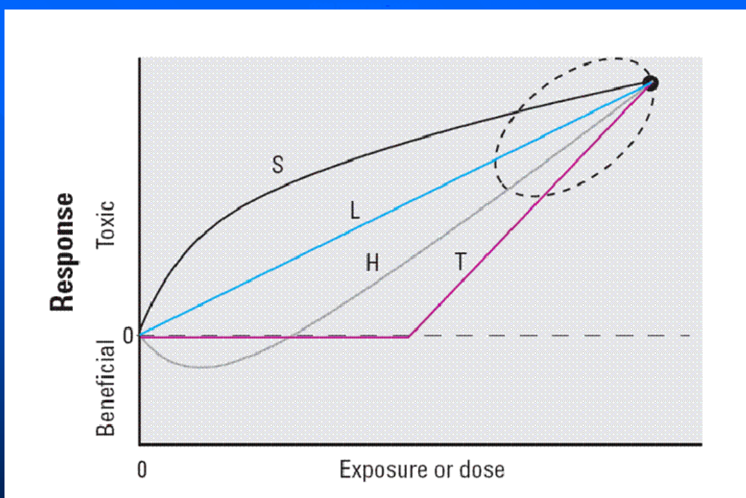

Oberdorster et al Environ Health Perspect 113:823–839 (2005)

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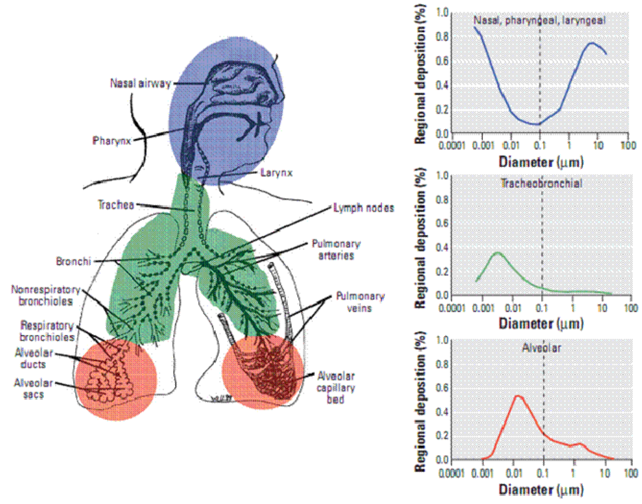

Figure 8. Predicted fractional deposition of inhaled particles in the nasopharyngeal, tracheobronchial, and alveolar region of the human respiratory tract during nose breathing. Based on data from the International Commission on Radiological Protection (1994). Drawing courtesy of J. Harkema.

Günter Oberdörster, Eva Oberdörster, Jan Oberdörster. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect 113:823–839 (2005).

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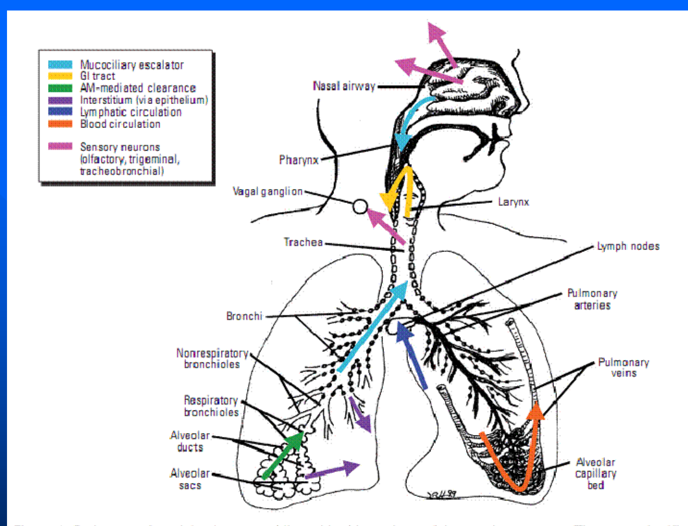

Figure 9. Pathways of particle clearance (disposition) in and out of the respiratory tract. There are significant differences between NSPs and larger particles for some of these pathways (see "Disposition of NSPs in the respiratory tract"). Drawing courtesy of J. Harkema.

Günter Oberdörster, Eva Oberdörster, Jan Oberdörster. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect 113:823–839 (2005).

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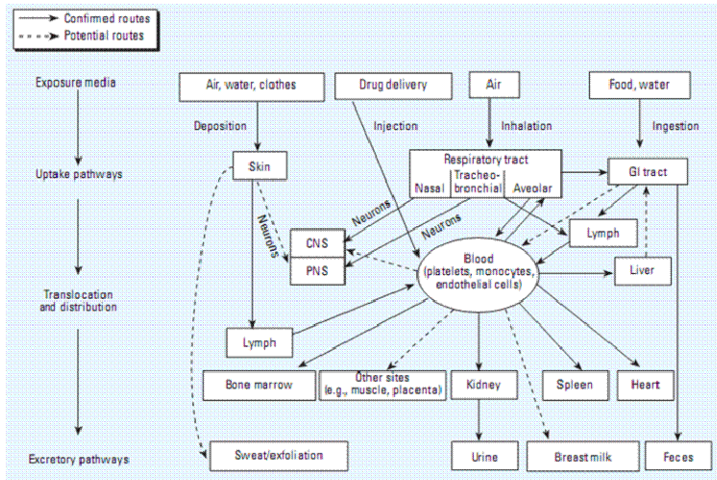

Figure 16. Biokinetics of NSPs. PNS, peripheral nervous system. Although many uptake and translocation routes have been demonstrated, others still are hypothetical and need to be investigated. Translocation rates are largely unknown, as are accumulation and retention in critical target sites and their underlying mechanisms. These, as well as potential adverse effects, largely depend on physicochemical characteristics of the surface and core of NSPs. Both qualitative and quantitative changes in NSP biokinetics in a diseased or compromised organism also need to be considered.

Günter Oberdörster, Eva Oberdörster, Jan Oberdörster. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect 113:823–839 (2005).

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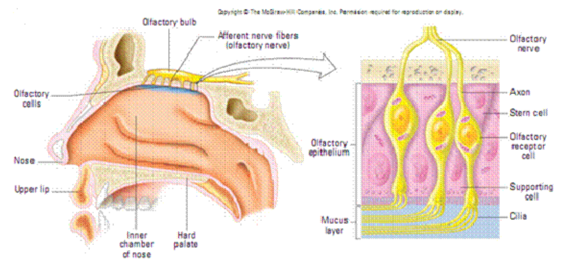

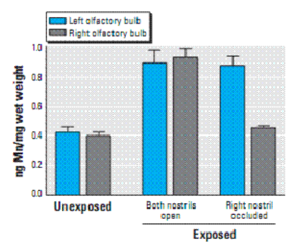

Figure 12. Close proximity of olfactory mucosa to olfactory bulb of the CNS. Inhaled NSP[s], especially below 10 nm, deposit efficiently on the olfactory mucosa by diffusion, similar to airborne "smell" molecules which deposit in this area of olfactory dendritic cilia. Subsequent uptake and translocation of solid NSP[s] along axons of the olfactory nerve has been demonstrated in non-human primates and rodents. Surface chemistry of the particles may influence their neuronal translocation. Copyright © the McGraw-Hill Companies, Inc. Reproduced from Widmaier et al. (2004) with permission from McGraw-Hill.

Figure 13. Occlusion of the right nostril of rats during 6-hr inhalation of nanosized MnO_2 particles (~ 30 nm CMD, ~ 450 μg/m^3) resulted in accumulation of Mn only in the left olfactory bulb only at 24 hr after dosing. Data are mean ± SD. Data from Feikert et al. (2004).

Günter Oberdörster, Eva Oberdörster, Jan Oberdörster. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect 113:823–839 (2005).

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Table 5. Translocation of NSPs in the blood circulation to bone marrow in mice.

Particle size	Type	Finding	Reference
~10 nm	PEG quantum dots	Fast appearance of quantum dots in liver, spleen, lymph nodes, and bone marrow (mouse)	Ballou et al. 2004
< 220 nm	Metallo-fullerene	Highest accumulation in bone marrow after liver; continued increase in bone marrow but decrease in liver (mouse)	Cagle et al. 1999
90–250 nm	HSA-coated polylactic acid nanoparticles	Significant accumulation in bone marrow, second to liver (rat)	Bazile et al. 1992
240 nm	Polystyrene (nonbiodegradable) polylisohexylcyonacrylate (biodegradable)	Rapid passage through endothelium in bone marrow, uptake by phagocytizing cells in tissue (mouse)	Gibaud et al. 1996, 1998, 1994

HSA, human serum albumin.

Table 6. Studies of neuronal translocation of UFPs from respiratory tract.

Reference	Study
Bodian and Howe 1941	Olfactory axonal transport of polio virus (30 nm) after intranasal instillation in chimpanzee; transport velocity, 2.4 mm/hr
de Lorenzo 1970	Olfactory axonal transport of 50 nm silver-coated gold after intranasal instillation in squirrel monkey; transport velocity, 2.5 mm/hr
Hunter and Dey 1998	Retrograde tracing of trigeminal neurons from nasal epithelium with microspheres
Hunter and Undem 1999	Rhodamine-labeled microspheres (20–200 nm) translocation via sensory nerves of TB region to ganglion nodosum in hamster after intratracheal instillation
Oberdörster et al. 2004	^{13}C particles (CMD ~ 36 nm) in olfactory bulb after whole-body inhalation exposure in rats

TB, tracheobronchial.

Günter Oberdörster, Eva Oberdörster, Jan Oberdörster. Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles. Environ Health Perspect 113:823–839 (2005).

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Passage of Inhaled Particles Into the Blood Circulation in Humans

A. Nemmar, DVM, PhD; P.H.M. Hoet, PhD; B. Vanquickenborne, MD; D. Dinsdale, PhD; M. Thomeer, MD; M.F. Hoylaerts, PhD; H. Vanbilloen, PhD;L. Mortelmans, MD, PhD; B. Nemery, MD, PhD

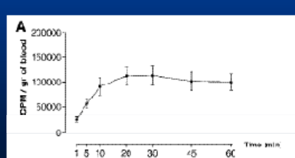
Background—Pollution by particulates has been consistently associated with increased cardiovascular morbidity and mortality. However, the mechanisms responsible for these effects are not well-elucidated.

Methods and Results—To assess to what extent and how rapidly inhaled pollutant particles pass into the systemic circulation, we measured, in 5 healthy volunteers, the distribution of radioactivity after the inhalation of "Technegas," an aerosol consisting mainly of ultrafine 99mTechnetium-labeled carbon particles (100 nm). Radioactivity was detected in blood already at 1 minute, reached a maximum between 10 and 20 minutes, and remained at this level up to 60 minutes. Thin layer chromatography of blood showed that in addition to a species corresponding to oxidized 99mTc, ie, pertechnetate, there was also a species corresponding to particle-bound 99mTc. Gamma camera images showed substantial radioactivity over the liver and other areas of the body.

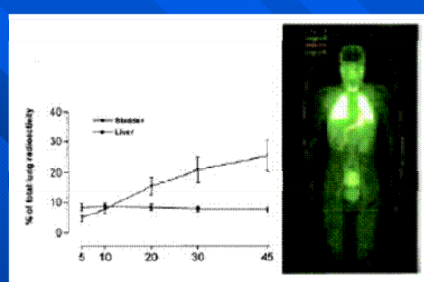
Conclusions—We conclude that inhaled 99mTc-labeled ultrafine carbon particles pass rapidly into the systemic circulation, and this process could account for the well-established, but poorly understood, extrapulmonary effects of air pollution.

(*Circulation*. 2002;105:411-414.)

Technegas consists on an aerosol suspension of 99mTc-labeled, ultrafine carbon particles produced in an atmosphere of high-purity argon. It was considered that 100% of the inhaled particles in Technegas were labeled with 99mTc and that the aerosol did not contain pertechnetate (TcO4). The size of the individualized particles was of the order of 5 to 10 nm, as we confirmed by electron microscopy of particles collected with a thermophoretic precipitator. However, particle aggregates were also seen. Inhalation of these particles enabled static and dynamic images in multiple projections to be acquired.



Radioactivity in blood at intervals after Technegas inhalation (mean ± SEM, n = 5



Time-activity curve over the liver and bladder expressed as percent of initial lung radioactivity.

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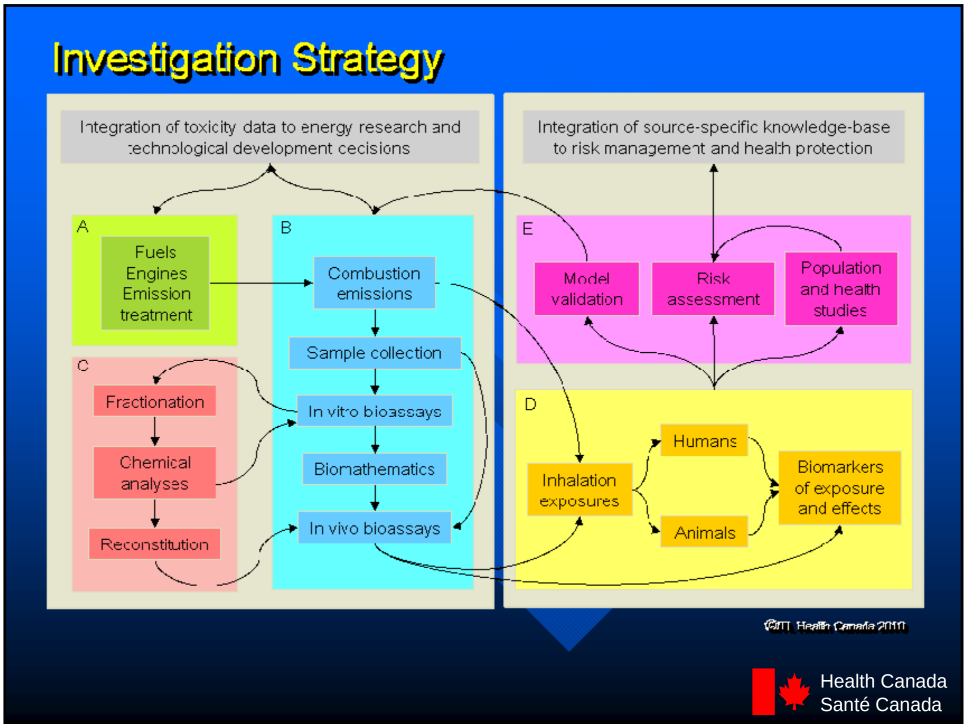
Investigation Strategy
Integration of toxicity data to energy research and technological development decisions
Integration of source-specific knowledge-base to risk management and health protection
A
Fuels
Engines
Emission
treatment
B
Combustion emissions
Sample collection
In vitro bioassays
Biomathematics
In vivo bioassays
C
Fractionation
Chemical analyses
Reconstitution
E
Model validation
Risk assessment
Population and health studies
D
Inhalation exposures
Humans
Animals
Biomarkers of exposure and effects
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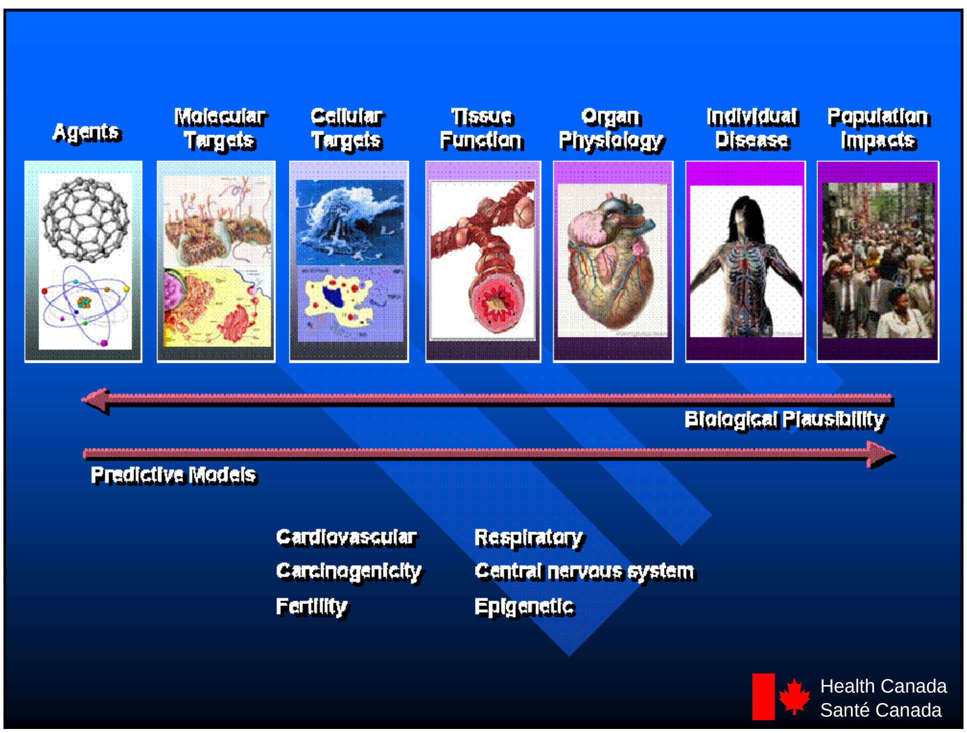
Agents
Molecular Targets
Cellular Targets
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Organ Physiology
Individual Disease
Population Impacts
Biological Plausibility
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Cardiovascular
Carcinogenicity
Fertility
Respiratory
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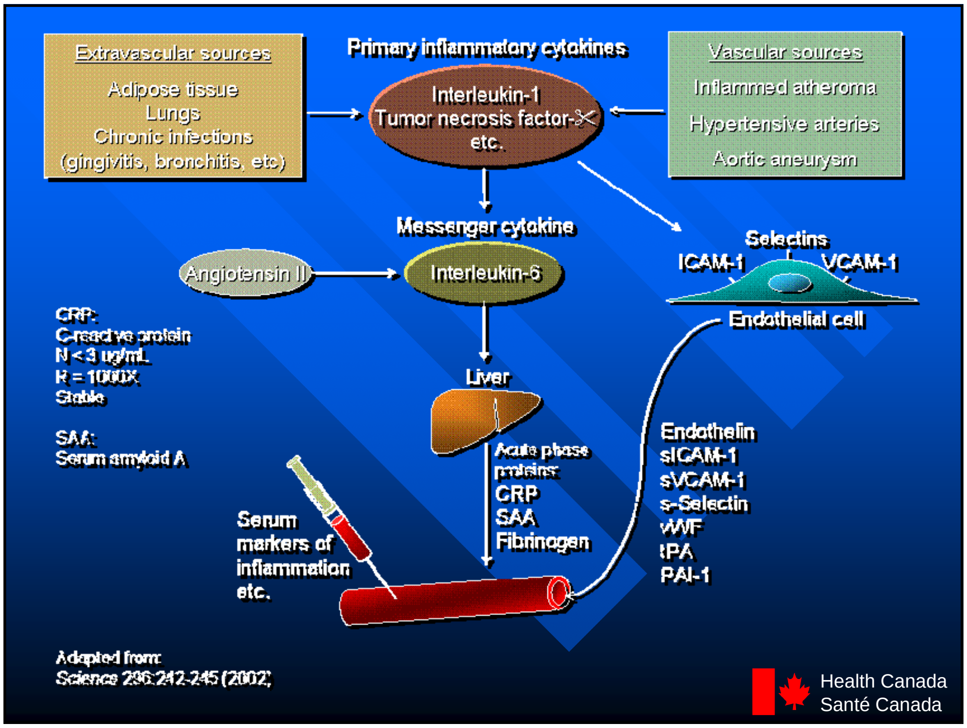

Integrated Approach

In-vitro bioassays

cytotoxicity, inflammation, proteomics, gene expression, epigenetics

In-vivo bioassays

relative toxicity, acute pulmonary and cardiovascular effects, biomarkers

Inhalation studies in animal models

toxicity confirmation, endpoints validation

Inhalation studies in human subjects

model validation, health relevance

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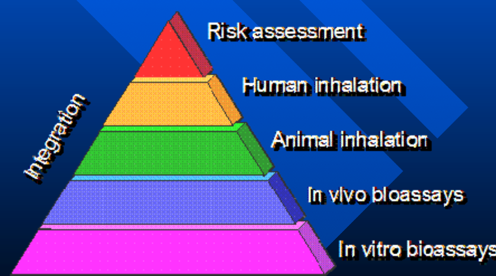
Strengths and Limitations of Assessment Approaches

	Throughput	Technical challenge	Health relevance
In vitro bioassays	*Very high*	*Very low*	*Low*
In vivo bioassays	*Medium*	*Low*	*Medium*
Animal Inhalation	*Low*	*Medium*	*High*
Human Inhalation	*None*	*High*	*Direct*



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Identification of Agents Responsible for Health Effects

In Vitro

- Cell culture models *(human and animal cells)*
- General cytotoxicity endpoints
- Pathophysiology-relevant endpoints *(eg regulation of ET-1, ECE-1, ETBR)*
- Mechanistic studies
- High throughput analysis of potency (vs chemistry, geography, sources)
- Assessment of technological developments (eg emissions control)

In Vivo

- Inhalation studies with model particles
- Chemical modifications vs biological potency
- Validation of pathophysiology pathways
- Pre-clinical investigation
- Identification of new biomarkers of exposure and effects

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Identification of Susceptibility Factors

Animal Studies

- Biological sensitivity models *(spontaneous hypertensive rats, stroke prone rats, hyperlipidemic rabbits or mice, heart ischemia models)*
- Pharmacological modification of responses (ET receptor antagonists, antioxidants)
- Strain effect on ET response *(preproET-1 induction, ETaR inhibition, receptor sensitivity, dose- and time-dependent changes vs genetic determinants)*

Human Studies

- Ecological studies and cohorts studies *(congestive heart failure patients, cardiac rehabilitation, pulmonary hypertension, pregnancy)*
- Pharmacological modification of responses (ET receptor antagonists, antioxidants)
- Individual sensitivity *(preproET-1 induction, ETaR inhibition, receptor sensitivity, dose- and time-dependent changes vs genetic determinants)*

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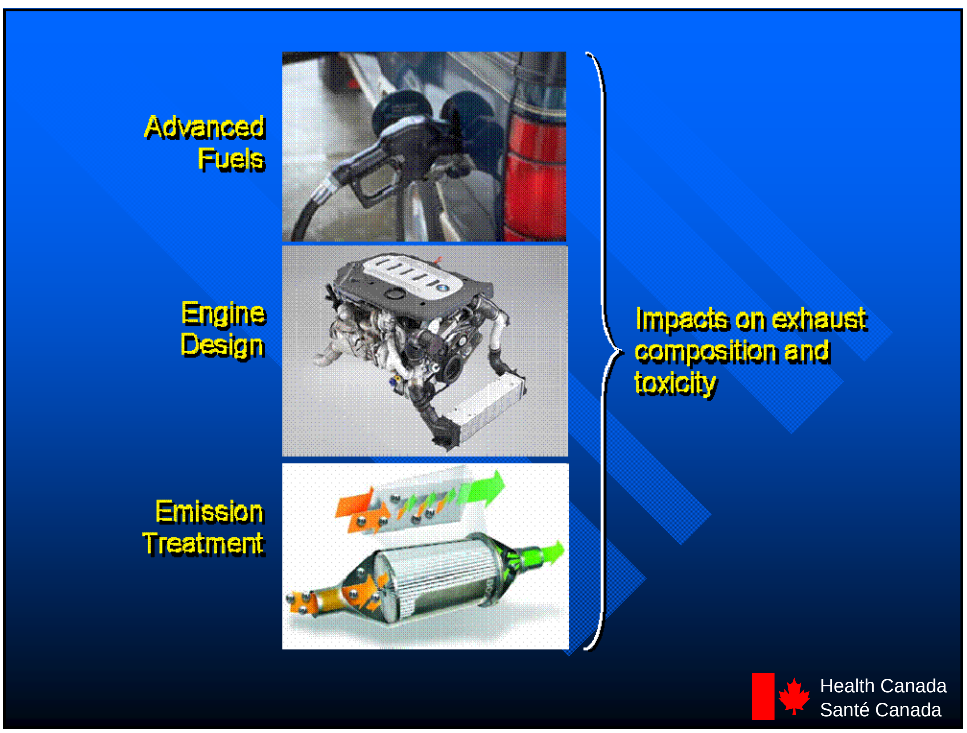

Table 2. Biodiesel Fuels Analysis

Fuel Identification	Method	Canola B100	Soy B100	Animal Tallow B100
Density, kg/m³ @ 15 °C	ASTM D4052	882.7	884.8	877.0
Cetane No. D613	ASTM D613	52.3	54.7	66.7
Carbon, %m	ASTM D5291	76.76	76.80	76.27
Hydrogen, %m	ASTM D5291	12.02	11.44	11.66
Viscosity @ 40 °C, (cSt)	ASTM D445	4.382	4.242	4.737
Sulphur, mg/kg	ASTM D5453	4	1.0	14
Total Nitrogen, mg/kg	ASTM D4629	9.60	2.57	75.58
Ash, Sulphated, Mass %	ASTM D874	0.000	0.001	0.002
Cloud Point, deg C	ASTM D2500	-8	0	12
Copper Corrosion	ASTM D130	1a	1a	1a
Flash Point, Deg C	ASTM D93, Procedure A	136.0	130.0	167.0
Carbon Residue, Mass %	ASTM D4530	0.000	0.001	0.001
Acid Number mg KOH/g	ASTM D664	0.26	0.27	0.40
Free Glycerine, mass %	ASTM D6584	<0.001	<0.001	0.001
Total Glycerine, mass %	ASTM D6584	0.102	0.134	0.061
Monoglycerides, mass %	ASTM D6584	0.319	0.463	0.152
Diglycerides, mass %	ASTM D6584	0.095	0.081	0.120
Triglycerides, mass %	ASTM D6584	0.015	0.012	0.027
Water and Sediment, Volume %	ASTM D2709	Not tested	0.000	0.000
Inductively Coupled Argon Plasma				<0.001*
Group I metals (Na + K), mg/kg	EN 14107 modified	<1	-	-
Group II metals (Ca + Mg), mg/kg	EN 14107 modified	<1	-	-
Phosphorus, mg/kg	EN 14107 modified	<1	-	-
Calcium (Ca), mg/kg	ASDTM D5185 modified	-	<0.05	<0.05
Potassium (K), mg/kg	ASDTM D5185 modified	-	<0.05	<0.05
Magnesium (Mg), mg/kg	ASDTM D5185 modified	-	<0.05	<0.05
Sodium (Na), mg/kg	ASDTM D5185 modified	-	3.5	1.0
Phosphorus (P), mass %	ASDTM D5185 modified	-	<0.001	<0.001
ARC Lab Sample Number	-	GO-2006-7292	GO-2007-1106	GO-2007-1107

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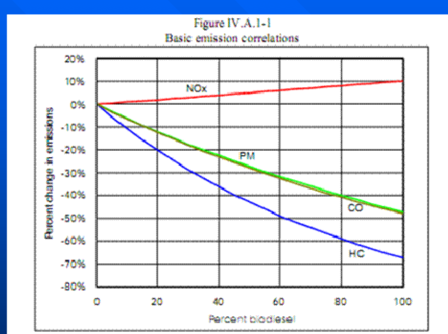
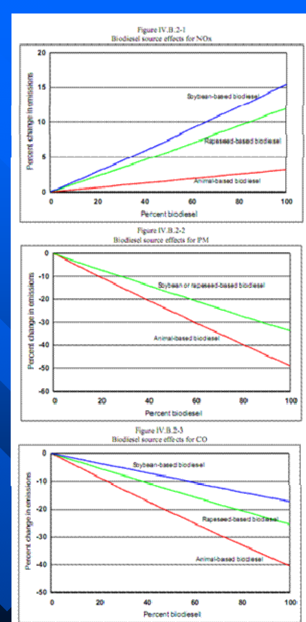
Biodiesel





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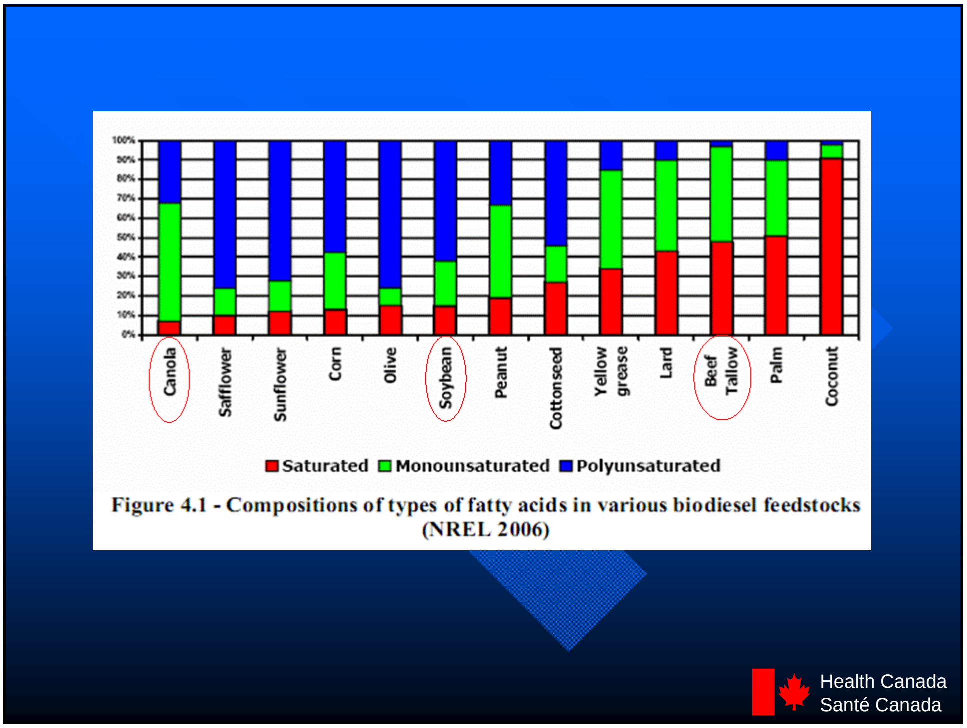
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
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Canola
Safflower
Sunflower
Corn
Olive
Soybean
Peanut
Cottonseed
Yellow grease
Lard
Beef Tallow
Palm
Coconut
Saturated
Monounsaturated
Polyunsaturated
Figure 4.1 - Compositions of types of fatty acids in various biodiesel feedstocks (NREL 2006)
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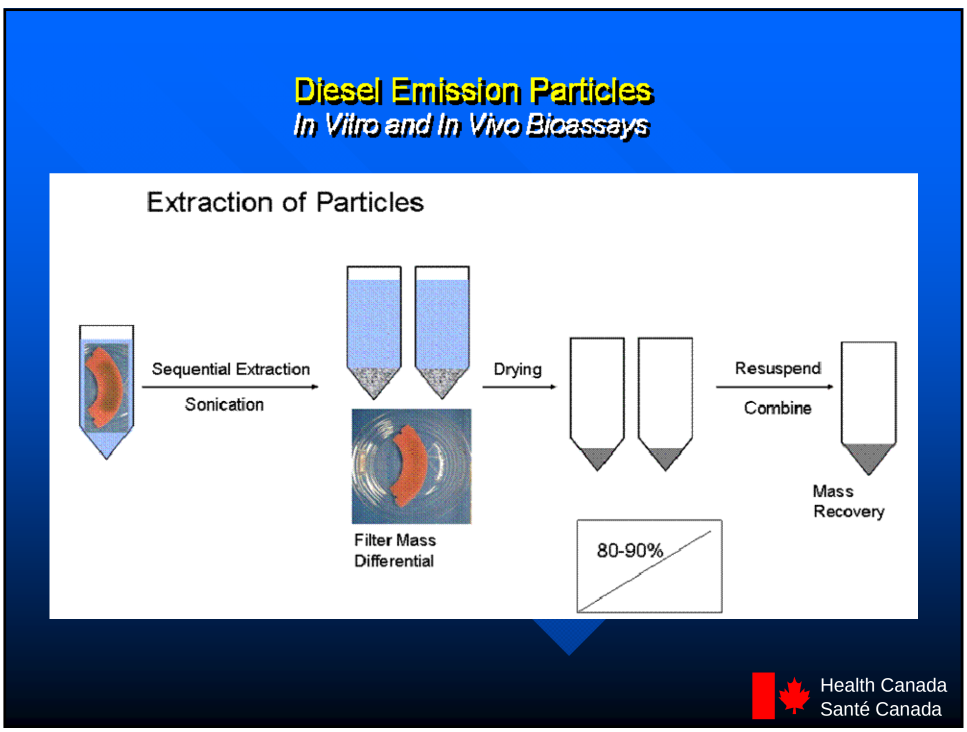
Diesel Emission Particles
In Vitro and In Vivo Bioassays
Extraction of Particles
Sequential Extraction
Sonication
Drying
Resuspend
Combine
Filter Mass Differential
Mass Recovery
80-90%
Health Canada
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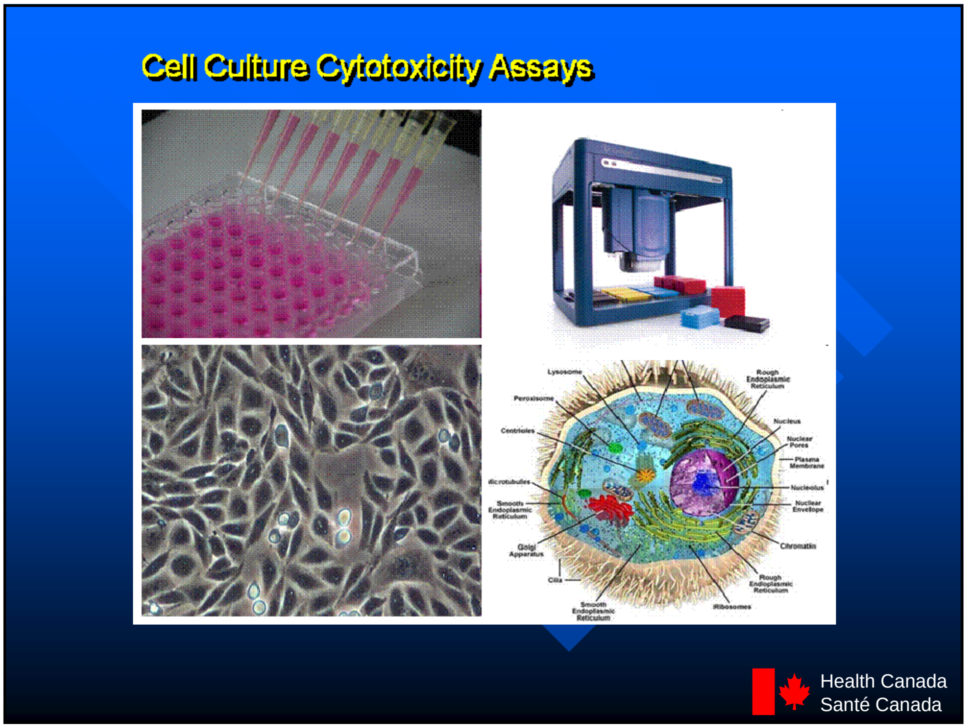
Cell Culture Cytotoxicity Assays
Lysosome
Peroxisome
Centrioles
Microtubules
Smooth Endoplasmic Reticulum
Golgi Apparatus
Cilia
Smooth Endoplasmic Reticulum
Rough Endoplasmic Reticulum
Nucleus
Nuclear Pores
Plasma Membrane
Nucleolus
Nuclear Envelope
Chromatin
Rough Endoplasmic Reticulum
Ribosomes
Health Canada
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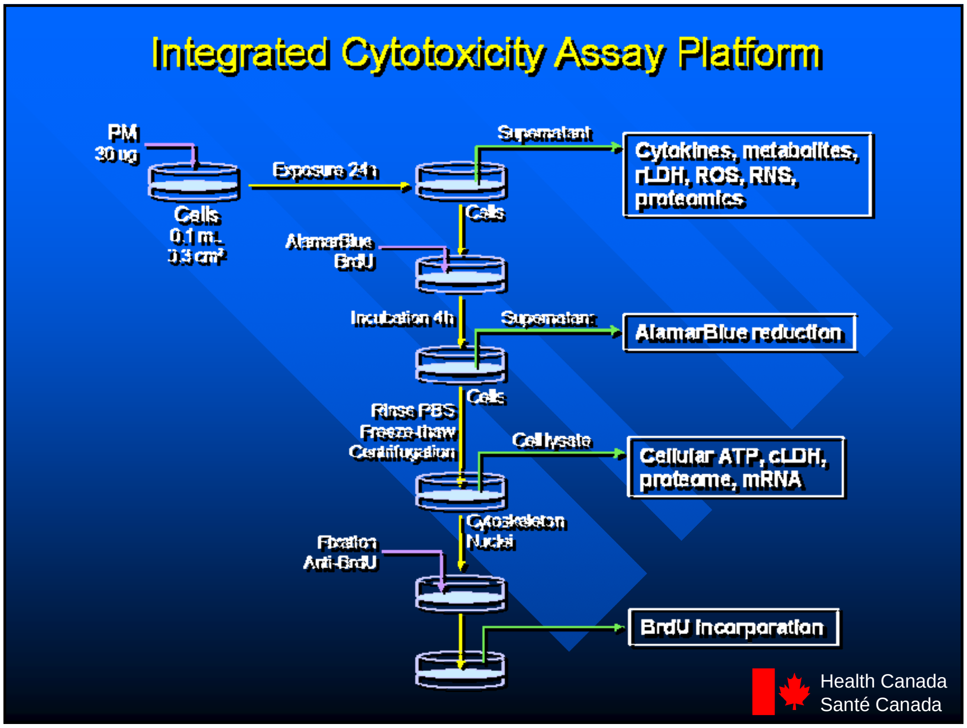
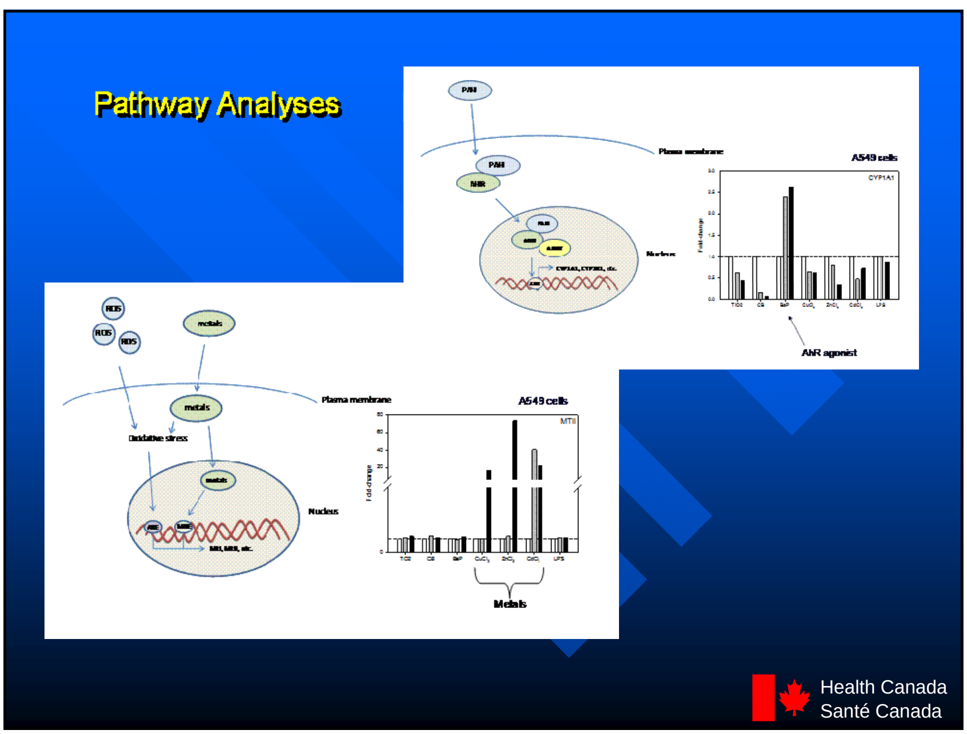
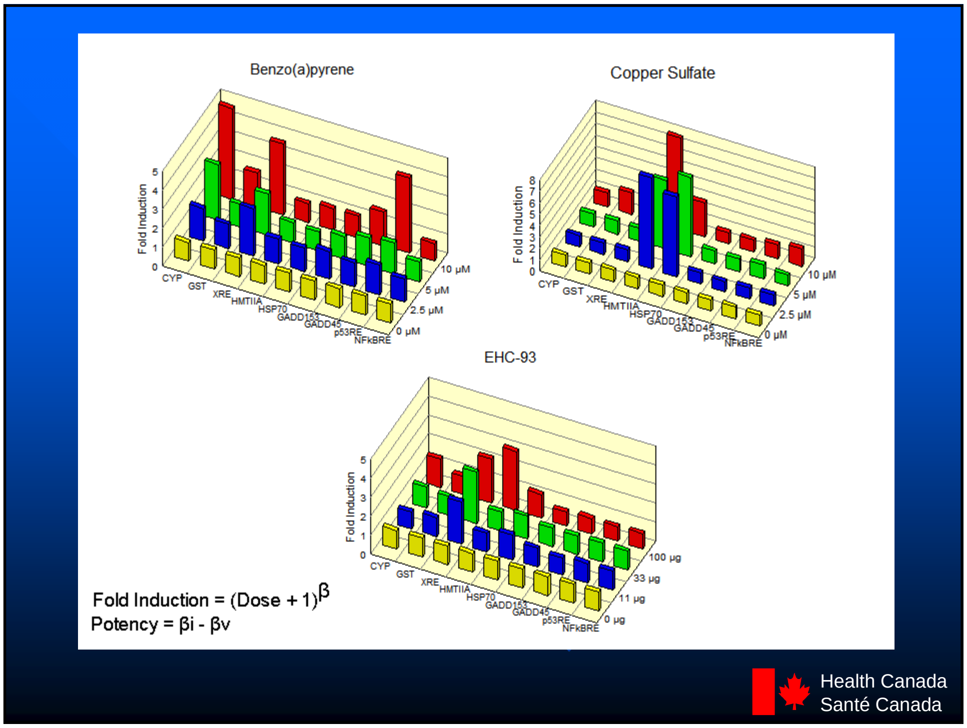

Integrated Cytotoxicity Assay Platform
PM
30 µg
Cells
0.1 mL
0.3 cm²
Exposure 24 h
Supernatant
Cytokines, metabolites, rLDH, ROS, RNS, proteomics
Cells
AlamarBlue
BrdU
Incubation 4h
Supernatant
AlamarBlue reduction
Cells
Rinse PBS
Freeze-thaw
Centrifugation
Cell lysate
Cellular ATP, cLDH, proteome, mRNA
Cytoskeleton
Nuclei
Fixation
Anti-BrdU
BrdU incorporation
Health Canada
Santé Canada


Pathway Analyses
PAH
Plasma membrane
A549 cells
CYP1A1
Nucleus
AhR agonist
ROS
metals
Plasma membrane
A549 cells
Oxidative stress
Nucleus
Metals
Health Canada
Santé Canada


Benzo(a)pyrene
Copper Sulfate
EHC-93
Fold Induction
CYP
GST
XRE
HMTIIA
HSP70
GADD153
GADD45
p53RE
NFkBRE
10 µM
5 µM
2.5 µM
0 µM
100 µg
33 µg
11 µg
0 µg
Fold Induction = (Dose + 1)$^{\beta}$
Potency = βi - βv
Health Canada
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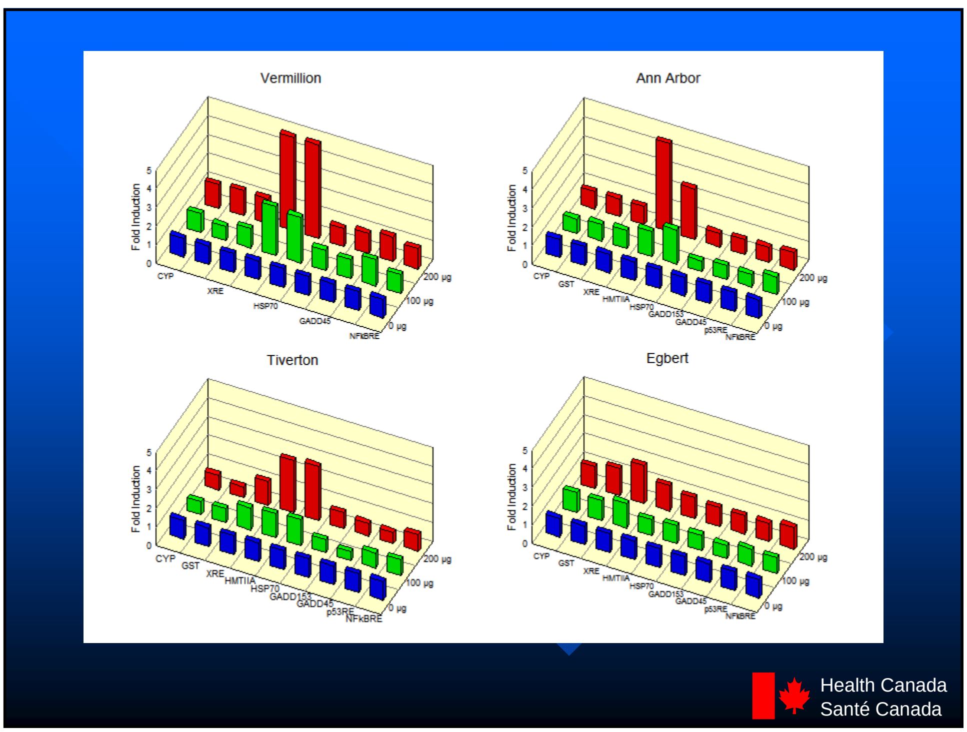
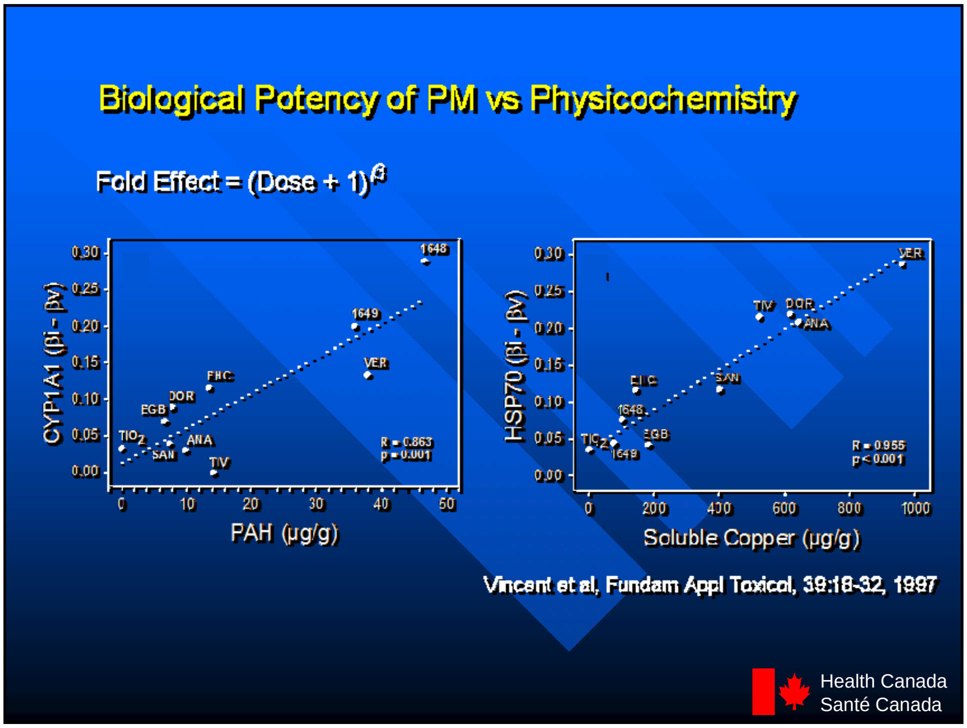
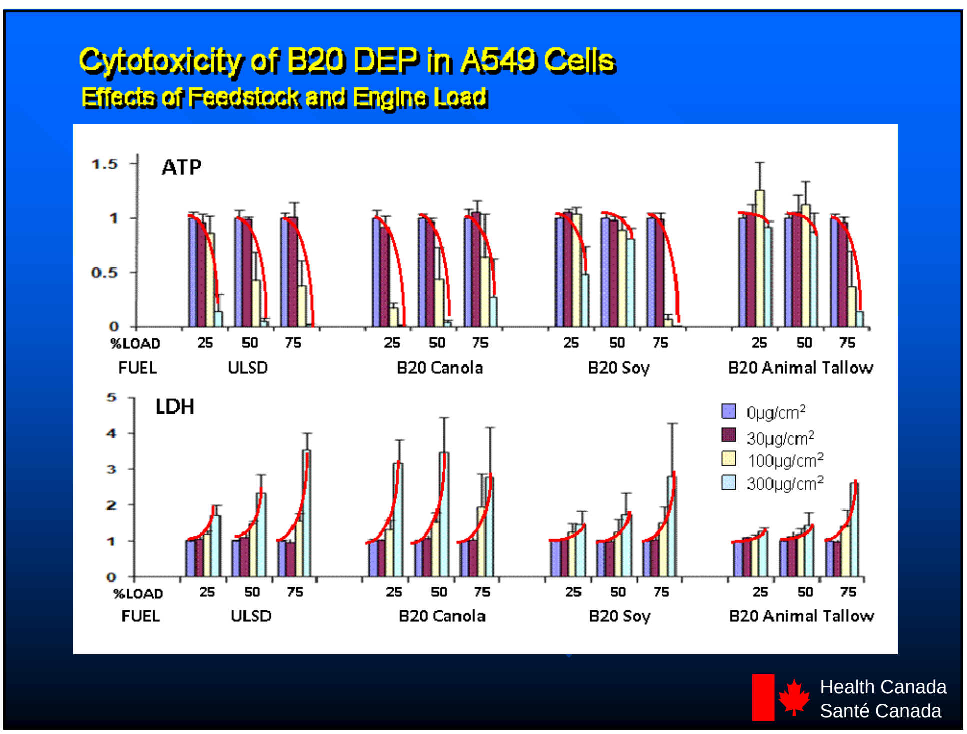
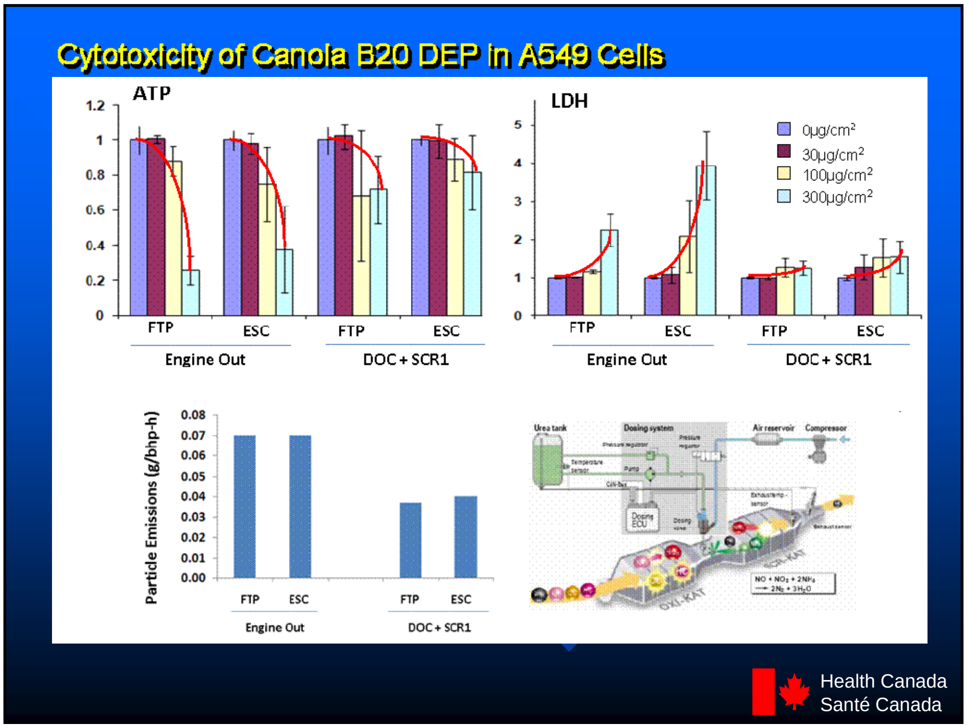
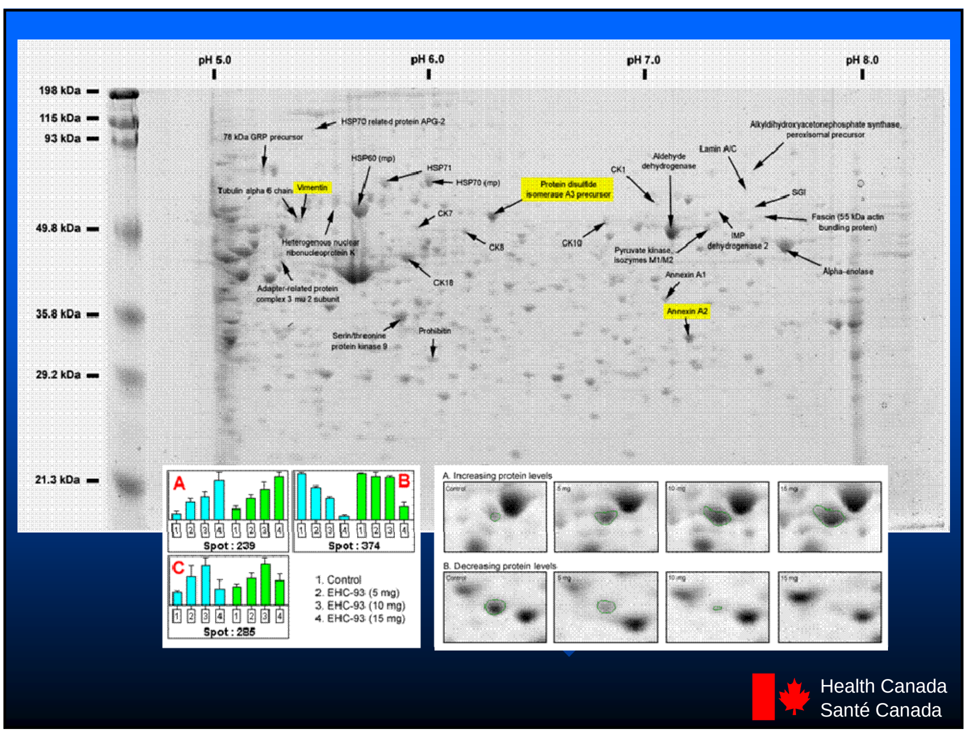

Vermillion
Ann Arbor
Tiverton
Egbert
Fold Induction
CYP
GST
XRE
HMTIIA
HSP70
GADD153
GADD45
p53RE
NFkBRE
200 µg
100 µg
0 µg
Health Canada
Santé Canada


Biological Potency of PM vs Physicochemistry
Fold Effect = (Dose + 1)^β
CYP1A1 (βi - βv)
PAH (μg/g)
R = 0.863
p = 0.001
HSP70 (βi - βv)
Soluble Copper (μg/g)
R = 0.955
p < 0.001
Vincent et al, Fundam Appl Toxicol, 39:18-32, 1997
Health Canada
Santé Canada

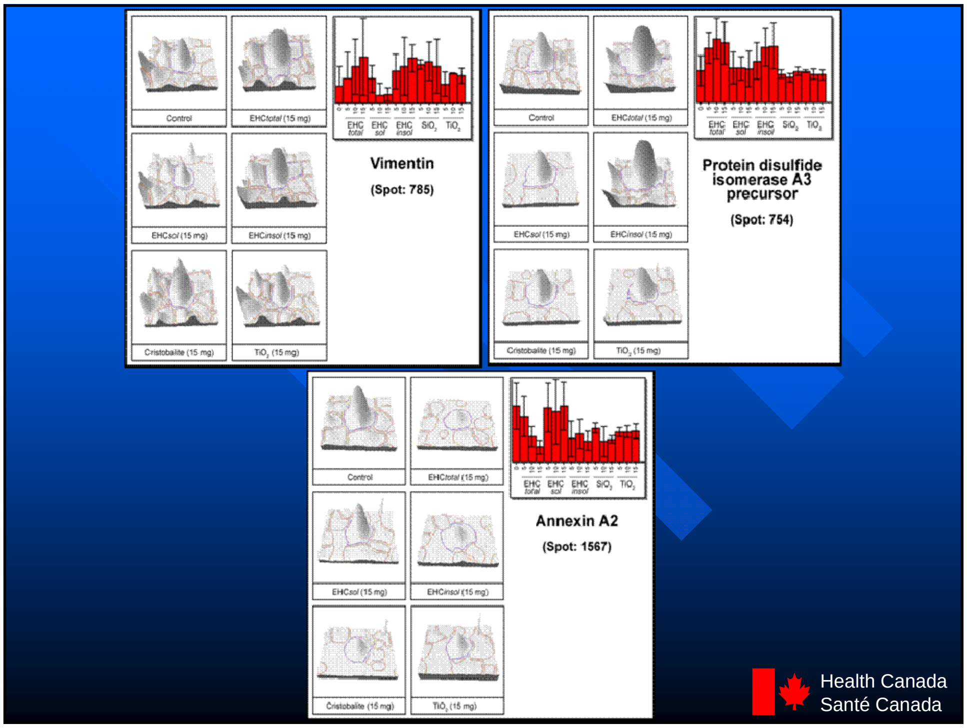

Cytotoxicity of B20 DEP in A549 Cells
Effects of Feedstock and Engine Load
ATP
LDH
%LOAD
FUEL
ULSD
B20 Canola
B20 Soy
B20 Animal Tallow
0μg/cm²
30μg/cm²
100μg/cm²
300μg/cm²
Health Canada
Santé Canada

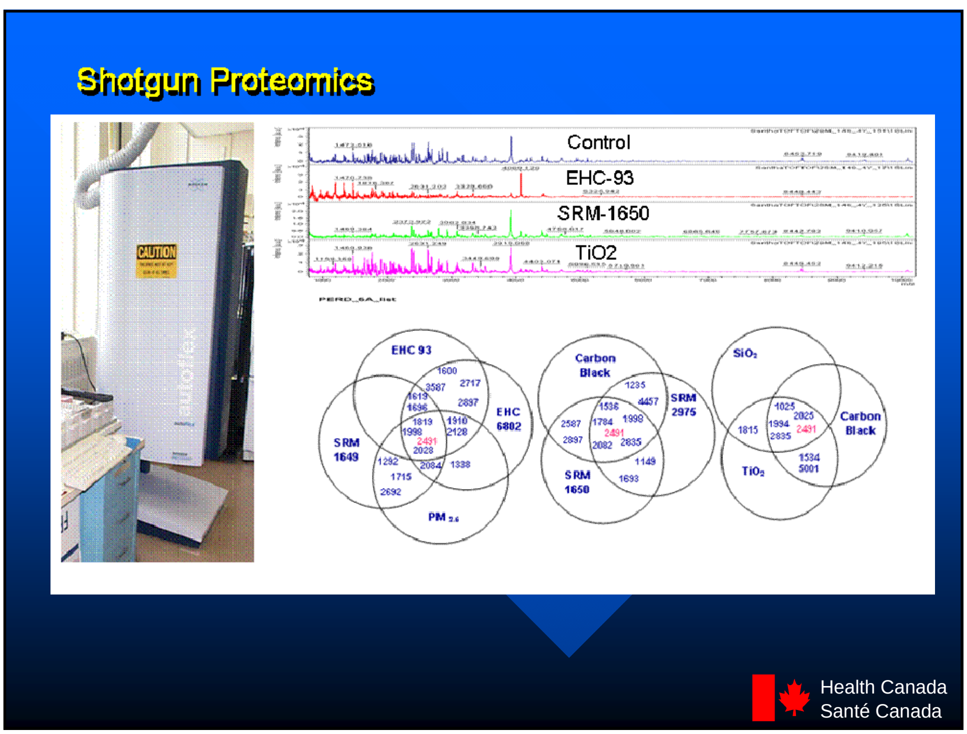


Cytotoxicity of Canola B20 DEP in A549 Cells
ATP
1.2
1
0.8
0.6
0.4
0.2
0
FTP
ESC
FTP
ESC
Engine Out
DOC + SCR1
LDH
5
4
3
2
1
0
0μg/cm²
30μg/cm²
100μg/cm²
300μg/cm²
Particle Emissions (g/bhp-h)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Urea tank
Dosing system
Air reservoir
Compressor
Dosing ECU
OXI-KAT
Health Canada
Santé Canada



pH 5.0
pH 6.0
pH 7.0
pH 8.0
198 kDa
115 kDa
93 kDa
49.8 kDa
35.8 kDa
29.2 kDa
21.3 kDa
HSP70 related protein APG-2
78 kDa GRP precursor
HSP60 (mp)
HSP71
HSP70 (mp)
Tubulin alpha 6 chain
Vimentin
Heterogenous nuclear ribonucleoprotein K
Adapter-related protein complex 3 mu 2 subunit
CK7
CK8
CK18
CK10
CK1
Protein disulfide isomerase A3 precursor
Aldehyde dehydrogenase
Lamin A/C
Alkyldihydroxyacetonephosphate synthase, peroxisomal precursor
SGI
Fascin (55 kDa actin bundling protein)
IMP dehydrogenase 2
Pyruvate kinase, isozymes M1/M2
Alpha-enolase
Annexin A1
Annexin A2
Serin/threonine protein kinase 9
Prohibitin
Spot : 239
Spot : 374
Spot : 285
1. Control
2. EHC-93 (5 mg)
3. EHC-93 (10 mg)
4. EHC-93 (15 mg)
A. Increasing protein levels
B. Decreasing protein levels
Health Canada
Santé Canada


Control
EHCtotal (15 mg)
EHCsol (15 mg)
EHCinsol (15 mg)
Cristobalite (15 mg)
TiO2 (15 mg)
Vimentin
(Spot: 785)
Protein disulfide isomerase A3 precursor
(Spot: 754)
Annexin A2
(Spot: 1567)
Health Canada
Santé Canada


Shotgun Proteomics
Control
EHC-93
SRM-1650
TiO2
EHC 93
EHC 6802
SRM 1649
PM 2.5
Carbon Black
SRM 2975
SRM 1650
SiO2
TiO2
Carbon Black
Health Canada
Santé Canada

In Vitro - In Vivo Comparisons

Assessment of a set of validated in vitro assays as predictors of in-vivo (animal toxicity)

Validation involved A549 & J774 cell lines exposed to Ottawa urban particles, ambient fine PM2.5 and diesel emission particles

Intratracheal instillation of particles in mice.

Lung neutrophils (inflammation)

Endothelin-1 (cardiovascular response)

CYP1A1 gene expression (metabolic activation of aromatic hydrocarbons).

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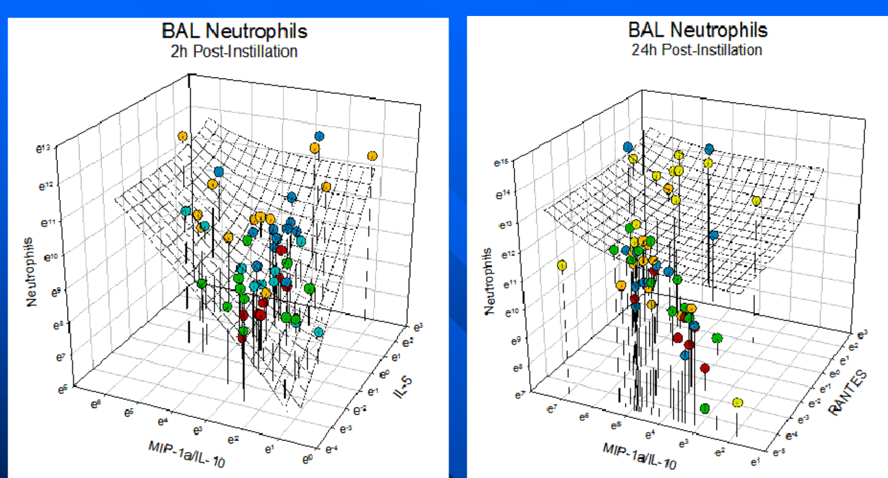
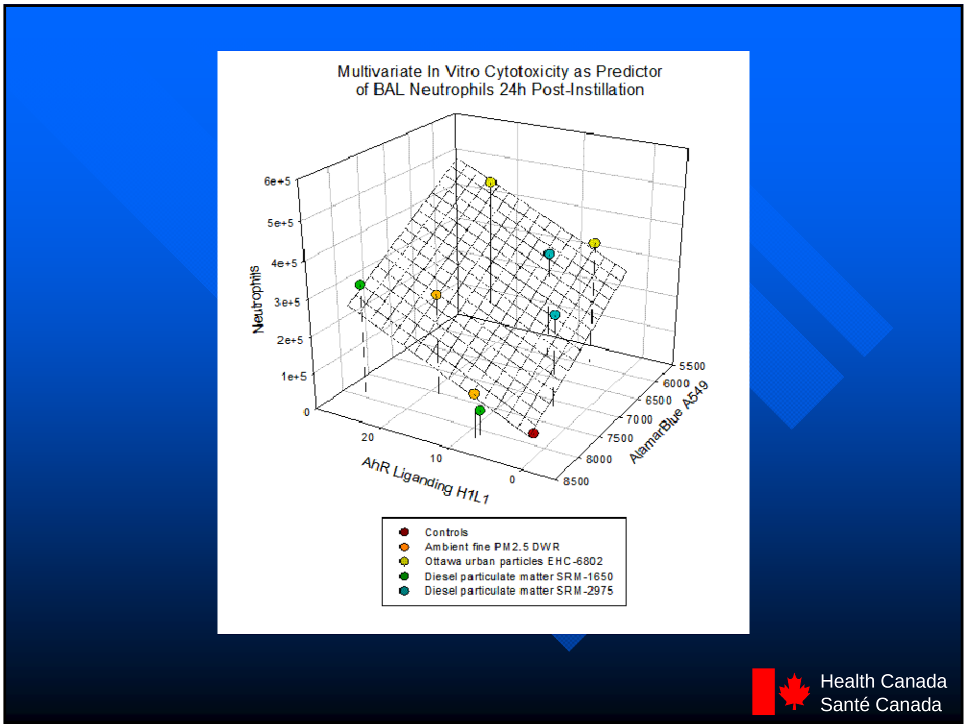
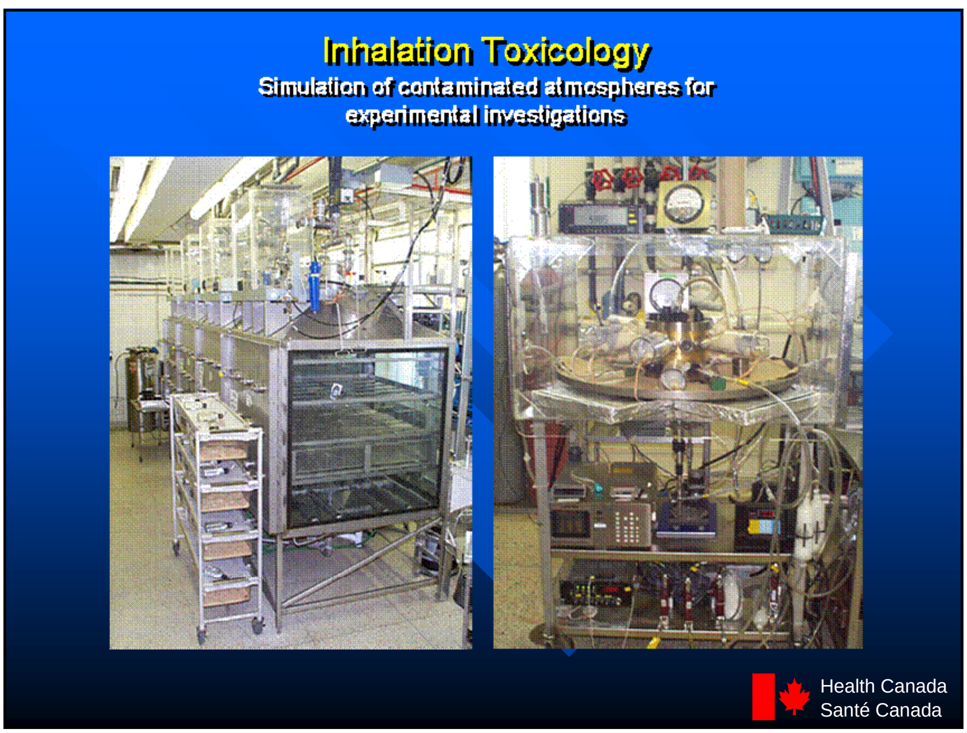
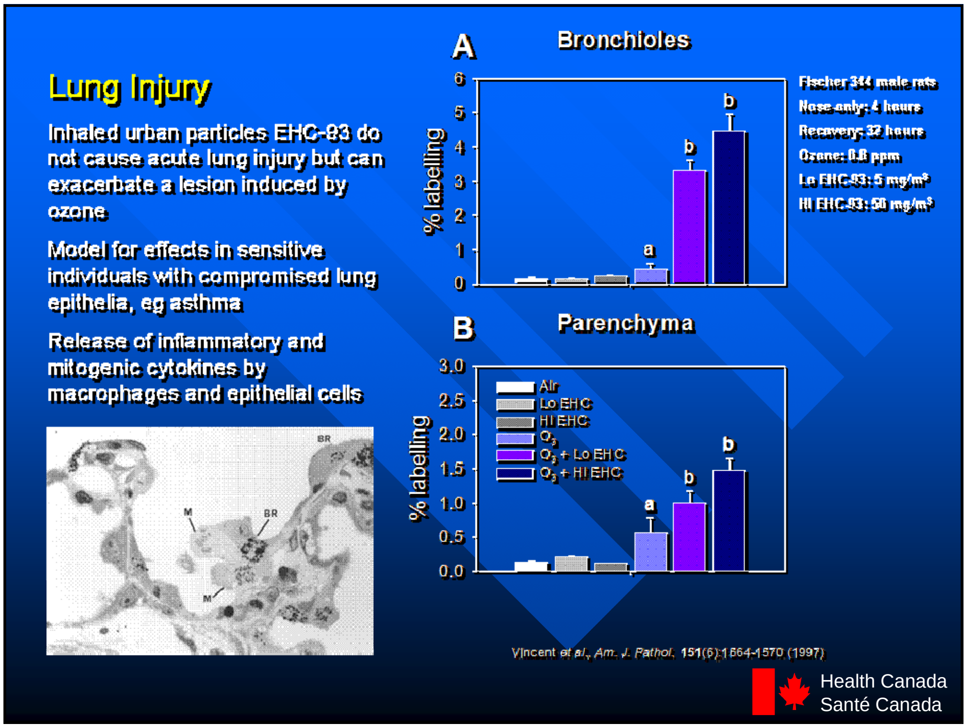
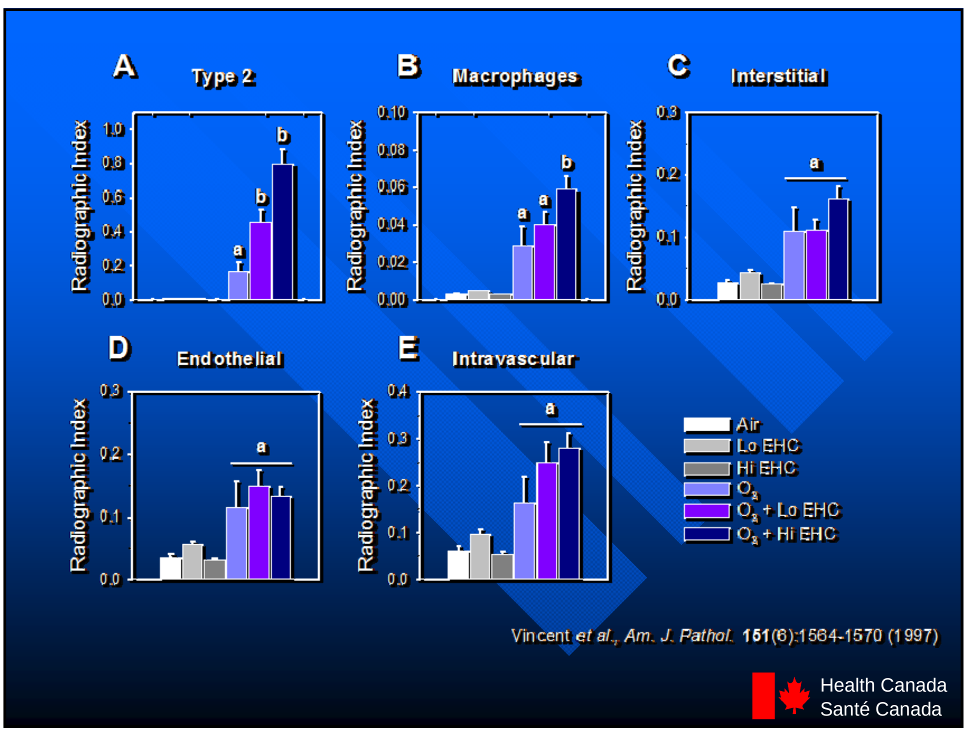


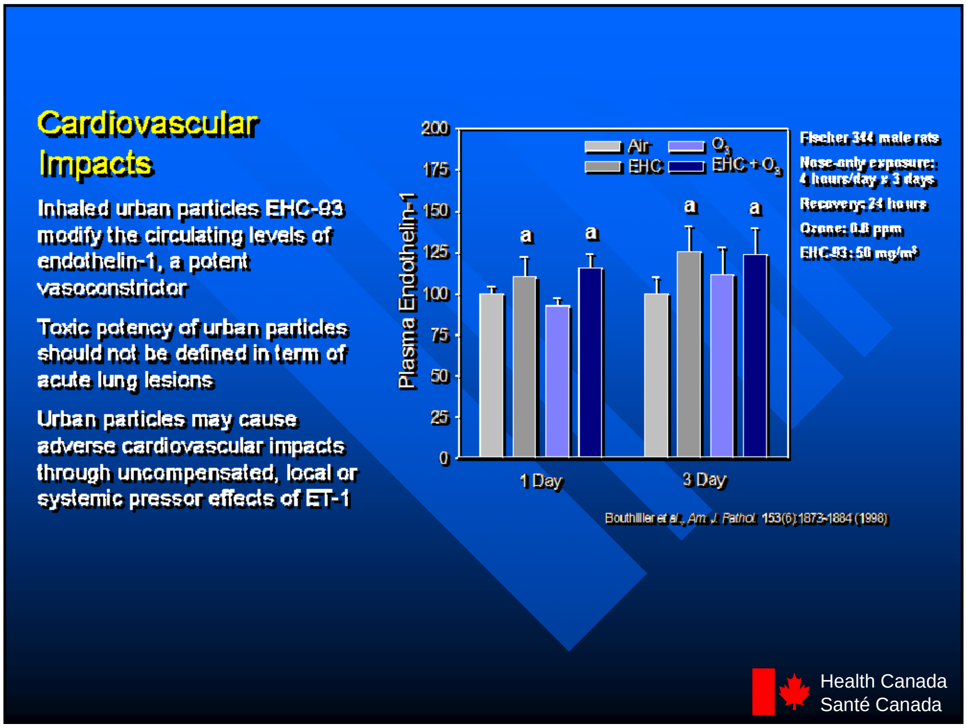
Health Canada
Santé Canada

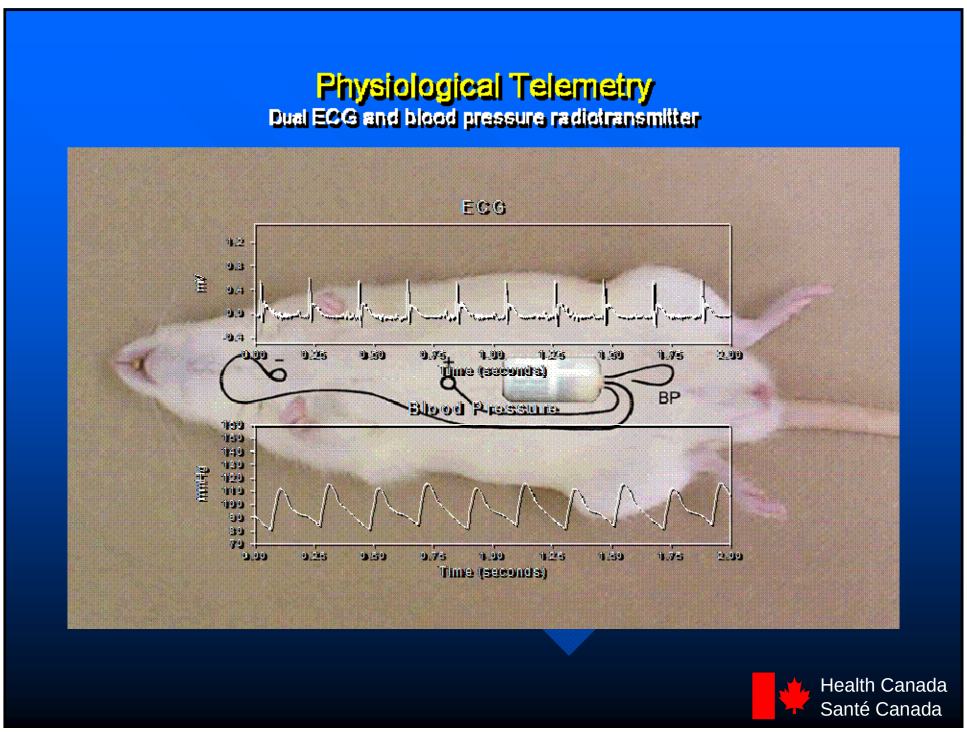

Multivariate In Vitro Cytotoxicity as Predictor
of BAL Neutrophils 24h Post-Instillation
Neutrophils
6e+5
5e+5
4e+5
3e+5
2e+5
1e+5
0
20
10
0
AhR Liganding H1L1
5500
6000
6500
7000
7500
8000
8500
AlamarBlue A549
Controls
Ambient fine PM2.5 DWR
Ottawa urban particles EHC-6802
Diesel particulate matter SRM-1650
Diesel particulate matter SRM-2975
Health Canada
Santé Canada

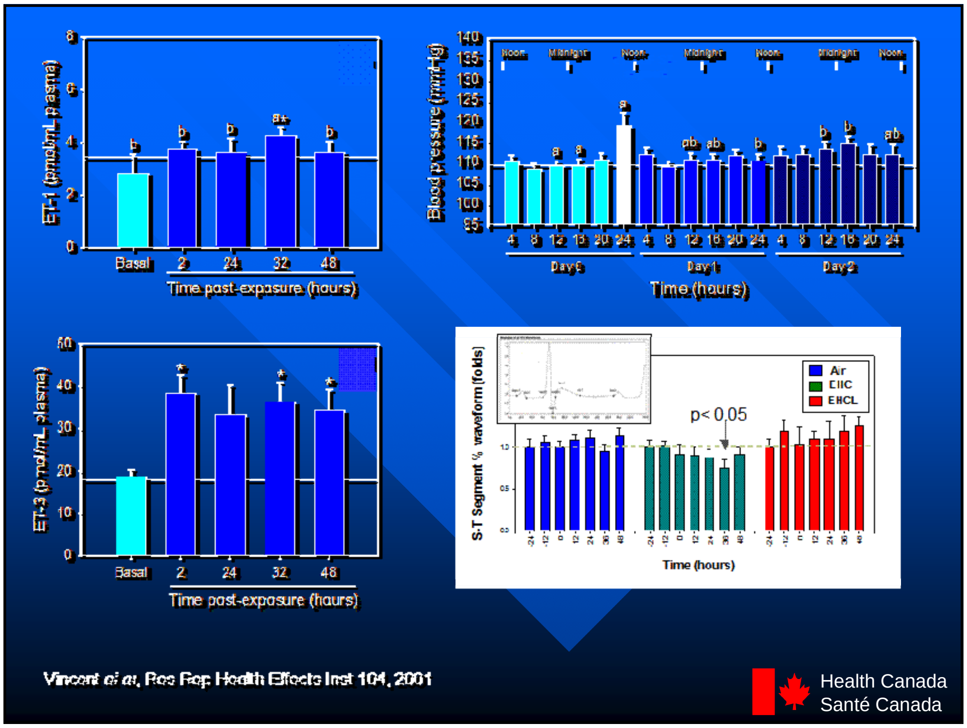

Inhalation Toxicology
Simulation of contaminated atmospheres for
experimental investigations
Health Canada
Santé Canada

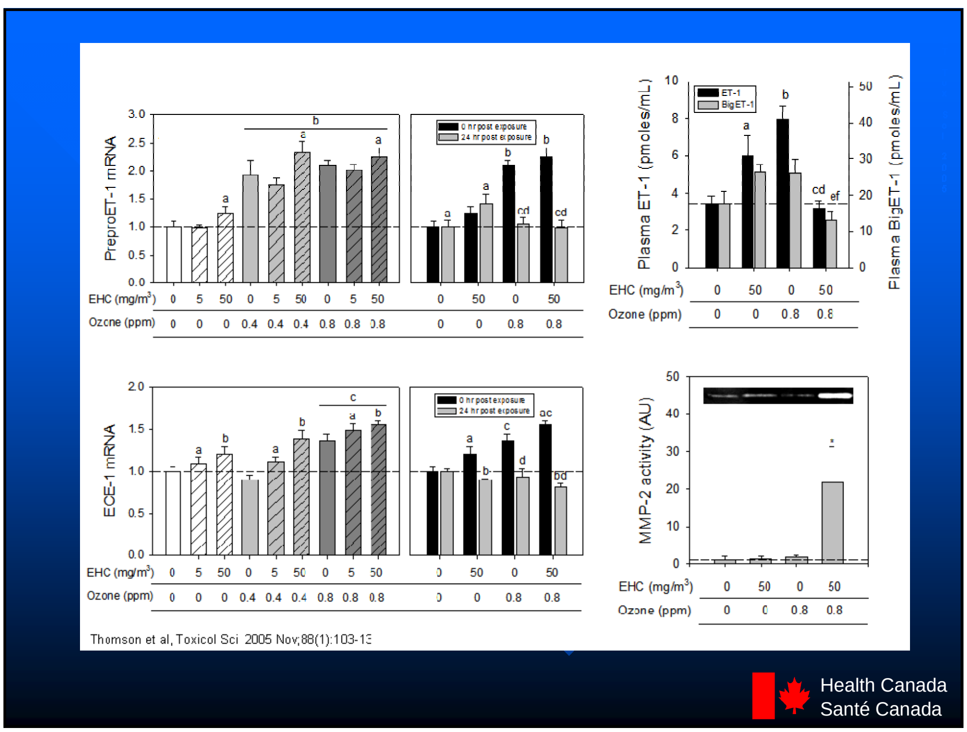

Lung Injury
Inhaled urban particles EHC-93 do not cause acute lung injury but can exacerbate a lesion induced by ozone
Model for effects in sensitive individuals with compromised lung epithelia, eg asthma
Release of inflammatory and mitogenic cytokines by macrophages and epithelial cells
A Bronchioles
% labelling
Fischer 344 male rats
Nose-only: 4 hours
Recovery: 32 hours
Ozone: 0.8 ppm
Lo EHC-93: 5 mg/m³
Hi EHC-93: 50 mg/m³
B Parenchyma
% labelling
Air
Lo EHC
Hi EHC
O3
O3 + Lo EHC
O3 + Hi EHC
Vincent et al., Am. J. Pathol. 151(6):1564-1570 (1997)
Health Canada
Santé Canada

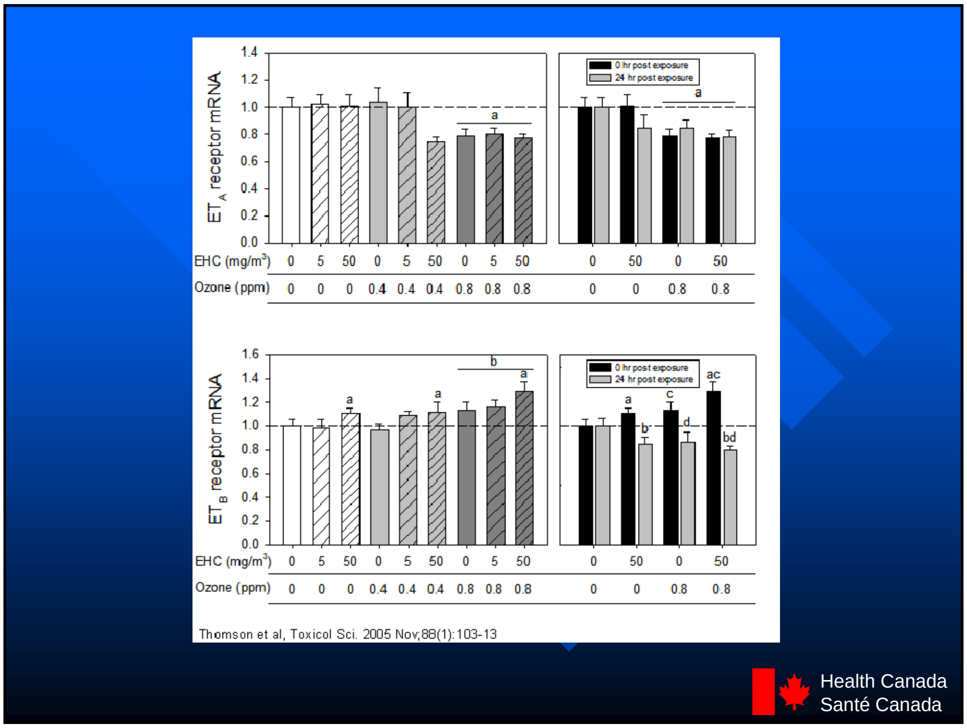

A Type 2
B Macrophages
C Interstitial
D Endothelial
E Intravascular
Radiographic Index
Air
Lo EHC
Hi EHC
O3
O3 + Lo EHC
O3 + Hi EHC
Vincent et al., Am. J. Pathol. 151(6):1564-1570 (1997)
Health Canada
Santé Canada


Cardiovascular Impacts
Inhaled urban particles EHC-93 modify the circulating levels of endothelin-1, a potent vasoconstrictor
Toxic potency of urban particles should not be defined in term of acute lung lesions
Urban particles may cause adverse cardiovascular impacts through uncompensated, local or systemic pressor effects of ET-1
Plasma Endothelin-1
200
175
150
125
100
75
50
25
0
Air
EHC
O_3
EHC + O_3
a
1 Day
3 Day
Fischer 344 male rats
Nose-only exposure: 4 hours/day x 3 days
Recovery: 24 hours
Ozone: 0.8 ppm
EHC-93: 50 mg/m^3
Bouthillier et al., Am. J. Pathol. 153(6):1873-1884 (1998)
Health Canada
Santé Canada


Physiological Telemetry
Dual ECG and blood pressure radiotransmitter
ECG
Time (seconds)
Blood Pressure
BP
Health Canada
Santé Canada


ET-1 (pmol/mL plasma)
Time post-exposure (hours)
Basal
2
24
32
48
Blood pressure (mmHg)
Noon
Midnight
Day 0
Day 1
Day 2
Time (hours)
ET-3 (pmol/mL plasma)
S-T Segment % waveform (folds)
Air
EHC
EHCL
p< 0.05
Time (hours)
Vincent et al, Res Rep Health Effects Inst 104, 2001
Health Canada
Santé Canada


PreproET-1 mRNA
0 hr post exposure
24 hr post exposure
EHC (mg/m³)
Ozone (ppm)
Plasma ET-1 (pmoles/mL)
Plasma BigET-1 (pmoles/mL)
ET-1
BigET-1
ECE-1 mRNA
MMP-2 activity (AU)
Thomson et al, Toxicol Sci 2005 Nov;88(1):103-13
Health Canada
Santé Canada


ET$_A$ receptor mRNA
EHC (mg/m^3)
Ozone (ppm)
0 hr post exposure
24 hr post exposure
ET$_B$ receptor mRNA
Thomson et al, Toxicol Sci. 2005 Nov;88(1):103-13
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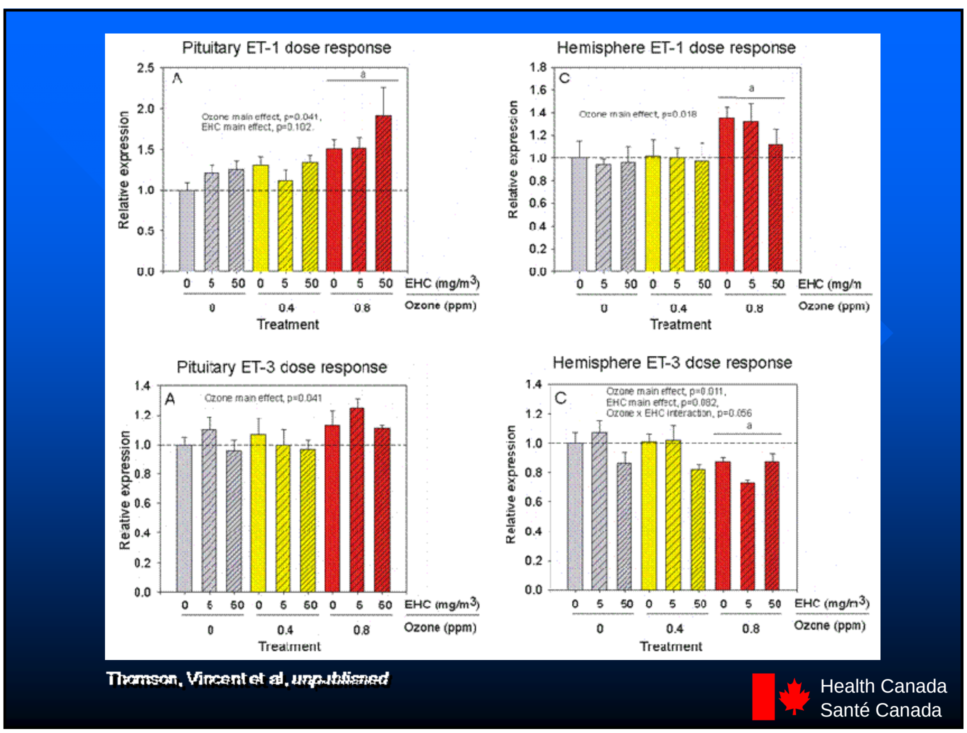
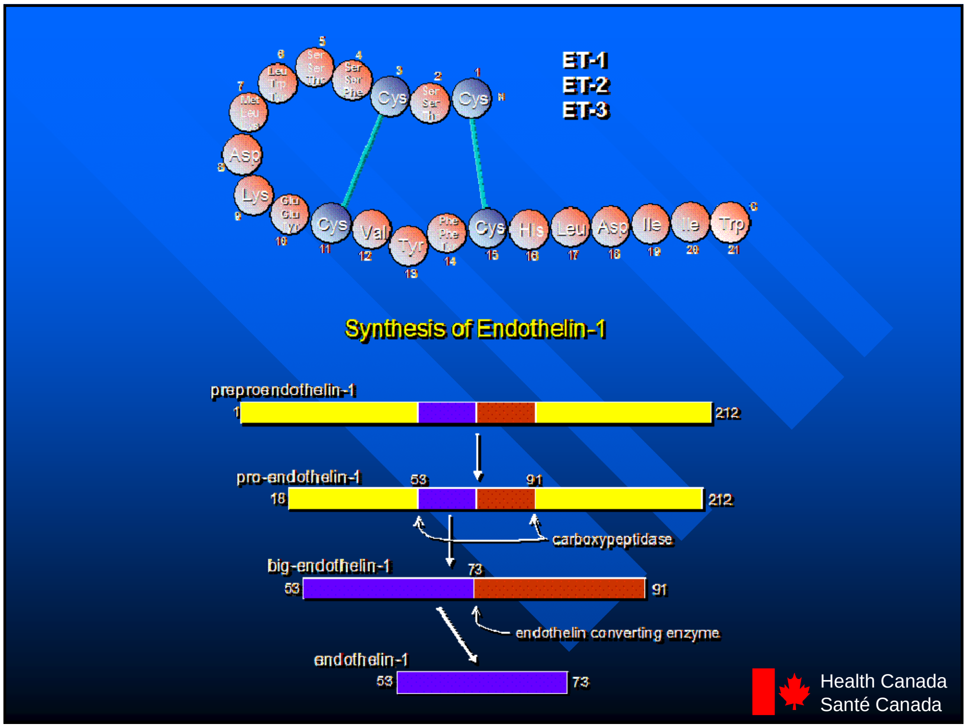
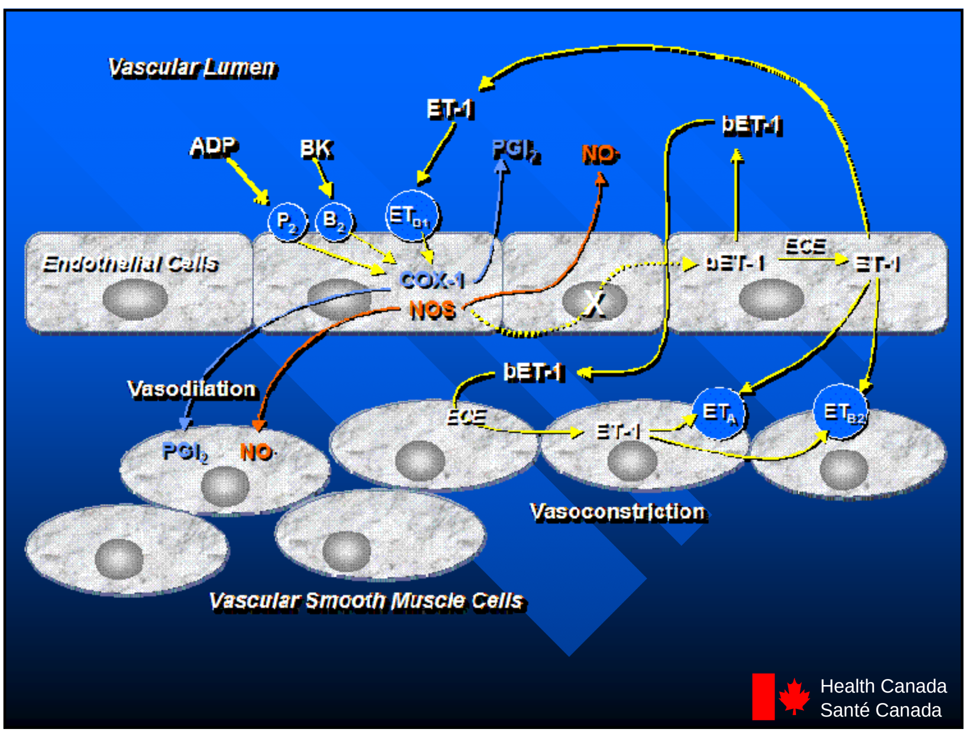
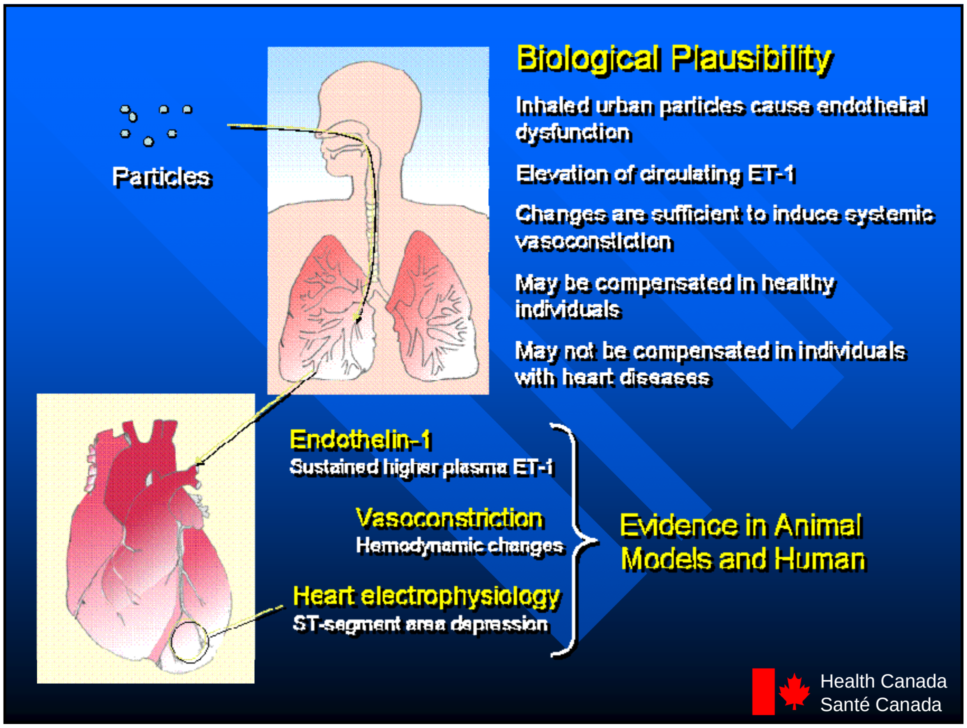

Pituitary ET-1 dose response
Ozone main effect, p=0.041,
EHC main effect, p=0.102.
Hemisphere ET-1 dose response
Ozone main effect, p=0.018
Pituitary ET-3 dose response
Ozone main effect, p=0.041
Hemisphere ET-3 dose response
Ozone main effect, p=0.011,
EHC main effect, p=0.082,
Ozone x EHC interaction, p=0.056
Relative expression
EHC (mg/m^3)
Ozone (ppm)
Treatment
Thomson, Vincent et al, unpublished
Health Canada
Santé Canada


ET-1
ET-2
ET-3
Synthesis of Endothelin-1
preproendothelin-1
pro-endothelin-1
carboxypeptidase
big-endothelin-1
endothelin converting enzyme
endothelin-1
Health Canada
Santé Canada


Vascular Lumen
ET-1
ADP
BK
PGI2
NO·
bET-1
Endothelial Cells
COX-1
NOS
ECE
Vasodilation
Vasoconstriction
Vascular Smooth Muscle Cells
Health Canada
Santé Canada



Particles
Biological Plausibility
Inhaled urban particles cause endothelial dysfunction
Elevation of circulating ET-1
Changes are sufficient to induce systemic vasoconstriction
May be compensated in healthy individuals
May not be compensated in individuals with heart diseases
Endothelin-1
Sustained higher plasma ET-1
Vasoconstriction
Hemodynamic changes
Heart electrophysiology
ST-segment area depression
Evidence in Animal Models and Human
Health Canada
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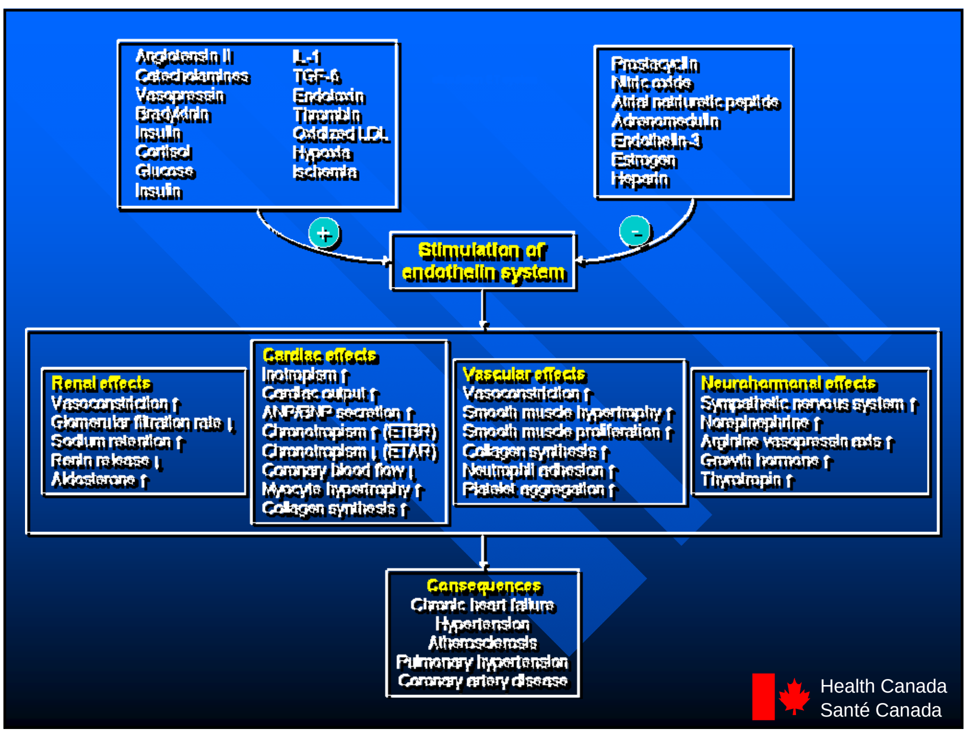

Angiotensin II
Catecholamines
Vasopressin
Bradykinin
Insulin
Cortisol
Glucose
Insulin
IL-1
TGF-ß
Endotoxin
Thrombin
Oxidized LDL
Hypoxia
Ischemia
Prostacyclin
Nitric oxide
Atrial natriuretic peptide
Adrenomedullin
Endothelin-3
Estrogen
Heparin
+
-
Stimulation of endothelin system
Renal effects
Vasoconstriction ↑
Glomerular filtration rate ↓
Sodium retention ↑
Renin release ↓
Aldosterone ↑
Cardiac effects
Inotropism ↑
Cardiac output ↑
ANP/BNP secretion ↑
Chronotropism ↑ (ETBR)
Chronotropism ↓ (ETAR)
Coronary blood flow ↓
Myocyte hypertrophy ↑
Collagen synthesis ↑
Vascular effects
Vasoconstriction ↑
Smooth muscle hypertrophy ↑
Smooth muscle proliferation ↑
Collagen synthesis ↑
Neutrophil adhesion ↑
Platelet aggregation ↑
Neurohormonal effects
Sympathetic nervous system ↑
Norepinephrine ↑
Arginine vasopressin axis ↑
Growth hormone ↑
Thyrotropin ↑
Consequences
Chronic heart failure
Hypertension
Atherosclerosis
Pulmonary hypertension
Coronary artery disease
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Mobile Inhalation Toxicology Exposure System

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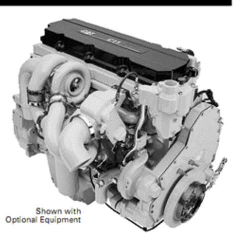
CATERPILLAR®

On-Highway Diesel Engine with ACERT® Technology

C11

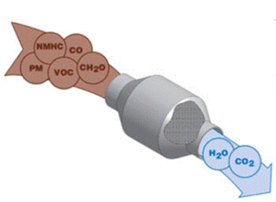
305-370 hp @ 2100 rpm
1050-1450 lb-ft @ 1200 rpm Peak Torque

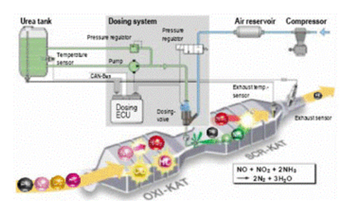


Shown with Optional Equipment

Table 1. Test Engine Specifications and Certified Emission Rates

Engine Specifications	
Engine Manufacturer	Caterpillar
Model	C11
Year	2004
Serial Number	KCA018109
Engine Family	4CPXH0680EBK
Air Handling System	Series Turbo-Charged
Control	Electronic ACERT
Bore (mm)	130
Stroke (mm)	140
Cycles	4
Number of Cylinders	6
Displacement (litres)	11.1
Curb-Idle Speed (rpm)	700
Rated Test Speed (rpm)	2100
Maximum Torque (lb-ft)	1150 @ 1200 rpm
Maximum Power (bhp)	305 @ 2100 rpm
Compression Ratio	17.1
Certified Emissions with original DOC[2]	
NO_x (g/bhp-hr)	2.3
CO (g/bhp-hr)	1.6
PM (g/bhp-hr)	0.09





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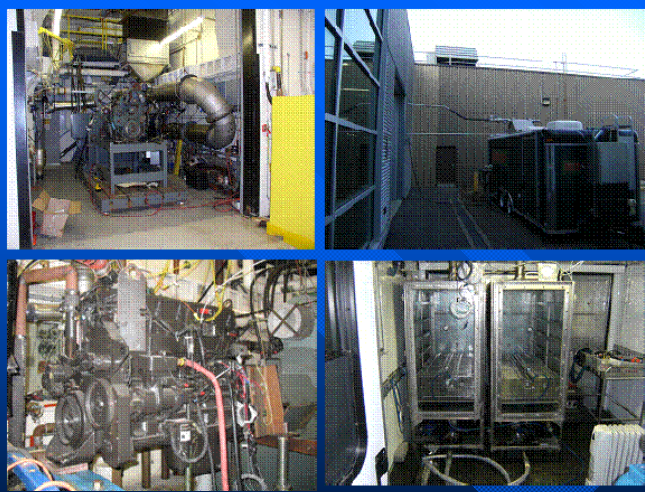

ENGINE

Heavy-duty diesel engine; Model Year 2004 Cummins ISM 280, 10.8 L, Inline 6 cylinder, 280 bhp @ 2100 rpm, 2004 emission standard.

DIESEL PARTICULATE FILTER

Catalyzed passive regenerating diesel particulate filter

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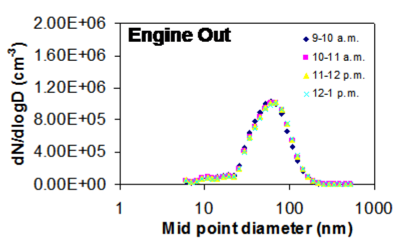
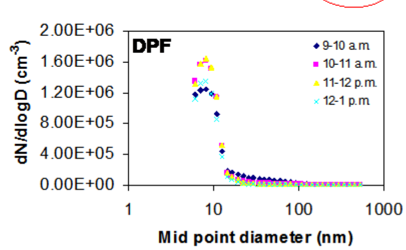
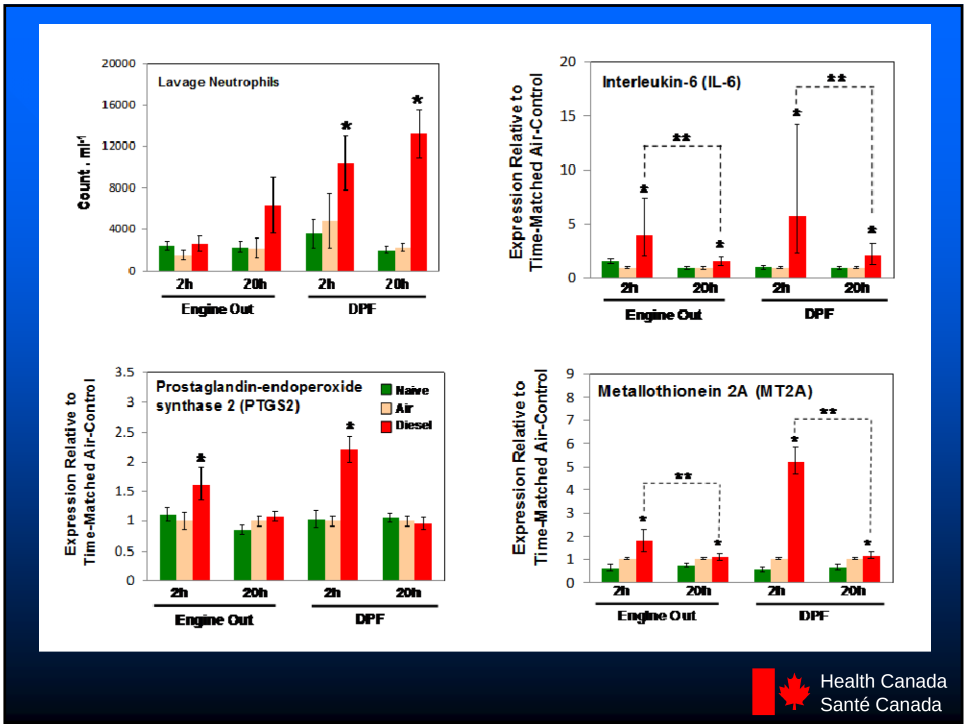
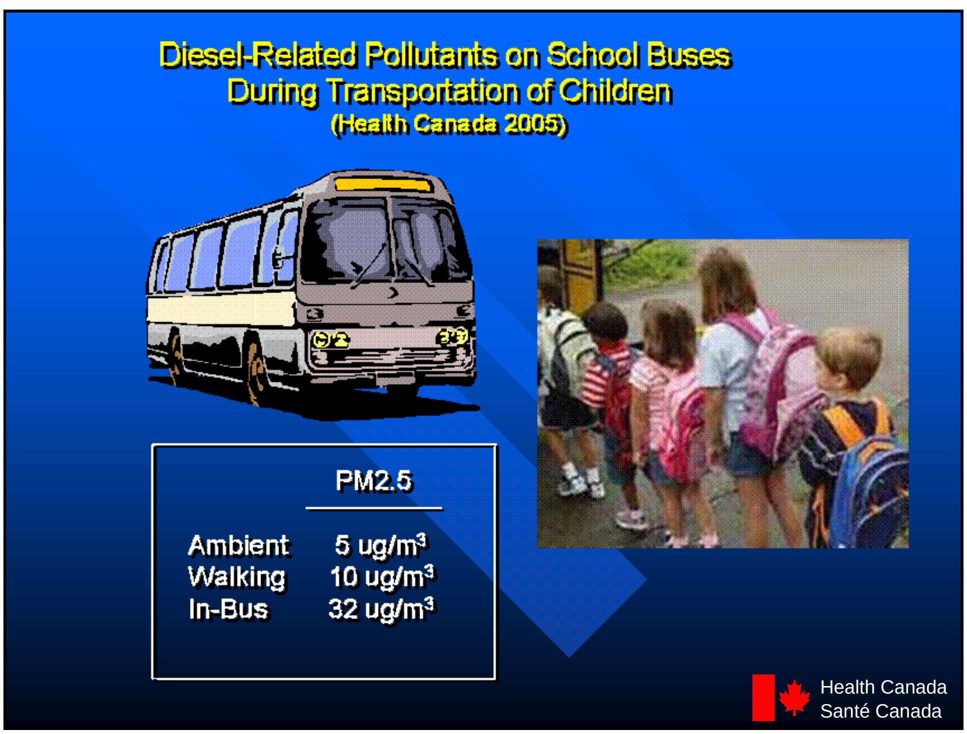
Treatment	Engine			Dilution Tunnel Concentrations						Exposure Chamber				
	Speed (rpm)	Torque (lb-ft)	Power (bhp)	CO (ppm)	CO_2 (%)	NOx (ppm)	NO (ppm)	NO_2 (ppm)	HC (ppm)	CO (ppm)	NOx (ppm)	NO (ppm)	NO2 (ppm)	Mass (µg/m³)
EO	1201	650	149	6.4	0.9	49	45	4	10	6.1	48	44	4	269
DPF	1200	638	146	1.2	0.9	37	21	16	3	1.2	36	20	16	<2





Health Canada
Santé Canada


Lavage Neutrophils
Count . ml-1
20000
16000
12000
8000
4000
0
2h
20h
2h
20h
Engine Out
DPF
Interleukin-6 (IL-6)
Expression Relative to Time-Matched Air-Control
20
15
10
5
0
Prostaglandin-endoperoxide synthase 2 (PTGS2)
Naive
Air
Diesel
3.5
3
2.5
2
1.5
1
0.5
0
Metallothionein 2A (MT2A)
9
8
7
6
5
4
3
2
1
0
Health Canada
Santé Canada


Diesel-Related Pollutants on School Buses
During Transportation of Children
(Health Canada 2005)
PM2.5
Ambient 5 ug/m3
Walking 10 ug/m3
In-Bus 32 ug/m3
Health Canada
Santé Canada

Commuting can pose a health hazard: study

CTV.ca News Staff

A new study by a team of German researchers suggests that commuting could be hazardous to your health. The study found an increased risk in having a heart attack, within two hours of being in traffic. Interestingly, patients who had taken the bus or ridden a bike were even more likely to have an attack.

The research team, led by Annette Peters of the National Research Center for Environment and Health in Neuherberg, looked at 691 people who suffered a heart attack between 1999 and 2001. **They found that nearly one in 12 attacks was linked to being stuck in traffic.**

People caught in traffic were roughly **three times more likely to suffer a myocardial infarction within an hour**, compared with those who avoided the journey altogether. The researchers believe that breathing in polluted air may be part of the problem. They noted:

- drivers were 2.6 times more likely to suffer a heart attack than those who weren't in traffic,
- public transportation users were 3.1 times more likely,
- and cyclists, 3.9 times more likely.

"Because the association was also observed for persons who used public transportation, it is unlikely that the effect is entirely attributable to the stress linked with driving a car," the researchers said. But they added "given our current knowledge, it is impossible to determine the relative contribution of risk factors such as stress and traffic-related air pollution."

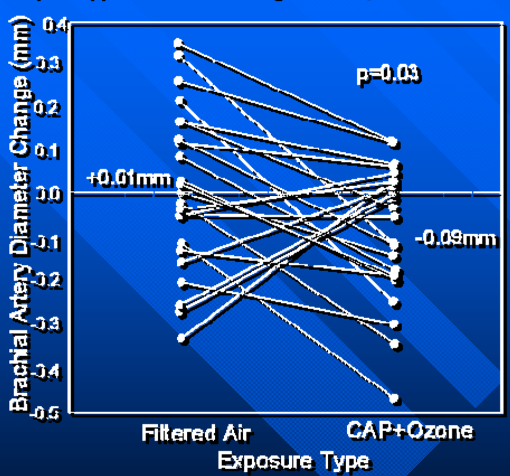
The study was funded partly by the U.S. Environmental Protection Agency and published in the Thursday edition of *The New England Journal of Medicine*.

http://www.ctv.ca/servlet/ArticleNews/story/CTVNews/1098294493645_93703693/?hub=CTVNewsAt11

Health Canada
Santé Canada

Brachial Artery Diameter Change (post – pre)

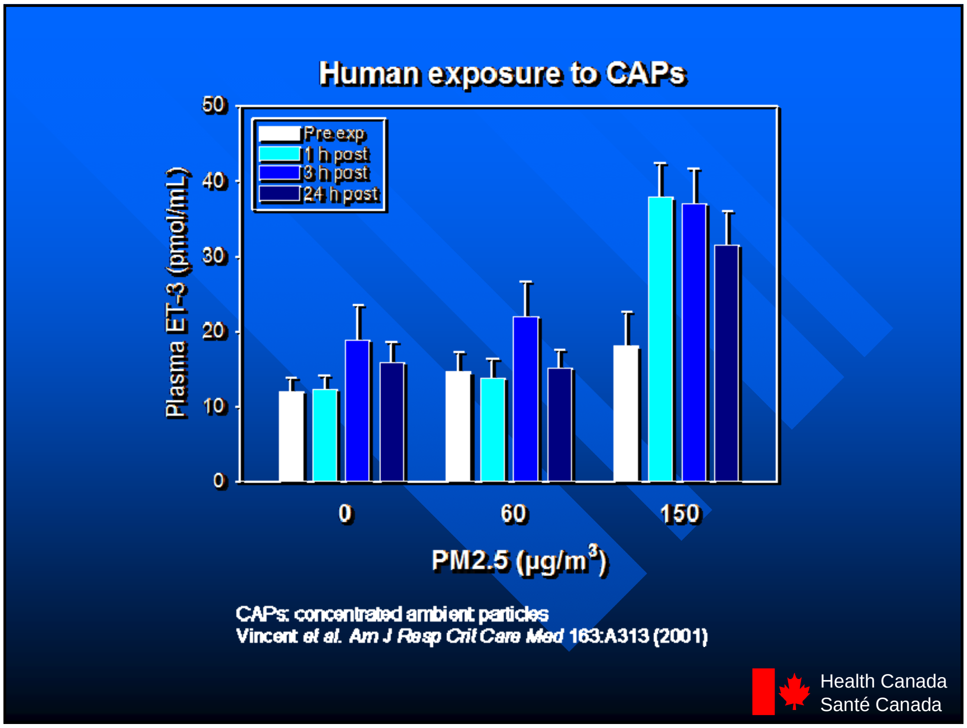
Human Subjects Exposed to Toronto $PM_{2.5}$
(0.12 ppm ozone + 153 ug/m³ CAP, 2 hours at rest)

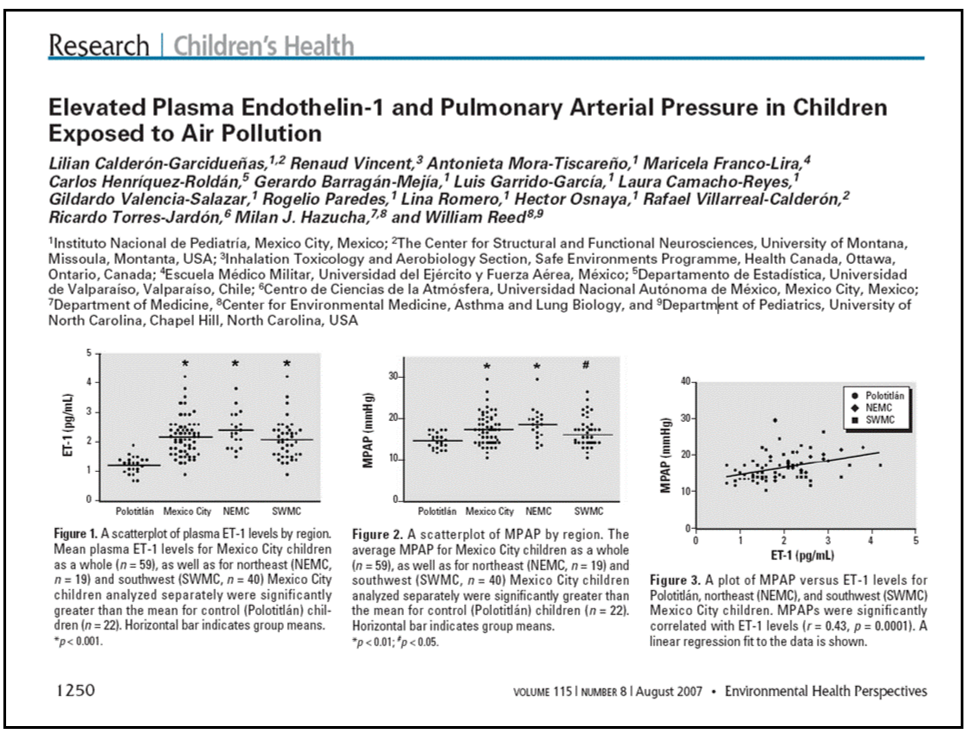


Note: no change of blood pressure, no change of flow mediated dilation

Brook *et al. Circulation* 105:1534-1536 (2002)

Health Canada
Santé Canada




Research | Children's Health

Elevated Plasma Endothelin-1 and Pulmonary Arterial Pressure in Children Exposed to Air Pollution

Lilian Calderón-Garcidueñas,[1,2] Renaud Vincent,[3] Antonieta Mora-Tiscareño,[1] Maricela Franco-Lira,[4] Carlos Henríquez-Roldán,[5] Gerardo Barragán-Mejía,[1] Luis Garrido-García,[1] Laura Camacho-Reyes,[1] Gildardo Valencia-Salazar,[1] Rogelio Paredes,[1] Lina Romero,[1] Hector Osnaya,[1] Rafael Villarreal-Calderón,[2] Ricardo Torres-Jardón,[6] Milan J. Hazucha,[7,8] and William Reed[8,9]

[1]Instituto Nacional de Pediatría, Mexico City, Mexico; [2]The Center for Structural and Functional Neurosciences, University of Montana, Missoula, Montanta, USA; [3]Inhalation Toxicology and Aerobiology Section, Safe Environments Programme, Health Canada, Ottawa, Ontario, Canada; [4]Escuela Médico Militar, Universidad del Ejército y Fuerza Aérea, México; [5]Departamento de Estadística, Universidad de Valparaíso, Valparaíso, Chile; [6]Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, Mexico City, Mexico; [7]Department of Medicine, [8]Center for Environmental Medicine, Asthma and Lung Biology, and [9]Department of Pediatrics, University of North Carolina, Chapel Hill, North Carolina, USA

Figure 1. A scatterplot of plasma ET-1 levels by region. Mean plasma ET-1 levels for Mexico City children as a whole ($n = 59$), as well as for northeast (NEMC, $n = 19$) and southwest (SWMC, $n = 40$) Mexico City children analyzed separately were significantly greater than the mean for control (Polotitlán) children ($n = 22$). Horizontal bar indicates group means. *$p < 0.001$.

Figure 2. A scatterplot of MPAP by region. The average MPAP for Mexico City children as a whole ($n = 59$), as well as for northeast (NEMC, $n = 19$) and southwest (SWMC, $n = 40$) Mexico City children analyzed separately were significantly greater than the mean for control (Polotitlán) children ($n = 22$). Horizontal bar indicates group means. *$p < 0.01$; #$p < 0.05$.

Figure 3. A plot of MPAP versus ET-1 levels for Polotitlán, northeast (NEMC), and southwest (SWMC) Mexico City children. MPAPs were significantly correlated with ET-1 levels ($r = 0.43$, $p = 0.0001$). A linear regression fit to the data is shown.

1250

VOLUME 115 | NUMBER 8 | August 2007 • Environmental Health Perspectives

EPA EMISSIONS , TIER IV INTERIM AND TIER IV FINAL TECHNOLOGY

By
Steve "Skinner" Forbush
Arch Coal Technical Service
Troy Terrillion
Newmont USA Limited
Leeville Complex

Emissions Standards: 2004-2014

Hp	Class	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
<11		Tier 1						Tier 4F				
11-24												
25-48							Tier 4I					
49-74	Skid Steer Loaders		Tier 2									
75-99	Air Compressors & Welders											
100-173	UG Diesel Equipment											
174-301	UG Diesel Equipment				Tier 3					Tier 4I		
302-602	D9s & D10s, 16 & 24MG, 988 Loaders		CD									Tier 4F
603-751			CD									
>751	D11s, 150-363T Trucks, 992-993-994 Loaders	Tier 1			Tier 2							

EPA Tiers 1-4

SEGMENT NOx / PM LIMITS

Heavy Duty On-Highway

EPA 99 4.0 / 0.1

EPA 04 2.5 / 0.1

EPA 07 1.2 / 0.01

EPA 10 0.2 / 0.01

Heavy Duty Off-Highway (75 - 750 hp)

Tier 1 (1996) 9.2 / 0.54

Tier 2 (2001) (6.4) / 0.2

Tier 3 (2005) (4.0) / 0.2

Tier 4 I (2011) 2.0 / 0.02

Tier 4 F (2014) 0.4 / 0.02

High Horsepower High Horsepower (> 751 hp)

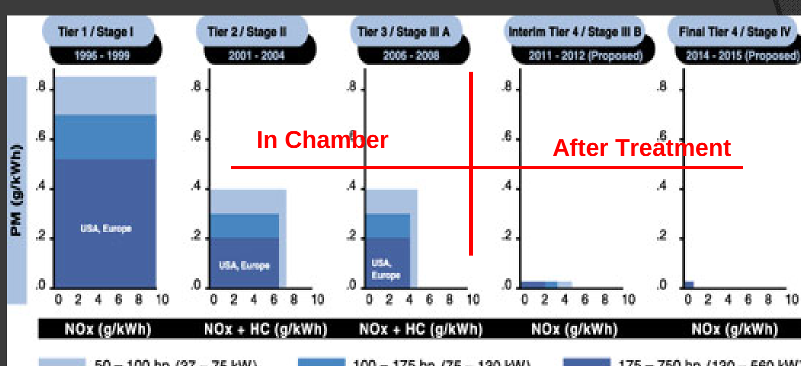
Tier 1 (2000) 9.2 / 0.54

Tier 2 (2006) (6.4) / 0.20

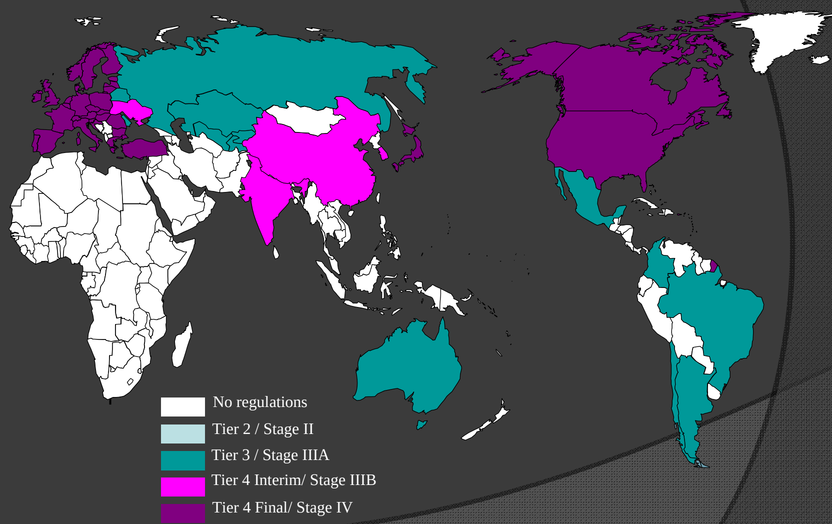
Tier 4 I (2011) 3.5 / 0.10

Tier 4 F (2015) 3.5 / 0.04

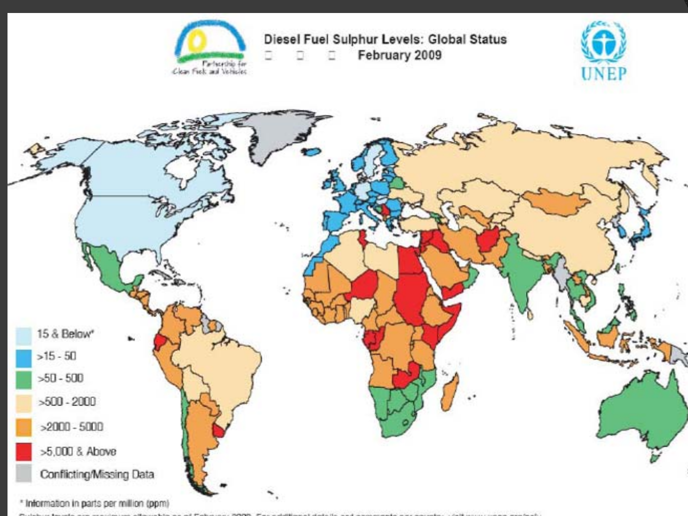
EPA Tiers 1-4



Worldwide Emissions Regulations - 2015



Worldwide Fuel Sulfur Levels

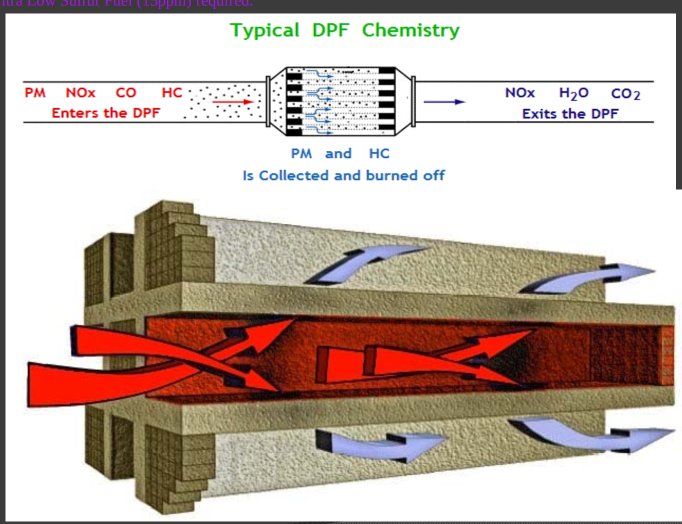


Emissions Control Systems

- Diesel Oxidation Catalyst: DOC, converts Monoxides to Dioxides. Will convert Hydro Carbons (HC) to CO_2, NO to NO_2 and CO to CO_2. Very little impact to operation of machine.
- Exhaust Gas Recirculation: EGR is used to reduce NOX. It puts a percentage (5%-30%) of exhaust back into the combustion chamber. May cause operational problems.
- Diesel Particulate Filter: DPF's trap and then burn the particulate matter. Trapping soot is easy. Getting the soot out is the problem. May cause operational problems.
- Selective Catalyst Reduction: SCR coverts NOX to free oxygen and nitrogen. The process requires a catalyst and Diesel Exhaust Fluid (UREA). May cause operational problems.

Diesel Particulate Filter (DPF)

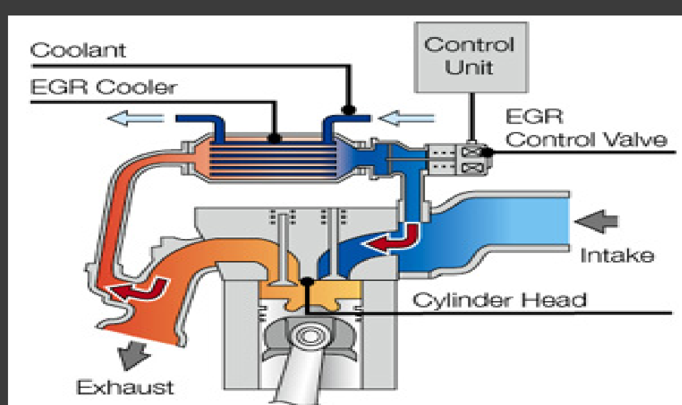
Purpose - Remove Soot and come in 4 major categories; Silicon Carbide, Cordierite, Sintered Metal, and Disposable. Each can be subdivided into different subcategories for different uses. Tier 4 Off-Highway and Highway typically use either the Cordierite or Silicon Carbide. Ultra Low Sulfur Fuel (15ppm) required.



Exhaust Gas Recirculation

- Early 70's on gas vehicles
- Works by recirculating 5%-30% of burnt exhaust gas through intake system and into combustion chamber
- Intention to reduce Nox, by reducing combustion chamber temperatures
- VGT, high pressure rail systems
- Large capacity cooler needed for EG/ increased problems in UG environment due to heat
- Requires sophisticated ECM/ too much retards causes hesitation/ too little causes Nox and ping
- Increases soot accumulation
- Increases abrasive contaminants to oil causing oil acidity reducing engine life

Cooled EGR with Controls



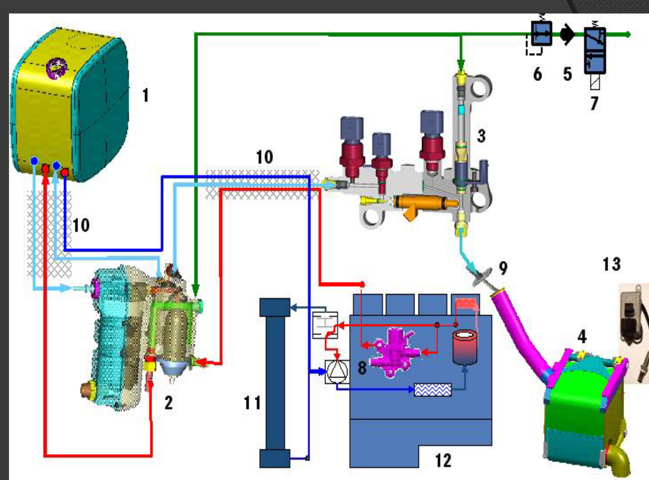
Tier 4i w/ SCR Technology

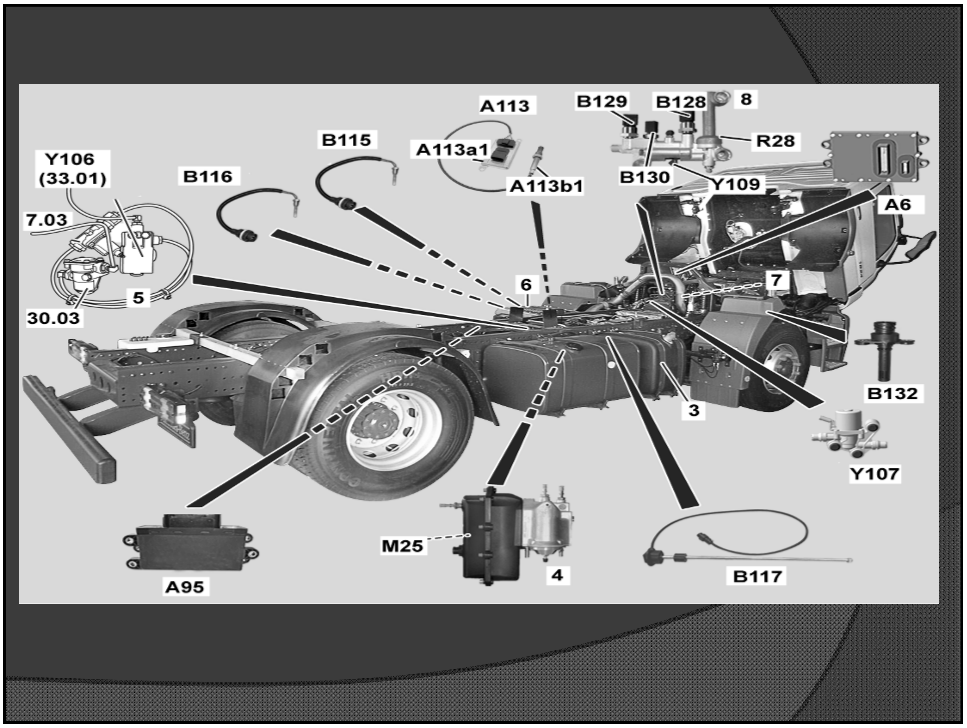
- Mercedes Benz OM926LA EU3b-T4i
- Engine family BMBXL07.2RJB
- 7.2 Liter 322 HP
- Non EGR/ All controls are internal
- Tier 1-2 application
- No particulate filter
- G/HR .002
- SCR system has its own integrated control module that communicates through CAN bus with engine ECM to control sequence of events.
- Will not dose if catalyst is below 200 degrees C.
- If Nox is above set limit, post catalyst, engine will de-rate.
- DEF consumption rate varies 3%-11%.

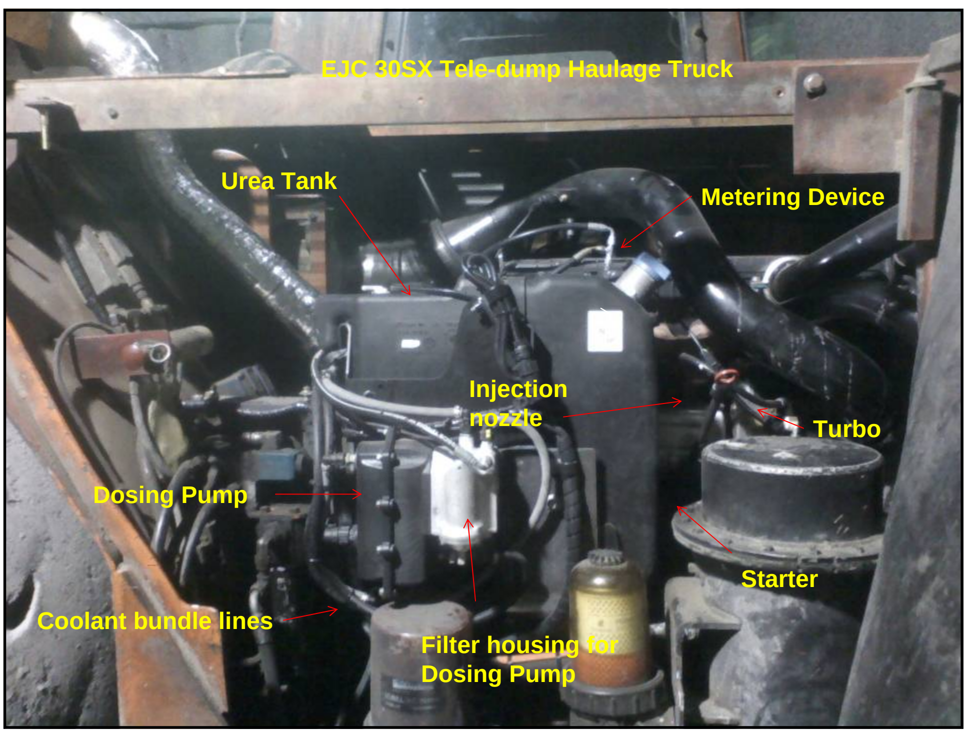
Diesel Exhaust Fluid (Urea) For SCR

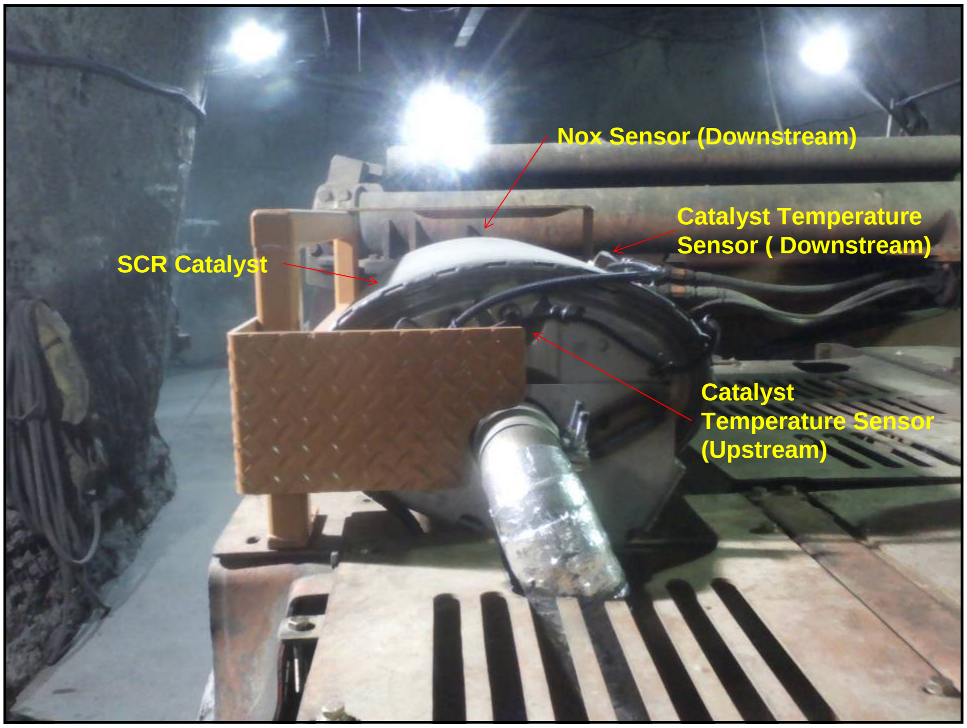
- Non Toxic
- Synthetic Urea
- Cost between $2.50-$6.00/gallon
- Usage. 3%-15% depending on duty cycle and engine performance.
- Will freeze below 32F.
- Shelf life is 1 year.
- Shelf life is shortened when temperature is over 90F.
- Engine will derate if DEF tank is empty.

Legend
1 Ad Blue tank
2 Pump module
3 Metering device
4 Muffler with catalytic converter
5 Check valve
6 Pressure limiting valve with ventilation out
7 Venting 3/2-way valve
8 SCR tank heater solenoid valve
9 Injection
10 Bundled lines
11 Radiator
12 Engine
13 NOx sensor with controller unit

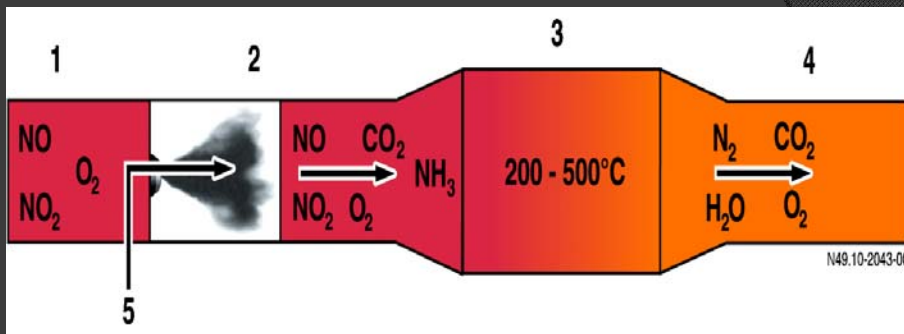



A113
B129
B128
8
B115
A113a1
R28
Y106
(33.01)
B116
A113b1
B130
Y109
A6
7.03
6
7
5
30.03
B132
3
Y107
M25
4
A95
B117


EJC 30SX Tele-dump Haulage Truck
Urea Tank
Metering Device
Injection nozzle
Turbo
Dosing Pump
Starter
Coolant bundle lines
Filter housing for Dosing Pump


Nox Sensor (Downstream)
Catalyst Temperature Sensor (Downstream)
SCR Catalyst
Catalyst Temperature Sensor (Upstream)


Comprised of Titanium Dioxide, Tungsten oxide, Vanadium Pentoxide
Nox Sensor (Downstream)
Upstream Catalyst Temperature Sensor



1. **Exhaust entering from engine**
2. **Hydrolysis segment**
3. **SCR Catalytic Converter**
4. **Exhaust after reduction**
5. **Ad Blue/DEF injection CO(NH2)2+H2O**

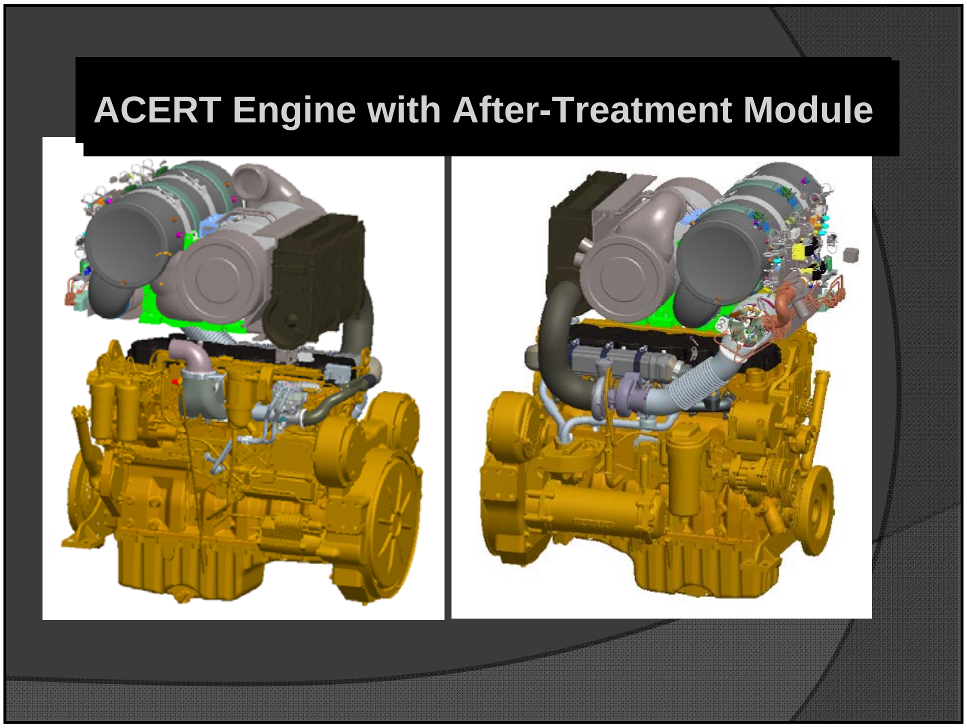
Equipment Emissions Data									
DOC/DPF	SCR								
Mine:	Leeville								
Unit Number:	UHT059								
Unit Type, Mfg. & Model; Engine Mfg., Model, Hp.:	Tamrock EJC 30sx W/Mercedes 926 T4i w/SCR 322 HP								
DOC Mfg., Model, Exhaust Diameter:	SCR Mercedes 4" Exhaust								
Exhaust Analyzer Make & Model:	ECOM AC			ECOM AC			ECOM AC		
Date:	02/24/11			03/10/11			04/28/11		
Location	DETB			DETB			DETB		
Oil Change									
Hour Meter Reading:				101	MR2		631	MR2	
Hour Meter When DOC/DPF installed	3.3 PLD			1	MR2		1	MR2	
Cumul hours on DOC/DPF				100			630		
	Pre SCR	Post SCR	% Change	Pre SCR	Post SCR	% Change	Pre SCR	Post SCR	% Change
Boost Pressure	37lbs		#VALUE!	37lbs		#VALUE!	36lbs		#VALUE!
TPS Counts									
Fuel Pressure	62.0								
Cut out Test									
No cutout pulse									
1-4 Pulse Width									
1									
2									
3									
4									
Response Times									
1									
2									
3									
4									
RPM Stall Speed	1,845			1855.0			1855.0		
Rated RPM									
Fuel Temperature	100 F			87.0			134.0		
Coolant Temperature	177 F			186.0			190.0		
Oil Temperature	181.0			190.0			184.0		
Air Temperature	95.0			92.0			120.0		
High Idle Torque Stall									
Temp. Air	69.0	68.0		74.0	74.0		72.0	74.0	
Temp Gas	950.0	688.0		959.0	722.0		963.0	770.0	
O_2 %	6.7	6.9	3	6.4	6.2		6.3	5.4	
CO ppm	102.0	10.0	-90	118.0	14.0	-88	116.0	24.0	-79
NO ppm	1040.0	88.0	-92	1069.0	101.0	-91	1145.0	112.0	-90
NO_2 ppm	35.0	5.0	-86	31.0	8.0	-74	22.0	5.0	-77
NOx ppm	1075.0	93.0	-91	1100.0	109.0	-90	1167.0	117.0	-90
CO_2 %	10.5	10.3	-2	10.7	10.9	2	10.8	11.4	
Operator Noise Db									
Smoke No.	4	3	-25	2.5	2.5	0	5	3.5	-30
Back Pres. In. W.G.		0.0							
Gear	3	3		3	3				
UHT059- Readings before and after SCR system. After run time of 100 hours, will re-sample emissions.									

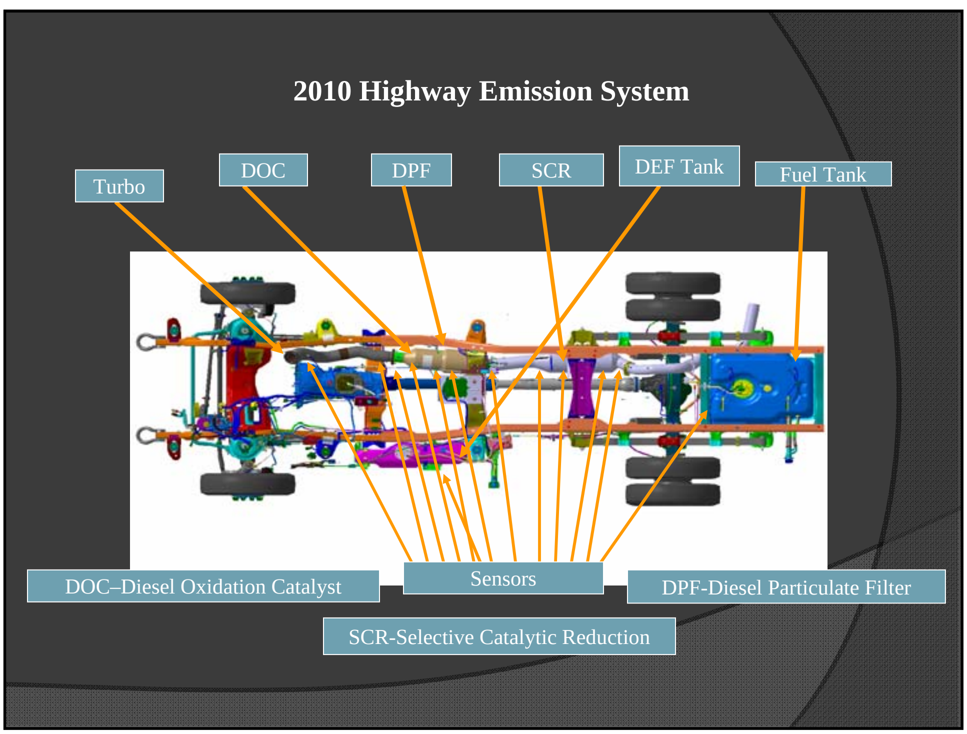
Equipment Emissions Data									
DOC/DPF	SCR								
Mine:	Leeville								
Unit Number:	UHT059								
Unit Type, Mfg. & Model; Engine Mfg., Model, Hp.:	Tamrock EJC 30sx W/Mercedes 926 T4i w/SCR 322 HP								
DOC Mfg., Model, Exhaust Diameter:	SCR Mercedes 4" Exhaust								
Exhaust Analyzer Make & Model:	ECOM AC			ECOM AC			ECOM AC		
Date:	05/26/11			07/08/11			08/10/11		
Location	DETB			DETB			DETB		
Oil Change									
Hour Meter Reading:	999 MR2			1,284	MR2		163 (New MR2)		
Hour Meter When DOC/DPF installed	1			1	MR2				
Cumul hours on DOC/DPF	998			1,283			Approximately 1563		
	Pre SCR	Post SCR	% Change	Pre SCR	Post SCR	% Change	Pre SCR	Post SCR	% Change
Boost Pressure	2250.0		-100	2380.0		-100	2475.0		-100
TPS Counts									
Fuel Pressure									
Cut out Test									
No cutout pulse									
1-4 Pulse Width									
1									
2									
3									
4									
Response Times									
1									
2									
3									
4									
RPM Stall Speed	1790.0			1803.0			1820.0		
Rated RPM									
Fuel Temperature	34.0			52.0			39.0		
Coolant Temperature	90.0			85.0			84		
Oil Temperature	96.0			98.0			88		
Air Temperature	44.0			57.0			46		
High Idle Torque Stall									
Temp. Air	67.0			85.0			82.0	82.0	
Temp Gas	1009.0			971.0			907.0	635.0	
O_2 %	5.9			6.2			7.3	7.1	-3
CO ppm	190.0			122.0			103.0	10.0	-90
NO ppm	1203.0			1049.0			1071.0	66.0	-94
NO_2 ppm	19.0			20.0			21.0	1.0	-95
NOx ppm	1222.0			1069.0			1092.0	67.0	-94
CO_2 %	10.8			10.9			10.0	10.2	
Operator Noise Db									
Smoke No.	3.5			3					
Back Pres. In. W.G.									
Gear				3			3	3	

Nozzle Failure

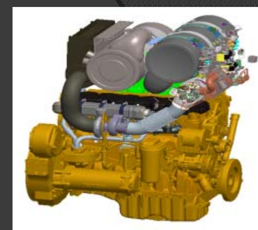

Urea leak at injection nozzle.
Approximately 18 hours
Starter


Urea injection
nozzle
Oil dipstick
Urea Tank


ACERT Engine with After-Treatment Module


2010 Highway Emission System
Turbo
DOC
DPF
SCR
DEF Tank
Fuel Tank
DOC–Diesel Oxidation Catalyst
Sensors
DPF-Diesel Particulate Filter
SCR-Selective Catalytic Reduction

Caterpillar Engines



- On-Highway
  - 2007 Added DPF
  - 2010 no longer in the On-Highway market
- Off-Highway
  - 2011 >75hp small change,
  - 2011 <75hp>750hp Add EGR and DPF
  - 2015 <75hp>750hp Add SCR
  - 2015 <750hp Uncertain, probably SCR

Cummins Engines

- On-highway
  - 2007 add DPF
  - 2010 add SCR

Off-Highway
  - 2011 >75hp small change,
  - 2011 <75hp>750hp Add EGR, VGT and DPF
  - 2015 <75hp>750hp Add SCR
  - 2015 <750hp Add SCR

MTU/Mercedes

- On-highway
  - 2007 add DPF
  - 2010 add SCR

Off-Highway
  - 2011 >75hp small change,
  - 2011 <75hp>750hp Add SCR
  - 2015 <75hp>750hp Add DPF
  - 2015 >750 Uncertain

Questions?

Natural Resources Canada | Ressources naturelles Canada

Field Emissions Testing of Engines and Aftertreatment: Best Practices, Methods and Maintenance

Brent Rubeli

Natural Resources Canada

1 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

Diesels Underground

- New engines destined for underground use must pass minimum type certification:
  - US EPA
  - MSHA
  - CAN/CSA

- In-use engines are usually regularly tested underground for emissions.

2 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

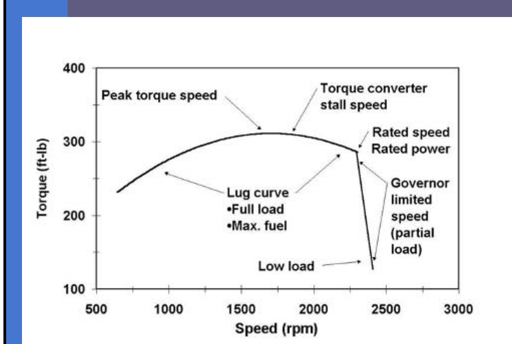
Certification Testing

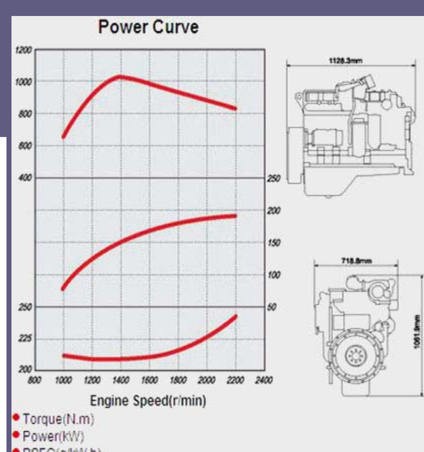
- Pass fail criteria (CSA)
  - CO – 2500 ppm
  - NOx – 1500 ppm
  - DPM – 150 mg/m^3
- Prescribed ventilation recommendation based on multi-mode emissions test data.

3 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

Where to test?

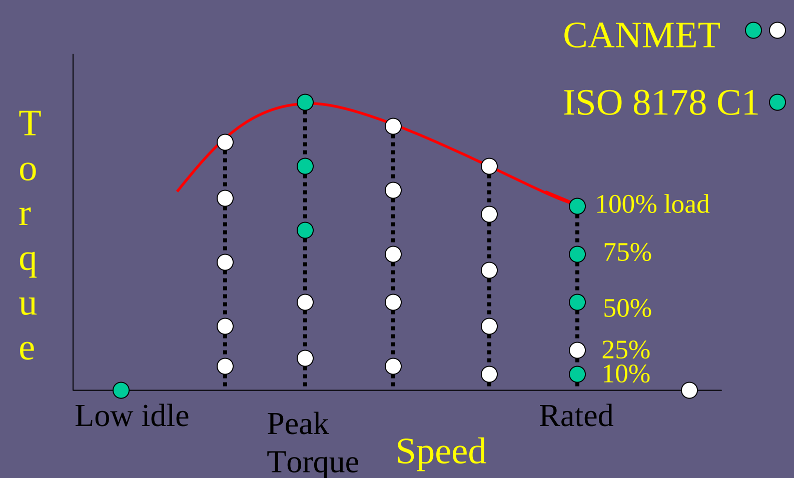
- Reflect "real world" engine performance.





4 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

Certification Test



Ventilation Certificate

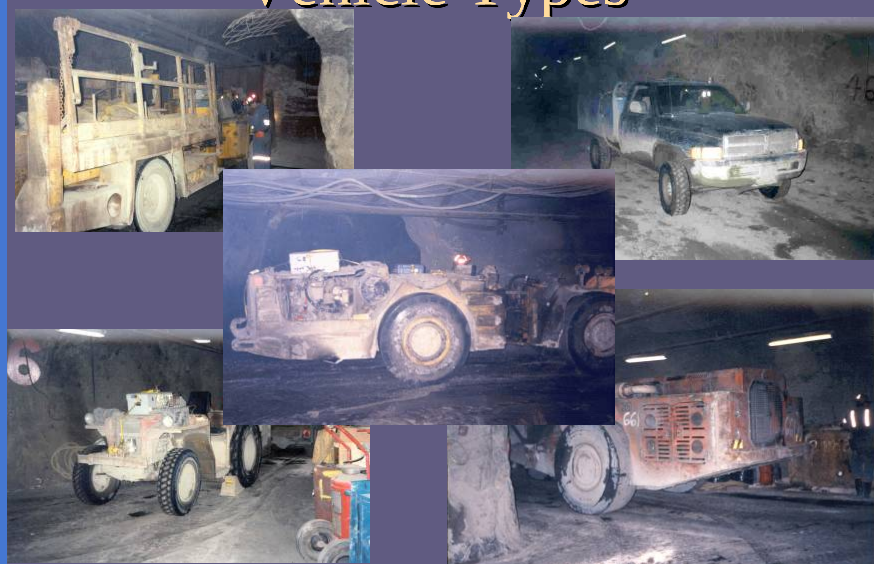
Example of a CANMET Approved Engine Ventilation Rates

Engine Manufacturer: Detroit Diesel
Engine Model: DDEC 8V-2000TA, R0837K32
Governing Standard: CSA M424.2-90 (Non-coal mines)

Certificate Number	Engine Rating and Maximum Fuel Rate at Sea Level	Sulphur in Fuel - %wt.	CSA Ventilation Prescription *	
			CFM	m^3/min
1103	650 HP @ 2100 RPM fuel 213.5 lb/hr	0.05	37,000	1,047.7
			47,500+	1,345.0+
		0.10	41,000	1,161.0
			47,500+	1,345.0+
		0.20	48,900	1,384.7
		0.25	52,900	1,498.0
		0.50	72800	2,061.5
			79,500+	2,251.5+

* The ventilation rates are suitable for low sulphur fuel if permitted by the appropriate regulatory authority
+ These ventilation rates are recommended where some of the gases govern ventilation rates rather than the EQI criterion

Vehicle Types



7 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

Emissions Underground

- Mining is a confined space so poor engine emission quality can quickly become a serious safety hazard.
- Legislated in-use testing:
  - Catches defects or failures.
  - Verifies maintenance.
  - Confirms type certification emission levels are being maintained by the engine.

8 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

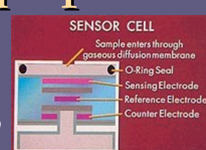
Underground In-use testing

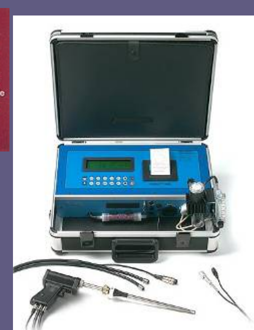
- Over and above legislative requirements, some mines use in-use testing for predictive maintenance and proactive air quality.

9 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

Test Equipment

- Stain tubes
- Electrochemical cells
- Smoke dot
- Opacity
- NDIR / PAS

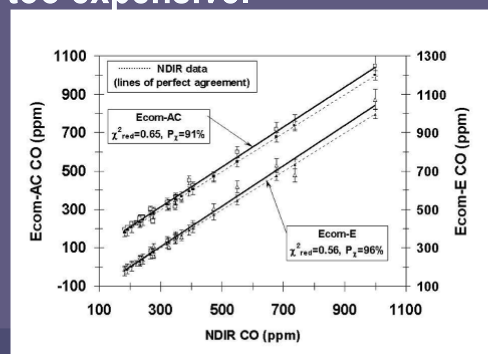




10 CANMET MINING AND MINERAL SCIENCES LABORATORIES Canada

Accuracy for Mining

- EC cells are very good provided they are calibrated properly and often.
- Stain tubes have too many interferences.
- NDIR, etc are often too expensive.

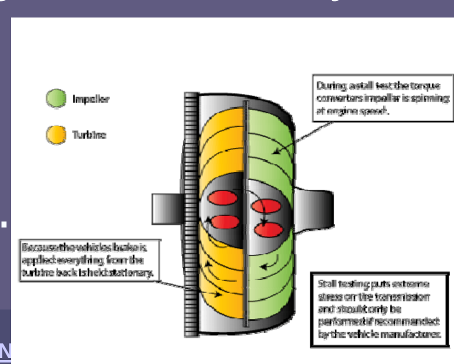


How to test - Loading

- Meaningful data is only obtained with engine under loaded conditions.
- Torque converter/hydraulic stall procedure.
- Idle does not have significant fuel delivery of temperature.
- Snap acceleration

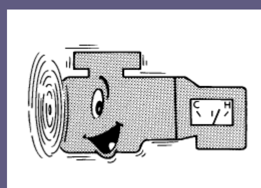
test does achieve

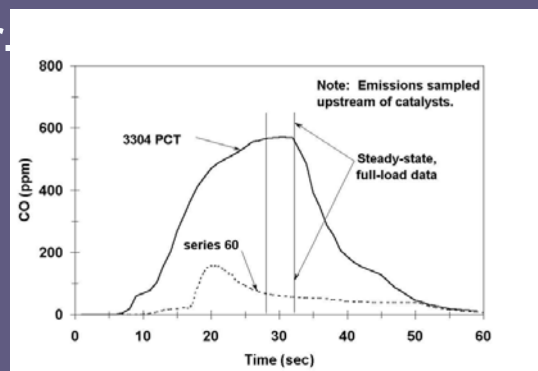
full fuel but only briefly.



Stall testing

- This is not a trivial test!
- Safety audits, training, etc.
- Measure for target gases.
- Watch converter.





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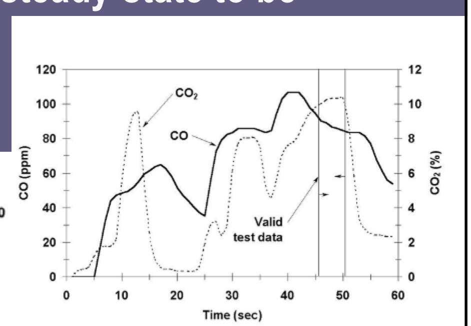
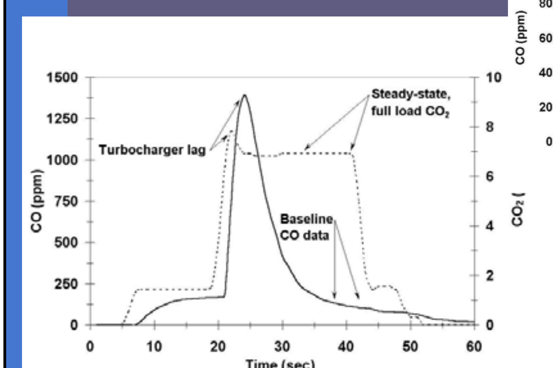
How to test - Interpretation

- Emissions must be at steady-state to be repeatable.
- Wait for CO peaks.





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NIOSH EAMP

- Emissions-assisted maintenance procedure.
- Support of emissions testing regulation.
- Defined a repeatable emissions test procedure.
- Tested field and laboratory grade instruments.
- Evaluated different engine types.
- http://www.cdc.gov/niosh/mining/topics/diesel/eamp/eamp.html

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So what will your standards be?

- Legislation first and foremost – you must comply with the test requirements in you jurisdiction.
- Why not develop your own internal guidelines for pass / fail.
- Ultimately try individual engine emissions tracking for the complete picture.

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Current Legislation

- Example: Ontario Provincial Mining Regulation recently changed to reflect cleaner engine deployment.
- Undiluted tailpipe CO from 1500 to 600 ppm.

(2) Subsections 182 (5) and (6) of the Regulation are revoked and the following substituted:

(5) An employer shall ensure that the undiluted exhaust emissions from diesel-powered equipment contain less than 600 parts per million by volume of carbon monoxide.

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Certification Engine Testing

- MSHA has guidance.
- CO lug curve data.
- Certification tests.

TORQUE CURVE TEST - ALL TESTS AT FULL THROTTLE		
MSHA # :	7E-B098-0	
Engine:	DaimlerChrysler OM 904LA	
Engine Rating:	174 HP @ 2200 RPM	
Engine Speed, RPM	CO, ppm	CO2, %
1200	1341	11.81
1400	318	10.32
1600	335	10.1
1800	299	10.09
2000	267	9.94
2200	222	9.58

TORQUE CURVE TEST ALL TESTS AT FULL THROTTLE		
MSHA # :	7E-B090	
Engine:	Deutz F3L 1011F	
Engine Rating:	44 HP @ 3000 RPM	
Engine Speed, RPM	CO, ppm	CO2, %
3000	982	10.9
1800	1834	11.7

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Build your own database!

Table 1. Emissions of New Equipment						
Engine	**Rated hp**	**CO2 %**	**CO ppm**	**NO ppm**	**NO2 ppm**	**Comments**
Series 60	375	6.9	139	586	31	Turbocharged, DI
Series 50	250	7.9	162	615	31	Turbocharged, DI
F8L413FW	180	9.7	91	605	15	Naturally aspirated, IDI
F8L413FW	180	7.9	95	708	23	Turbocharged, IDI
F6L912W	82	11.4	527	630	17	Naturally aspirated, IDI

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How to recognize faults

- In-use testing and diagnosis requires a knowledge base of how maintenance faults affect engine emissions.
- Effect of engine faults on mechanically-controlled engines is well known.
- Unclear how and when electronic engines would compensate for fault conditions.
- Emissions behavior could not be predicted.

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USBM

- 1985 study of simulated faults in engines.
- Combinations of faults more severe than individual faults applied separately.

PERCENT DEVIATION OF EXHAUST EMISSIONS FROM BASELINE CAUSED BY INDUCED FAULTS IN A DEUTZ F6L 912 W DIESEL ENGINE

TEST NO.	FAULT DESCRIPTION	DEGREE OF FAULT	HC	CO	NO_x	PARTICULATES* A	B	C
1-1	Intake Restriction (in - H_2O)	25	-28	+8	-15	+25	+31	+44
1-2	Intake Restriction (in - H_2O)	50	-36	+28	-12	+75	-11	+164
2-1	Exhaust Restriction (in - Hg)	3.0	+17	+1	+9	-15	+23	-6
2-2	Exhaust Restriction (in - Hg)	6.0	+2	+6	-3	-8	+16	-11
3-1	Timing Advance (from mfg. spec.)	-4•	+306	+53	-33	-4	+1037	-23

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21

What about modern engines?

- Some uncertainty for newer engines:
  - Turbocharger / Intercooler system.
  - Electronic control system behavior.
  - Warm-up emissions.
- Test procedures for vehicles with manual transmissions and light hydrostatic drives.

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CANMET-MMSL Tests

- Laboratory emissions testing.
- Deutz Engine:
  - Confirmation of some USBM work.
  - Air cooling system deficiencies.
- Detroit Engine:
  - General maintenance deficiencies.
  - Turbocharger / intercooler faults.
  - Sensor / electronics glitches.
  - Cold start and warm-up behavior.

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Test Engines

- Deutz F4L912W
- Detroit 11.1L Series 60

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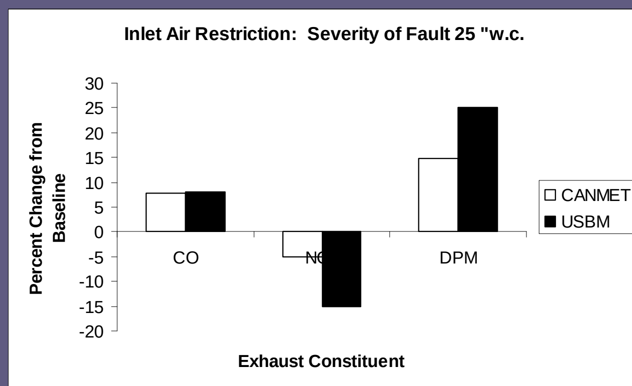
Deutz Engine Tests (1)

- General agreement with USBM results.



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Deutz Engine Tests (2)

- Air-cooled engine: cooling system faults

Operating Mode: 2300rpm & 100% load	Cooling System Fault (%)	Cooling System Fault & Restr. %
Intake Restriction	0	+60
Exhaust Restriction	0	+195
Cooling Air Outlet Temp	+8	+32
Exhaust Temperature	+11	+13
CO (% change)	+35	+56
NO_x (% change)	+2	-1
NO (% change)	+6	+3
NO_2 (% change)	-60	-77
HC (% change)	+66	+66
O_2 (% change)	0	-9
CO_2 (% change)	+1	+8
DPM (% change)	+57	+100

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26

Detroit S60 Engine Tests (1)

- General maintenance deficiencies.
- Stable operation even with faults.
- Requires severe degree of fault.

Simulated Faults at Rated Power	Percent Change From Baseline				
Fault Description	Degree of Fault	HC	CO	NOx	DPM
Intake Restriction	+67	+8	+2	+2	+18
Exhaust Restriction	+100	+0	+19	+4	+33
Intake / Exhaust Restriction	+67 / +100	+13	+28	+8	+56
Severe Intake and Exhaust Restriction	+250 / +140	+0	+79	+15	+114
Manifold Inlet Air Temperature (Cold)	-38	+29	+0	+105	+5
Cold Inlet Air Temp (sensor disconnected)	no signal	-8	+19	-19	+58
Manifold Inlet Air Temperature (Hot)	+46	+0	-7	+21	-14
Hot Inlet Air Temp (sensor disconnected)	no signal	-8	-9	+29	-10
Fuel Temperature Sensor disconnected	no signal	-12	-5	+1	+2
Disconnect SRS sensor while running	no signal	+0	-2	+1	+0
Loss of Turbo Boost Pressure	-55	-71	+1190	-21	+867

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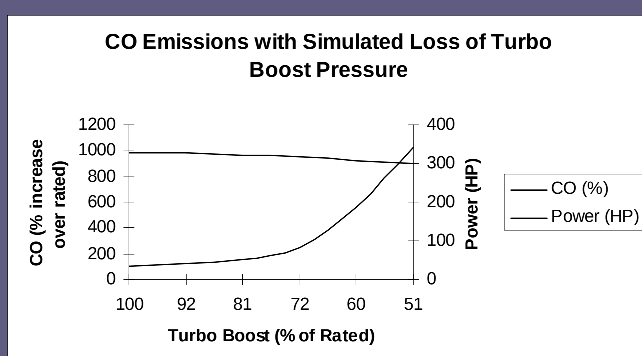
Detroit S60 Tests (2)

- Turbocharger / intercooler faults.



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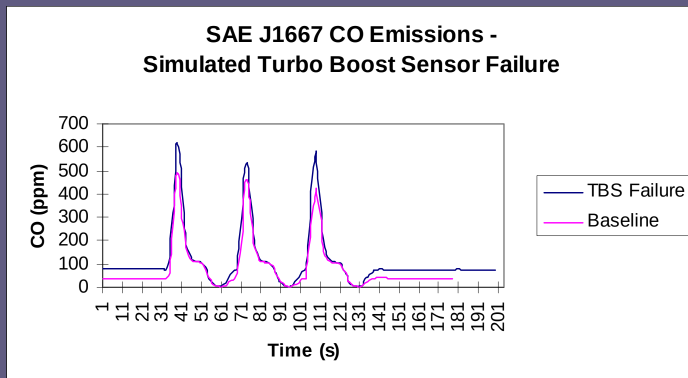
Detroit S60 Tests (3)

- Sensor / electronics glitches.



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Snap Acceleration Tests

- Some light-duty vehicles are difficult or impossible to test under load.
- 100% fuel delivery is often not achieved.
- SAE J1667 test procedure for snap acceleration based smoke emissions.
- Light extinction (opacity) meter for visual smoke measurement.
- Procedure is in-use already for Ontario, BC and other jurisdiction for highway vehicles.

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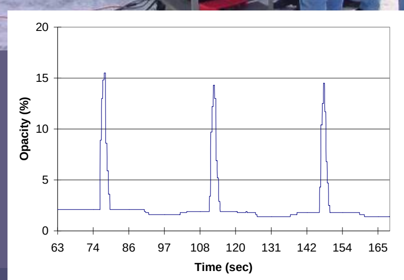
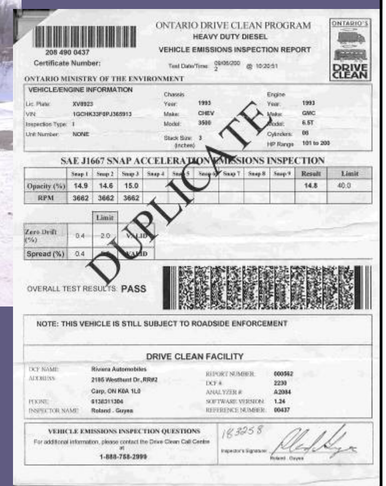
SAE J1667





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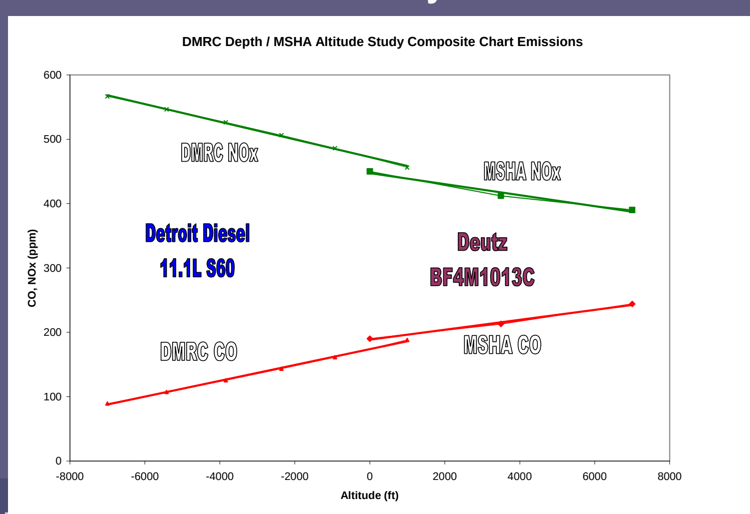
Altitude / Depth Effects

- Emissions are affected by altitude.



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Role of Diesel Emission Control Technologies

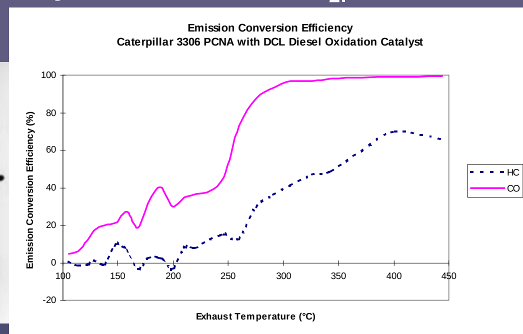
- Can address localized air quality problems.
- Control emissions at the source.
- Reduce overall mine emissions burden.
- Future regulations.
- OEM applications.

Best Available Diesel Emissions Control Technologies

- Diesel Oxidation Catalysts (DOC)
- Diesel Particulate Filters (DPF)
- Active Diesel Particulate Filters (A-DPF)
- Selective Catalytic Reduction (SCR)

Diesel Oxidation Catalyst

- Most basic type of control CO HC & some DPM only.
- $CO + \frac{1}{2}O_2 \rightarrow CO_2$
- $HC + O_2 \rightarrow H_2O + CO_2$
- Older formulations may oxidize NO to NO_2.



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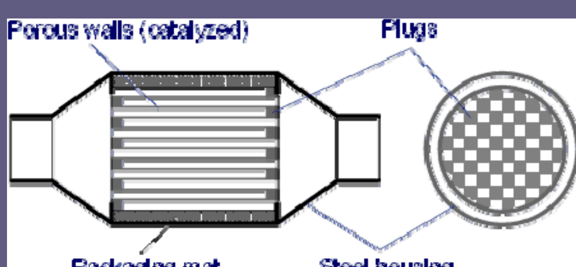
Diesel Particulate Filter (DPF)

- Ceramic monolith
- Closed channel – wall flow
- Best available control technology for DPM



MINE-X SOOTFILTER installed in a Wagner ST8B loader with a Cat 3406 PCTA engine.

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DPF - Performance – DPM filtration efficiency (% by mass)

	Mode A	Mode B	Mode C	Mode D	Average
Clean	80.3	66.7	75.9	87.1	77.5
Charged	95.5	90.0	88.9	91.1	91.4
Average	87.9	78.3	82.4	89.1	84.4

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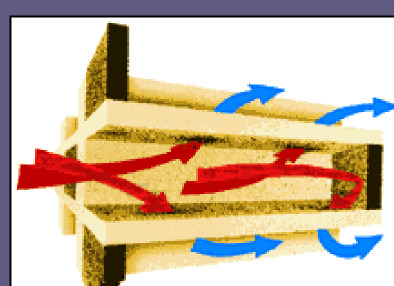
DPF Loading and Regeneration

- Collect DPM at high efficiency (>80%).
- Burn off DPM to CO_2.
- Ignition temperature very high 550°C
- Assist needed for regen: catalyst, fuel additive, active, etc.



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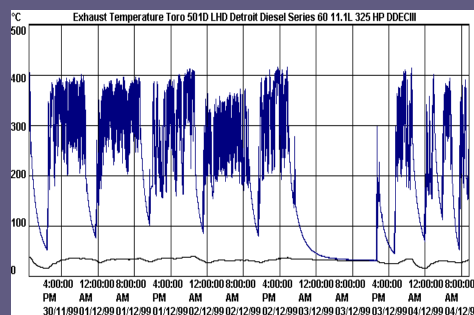
Regeneration Strategies

- Very important!
- Without periodic regeneration, DPF will clog and fail.
- This regeneration may happen automatically with sufficient exhaust temperatures – or may require external heat input.



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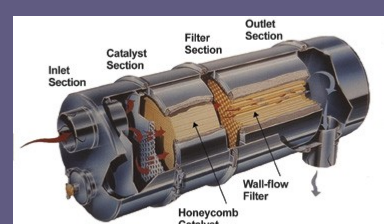
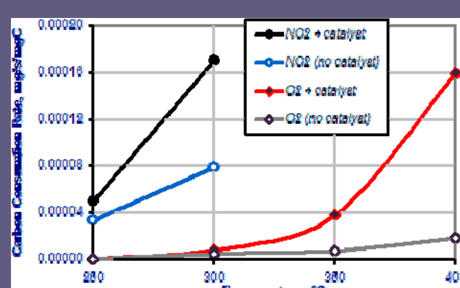
Catalyzed DPFs

- Catalyst lowers the required regeneration temperature so that more vehicle applications can use the DPF technology
- Catalyst can be applied directly to the filter monolith – where it works on the accumulated DPM directly.





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Active Regeneration - DPF

- Electrical / Diesel fuel
- On-board / exchangeable
- Additional heat input for periodic regen.

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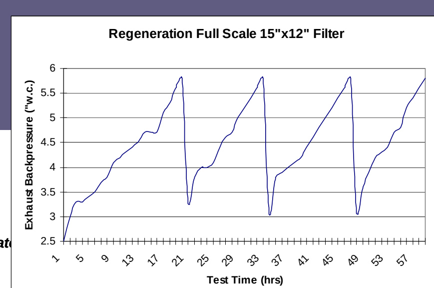
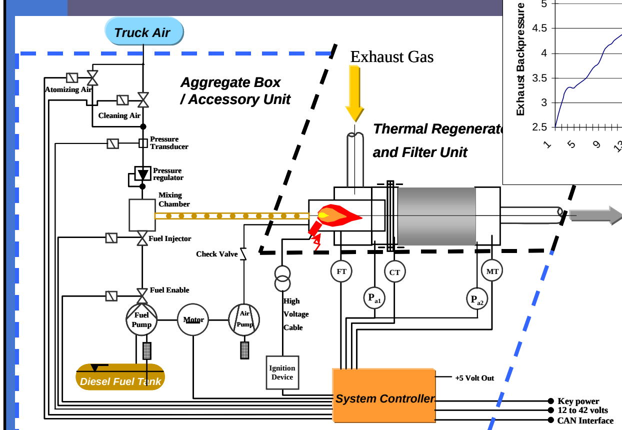
Diesel Burner for Active Regen





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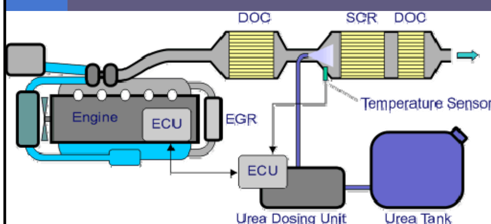
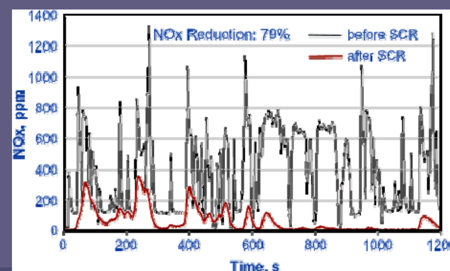
Selective Catalytic Reduction

- SCR for NO and NO_2 emissions control
- NOx reduction in lean environment
- Addition reductant sprayed into exhaust
- $4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$
- $6NO_2 + 8NH_3 \longrightarrow 7N_2 + 12\,H_2O$





SCR in U/G Mines

- Strong potential for mines with NO_2 issues.
- Field trials are currently underway.
- Urea handling and dosing.
- Dosing and feedback emissions control.

Control Technology Summary

Constituent	Oxidation Catalyst	Diesel Filter	Catalysed Filter	SCR	
CO2	0	0	0	0	
CO	60 - 80	0	60 - 80	60 - 80	
HC	60 - 80	0	60 - 80	60 - 80	
NO	0	0	0	60 - 80	
NO2	0 or increase	0	0 or increase	60 - 80	
SO2	0	0	0	0	
DPM	20 - 30	85 - 95	85 - 95	0	

Maintenance

- Some maintenance required!
- Inspection for physical damage and emissions performance.

Recognizing Device Failure

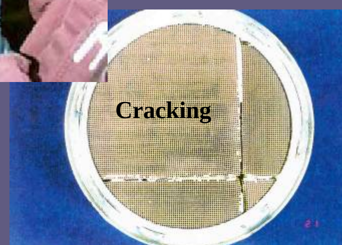
- Visual inspection at regular PM service:
  - Disassembly and cleaning as required.
- Engine backpressure increase over baseline.
  - Smoking exhaust.
  - Engine performance loss.
- Emissions-based maintenance program.
  - Regularly quantify device performance.

DOC Failure Modes

- Diesel Oxidation Catalyst:
  - Clogging / masking of active sites (DPM).
  - Poisoning – fuel sulphur, metals.
  - Loss of washcoat and catalyst material.
  - Physical damage:
    - Melting of ceramic.
    - Cracking (impact / thermal).
    - Separation of metal foils – vibration.

DOC Failures

- Visual Inspection:



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Particulate Filter (DPF) Failure Modes (1)

- Operational / Application:
  - Clogging DPM – insufficient regeneration.
  - Clogging ash – overdosing additive.
  - Water ingress – vehicle cleaning.
  - Oil ingress – turbocharger seal failure.
  - Melting – uncontrolled regeneration.

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DPF Failure Modes (2)

- Physical Damage:
  - Surface damage:
    - Impact abrasion – mishandling.
    - Substrate contact with can or retaining rings – vibration / deterioration of mat.
  - Melting – uncontrolled regeneration.
  - Cracking – vibration / impact / thermal stress (regeneration).

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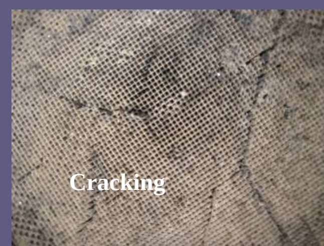

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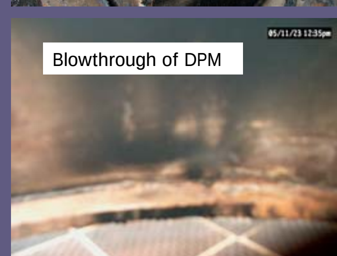
Inspection – Support failure



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Emissions Testing for Oxidation Catalyst Faults

- Diesel oxidation catalysts (DOC) can exhibit several faults: poor conversion due to blockage, soot accumulation, poisoning.
- Important to maintain and verify emissions performance.
- Older DOC's may increase NO_2 emissions. This can be monitored with EC analyzer.

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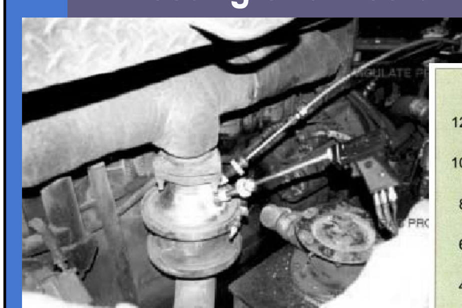
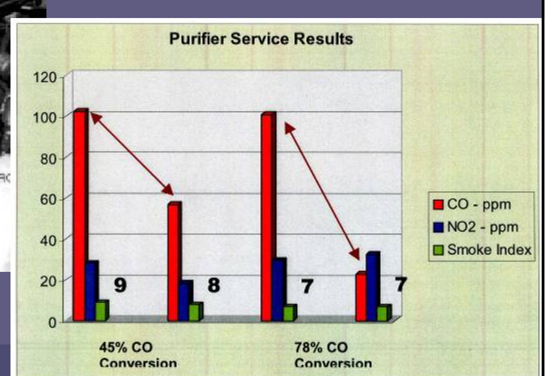
DEEP Catalyst Tests

- Systematic approach to maintenance.
- Fault diagnosis based on emissions testing.
- Testing of emission control devices.





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Catalyst Tests at Agnico

- Recent work at Agnico mine.
- Emissions testing comparing ECOM EC cell to stain tubes.
- Evidence of NO_2 formation.
- Note MSHA lug curve CO for Mercedes 904 (220ppm)

Camion 3102 (Detroit Diesel 60)		
Emission	Before Catalyst	After Catalyst
CO ppm	75	55
NO ppm	474	530
NO_2 ppm	0	56
CO_2 %	10.2	10.9

Vehicule de Service VS3104 (Merc. 904)		
Emission	Before Catalyst	After Catalyst
CO ppm	201	47
NO ppm	504	515
NO_2 ppm	0	0
CO_2 %	10.1	10.4

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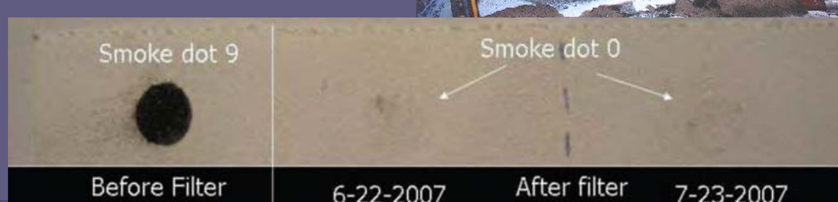
DPF Fault Testing

- DPM vs smoke
- Partial vs total failure
- Smoke dot (ECOM)
- PAS EC analyzer



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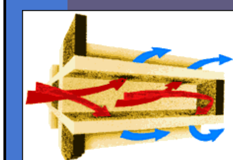
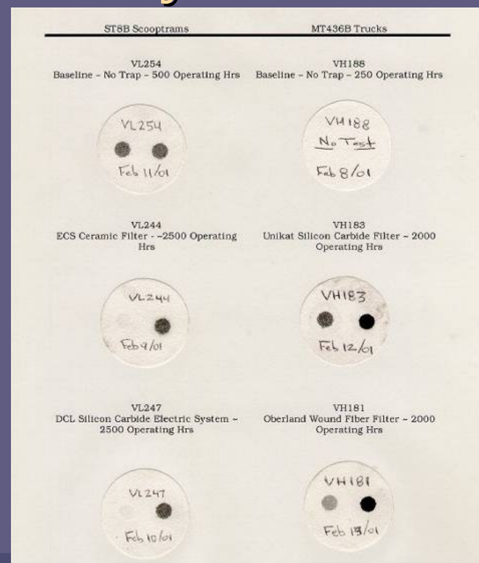
DPF DEEP Study Tests

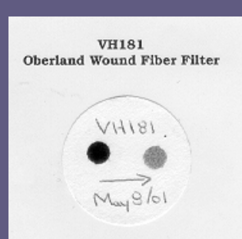




ST8B Scooptrams	MT436B Trucks
VL254 Baseline – No Trap – 500 Operating Hrs	VH188 Baseline – No Trap – 250 Operating Hrs
VL244 ECS Ceramic Filter - ~2500 Operating Hrs	VH183 Unikat Silicon Carbide Filter – 2000 Operating Hrs
VL247 DCL Silicon Carbide Electric System – 2500 Operating Hrs	VH181 Oberland Wound Fiber Filter – 2000 Operating Hrs

Wound fibre DPF

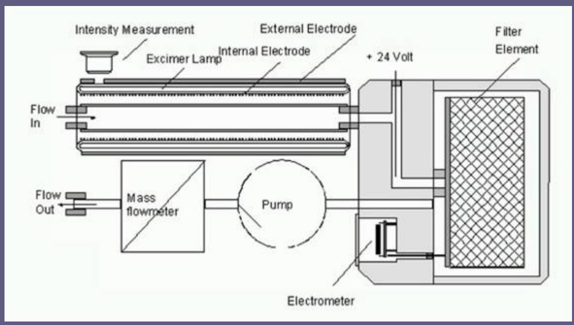
- Partial failure – blowing
- Fibre material broke up
- DPM passed through filter

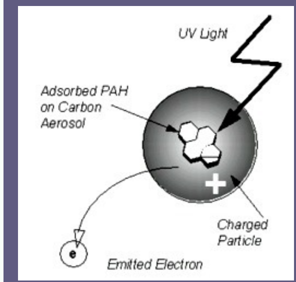


VH181
Oberland Wound Fiber Filter

PAS EC Analyzer

- UV light responsive to PAH on carbon.
- Excitation of DPM particle.
- Expensive…..





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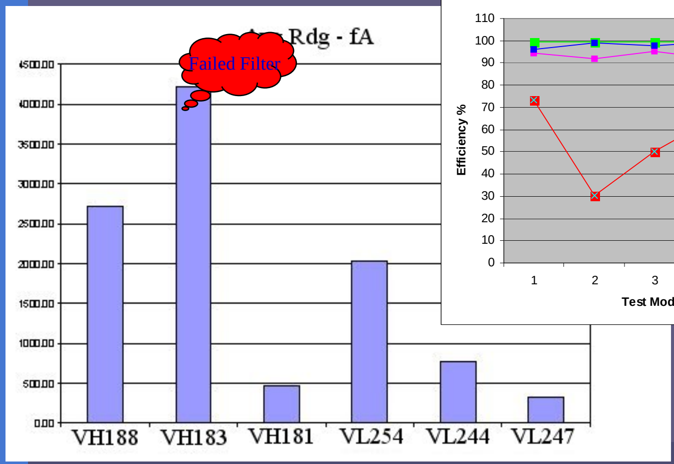
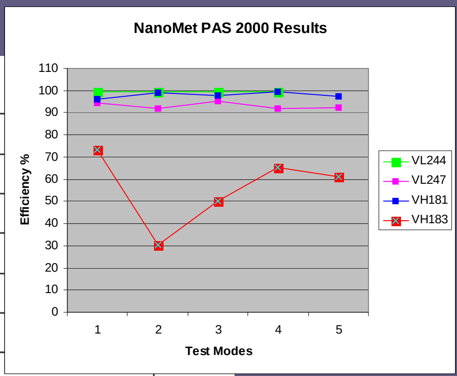
DPF Failure with PAS





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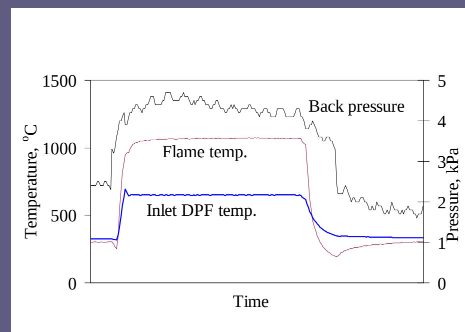
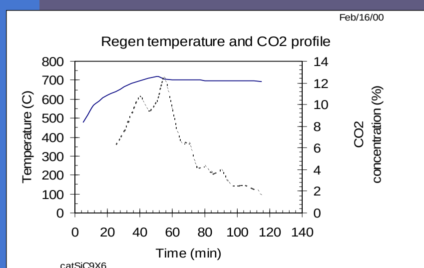
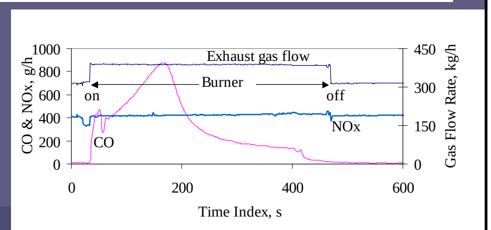
Regeneration Emissions Control

- Regeneration of filter produces emissions.
- Regeneration must take place in a controlled area with adequate ventilation.







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Advanced SCR Testing

- Field verification of NO / NOx reductions.
- Must be done with engine loaded since ammonia is not dosed below 250^{o}C exhaust temperature.

6
4
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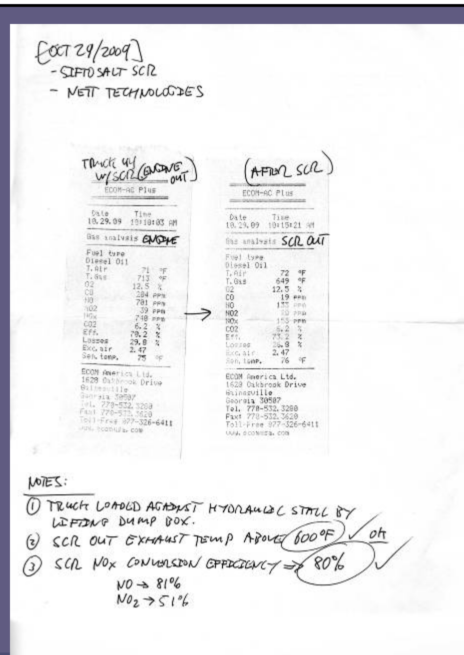
SCR Test

- NOx reduction at 80% during steady state test.
- Exhaust temp high enough for dosing.
- Ammonia slip…



[OCT 29/2009]
- SIFTO SALT SCR
- NETT TECHNOLOGIES

TRUCK 44 W/SCR (ENGINE OUT)			(AFTER SCR)		
ECOM-AC Plus			ECOM-AC Plus		
Date 10.29.09	Time 10:10:03 AM		Date 10.29.09	Time 10:15:21 AM	
Gas analysis ENGINE			Gas analysis SCR OUT		
Fuel type Diesel Oil			Fuel type Diesel Oil		
T.Air	71	°F	T.Air	72	°F
T.Gas	713	°F	T.Gas	649	°F
O2	12.5	%	O2	12.5	%
CO	284	ppm	CO	19	ppm
NO	701	ppm	NO	133	ppm
NO2	39	ppm	NO2	20	ppm
NOx	740	ppm	NOx	153	ppm
CO2	6.2	%	CO2	6.2	%
Eff.	70.2	%	Eff.	73.2	%
Losses	29.8	%	Losses	26.8	%
Exc.air	2.47		Exc.air	2.47	
Sen.temp.	75	°F	Sen.temp.	76	°F

ECOM America Ltd.
1628 Oakbrook Drive
Gainesville
Georgia 30507
Tel. 770-532.3280
Fax: 770-532.3620
Toll-Free 877-326-6411
www.ecomusa.com

NOTES:
(1) TRUCK LOADED AGAINST HYDRAULIC STALL BY LIFTING DUMP BOX.
(2) SCR OUT EXHAUST TEMP ABOVE 600°F ✓ ok
(3) SCR NOx CONVERSION EFFICIENCY ⇒ 80% ✓
$NO \rightarrow 81\%$
$NO_2 \rightarrow 51\%$

Conclusions

- Measurement technology is now available to reliably determine the emissions from diesel engines and aftertreatment.
- With adequate calibration, training, and safety audits; a diesel monitoring program can be implemented at any mine that will significantly improve emissions control.
- Aftertreatment devices are becoming more widespread and your mine's know-how must keep up.


Recommendations
Start your testing program today!
Lots of resources are available for base-lining emissions, training, etc.
Real measurement and documentation is the only way to verify technologies and avoid maintenance by guesswork.
67
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Acknowledgements
Ontario Ministry of Labour – Mining Legislative Review Committee (MLRC).
DEEP Maintenance Project
NRCan Diesel Emissions Laboratory
Vale / Agnico / Xstrata
NIOSH
MSHA
68
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Resources

- DEEP Maintenance Project
  - www.deep.org
- NIOSH EAMP Procedures
  - http://www.cdc.gov/niosh/mining/topics/diesel/eamp/eamp.html
- MSHA Diesel page CO database
  - http://www.msha.gov/01-995/coal/actiontable/actiontable.asp