Diesel fumes – are they the next "asbestos"? What can we do about it?

A Sequel to a paper authored by

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Australia v Rest of the World

- http://www.nanoparticles.ch/2018_ETH-NPC-22.html
  generalist,
  2019 was 23rd conference

- http://www.mdec.ca/
  Mining diesel,
  2019 is 25th conference

Particle sizes

	Diameter	Times bigger than 50 nm diesel particle
Ore grind in processing mills	65 – 135 micron	1300 - 2700
Human hair	100 micron	2000
Merino wool	16 micron	320
Talcum power	10 micron	200
Red blood cell	8 micron	160
Bacteria	2 micron	40
Wood smoke	400-700 nano metres	8 - 14
Hepa filter	Removes 99.97% @ 300 nano metres	6
Carbon nano particle UG Surface	50 – 70 nano metres 15 – 25 nano metres	1 1/3

There is a solution!

This talk will be in 2 sections

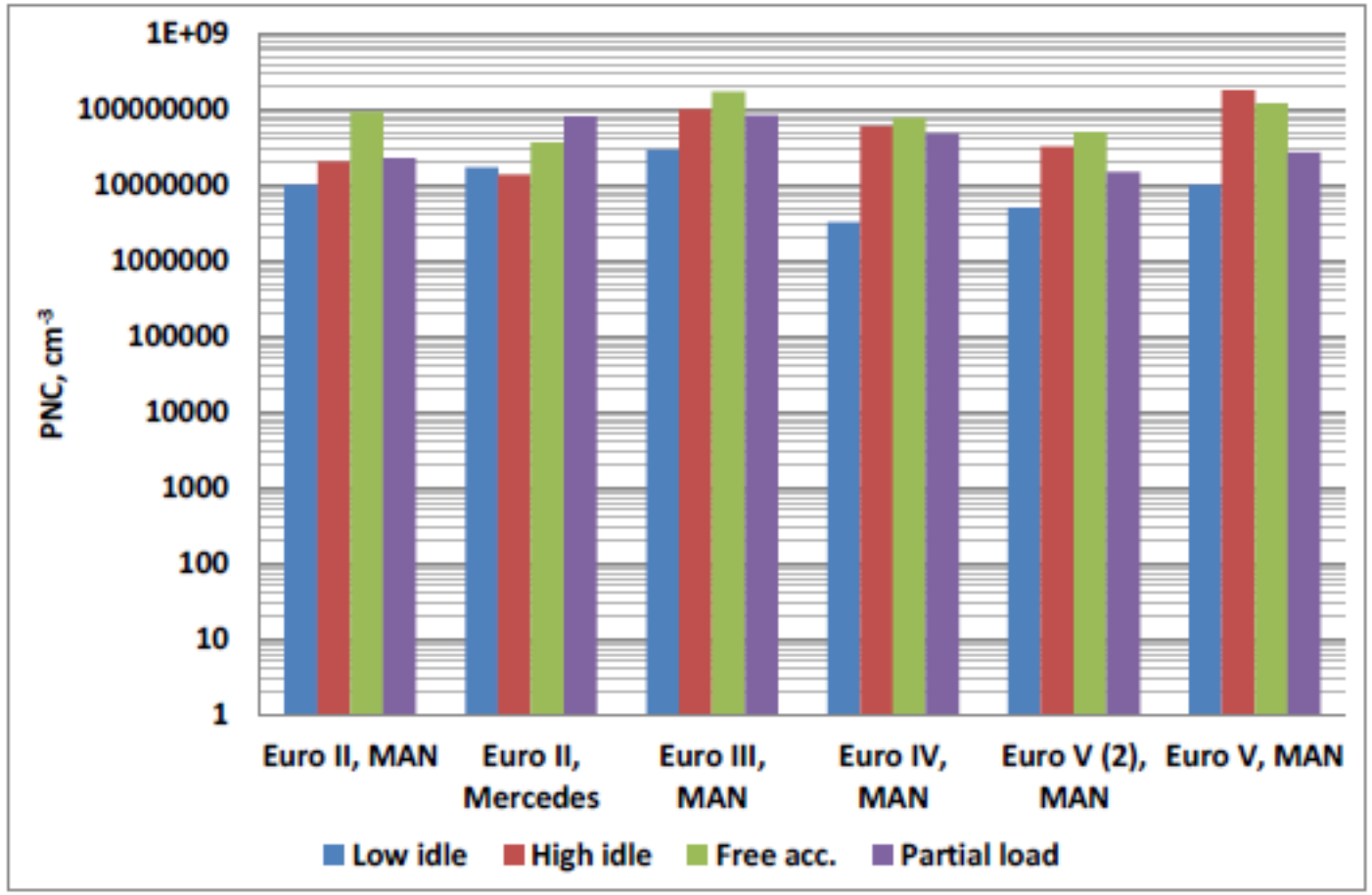
1. The Problem
2. The Solution

Recognition of diesel engine fumes as carcinogenic

- USA National Institute for Occupational Safety and Health (NIOSH) and the National Cancer Institute's (NCI) 20-year Diesel Exhaust in Miners Study (2012)
- International Agency for Research on Cancer (IARC) re-categorised diesel exhaust as "Carcinogenic to Humans – Group 1", (2012)

Nanoparticle number concentrations

Steady-state regimes



. Tartakovsky et al. / Atmospheric Environment 107 (2015) 273e280

Complexity of the issue

- Proximity of mineworker to the source
- Level, duration and variability of exposure
- The type, condition, age, duty cycle and number of the diesel engines
- The effectiveness of a mine ventilation system in diluting the pollutants both locally and throughout the ventilation circuit
- Control measures in place, including tail-pipe after treatment devices and their effectiveness
- The temperature and humidity of the ambient air flow

Composition of Diesel Engine Exhaust Fumes

Include, (this is not an exhaustive list)

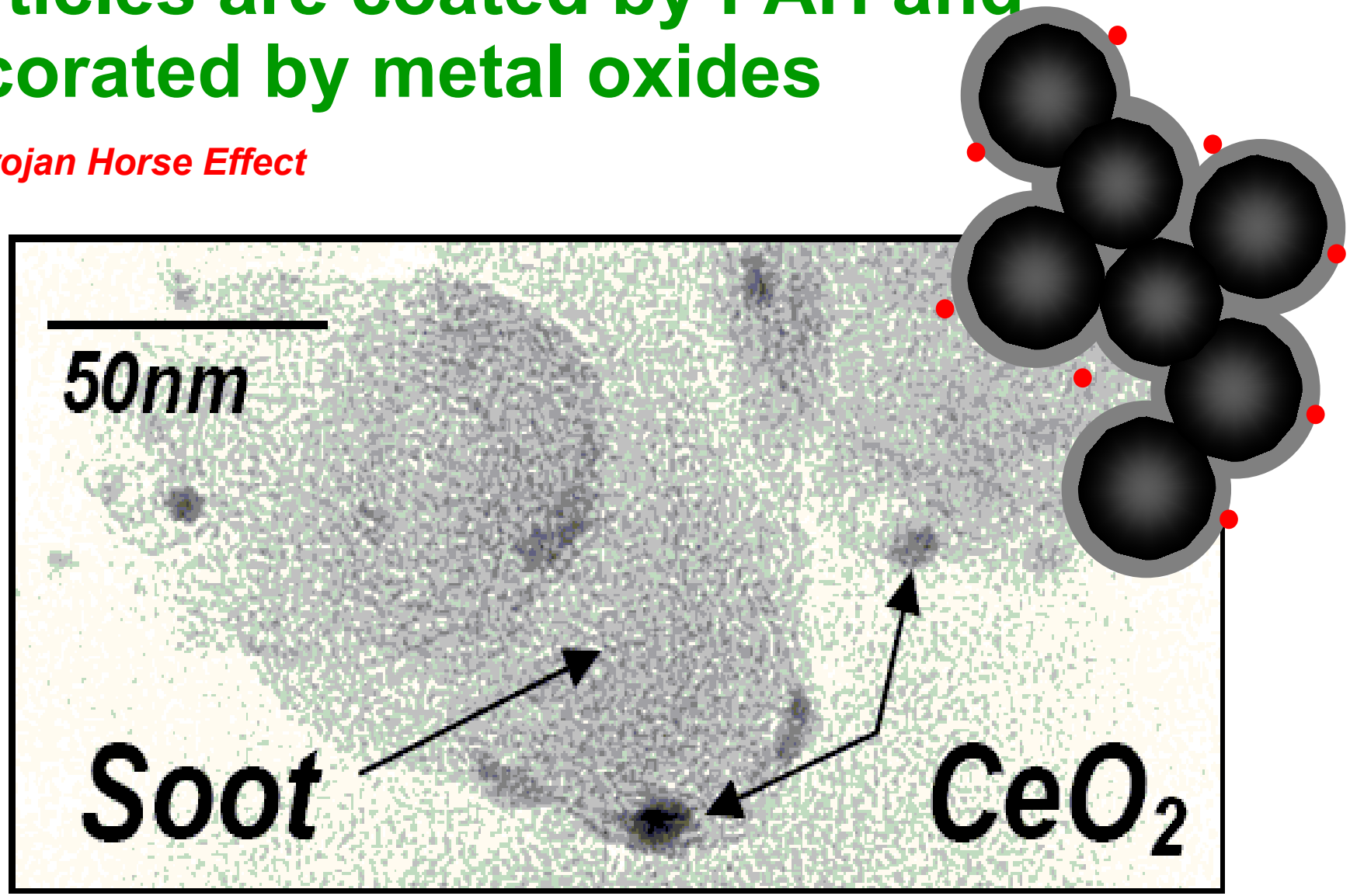
- Carbon monoxide
- Oxides of nitrogen NOX
- Sulphur dioxide SOX
- Volatile organic compounds including benzene and toluene VOC
- Polycyclic aromatic hydrocarbons PAH

And last but not least

- Unburnt carbon particulates , both + micron, and
- Nano DPM

Particles are coated by PAH and decorated by metal oxides

The Trojan Horse Effect

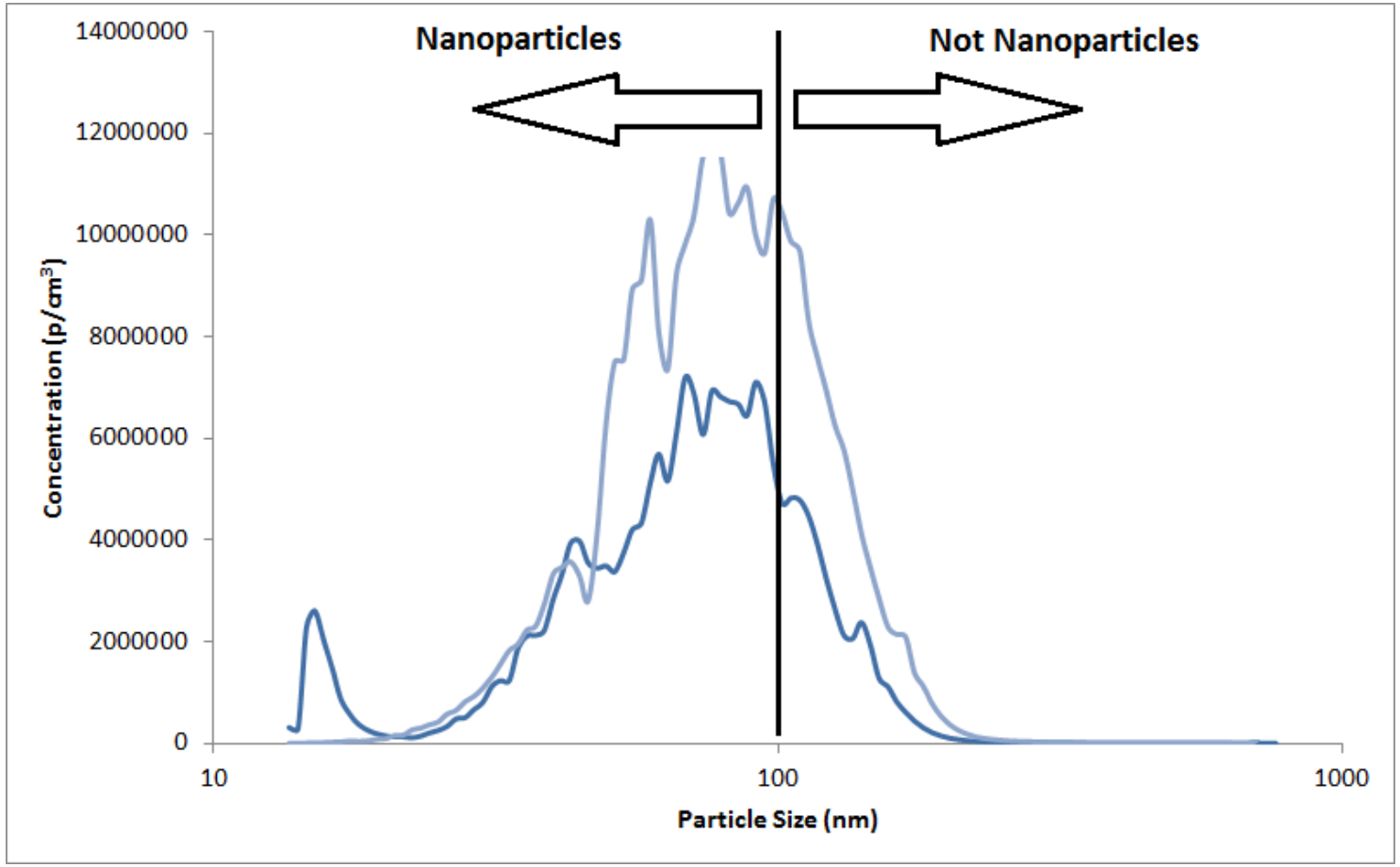


Diesel engine exhaust fumes

How do they get around?

- They move with the ventilation flow
- They may condense among themselves or on the surface of large carbon particles and settle out
- Or they may hitch a ride on nDPM

There are a lot of them!



Real Current measurements

Activity	Monitor Location	Air Flow (m3/s)	Machine - Engine kW	Av number of particles per cubic centimetre	Av Diameter (nm)	Av LDSA (um2/m3	Av Mass (ug/m3)	DPF
Bogger	In Drive	14	R1700 - 242kW	109,000	74	405	342	Mammoth
Bogger	In Cabin	14	R1700 - 242kW	67,000	71	185	63	Mammoth
Bogger	In Drive	20.5	LH410 - 220kW	885,000	59	2337	589	Mammoth
Shotcrete	In Drive	28	Normet - 74.9kW	149,000	60	421	119	Mammoth
Bogger	In Cabin	13	LH621 - 345kW	50,000	50	134	30	No DPF - Tier 4i
Bogger	In Drive	13	LH621 - 345kW	170,000	61	513	172	No DPF - Tier 4i
Bogger	In Cabin	36	R2900 - 333kW	79,000	73	290	152	Cat - Original
Shotcrete	In Drive	13	Jacon Combo 6000 - 207kW + Agi Combo 6000 - 205kW	1,191,000	66	3011	1,271	Mammoth

Impact on the respiratory system

- + micron sizes deposit in the trachea-bronchial tract and are cleared within minutes / hours / days of inhalation by coughing, sneezing, swallowing and/or spitting
- But the – 500 nm particles can take weeks or months to clear
- This long retention allows
  - interactions with the alveolar cellular lining, which is not evolved for this exposure
  - transport across the pleural membrane into the blood stream and onward

Outcomes

There have been a host of recent papers on the consequences of long term exposure to diesel exhaust fumes. A sample of these are

- Peters et al (2016) Lung cancer
- Latifofic et al (2015) Bladder cancer
- Duan et al (2016) DNA damage

Ultrafine particle dangers (University of Edinburgh)

- More health effects coming to light:
- AIR QUALITY AND HEALTH WORKSHOP: Fate and transport of ultrafine particles
  - Dr Nicholas Mills, University of Edinburgh

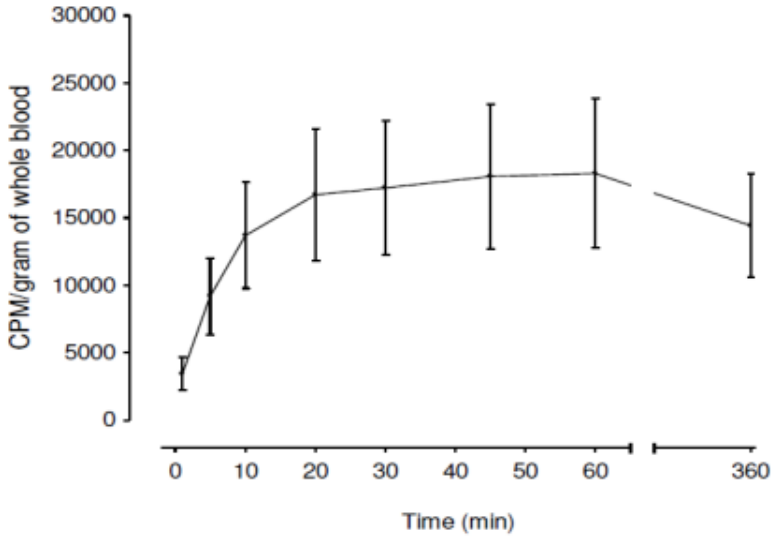
Human exposure studies to understand the effect of air pollution on the heart and blood vessels

PM concentration 300μg/m^3 (median diameter 54nm; range 20-120); particle number = $1.26 \pm 0.01 \times 10^6$ particles/cm^3; NO_x = 4.45±0.02ppm; NO_2 =1.01±0.01ppm; NO = 3.45±0.03ppm; CO = 2.9±0.1ppm; total hydrocarbon 2.8±0.1ppm

Ultrafine particle dangers

2. Can ultrafine particles translocate into the circulation?

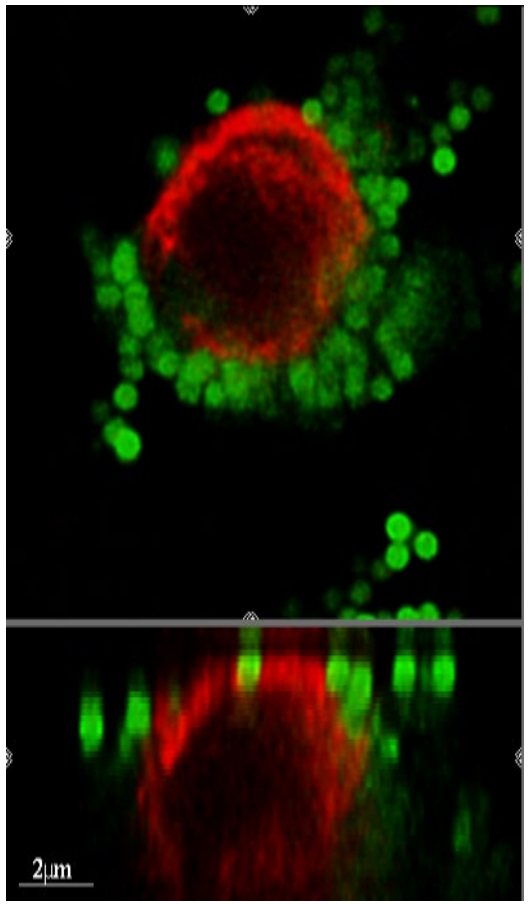
^{99m}Technecium-labelled carbon nanoparticulate (5-20nm) - Technegas



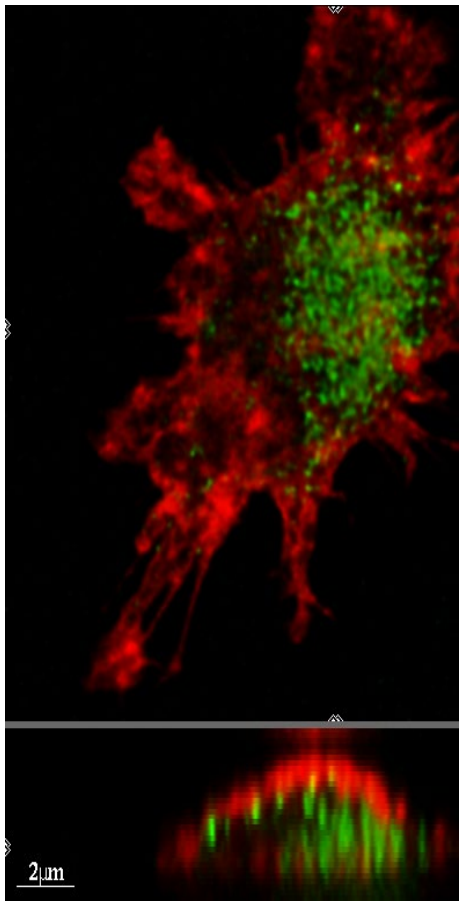
Radioactivity detected rapidly in the bloodstream

Particle Size Penetrating Membranes

1000 nm
Polystyrene Particles



78 nm
Polystyrene Particles



Solid particles smaller than 500 nmØ reach the alveoli.

About 5% of them translocate readily into the blood stream.

They may infiltrate the bladder, the liver, the brain – all of our organs.

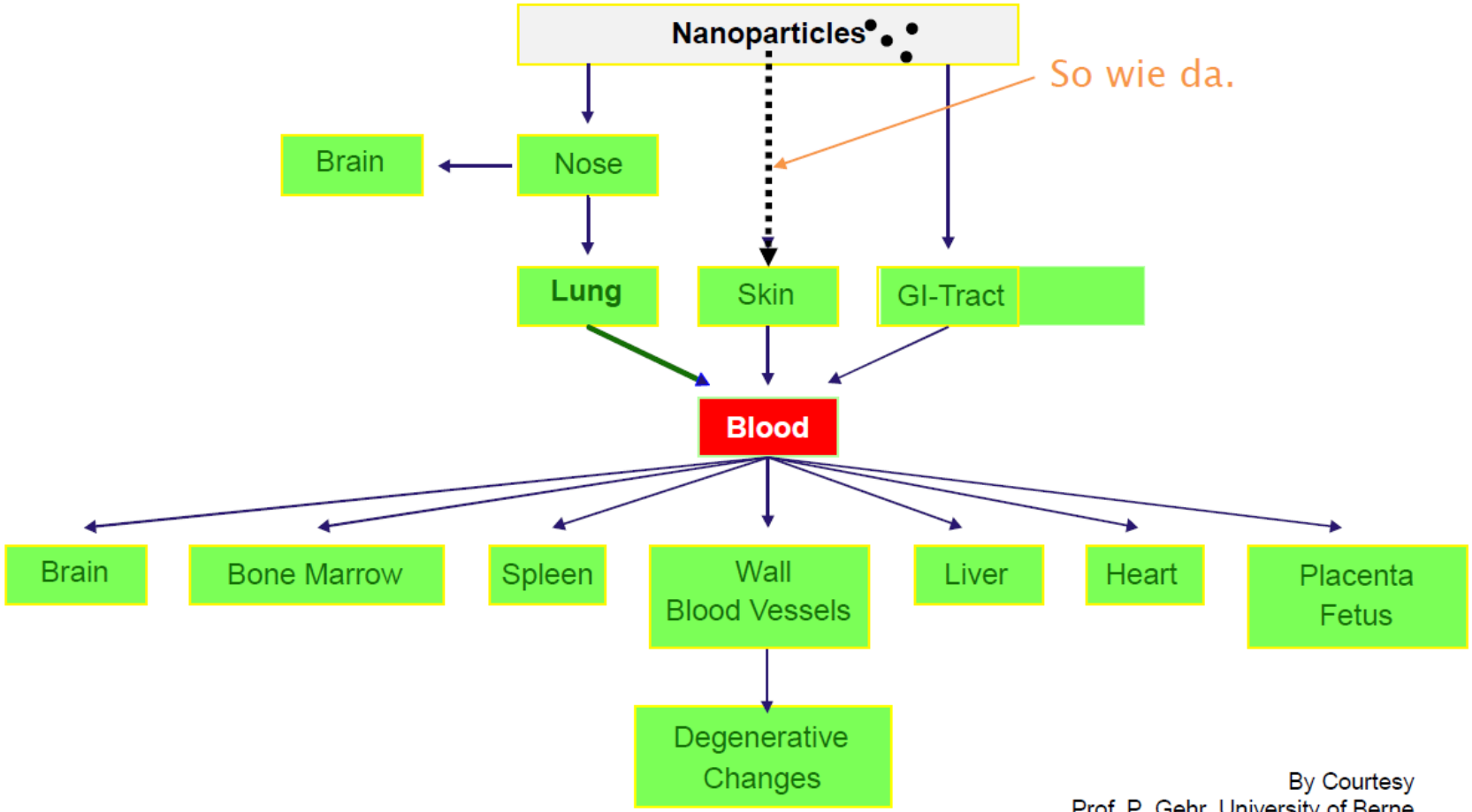
Small particles around **100 nmØ**, the typical size of Diesel UFP, may enter the cell causing damage to the DNA of the genes.

This demonstrates, why size matters and not mass, and why particles have to be monitored by number.

Laser Scanning Microscopy

B. Rothen-Rutishauser, University Berne

Translocation of Nanoparticles



By Courtesy
Prof. P. Gehr, University of Berne

Exposure metrics

- Many jurisdictions rely on one metric, elemental carbon (EC)

  The EC metric is obsolete and should not be used

- It has become clear than, because the complexity of the UG atmosphere, something else is needed
- Just measuring the number and size distribution of nDPM cannot be considered an effective metric as it has no regard to the gases adhering to the particles
- However, by lowering the nDPM number, the availability of adhering gases to penetrate tissue will be radically reduced

Has any one died of nDPM?

- After a long fought court battle in Canada (2005 – 2013), Claude Fortin (who died of lung cancer in 2009) was granted compensation for his injury working at an IAMGOLD mine

- **NO ONE IS TRACKING NDPM DEATHS OR LONG TERM HEALTH OUTCOMES**

Extracts from the current WA Guideline Management of diesel emissions in Western Australian mining operations

- "Safety over the past few years indicate that it is reasonably practicable for underground mines to achieve compliance with the AIOH recommendation of 0.1 mg/m3 for DPM. However, some sites have not effectively controlled emissions to maintain employee DPM exposure levels below 0.1 mg/m3"
- "The Department of Mines and Petroleum is aware that technological advances, particularly in regard to monitoring nanoparticles in diesel emissions, and emerging epidemiological studies may lead to calls for an exposure standard, and mining operators should consider this when developing their long-term management strategies."
- Read section 3 of the guideline. It's all there

A mine wide study

A study was done at an UG mine in Western Australia in 4/4 2017. It was a first for Australia and maybe the world in its scope and size, including examining

- Exhaust gases and their behavior through the ventilation system
- Cardiac and respiratory function before and after shift
- Blood and urine samples from up to 100 workers pre and post shift

This study may progress the development of biomarkers to better measure and assess exposure to diesel exhaust

International Council for Clean Transportation

Table 3. The Euro V and Euro VI heavy-duty vehicle emission standards for diesel engines

	Euro V Heavy-Duty		Euro VI Heavy-Duty	
	Euro V SS[a]	Euro V T[b]	Euro VI SS[a]	Euro VI T[b]
Emission limits (g/km)				
CO	1.5	4.0	1.5	4.0
HC	0.46	0.55	0.13	0.16[d]
CH_4[c]		1.1		0.5
NO_x	2.0	2.0	0.4	0.46
PM	0.02	0.03	0.01	0.01
PN (#/km)			8.0×10^{11}	6.0×10^{11}
Smoke (1/m)	0.5			
Ammonia (ppm)[12]			0.01	0.01
Fuel Sulfur Limit (ppm)	10	10	10	10
Test Cycle	ESC & ELR	ETC	WHSC	WHTC

[a] Steady-state testing; [b] Transient testing; [c] For Euro V for Natural Gas only, for Euro VI, NG and LPG; [d] Total HC for diesel engines, non-methane HC for others

ICCT continued

- For certification of heavy-duty vehicle emissions, engines are tested on a test bed and emissions are reported as g/kWh. The WHSC is a steady-state cycle also based on a weighted sum of emissions over thirteen modes, which are combinations of engine speed and load. The cycle is based on real-world drives in Europe, the United States, Japan, and Australia. It is a hot-start cycle following preconditioning at an engine speed of 55% and 50% load. The WHTC test is a transient engine test of 1800 seconds, with several motoring segments, originally developed by the UNECE Working Party on Pollution and Energy. It is based on the worldwide pattern of real-world heavy commercial vehicle use based on typical driving conditions found in Europe, the United States, Japan, and Australia.

The Solution

In DECREASING COST

1. Shut the mine down
2. Go all electric
3. Ventilation
4. Filtration

Go all electric

Several mines in Canada have gone electric,

1. All are shaft mines
   - Borden
   - Onaping Deeps
2. All (most?)are owner operator
3. All are down hill loaded haul
4. The capital cost of the equipment is approximately 3 times that of diesel (GMMG battery meeting Perth Nov 2018)

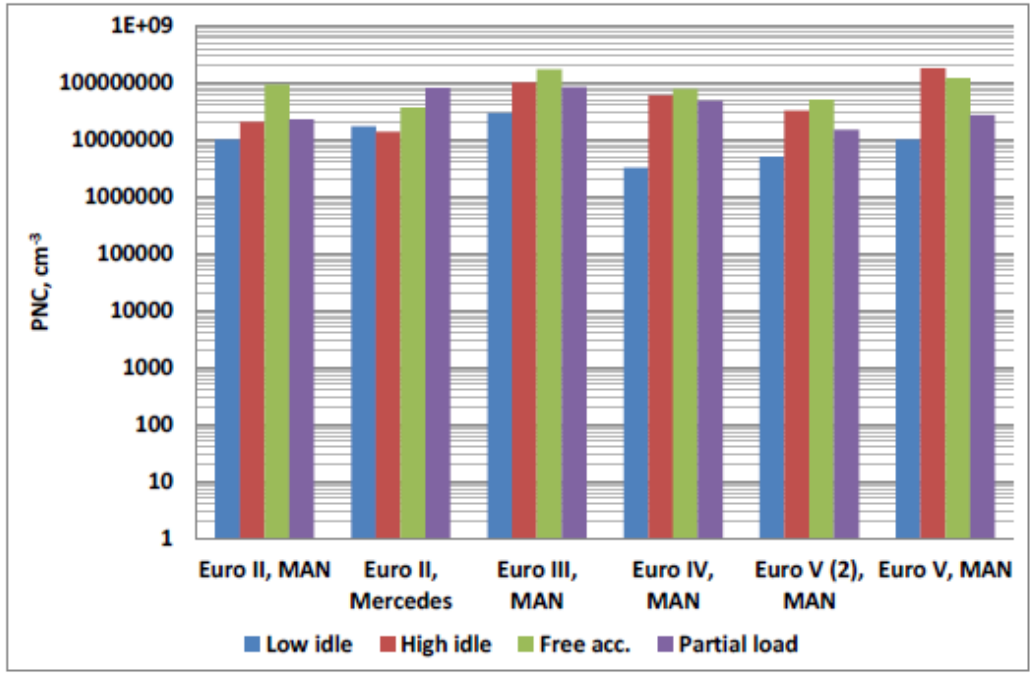
Ventilation

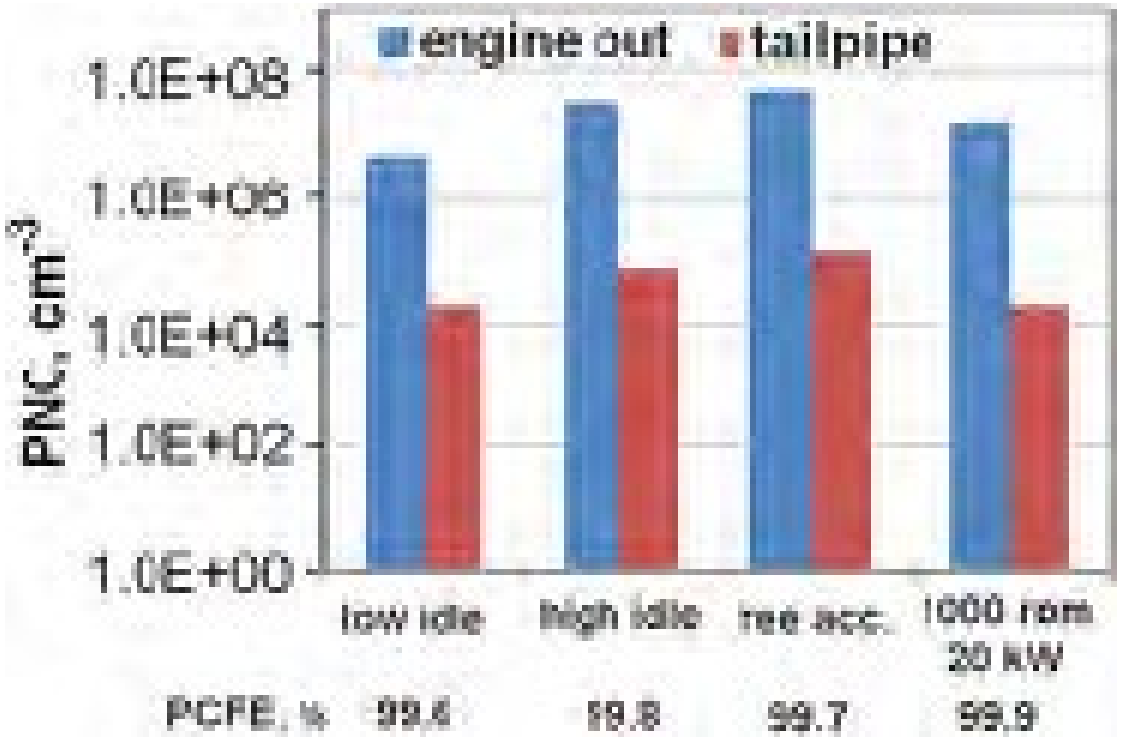
1. **Do not use the decline for primary ventilation**
2. Have a Fresh Air Raise and a Return Air Raise
3. Use vent doors to control flow
4. Use a Particle count monitor such as the testo Discmini or Naneos Partector to understand the amount of nDP present
5. You will find that “dead heads” might have nDP lurking
6. Forget the Particle Mass criteria, it is OBSOLETE

Voodoo

- Add blue
- Burn diesel on the DPF

Filtration





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Volvo / Sandvik Load and Haul < 560kw

NANO PARTICLE EMISSION TEST RESULTS

Engine	Average	Min	Max
Stage II *	6,880,000 / cm^3	1,020,000 / cm^3	26,100,000 / cm^3
Stage IV	1,940,000 / cm^3	761,000 / cm^3	14,100,000 / cm^3
Stage V	**6990 / cm^3**	**2170 / cm^3**	**17,900 / cm^3**

Average, minimum and maximum particle concentration (PM10) over the 60 second idle-stall-idle cycle.
Particle sizes from 10 nm up to 10 µm were measured with up to 10 Hz sampling rate.
* Stage II uses Catalytic Purifier and Muffler

Volvo / Sandvik Load and Haul < 560kw

NANO PARTICLE EMISSION TEST RESULTS

Engine	Average	Max
Stage II + Sandvik DPF *	600 / cm^3	4000 / cm^3
Stage II + Sandvik DPF **	0.0 mg / m^3	0.0 mg / m3

Test conducted in Perth, November 2018.
Average, minimum and maximum particle concentration (PM10) over the 60 second idle-stall-idle cycle.
* 'Indicative of a very clean engine to begin with, coupled with an effective DPF' (Sandvik twin sintered metal filter)
** Laser light scattering mass detection devices cannot detect below 100 nanometers in size.
- Test machine uses Volvo 16L engine

Emission Testing By:
Freudenberg Filtration Technologies (Aust) Pty Ltd
69 Malcolm Road, Braeside,
Victoria Australia 3195
Ph: +61(3) 9587 9488

Third party verification by:
Rapallo Perth
10 Elmsfield Road Midvale
Western Australia 6056
Ph: (08) 6279 0900

HOW OLD IS YOUR EQUIPMENT?

• +8,000 hour	buy and INSTALL a good DPF Refer to previous slide	$45k
• 2,000 – 4,000 hours	re- engine with a new Stage II	~$200k
• Ready to buy	new Stage V equipment can achieve ~ 7k nDP. Same price for good and poor nDPF	<$2M

SO WHAT SHOULD YOU DO?

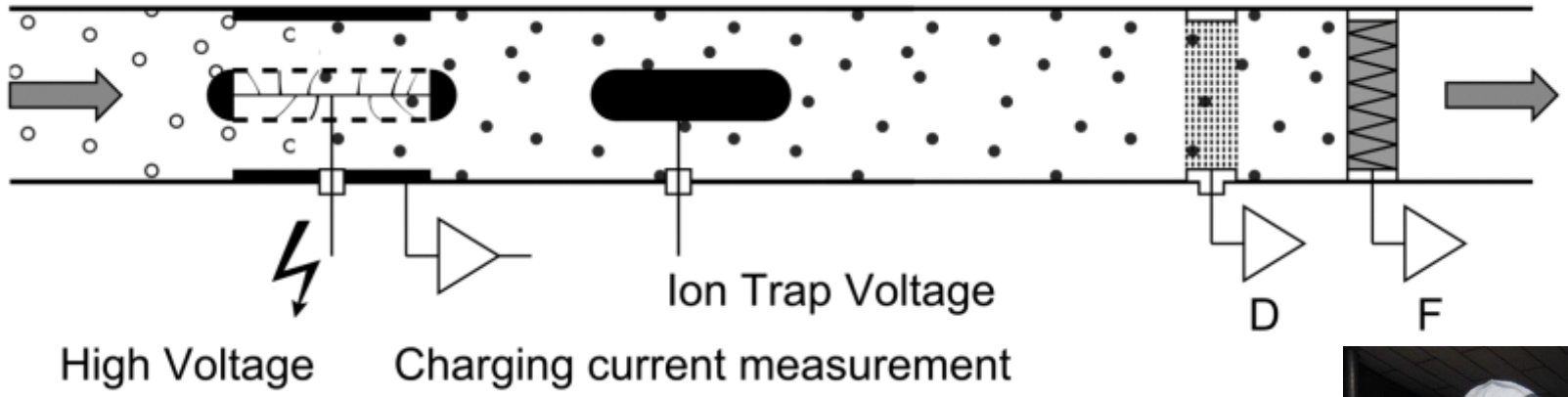
1. Install filters that are NOT ALARP / ALARA , but are BAT
   - As low as reasonably possible / achievable, Best Available Technology
2. Buy and use a hand held nDPM meter
3. Review your ventilation system
4. Implement a health surveillance system

Additional info not in presentation, use if time

- HEPA filters
  - High efficiency particulate air, must remove (from the air that passes through) 99.97% of particles that have a size of 0.3 μm
  - The 0.3 μm is 300 nm, much bigger than nDPM (50 – 70nm)
  - HEPA filters are not the solution
- ALARP / ALARA / BAT
  - As low as reasonably possible / achievable
  - Cannot apply to nDPM. At this time there is no clear dose level
  - BAT should used to identify and use the best available for underground miners inhalation, **NOT surface highway trucks visible soot**
- Elemental carbon is the current criteria @ 0.1 mg / m^3
  - This is now obsolete and has no coherent justification. You cannot use it

Diffusion Charging by TESTO and NANEOS

for Laboratory, PEMS, Maintenance and Personal Sampling



Why should we introduce DPF ? Question of Swiss government 2002

1. because of the health effects of solid nanosize particles at the working place and in the public

2. because of the impact of black carbon nanoparticles on global warming

3. because the Benefit/Cost of DPF is > 10 which means that the society is gaining money by this investment, reducing health cost

Conclusion

- Existing exposure metrics are inadequate
- There appears to no one single adequate metric
- There are solutions that should be achievable within your budget

- **Thank you for listening to me**

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