University of Massachusetts Lowell

The construction painters' exposure to chemical mixtures, health implications, and opportunities for disease prevention

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and the research team (P Patel, K Biswas, Y Xu, L Chanetsa, M Mellette, etc.)

Webinar CPWR - The Center for Construction Research and Training (CPWR)

January 28th 2025

Presentation Overview

- Industrial metal structure coating systems
  - Motivation
  - Documenting and prioritizing chemicals of concern and endpoints in coatings
- Amine hardeners in epoxy systems – targets and exposures
- Urinary biomonitoring data among industrial painters
  - Metals
  - PFAS
- Urinary effect biomarkers
  - Oxidative stress
  - Kidney injury
  - Heat stress

Ongoing Project: **Developing a national roadmap to reduce per- and polyfluoroalkyl (PFAS) exposures among construction painters and allied trades**

A decade of research on chemical exposures in construction

Reactive Chemical Systems- Two main cohorts

- Industrial Painters: Metal Structure Coating
- Insulation Workers: Spray Polyurethane Foams Insulation (SPF)

Part A: *Isocyanate and Epoxy resins*
Part B: *Amine catalysts & hardeners, flame retardants, solvents, and nanofillers*

Goal: To minimize worker exposure to chemicals in construction through:

- Documenting exposure levels, work practices, and existing controls
- Developing data-driven recommendations

Motivation: Why painters ?

- Occupational exposure as a painter has been classified by IARC as a Group 1 – Known Human Carcinogen (Mon vol 47, 1989; reaffirmed in 2010)
  - Increased risk of *lung and urinary bladder cancers*
  - Complex exposures - agents responsible partly understood
- Other major concerns
  - Allergic contact dermatitis (hands, forearms, face)
  - Respiratory sensitization and asthma (isocyanates, epoxies)
- Limited health effects data among US construction painters!

Contact dermatitis on hand

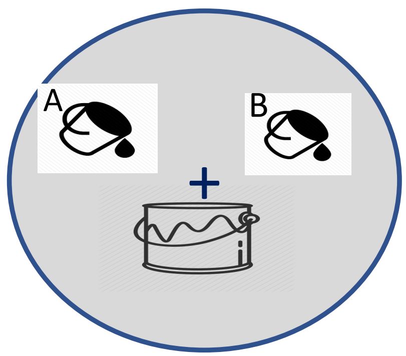
Figure credit: CPWR report on epoxy resins in construction

Documenting and prioritizing chemicals of concern in coatings

Coating formulations are two or more component reactive chemical systems

Part A

EPOXY
or
Isocyanate



Part B

AMINE Hardeners

SOLVENTS

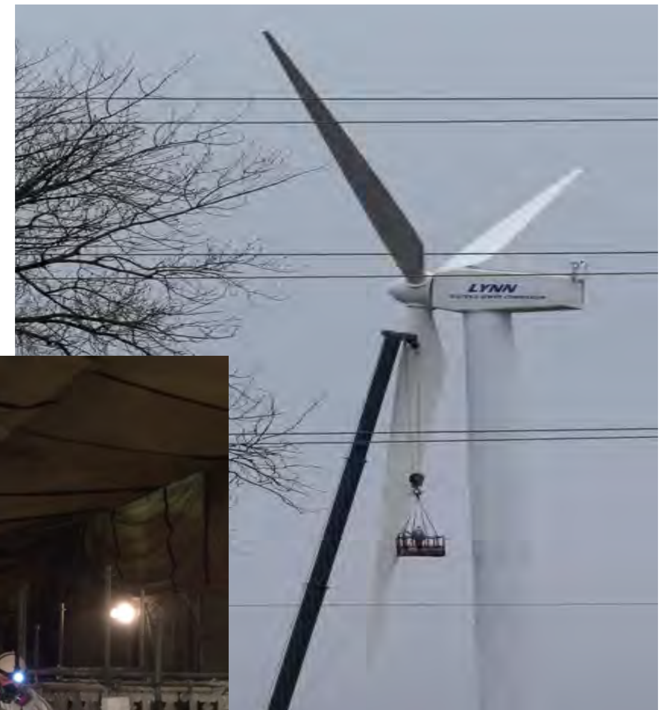
Nano FILLERS

CATALYSTS

Other additives

ROLLER/BRUSH or/and SPRAY

Metal Structure Coatings Application



Coating Products: Reactive chemical systems - Part A

Webinar 1: Exposures and urinary biomonitoring of aliphatic isocyanates in construction metal structure coating (March 2019)

Webinar 2: Occupational exposures to epoxy resins among construction painters: Methods to monitor exposures and urinary biomarkers (June 2021)

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Exposures and urinary biomonitoring of aliphatic isocyanates in construction metal structure coating

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Urinary biomonitoring of occupational exposures to Bisphenol A Diglycidyl Ether (BADGE) – based epoxy resins among construction painters in metal structure coating

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Original Article

Original Article

Characterization and Quantitation of Personal Exposures to Epoxy Paints in Construction Using a Combination of Novel Personal Samplers and Analytical Techniques: CIP-10MI, Liquid Chromatography–Tandem Mass Spectrometry and Ion Chromatography

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Evaluation of disposable protective garments against epoxy resin permeation and penetration from anti-corrosion coatings

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Coating Products: Reactive chemical systems - Part B

*We reviewed coating products approved by the **Northeast Protective Coating Committee (NEPCOAT)** for use in steel bridges in New England*

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REVIEW ARTICLE | Open Access

Identifying and Prioritizing Hazardous Chemicals in Construction Metal Structure Coating Systems: A Roadmap for Data-Driven Disease Prevention

Paridhi Patel, Dhimiter Bello, Anila Bello

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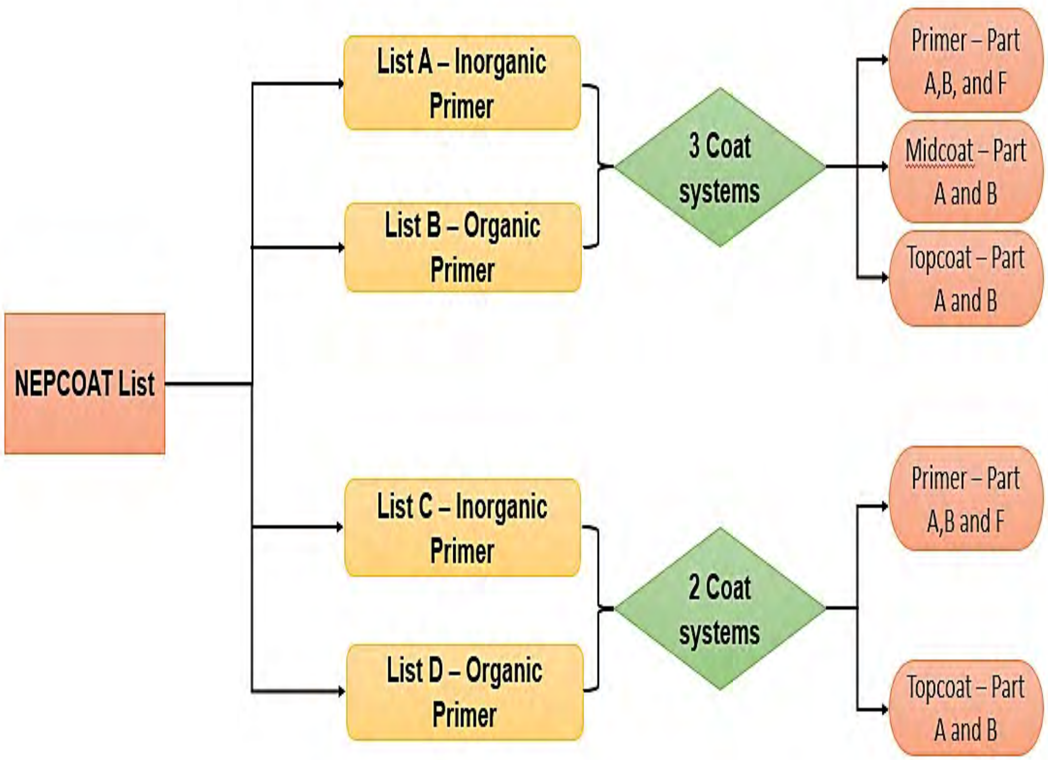
Objectives:

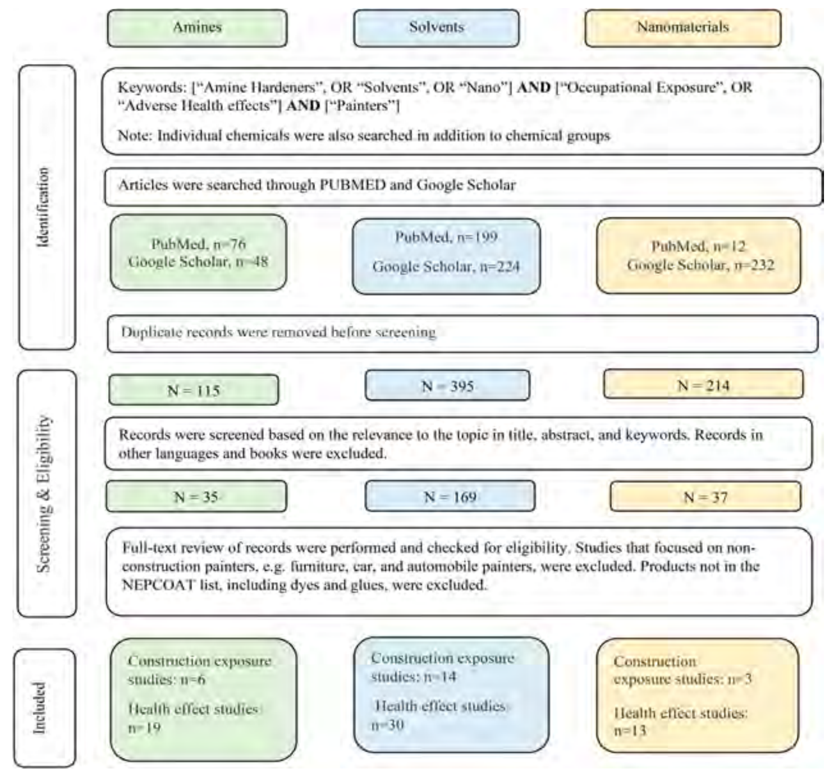
- Document the chemistry and hazardous ingredients in Part B of reactive systems
- Identify major data and knowledge gaps related to occupational exposures, biomonitoring of Part B.
  - *To prioritize ingredients/chemical groups for subsequent exposure and health effects studies*

NEPCOAT coating systems

Reviewed chemistries, exposure data and chemical toxicology



Schematic diagram of literature review related to exposure and health effects of chemicals in construction coating systems



Chemistry of coating systems – A systematic review and database

Primer

Zinc Clad 4100 Organic Zinc Rich

Part A

Chemical Name	Weight by %
Epoxy Polymer	≥25 - ≤50
Methyl Ethyl Ketone	≥10 - ≤25
Methyl N-Amyl Ketone	≥10 - ≤23
Xylene, mixed isomers	≤13
1,2,4-Trimethylbenzene	≤5
Light Aromatic Hydrocarbons	≤3
Ethyl Benzene	≤2.7
1,3,5-Trimethylbenzene	≤1
Cumene	≤1
1,2,3-Trimethylbenzene	≤1

Part B

Chemical Name	Weight by %
Xylene, mixed isomers	>25 - <34
Crystalline Silica, respirable powder	≥10 -≤25
Phenol, isobutylenated methylstyrenated	≥10 -≤25
Polyamidoamine	≥10 -≤25
Ethyl benzene	≤10
Tri(dimethylaminomethyl)phenol	≤1.9
Med. Aliphatic Hydrocarbon Solvent	≤0.3
Fatty Acid Amine	≤0.3
Toluene	≤0.3
Heavy Aliphatic Solvent	≤0.3
Triethylene Tetramine	≤0.3

Part F

Chemical Name	Weight by %
Zinc Powder	100

Intermediate

Macropoxy 646 Fast Cure Epoxy

Part A

Chemical Name	Weight by %
Crystaline Sillica, respirable powder	≥50- ≤75
Epoxy Polymer	≥10 - ≤25
Methyl Isobutyl Ketone	≤10
Xylene	≤3

Part B

Chemical Name	Weight by %
Titanuim Dioxide	≥25 - ≤505
p-Chlorobenzotrifluoride	≥10 - ≤25
Phenol, isobutylenated methylstyrenated	≥10 - ≤25
Xylene	≤3
Polamide	≤10
Talc	≤10
Ethylbenzene	≤0.3
Triethylene Tetramine	<1
2-Ethyl-2-(hydroxymethyl)-1,3-propanediol	≤0.3

Topcoat

Acrolon 218 HS

Part A

Chemical Name	Weight by %
Hexamethylene Diisocyanate (max)	<1
Hexamethylene Diisocyanate Polymer	≥90

Part B

Chemical Name	Weight by %
Titanium Dioxide	≥10 - ≤25
Crystalline Sillica	≥10 - ≤25
n-Butyl Acetate	≤8.4
2-methoxy-1-methylethyl acetate	≤4.9
Methyl Ethyl Ketone	≤4.9
Xylene	≤5
Heavy aromatic naphtha	≤1.5
Ethylbenzene	<1
Heavy aliphatic solvent	<1
Light Aliphatic Hydrocarbon	≤0.3
Naphthalene	≤0.3
Bis(pentamethyl-4-piperidyl)sebacate	≤0.3
UV Light absorber	≤0.3
Benzotriazole hydroxyphnyl polymer	≤0.3

Information available from SDSs!

- 42 chemicals in primers
- 32 in mid coat
- 51 in topcoat

12 CAS No - Amines
28 CAS No - Solvents
19 - Nano/particulate fillers
4 - Other additives

Skin and respiratory sensitizers present in coating products

- 14 Skin sensitizers
  - 9 amines
  - 4 solvents
  - 1 nanofiller
- Amines: Class I - potent sensitizers
- Other construction products
  - e.g. glues
  - 13.1M workers handle epoxy resins in the USA (ACC)
  - 28k bridges undergoing repair

Nr.	Chemicals	Chemical group	CAS Number	Site/Organ	Skin potency category[a]	GHS classification[b]	References	Layer[g]
1	Bis(pentamethyl-4-piperidyl) sebacate / Bis(1,2,2,6,6-pentamethyl-4-piperidyl) sebacate	Amine hardener	41556-26-7	Skin	NA	Skin sensitization. 1A	ECHA[c], PubChem[d]	T
2	Polyamidoamine (PAMAM)	Amine hardener	68082-29-1	Skin	HS	Skin sensitization.1A	ECHA, PubChem, IVDK 2016[27], and DGUV 2021[69]	P, M
3	2,4,6-Tris(dimethylaminomethyl) phenol (Tris-DMP)	Amine hardener	90-72-2	Skin	GMS	NA	RøMyhr et al. 2006[32], Aalto-Korte et al. 2014[33], Kanerva et al. 1996[57], IVDK[e] 2016[27], DGUV[f] 2021[69]	P, M
4	Pentamethyl piperidyl sebacate / Methyl 1,2,2,6,6-pentamethyl-4-piperidyl sebacate	Amine hardener	82919-37-7	Skin	NA	Skin sensitization. 1	ECHA, PubChem	T
5	1,2-Diamino cyclohexane (DACH)	Amine hardener	694-83-7	Skin	NA	Skin sensitization. 1A	ECHA, PubChem	Layer – P, M
6	Triethylene tetramine (TETA)	Amine hardener	112-24-3	Skin	HS	Skin sensitization. 1	ECHA, PubChem, IVDK 2016[27], DGUV 2021[69]	P, M
7	Triethoxysilyl Propylamine / (3-Aminopropyl)triethoxysilane (TESPA)	Amine hardener	919-30-2	Skin	GMS	Skin sensitization. 1	ECHA[a], PubChem[b], IVDK 2016[27], DGUV 2021[69]	T
8	Fatty Acid Amine (FAA)	Amine hardener	85711-55-3	Skin	NA	Skin sensitization. 1A	ECHA, PubChem	P, M
9	Polyamide (PAmD)	Amine hardener	68410-23-1	Skin	U	Skin sensitization.1A	ECHA, PubChem, IVDK 2016[27], DGUV 2021[69]	M
10	4-Morpholinecarboxaldehyde	Solvent	4394-85-8	Skin	NA	Skin sensitization.1B	ECHA, PubChem	T
11	Polycarboxylic acid ester	Solvent	91001-64-8	Skin	NA	Skin sensitization. 1	ECHA, PubChem	P
12	Dibutyltin bis (2,4-pentadionate) / Dibutyltin bis(acetylacetonate)	Solvent	22673-19-4	Skin	NA	Skin sensitization.1	ECHA, PubChem	P
13	Dibutyltin dilaurate	Solvent	77-58-7	Skin	NA	Skin sensitization. 1	ECHA, PubChem	P
14	Wollastonite	Nanomaterial	13983-17-0	Respiratory	NA	Respiratory sensitization. 1	ECHA, PubChem	T

[a] Skin potency category derived from evidence found from human health studies and the local lymph node assay [27,69]
HS → SHS – High sensitizing potency with limited data indicating tendency of chemical to be of very high sensitizing potency.
HS – High sensitizing potency.

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Carcinogens identified in Part B of coating systems: IARC classification

Literature:
- 2 group 1 carcinogens
- 7 group 2B carcinogens
- No amines in the IARC list

- 2 Amines identified as potential carcinogens & associated with stomach cancer (Shah et al. 2020)*
  - 1,2 Diamino cyclohexane
  - Polyamide

Nr.	Chemicals by group	CAS Number	IARC classification [a]	Type of cancer [b]
1	Methyl isobutyl ketone	108-10-1	Group 2B (IARC monographs 101, 2013)	Liver and kidney
2	Ethyl benzene	100-51-6	Group 2B (IARC monographs 77, 2000)	Lung and liver
3	Naphthalene	91-20-3	Group 2B (IARC monographs 82, 2002)	Kidney, olfactory neuroblastoma, and lung
4	Ethanol	64-17-5	Group 1 (IARC monographs 96, 2012)	Oral cavity, pharynx, larynx, esophagus, liver, colorectum and female breast
5	4-Chlorobenzotrifluoride	98-56-6	Group 2B (IARC monographs 125, 2020)	Lung, liver, and thyroid
6	Cumene	98-82-8	Group 2B (IARC monographs 101, 2013)	Liver, lung and kidney
7	Crystalline Silica	14808-60-7	Group 1 (IARC monographs Sup[c] 7 68, 100C, 2012)	Lung, esophagus, stomach and kidney
8	Titanium Dioxide	13463-67-7	Group 2B (IARC monographs 93, 2010)	Lung
9	Carbon Black	1333-86-4	Group 2B (IARC monographs 93, 2010)	Lung

[a] International Agency for Research on Cancer (IARC) classification.[70]
Group 1 – Carcinogens to humans
Group 2A – Probably carcinogenic to humans
Group 2B – Possibly carcinogenic to humans
Group 3 – Not classifiable as to its carcinogenicity to humans
[b] The type of cancer has been determined based on human and animal studies included in the IARC monographs.
[c] Sup - Supplemental

**Aromatic amines exposures were 2.92 (95% CI: 1.36–6.26) gastric cancer.*

Shah SC et al." Occupational exposures and odds of gastric cancer: a StoP project consortium pooled analysis”. Int J Epidemiol. 2020 Apr 1;49(2):422-434

Other possible health effects

TABLE 4 | Existing occupational exposure limits and other health effects of Part B ingredients.

Chemicals by group	CAS number	NIOSH REL[a]	OSHA PEL[b]	ACGIH TLV[c]	Other health endpoints	References for health endpoints
Amines						
Triethylene tetramine	112-24-3	NA	NA	NA	Developmental toxicity Teratogenesis Genotoxicity	Korhenen et al. [64], Rochelle et al. [65], Cohen et al. [68], Leung [66]
Solvents						
Methyl *N*-amyl ketone Methyl ethyl ketone Methyl isobutyl ketone	110-43-0 78-93-3 108-10-1	TWA 100 ppm (465 mg/m^3) TWA 200 ppm (590 mg/m^3) ST 300 ppm (885 mg/m^3) TWA 50 ppm (205 mg/m^3) ST 75 ppm (300)	TWA 100 ppm (465 mg/m^3) TWA 200 ppm (590 mg/m^3) TWA 100 ppm (410 mg/m^3)	TWA 50 ppm (233) TWA 75 ppm STEL 150 ppm TWA 20 ppm (82 mg/m^3) STEL 75 ppm (307 mg/m^3)	Hepatotoxicity	PubChem,[d] ECHA[e]
Ethyl benzene Benzyl alcohol	100-41-4 100-51-6	TWA 100 ppm (435 mg/m^3) ST 125 ppm (545 mg/m^3)	TWA 100 ppm (435 mg/m^3)	TWA 20 ppm	Neurotoxicity Ototoxicity	Lee et al. [50], Pollastrini et al. 1994 [78], The Nordic Expert Group [79]
Xylene, mixed isomers	1330-20-7 108-38-3 106-42-3	TWA 100 ppm (435 mg/m^3) ST 150 ppm (655 mg/m^3)	TWA 100 ppm (435 mg/m^3)	TWA 20 ppm	Neurotoxicity Reproductive toxicity Kidney toxicity Gastrointestinal injury Ototoxicity	NIOSH [80], Jang et al. [48], Lee et al. [50], Lim et al. 2023 [81], The Nordic Expert Group [79]
Toluene	108-88-3	TWA 100 ppm (375 mg/m^3) ST 150 ppm (560 mg/m^3)	TWA 200 ppm	TWA 20 ppm	Neurotoxicity Genotoxicity Kidney toxicity Ototoxicity	NIOSH [80], Jang et al. [48] Tokunga et al. [77], Lim et al. [81], The Nordic Expert Group [79]
1,3,5-Trimethylbenzene 1,2,4-Trimethylbenzene 1,2,3-Trimethylbenzene	108-67-8 95-63-6 526-73-8	TWA 25 ppm (125 mg/m^3)	None	NA	Neurotoxicity	PubChem, ECHA
N-butyl acetate, *t*-Butyl acetate	123-86-4 540-88-5	TWA 150 ppm (710 mg/m^3)	TWA 150 ppm (710 mg/m^3)	TWA 50 ppm (238 mg/m^3)	Neurotoxicity Hepatotoxicity	PubChem, ECHA

(Continues)

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Common endpoints

- **Neurotoxicity**
- **Hepatotoxicity**
- **Nephrotoxicity** (kidney)
- Ototoxicity
- Reproductive tox
- Genotoxicity
- GI toxicity
- Cardiovascular toxicity
- Lung fibrosis / silicosis
- COPD

Exposure and urinary biomonitoring

- Workplace observations & products analysis
- Inhalation exposures
- Skin exposures

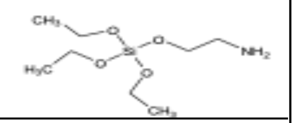
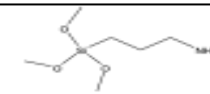
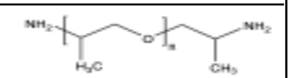
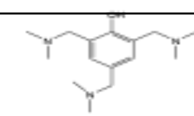
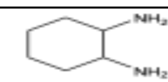
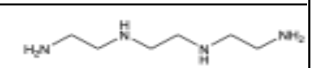
- Simultaneous assessment of urinary biomarkers pre- and post-shift
  - Specific gravity and creatinine adjustment
  - Chemical analysis – exposure and effect markers
    - *Epoxy biomarkers*
    - *Isocyanate biomarkers*
    - *Metals*
    - *PFAS*
      - *Oxidative stress markers*
      - *Kidney injury biomarkers*
      - *Heat stress*

Workplace exposure and biomonitoring work

Activity	Site visits	Number of samples		
		Air 	Glove pairs 	Urine [1] 
Spray Polyurethane Foam, SPF • Retrofit; new construction; injection	16	41 personal 43 area	37	87
• SPF trimming	2	10	n/a	5
Metal structure coatings ISOCYANATE-based mid- or top-coats Bridges; Tanks; Wind turbines	10	25 personal 7 area	31	53
EPOXY-based mid-coat in bridges	4	10	18	31
Floor coating, isocyanate based	3	6	5	8
Total	35	142	88	184

[1] *Includes pre-shift and post-shift urine samples*

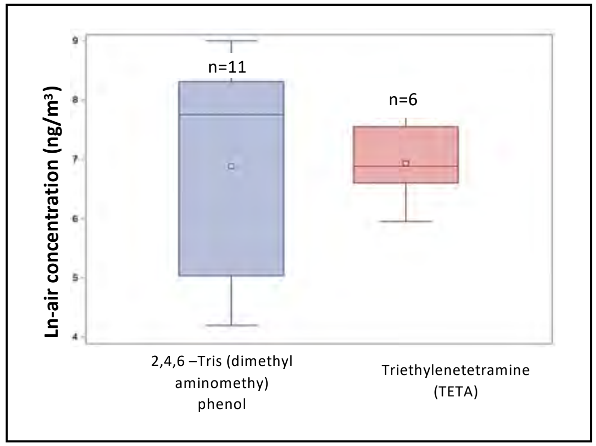
Targeted quantitation of amine hardeners in coating systems, preliminary data

Nr	Chemical Name	Abbreviation	Application	CAS Nr	Concentration in bulk product (% by weight)	Structure
1	Triethoxysilyl Propylamine	TESP	Topcoat	919-30-2	≥50 -≥90	
2	Polyamidoamine	PAdAm	Primer	68082-29-1	≥10 - ≤25	
3	Aminopropyl trimethoxysilane	APTMS	Topcoat	13822-56-5	≥10 - ≤25	
4	Polyoxypropylene diamine	POPD	Midcoat & Primer	9046-10-0	2.5 -<10	
5	Polyamide	PAmD	Midcoat	68410-23-1	10.01	
6	Tri (dimethylaminomethyl) phenol	TdMAmPh	Midcoat	90-72-2	1.0 - 10	
7	Diaminocyclo hexane	DMCH	Midcoat	694-83-7	1.0 -<10	
8	Cycloaliphatic Amine	CAM	Midcoat	Trade Secret	1.0 -< 2.5	
9	Triethylene Tetramine	TETA	Midcoat & Primer	112-24-3	≤0.3 - 0.64	
10	Fatty Acid Amine	FAA	Primer	85711-55-sc3	≤0.3	

Amine Hardeners in Epoxy Coatings - Inhalation and dermal exposure

#	Chemical Name	Abb.	CAS
1	2,4,6-Tris(dimethyl-amiomethyl) phenol)	TdMAmPh*	90-72-2
2	1,2-Diaminocyclohexane	DMCH*	694-83-7
3	Triethylene Tetramine[2]	TETA*	112-24-3
4	3-(Triethoxysilyl)-propylamine	TESP	919-30-2
5	(3-Aminopropyl)-trimethoxysilane	APTMS	13822-56-5
6	Fatty acids C18-unsatd dimers polymers with tall-oil fatty acids and triethylenetetramine	PAdAm	68082-29-1
7	Poly (propylene glycol) bis(2-aminopropyl ether)	POPD	9046-10-0

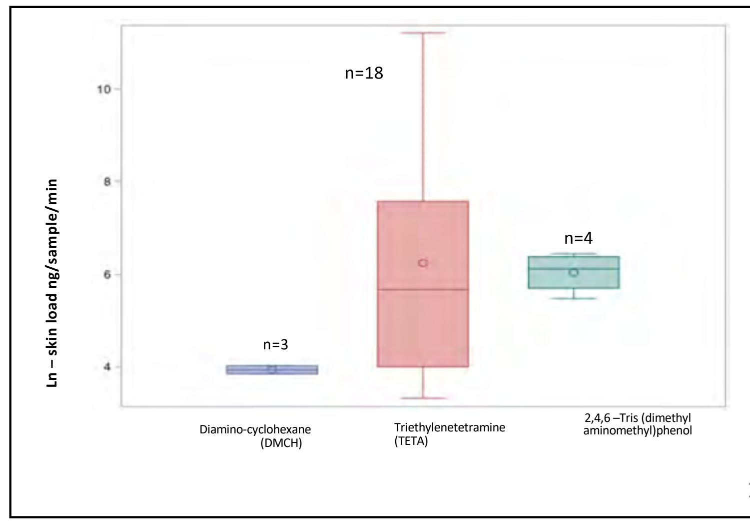
*Detectable amines
Blue colored amines are known sensitizers



Airborne exposure to amines
2 amines detected (lower % detected compared to SPF up to 23-42 % of samples)

There are no occupational standards related to these amines!

Dermal exposures
- 3 amines detected in glove samples
(11-52 % of samples)



Urinary levels of metals in coating workers

Urinary metals	% detects	Coating (n=78)			
		Pre (n=37)		Post (n=41)	
		GM (GSD)	Range	GM (GSD)	Range
Titanium (µg/L)	99.3	164.6 (2.5)	171.5 - 287.7	87.2 (5.2)	115.3 - 200
Vanadium (µg/L)	25.3		0.2 - 0.3	M 0.2	0.1 - 0.3
Chromium (µg/L)	2.7			.	
Manganese (µg/L)	24.0	M 0.6	0.3 - 1.4	M 1	0.7 - 2.2
Iron (µg/L)	83.3	19.6 (17.1)	40.2 - 218.9	28 (7.8)	47.4 - 112.7
Cobalt (µg/L)	80.0	0.2 (5.2)	0.2 - 0.7	0.3 (4.1)	0.4 - 1.2
Nickel (µg/L)	62.0	1.6 (20.2)	3.9 - 14.6	2.1 (14.5)	5.4 - 10.4
Copper (µg/L)	98.7	19.3 (2.1)	18.8 - 29.6	22 (2.3)	23 - 34.1
Zinc (µg/L)	100.0	683 (2.6)	718.4 - 1,117.0	717.2 (3.8)	846.9 - 1,254
Arsenic (µg/L)	83.3	13.2 (7.5)	17.6 - 94.4	16.6 (7.2)	27.9 - 96.2
Molybdemun (µg/L)	98.0	62.2 (3)	64.1 - 136.2	59.4 (6.1)	74.8 - 132.5
Cadmium (µg/L)	100.0	0.6 (2.1)	0.5 - 1	0.7 (2.2)	0.7 - 1.3
Tin (µg/L)	84.7	0.6 (9.7)	1.3 - 2.8	1.7 (15.3)	7.9 - 36.7
Antimony (µg/L)	71.3	0.1 (6.9)	0.2 - 0.4	0.2 (6.2)	0.3 - 0.5
Cerium (µg/L)	50.7	<0.01 (17)	<0.01 - 0.3	<0.01 (15.2)	<0.01 - 0.4
Lead (µg/L)	36.6	M 5.5	4.6 - 13.8	M 8.3	7.6 - 15.5
Mercury (µg/L)	11.3	-	-	-	-
Boron (g/L)	98.0	1.52 (2.4)	1.5 - 2.6	1.3 (4.2)	1.6 - 2.8
Magnesium (g/L)	100.0	102.35 (1.9)	99.8 - 145.1	84.5 (2.1)	86.4 - 124.6
Aluminium (µg/L)	100.0	107 (2.4)	3.2 - 431.9	148.7 (2.4)	148.2 - 277.3
Calcium (g/L)	100.0	196.73 (2.1)	186.3 - 331.9	131.5 (2.3)	136.5 - 215.2

- Zinc, Aluminum, Copper, and Arsenic urinary levels
  - Significantly higher in coating than SPF workers
- Metals – multiple present in coating systems:
  - Zn/ZnO / FeOx/ TiO2/ SiO2/ Sn/Mg (talk)/Ca
  - Alumina
- Potential exposure to lead paints and steel (Ni, Co, Mn, Mo) during abrasive blasting
- Comparison with the general population, BEIs, and clinical guidance values are in progress.

PFAS in construction

A wide range of materials in the construction industry

- Concrete mixtures
- Tiles
- Floor waxing
- Wood sealants
- Adhesives used in roofing, flooring, and carpeting
- Metal structure coating products

Limited data on PFAS content and often proprietary!
SDS do not report PFAS!!!

Healthy Building Network report

- 94 Paints from 8 major manufacturers
- 65% of the paints and coatings market share in North America
- 50% of paints contained Total Fluorine (maker for PFAS) at concentrations 42-688 ppm.
- Specific PFAS are not known but a recent report shows current formulations contain **short–chain PFAS**

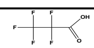
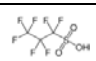
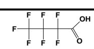
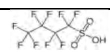
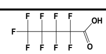
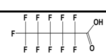
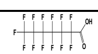
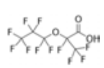
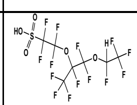
PFAS in coating products – pilot findings

Product	PFAS concentrations (ug/G, ppm)			
	PFPrA	PFBuS	PFBuA	GenX
SPF 1	LOD	249.0	23.5	4.5
SPF 2	70.0	127.0	17.5	2.5
Coating 1	LOD	70.4	15.7	3.9
Coating 2	605.0	293.0	16.6	6.1
Coating 3	LOD	309.0	16.1	6.6
Coating 4	348.0	289.0	14.9	2.8
Coating 5	LOD	304.0	17.1	7.3
Coating 6	LOD	306.0	15.4	5.0
Coating 7	LOD	335.0	16.6	7.1

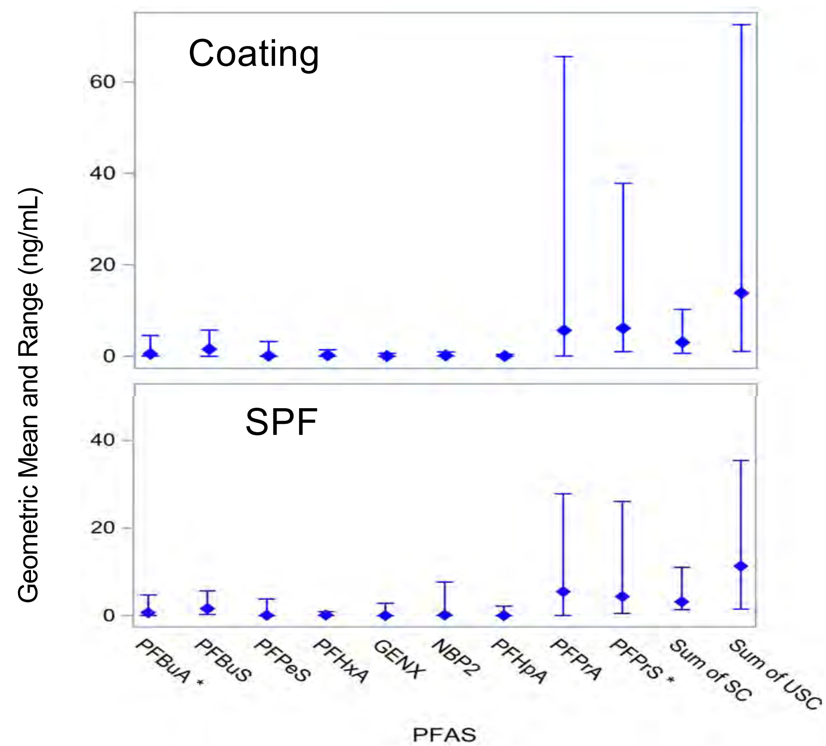
- LC-ESI-MS/MS – 49 PFAS
- Four PFAS found routinely in several products at sampled sites

PFAS in urine of construction workers -

LC-ESI-MS/SM method - 49 PFAS

Chemical Name	Acronym	Formula	CAS Number	Octanol-water partition constant (log Kow)	Boiling point	Half life in humans
Ultra-short chain						
Pentafluoropropionic acid (C3)	PFPrA		422-64-0	1.79	97°C	88 days[3]
Perfluoropropane sulfonic acid (C3)	PFPrS		423-41-6	2.75	196°C	
Short chain PFAS						
Perflurobutanoic acid (C4)	PFBuA		375-22-4	1.43	121°C	72 hours[4]
Perfluorobutane sulfonic acid (C4)	PFBuS		375-73-5	2.79	152°C	26 days[5]
Perfluoropentanoic acid (C5)	PFPeA		2706-90-3	1.35	113°C	
Perfluoropentane sulfonic acid (C5)	PFPeS		2706-91-4	3.38	218°C	0.63 years[6]
Perfluorohexanoic acid PFHxA (C6)	PFHxA		307-24-4	2.85	157°C	32 days[7]
Perfluoroheptanoic acid (C7)	PFHpA		375-85-9	2.05	146°C	1.5 years[8]
Other PFAS/precursors						
HFPO-DA propanoateammonium salt of heptafluoropropoxy-propanoate	GEnX		62037-80-3	5.12	180°C	
7H-Perfluoro-4-methyl-3,6-dioxaoctanesulfonic acid/ [PFESA (Nafion) Byproduct 2]	NBP-2		749836-20-2	5.98	221°C	292 days[9]

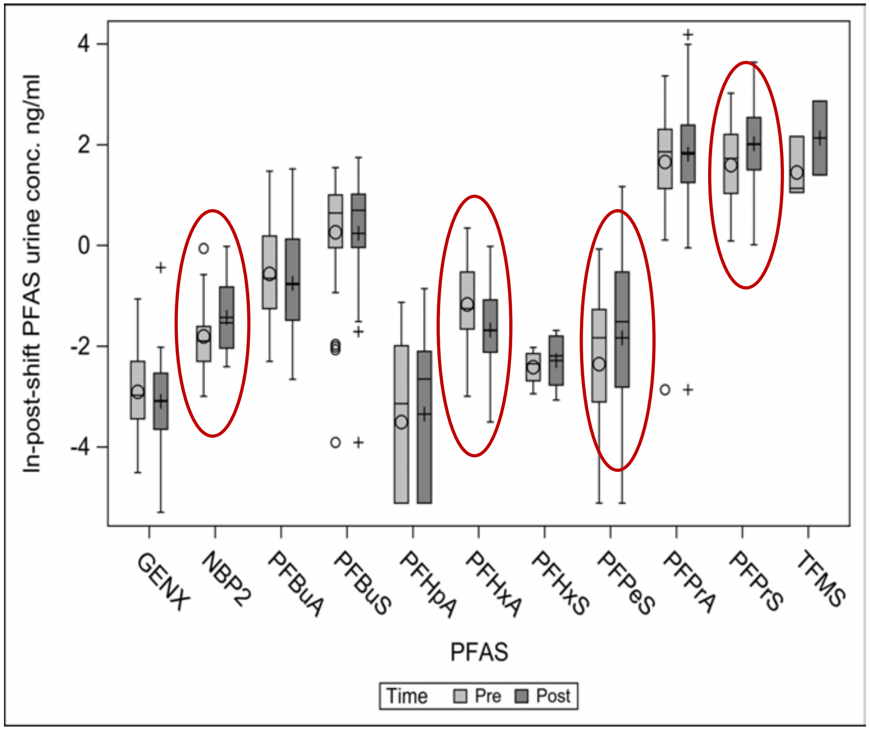
- 9 PFAS species routinely measured in urine
- 4 of them match PFAS in tested products
  - PFPrA, PFBuA, PFBuS, GenX



Cross-shift changes in urinary PFAS among coating workers (ng/mL, ppb)

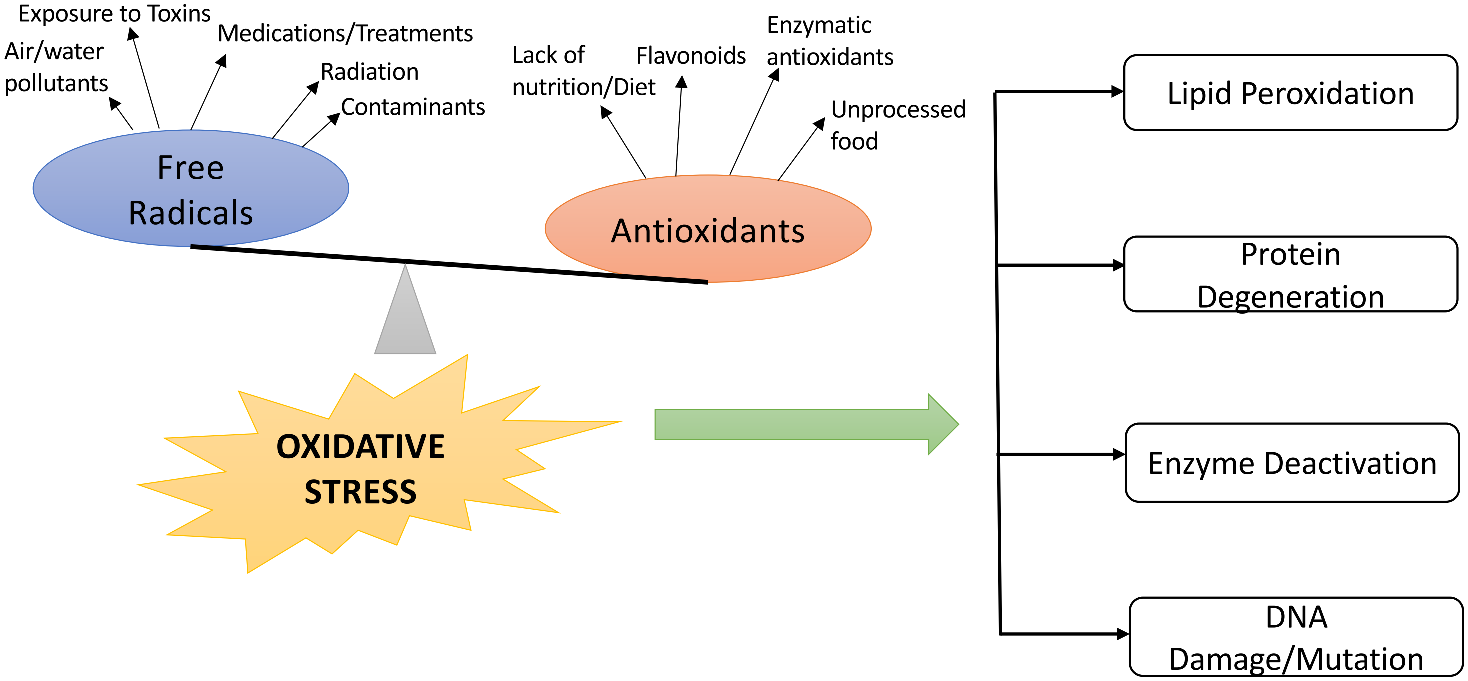
- Post-shift levels of PFPrS, PFHxA and NBP2 were significantly different than inpre-shift urine ($p<0.05$) of coating workers.

- **Concentrations of ultra-chain PFAS in urine samples of coating workers were 100 times higher than values reported in the general population** (Zheng et al. 2023*).



*Zheng G, Eick SM, Salamova A. Elevated Levels of Ultrashort- and Short-Chain Perfluoroalkyl Acids in US Homes and People. Environ Sci Technol. 2023 Oct 24;57(42):15782-15793. doi: 10.1021/acs.est.2c06715. Epub 2023 Oct 11. PMID: 37818968; PMCID: PMC10603771.

Markers of Oxidative Stress in Urine



- Asthma
- COPD
- Chronic inflammation
- Autoimmune disease
- Myocardial infarction
- Ischemia
- Hypertension
- Chronic Kidney diseases
- Nephritis
- Parkinson
- ADHD
- Stroke
- Melanoma
- Dermatitis
- Psoriasis
- Cancer

Urinary oxidative stress markers

DNA/RNA damage biomarkers:

- 8-hydroxy-2’-deoxyguanosine(8OHDG)
- 8-hydroxyguanosine (8OHG)
- 5-hydoxymethyluracil (5OHMeU)

Protein oxidation biomarkers:

- 3-Chlorotyrosine
- 3-Nitrotyrosine
- O-Tyrosine

Lipid peroxidation biomarkers:

- 8-Isoprostane
- 4-Hydroxy-2-nonenal (4-HNE)
- Malondialdehyde (MDA)

Urinary OS markers

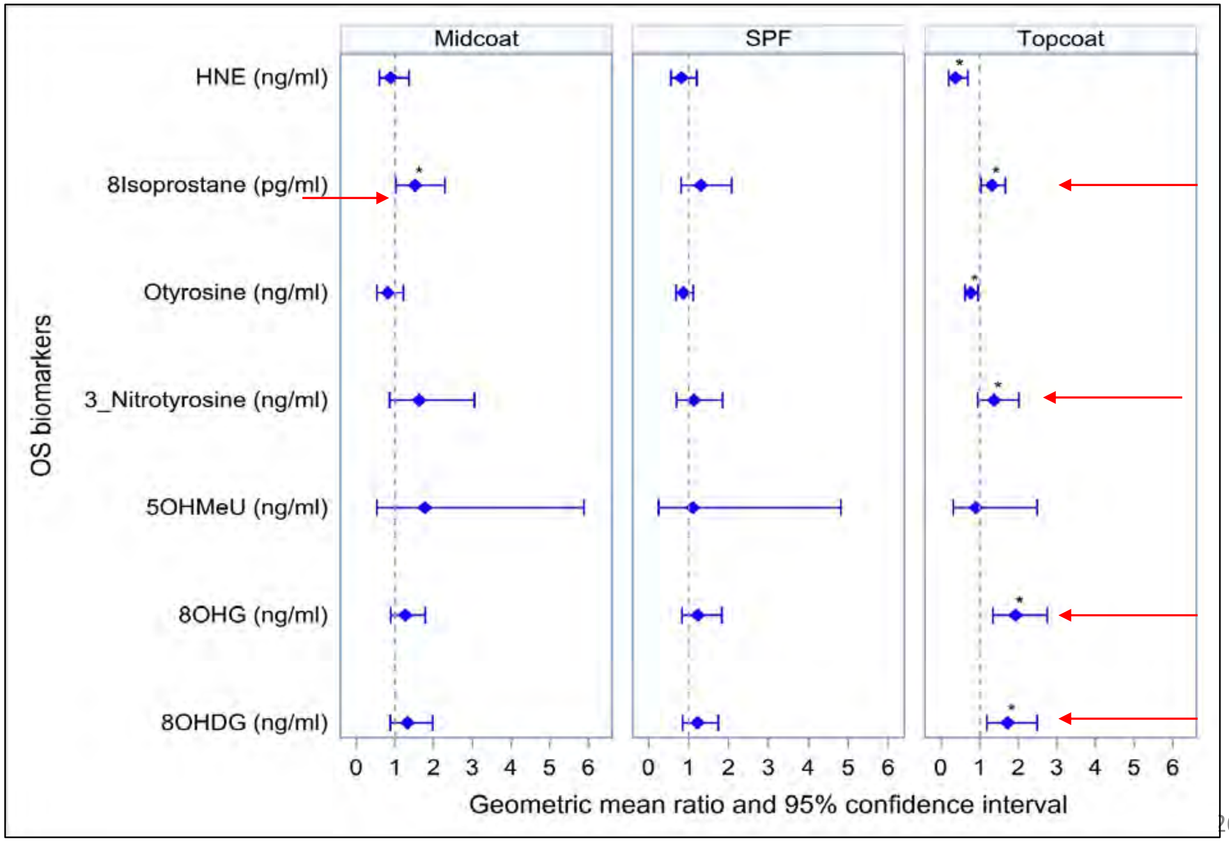
Biomarkers (ng/mg creatinine)	Midcoat (n= 14)			Topcoat (n=25)	
	% detects	**GM (GSD)**	**Range**	**GM (GSD)**	**Range**
8OHdG	100	3.26 (2.04)	1.22 - 9.35	2.35 (1.89)	0.69 - 5.53
8OHG	100	5.87 (1.66)	2.19 - 15.63	6.19 (1.46)	3.41 - 10.75
5OHMeU	68.8	0.1 (4.94)	0.02 - 15.72	0.1 (2.67)	0.01 - 0.45
3-Nitrotyrosine	75	0.16 (5.08)	0.01 - 2.61	0.44 (1.75)	0.16 -1.67
O-Tyrosine	100	1.33 (2.87)	0.37 - 10.17	0.88 (2.06)	0.18 - 2.88
8-Isoprostane	96	20.49 (7.75)	0.33 - 231.69	20.96 (2.15)	3.76 – 20.1
4-HNE	100	2.34 (2.97)	0.52 - 23.37	1.95 (2.51)	0.30 - 12.01
MnDAld	100	243.99 (1.88)	91.77 - 558.58	197.8 (1.53)	73.59 - 386.8

Cross-shift changes in urinary OS Markers

Top-coat: 4 oxidative stress markers were significantly higher in post-shift compared to pre-shift of top coating coating workers

Higher risk among coating workers compared to SPF workers!

Ratio of Post/Pre –shift Oxidative Stress Markers among coating workers vs SPF

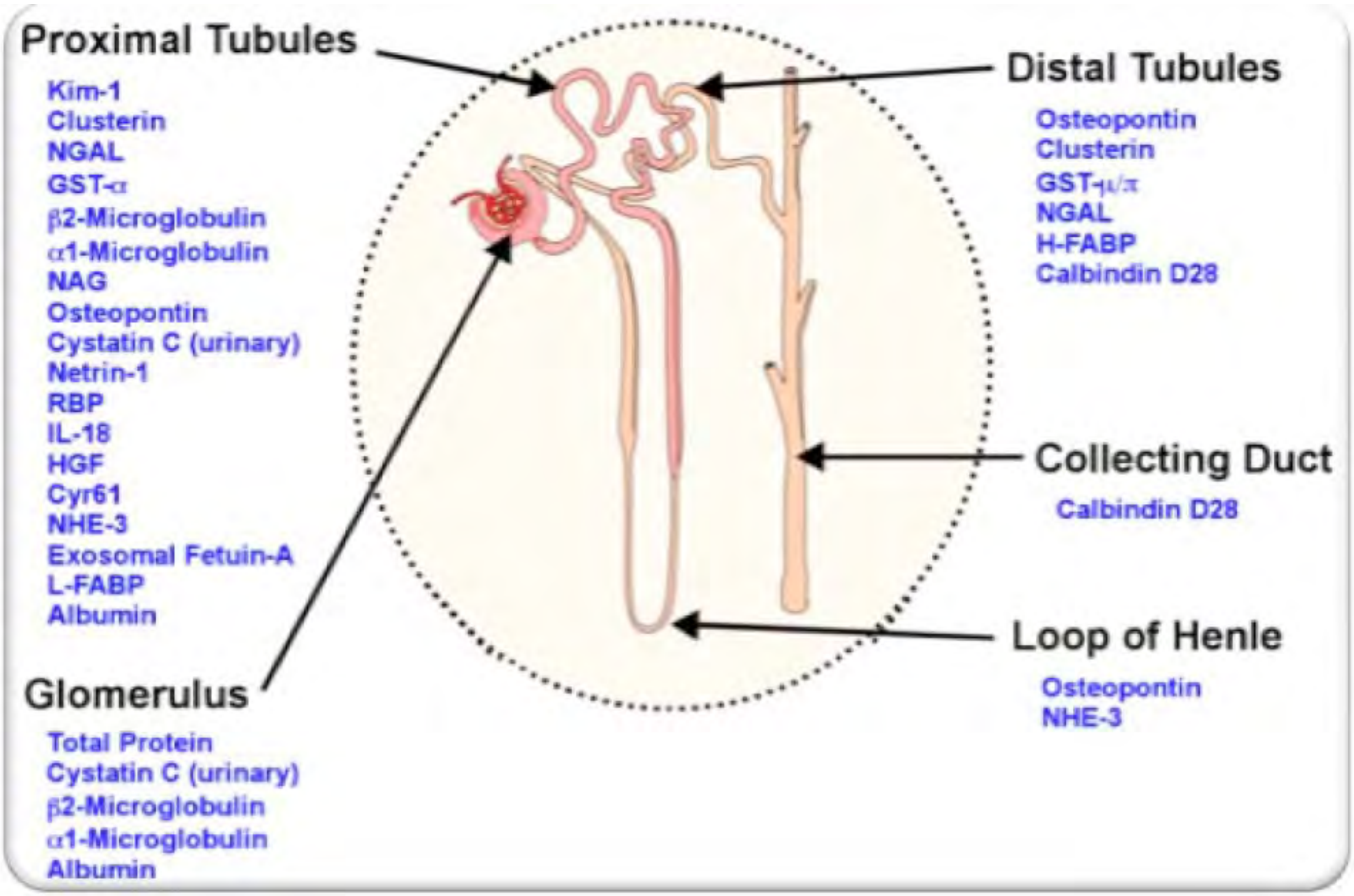


Association with urinary exposure biomarkers

$$\text{Ln-OS biomarkers} = \beta_0 + \beta_1 * \text{Ln-Biomarker} + \beta_2 * \text{Creatinine} + \beta_3 * \text{Age} + \varepsilon$$

OS Biomarker	Task	Exposure biomarker	β_1	P-value
8-OHdG	midcoat	BADGE*2H2O	0.24	0.04
4-HNE	midcoat	BADGE*2H2O	-0.03	0.02
8-OHdG	topcoat	HDA	0.20	0.03
8-Isoprostane	topcoat	HDA	0.19	0.08

Some candidate biomarkers for kidney damage/injury



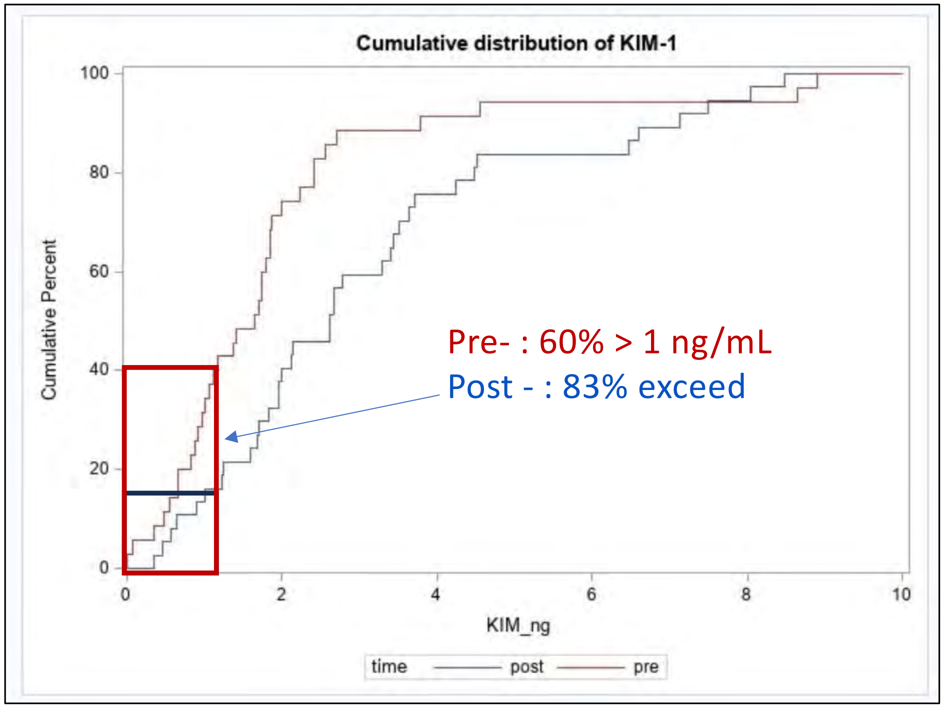
Slide courtesy of Dr. V. Vaidyia HSPH

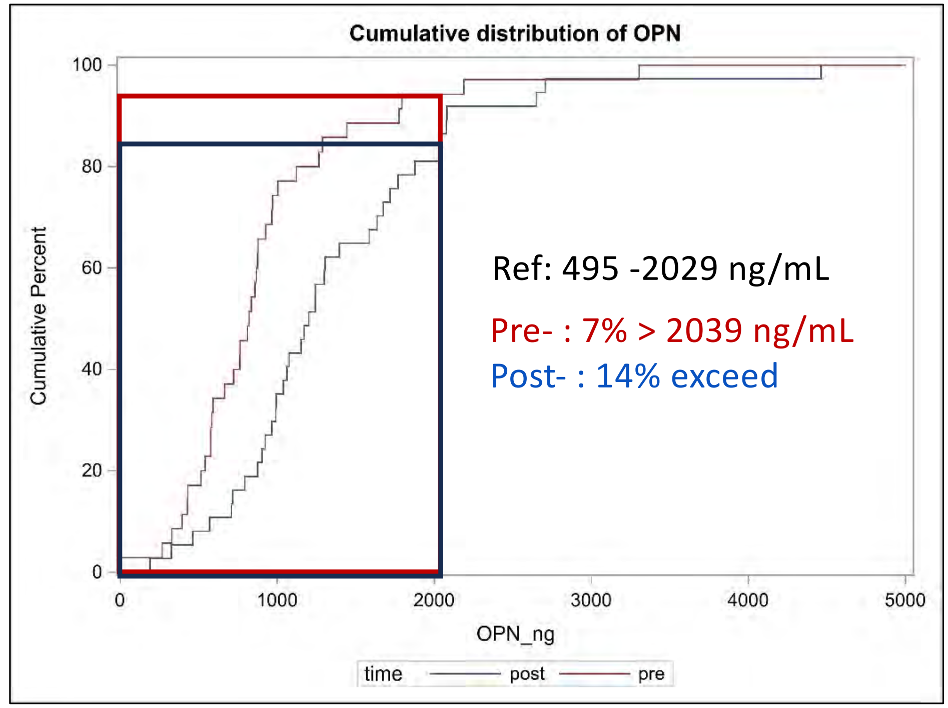
Clinical basis of AKI biomarkers

AKI Biomarker Name (unique ID uniprot)	Abbrev.	ORIGIN
Kidney Injury Molecule-1 (Q96D42)	**KIM-1**	**A type I transmembrane glycoprotein [**containing an ectodomain consisting of an immunoglobulin-like domain and a mucin domain] **that is strongly induced by ischemic and toxic insults to the kidney**.
Osteopontin (P10451)	**OPN**	A highly acidic glycoprotein expressed by many tissues that acts as a **macrophage adhesion and chemotactic molecule**.
Neutrophil gelatinase-associated lipocalin (P80188)	**NGAL**	Expressed in various tissues at low levels with upregulated transcription in **tubuloepithelial cells following ischemic and nephrotoxic kidney injuries**.
Urinary Clusterin (P10909)	**CLU**	A heterodimeric highly conserved secreted glycoprotein expressed in the proximal and distal tubules, glomerulus and collecting duct.
Cystatin-C (P01034)	**CysC**	A small serum protein produced by all nucleated cells and found in most tissues and body fluids. **CysC is freely filtered by the glomerulus and completely reabsorbed and catabolized in healthy renal tubular epithelium.**
Growth Differentiation Factor	GDF	Member of TGF β superfamily. Predicts CDK outcome and progression.
Fibrinogen	FG	Fibrinogen is a soluble 340-kD protein mainly synthesized by the liver; central function in hemostasis. **Predictor of interstitial fibrosis and tubular atrophy and independent risk factor for CKD**.

KIM-1 (ng/mL)

OPN (ng/mL)





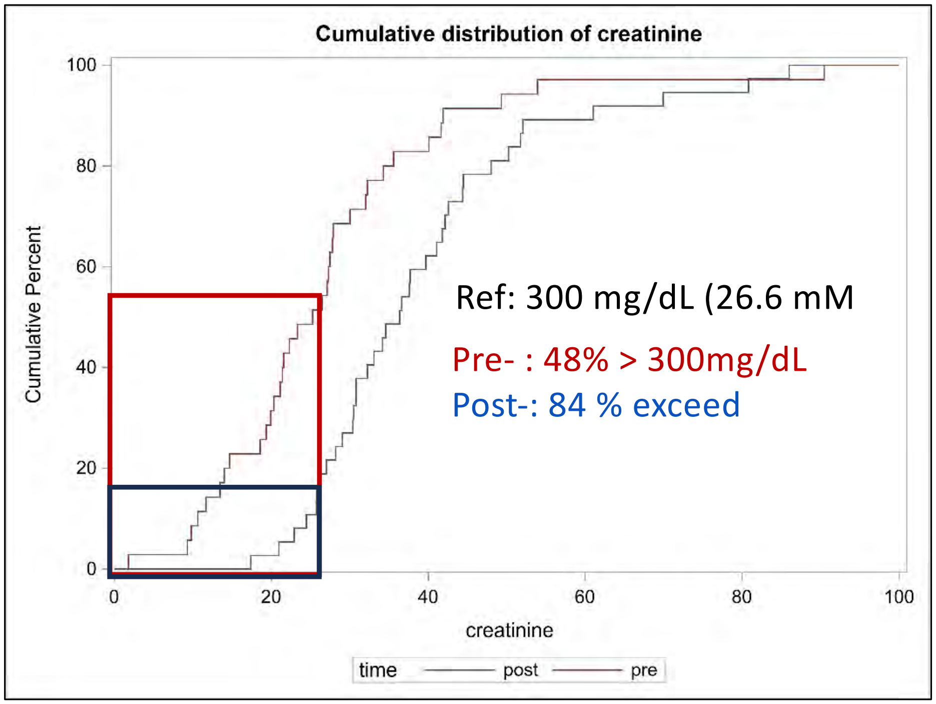
ng/mL

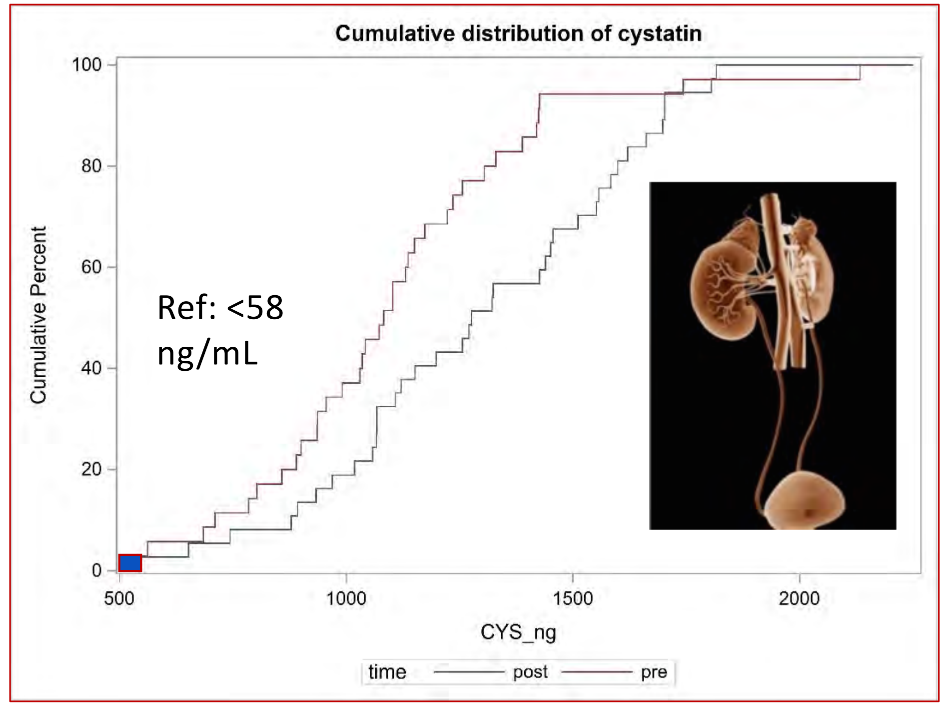
Proximal tubule injury

Systemic: macrophage adhesion and chemotactic molecule.

Creatinine

CysC





mM

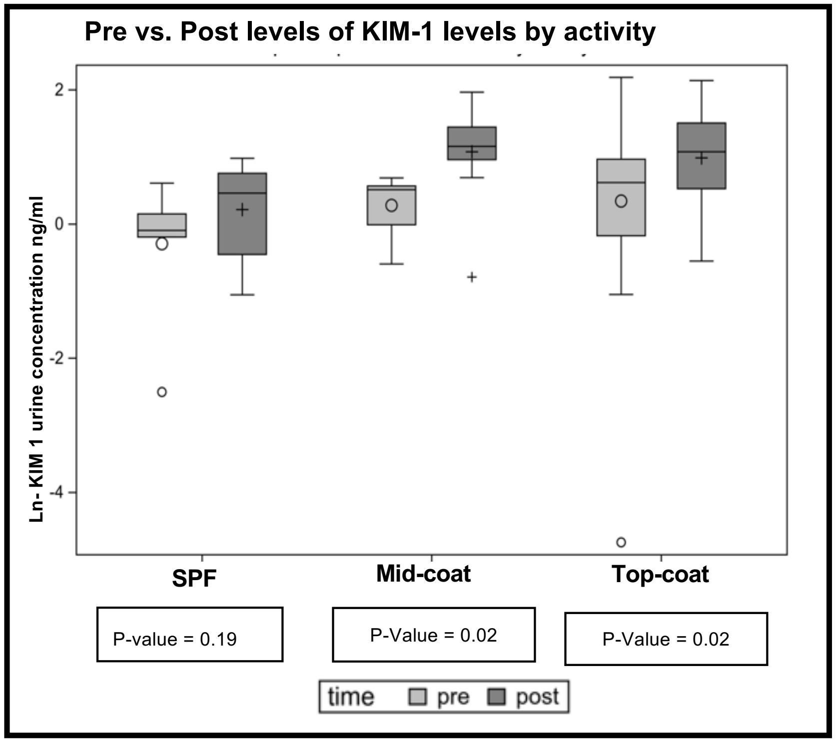
ng/mL

Systemic small protein; Freely filtered by the glomerulus and completely reabsorbed and catabolized in healthy renal tubular epithelium

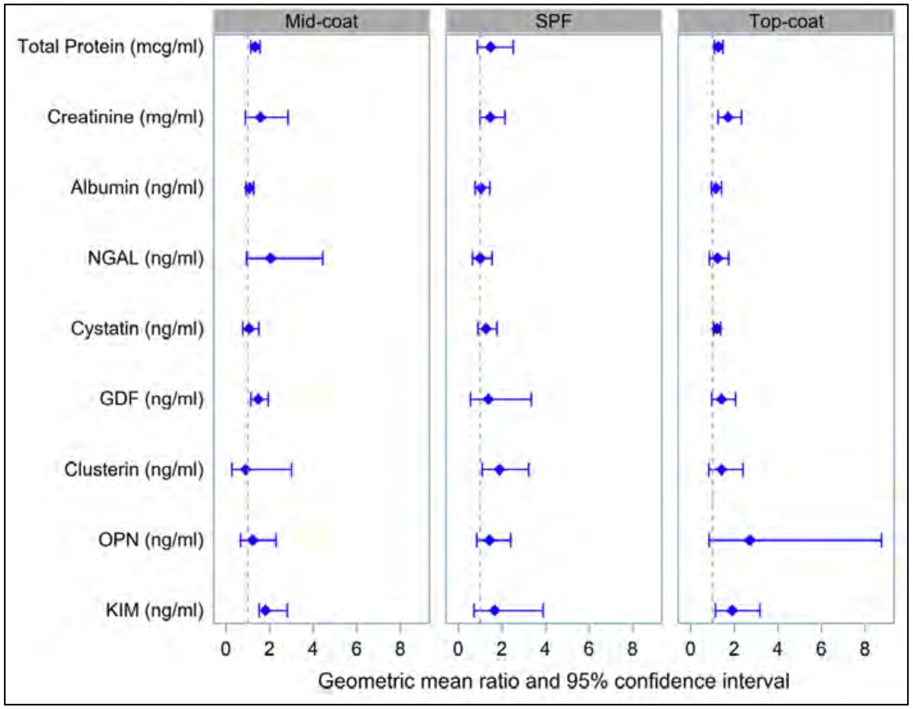
Glomerular filtration

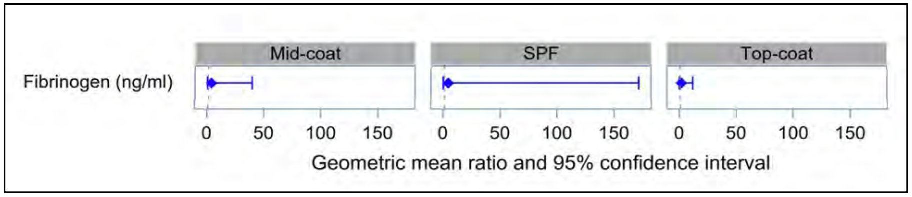
Post-shift KIM 1 is significantly higher than pre-shift urine in coating workers but not in SPF workers !!!

	KIM-1 (ng/mL)
SPF (n=7)	
Pre-Shift GM(GSD)	0.7 (2.8)
Post-Shift GM(GSD)	1.2 (2.1)
Range	0.1 – 2.7
Mid-coat (n=10)	
Pre-Shift GM(GSD)	1.3 (1.6)
Post-Shift GM(GSD)	2.9 (2.2)
Range	0.5 – 7.1
Top-coat (n=20)	
Pre-Shift GM(GSD)	1.4 (4.3)
Post-Shift GM(GSD)	2.7 (2.1)
Range	0.01 – 8.9



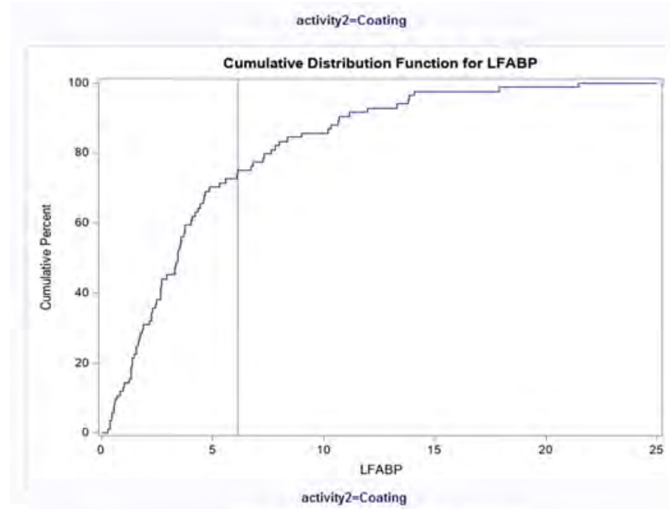
GM ratios of AKI biomarkers: Post-/Pre-shift

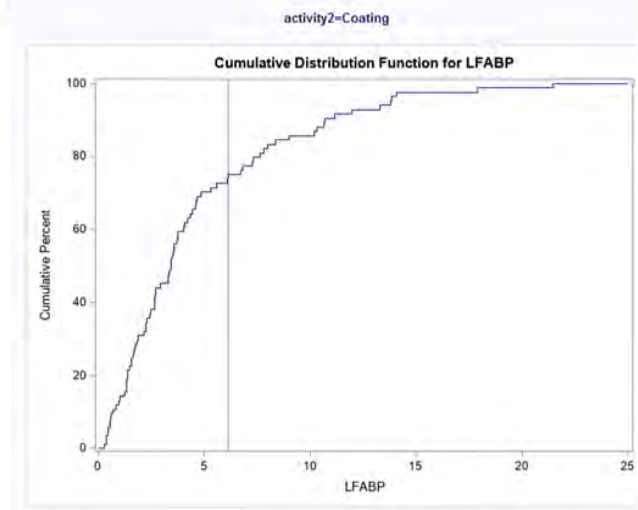




L-FABP, a promising heat stress biomarker *

L-FBAP (ng/ml)	n	Mean	Median	GM (GSD)	Range
Overall	156	4.33	3.87	2.84 (2.7)	0.28 - 21.46
Pre	69	3.73	2.64	2.52 (2.7)	0.28 - 13.32
Post	87	4.81	3.50	3.13 (2.7)	0.30 - 21.46
SPF					
Overall	70	3.82	2.51	2.52 (2.7)	0.28 - 13.62
Pre	30	3.76	2.51	2.53 (2.7)	0.28 - 11.01
Post	40	3.87	2.64	2.52 (2.7)	0.30 - 13.62
Coating					
Overall	84	4.67	3.42	3.07 (2.7)	0.28 - 21.46
Pre	38	3.66	2.67	2.46 (2.7)	0.28 - 13.32
Post	46	5.50	3.68	3.68 (2.6)	0.47 - 21.46
Injection					
Overall	2	8.00	8.00	7.6 (1.6)	5.50 - 10.50





* Goto et al 2022; Liver-type Fatty Acid Binding Protein, L-FABP

Spearman Correlation between L-FABP and exposure and kidney biomarkers

	Coating (n=49)		**SPF (n=14)**	
Biomarkers	L-FABP	p-Value	L-FABP	p-Value
Creatinine	0.42	**<0.01**	0.48	0.11
MDA	0.24	0.09	0.37	0.24
HDA	0.46	<0.01	-	-
Badge*2H2O	-0.04	0.78	-	-
KIM-1	0.41	**<0.01**	0.79	**0.03**
OPN	0.31	**0.03**	0.61	**0.03**
NGAL	0.28	**0.05**	0.06	0.84

New 3- year study

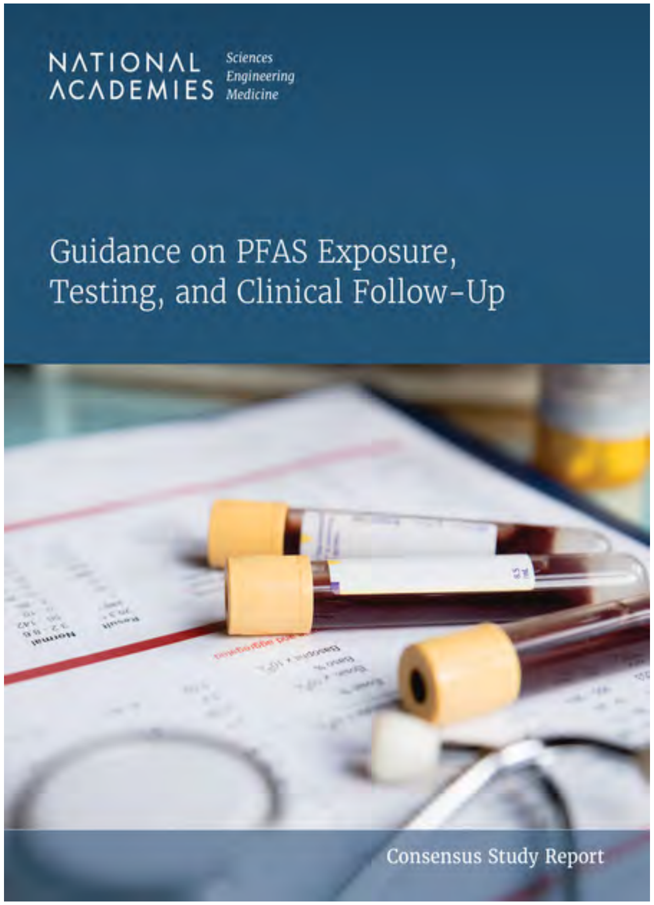
Developing a national roadmap to reduce per- and polyfluoroalkyl (PFAS) exposures among construction painters and allied trades

- ***Identify construction trades with the highest PFAS burden via blood and urine biomonitoring***
  - ***Use NASEM guidelines for clinicians to guide risk categorization & interventions***

- ***Document PFAS use in construction materials***
- ***Develop PFAS exposure and body burden reduction strategies***

Benefits to participants & trades

- Know you PFAS levels in blood and how much comes from work
- Be informed of ways to reduce your PFAS exposures and risks
- Help make construction chemically safer for all
- Provide input on materials to be tested

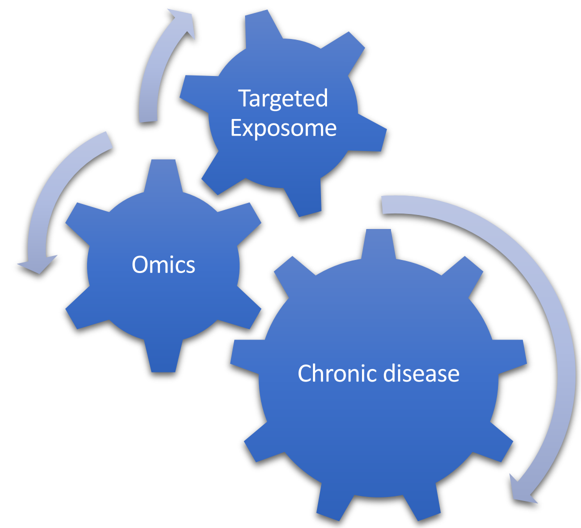


Our vision for the future of chemically-induced chronic diseases in construction

Painters were classified as a Class I occupational carcinogen as early as 1987.

- Real drivers of carcinogenicity not well known to this day
- Limited methods and tools to study chemical exposures and no ongoing prospective longitudinal studies
- Minor emphasis on chemical exposures as drivers of outcomes!
- BTMed – an excellent series of studies on health outcomes, but it reflects exposures of the past 30 years. Exposures of today – very different from 30 years ago - will define diseases of tomorrow!

Modern environmental health



Acknowledgment

We express our most sincere thanks to all contractors, painters, our industry collaborators; CPWR staff and our graduate students for their assistance with field and lab work.

Thank you for your attention!

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