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EFFICIENCY TESTING AND IMPLEMENTATION OF RISK MANAGEMENT MEASURES TO MITIGATE EXPOSURE TO NMS

HENK GOEDE, TOM LIGTHART, JODY SCHINKEL, WOUTER FRANSMAN

INTRODUCTION

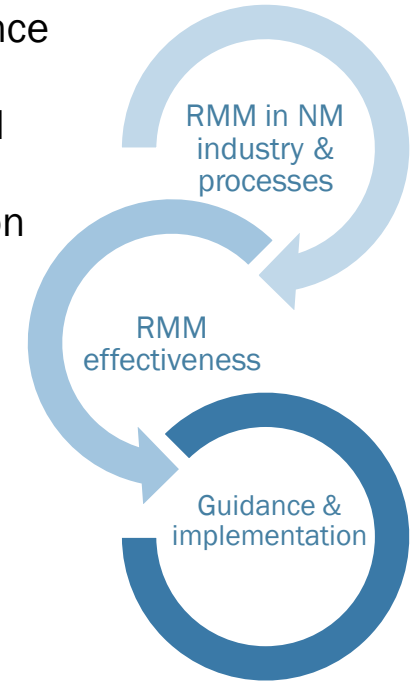
With increasing use of NMs, considerable effort needed to ensure safe use in occupational settings

To mitigate or reduce worker exposure & health effects, Risk Management Measures (RMM) should be introduced

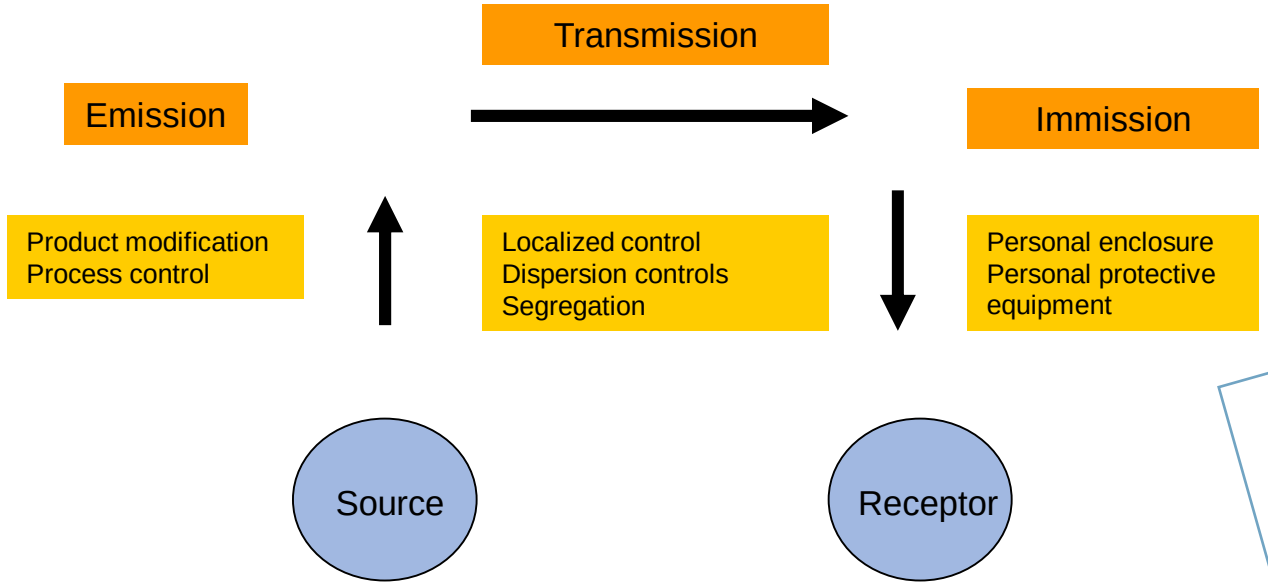
For risk assessment & modelling purposes, (i) RMM design criteria for NM applications and (ii) quantitative effectiveness values are required to recommend and implement RMM in the workplace

Valuable information is already available from recent projects & guidelines focusing on RMMs for NMs, e.g. NIOSH, OECD, LIFE NanoRISK, SUN, NANoREG and GUIDEnano

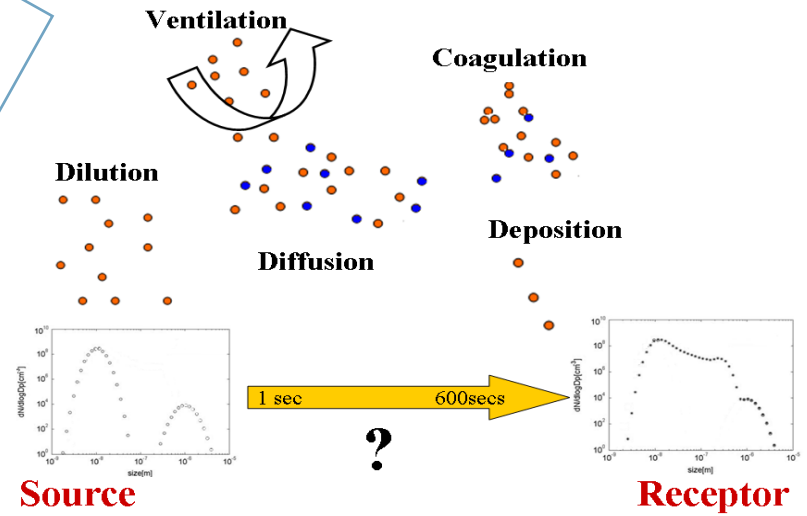
There is a need to integrate evidence to develop guidance and support implementation



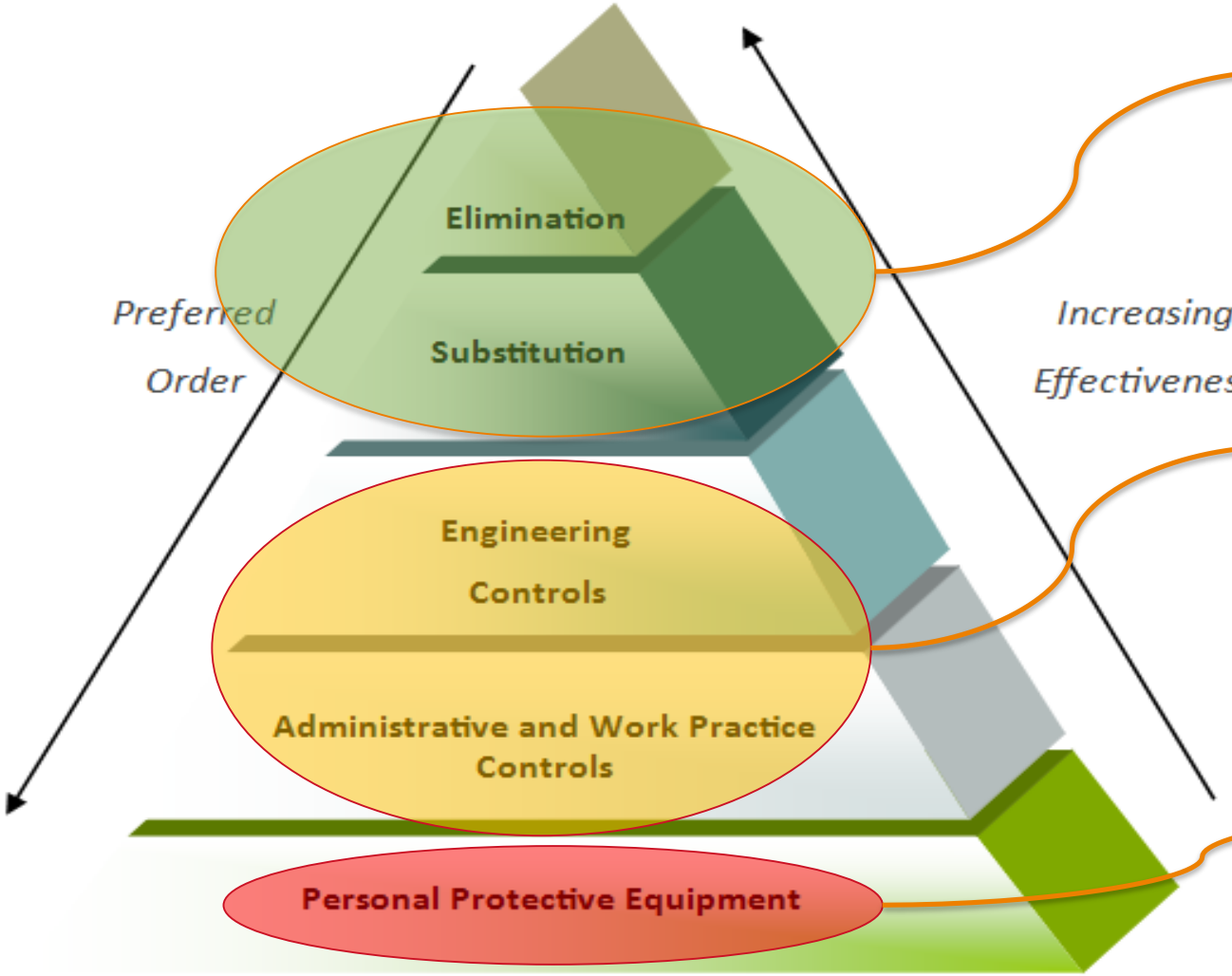
EXPOSURE TO NANOMATERIALS VS CONTROL



How effective are RMMs for nanomaterials?



PRIORITIZATION & MANAGING THE RISKS OF EXPOSURE



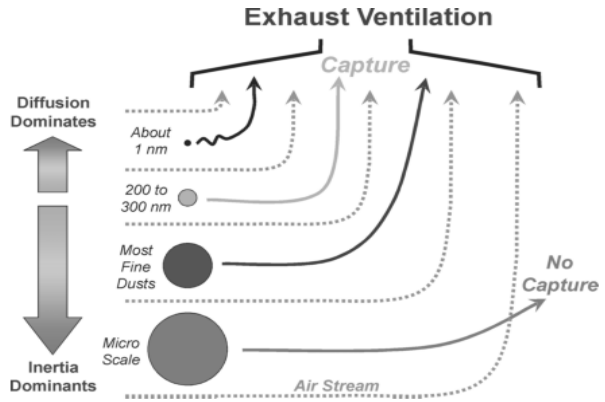
Safe-by-”material”-design

Safe-by-”process”-design

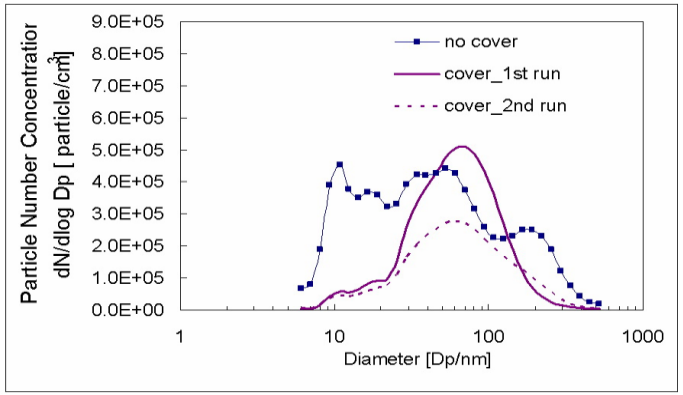
RMM EFFICIENCY: THEORY VS PRACTICE

Engineering controls

Diffusion vs inertia



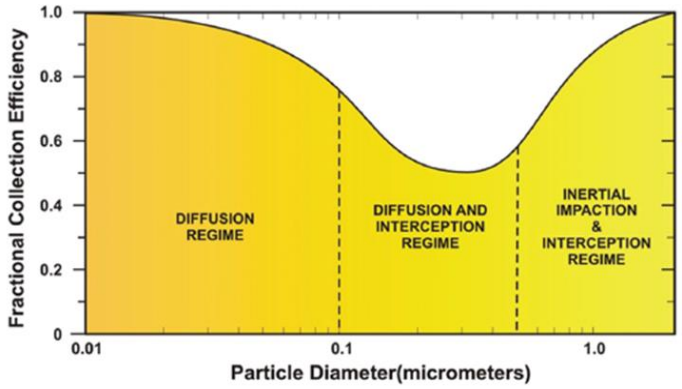
Particle capture efficiency in a ventilation system (Schulte et al., 2008)



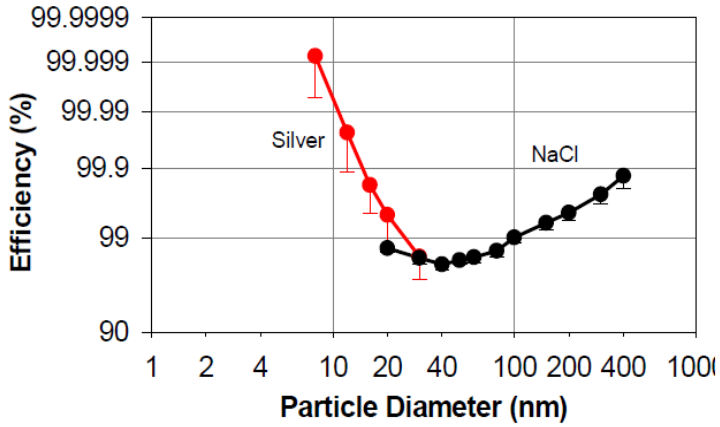
Example of engineering controls on particle number concentrations w/o cover (from Tsai et al, 2008)

Personal Protective Equipment (PPE)

Diffusion vs interception



Collection efficiency curve of the fractional collection efficiency versus particle diameter for a typical filter (from Lee and Liu, 1980)

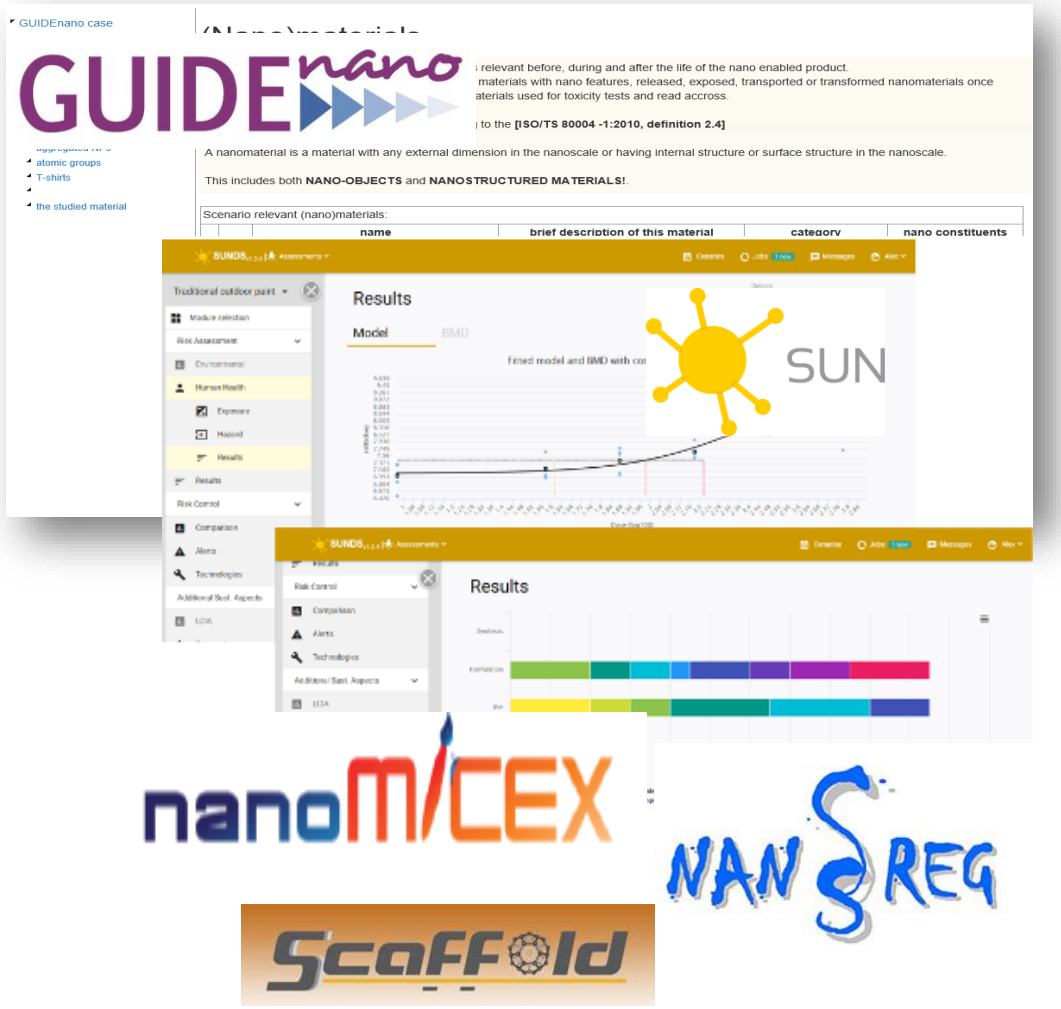


Filtration Performance of a Typical N95 Filtering Facepiece Respirator (FFR) (from Rengasamy et al., 2008)

RMM TESTING

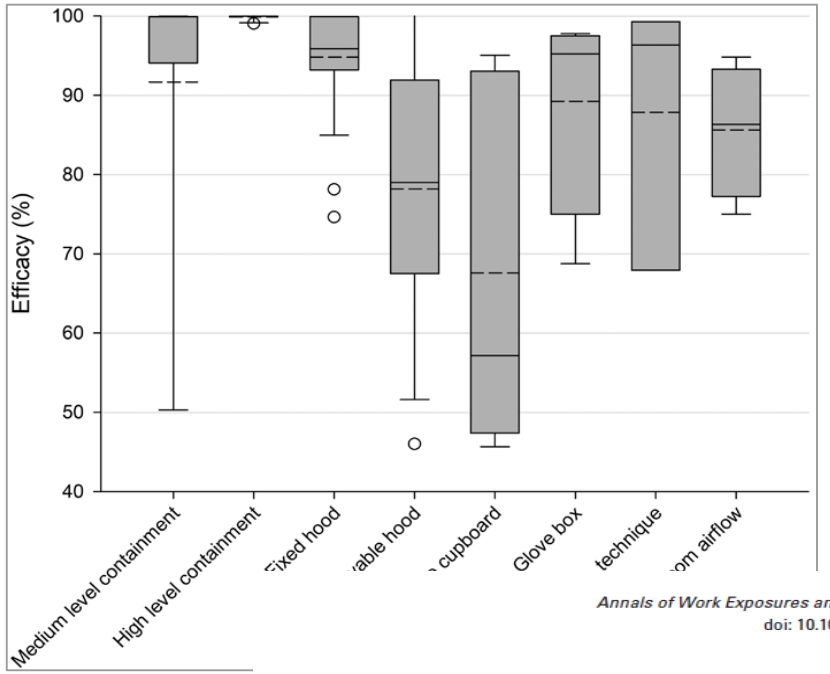
- RMM effectiveness (or efficiency) refers to the reduction in an (exposure) concentration, expressed as a percentage (%)
  - Calculated from control on/off, efficacy factor, protection factor (PF) or Total Inward Leakage (TIL)

- Obtained from a wide range of studies, for example:
  - Pre-/post- tests from field & intervention studies
  - Model estimates from large datasets / cross-sectional studies
  - Upstream/downstream tests from field / experimental studies RPE and SPE



LITERATURE REVIEWS & ANALYSIS

- Literature review & analysis RMMs for NMs (2005–2016)
- Key finding: (too) limited data available to derive RMM effectiveness values
- Engineering controls: effectiveness appears in same order of magnitude to that of conventional RMMs
  - Specific attention proposed for containment, fume cupboards, and glove boxes
- Respiratory Protective Equipment (RPE): mostly experimental data, but also field studies indicate high effectiveness
  - Filtering face respirators less effective - indicated the lowest PFs for particles between 80 and 200 nm



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Review

Review

A Review of Workplace Risk Management Measures for Nanomaterials to Mitigate Inhalation and Dermal Exposure

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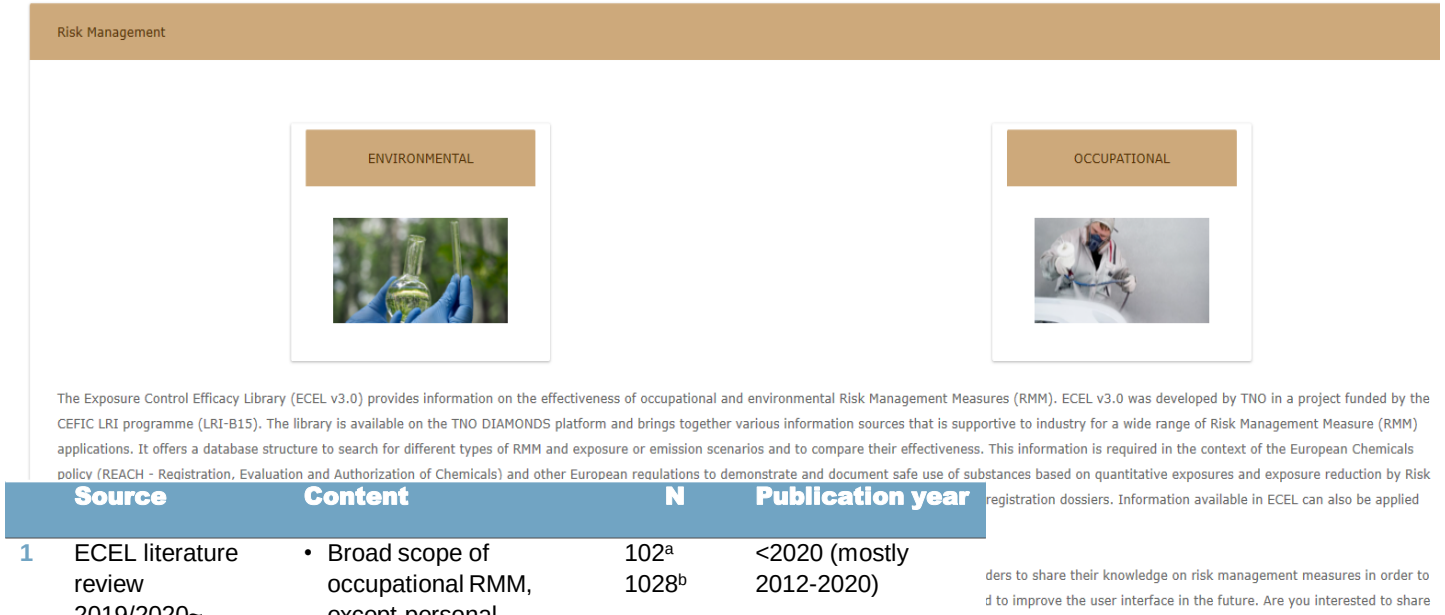
EXPOSURE CONTROL EFFICACY LIBRARY (ECEL)



	Source	Content	N	Publication year
1	ECEL literature review 2019/2020~	• Broad scope of occupational RMM, except personal protective equipment (PPE)	102[a] 1028[b]	<2020 (mostly 2012-2020)
2	ECEL v2.0*~	• Mostly engineering controls	73[a] 449[b]	<2012
3	ECEL v1.0*	• Mostly engineering controls	81[a] 361[b]	<2008
4	TNO MEC RMM manufacturers' data~	• On-tool extraction systems • On-tool wetting systems	287[a,b]	2003-2019
5	Nano-specific data*	• Engineering controls • Respiratory protective equipment (RPE) • Skin protective equipment (SPE)	43[a] ~872[b]	2005-2016
6	BROWSE PPE data*	• Skin protective equipment (SPE)	36[a] 446[b]	1994-2011

[a] *Number of studies*
[b] *Number of records*

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- Open-source library developed in the CEFIC LRI B15-3 project
- Scope: occupational and environmental RMM modules
- Nano-specific data focusing on engineering controls, RPE, SPE
- Content:

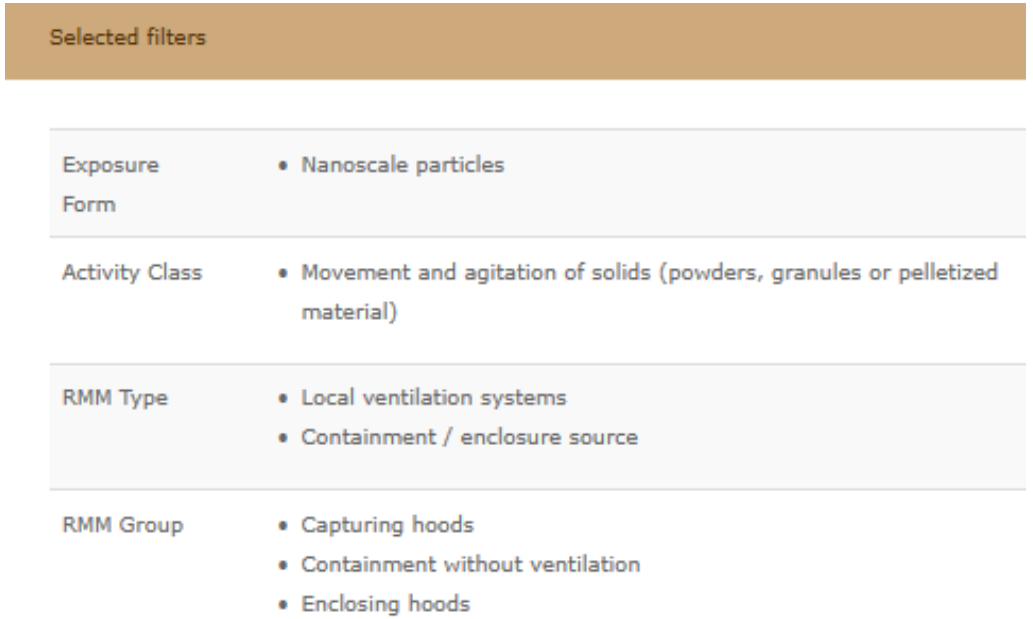
  EC = 183 records / 18 studies

  RPE = 430 records / 19 studies

  SPE = 259 records / 11 studies

EXPOSURE CONTROL EFFICACY LIBRARY (ECEL)

- Scenarios: apply filters for find relevant scenario, e.g.:
  - Type of RMM, agent, exposure/emission form, task, activity class, PROC, exposure route
- Two outputs:
  - *Compare RMM:* plot showing different RMMs found and their effectiveness
  - *RMM analysis:* % effectiveness (reduction in exposure) >> median and a 95% credible interval



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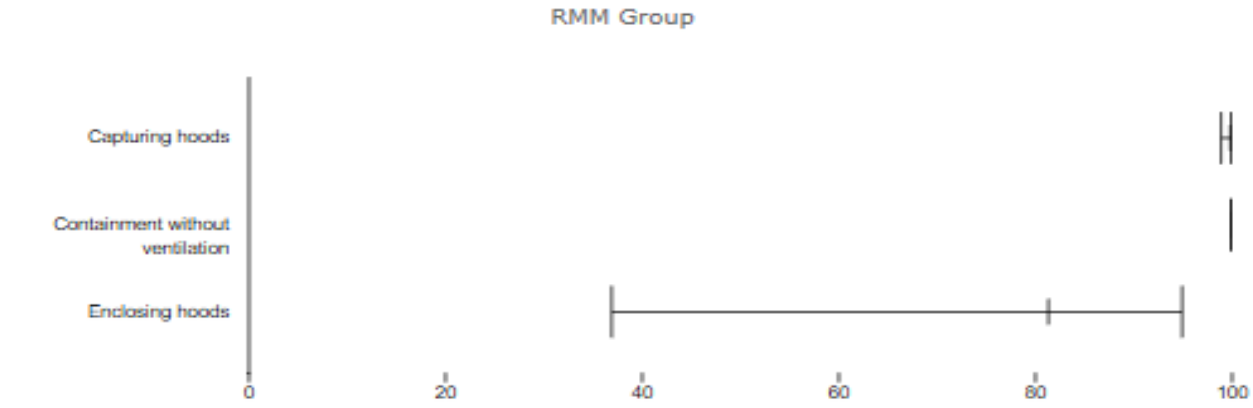

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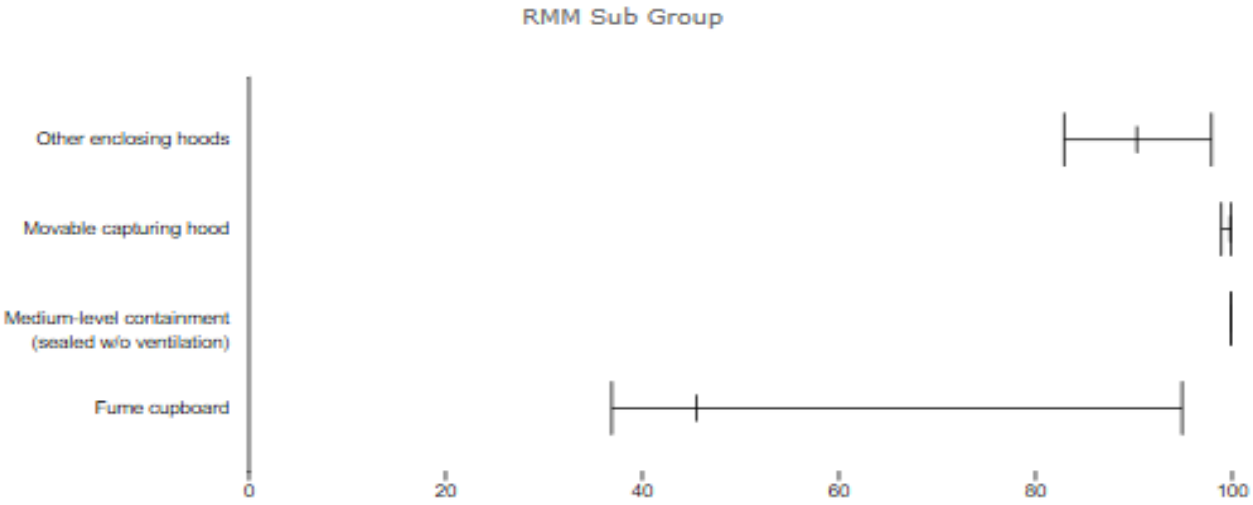

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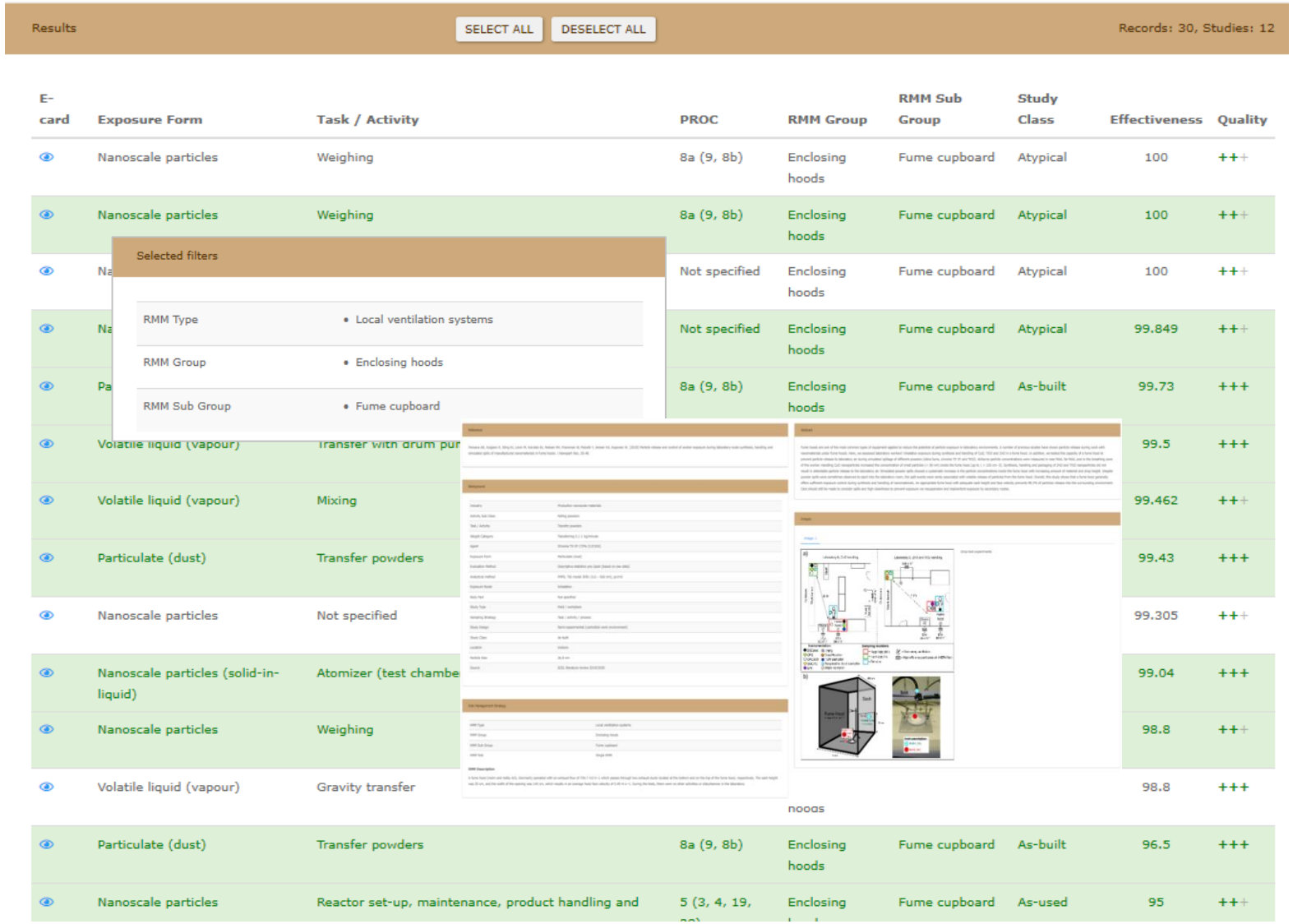

E-card	Exposure Form	Task / Activity	PROC	RMM Group	RMM Sub Group	Study Class	Effectiveness	Quality
	Nanoscale particles	Weighing	8a (9, 8b)	Enclosing hoods	Fume cupboard	Atypical	100	+++
	Nanoscale particles	Weighing	8a (9, 8b)	Enclosing hoods	Fume cupboard	Atypical	100	+++
	Na		Not specified	Enclosing hoods	Fume cupboard	Atypical	100	+++
	Na		Not specified	Enclosing hoods	Fume cupboard	Atypical	99.849	+++
	Pa		8a (9, 8b)	Enclosing hoods	Fume cupboard	As-built	99.73	+++
	Volatile liquid (vapour)	Transfer with drum pur					99.5	+++
	Volatile liquid (vapour)	Mixing					99.462	+++
	Particulate (dust)	Transfer powders					99.43	+++
	Nanoscale particles	Not specified					99.305	+++
	Nanoscale particles (solid-in-liquid)	Atomizer (test chambe					99.04	+++
	Nanoscale particles	Weighing					98.8	+++
	Volatile liquid (vapour)	Gravity transfer					98.8	+++
	Particulate (dust)	Transfer powders	8a (9, 8b)	Enclosing hoods	Fume cupboard	As-built	96.5	+++
	Nanoscale particles	Reactor set-up, maintenance, product handling and	5 (3, 4, 19,	Enclosing	Fume cupboard	As-used	95	+++

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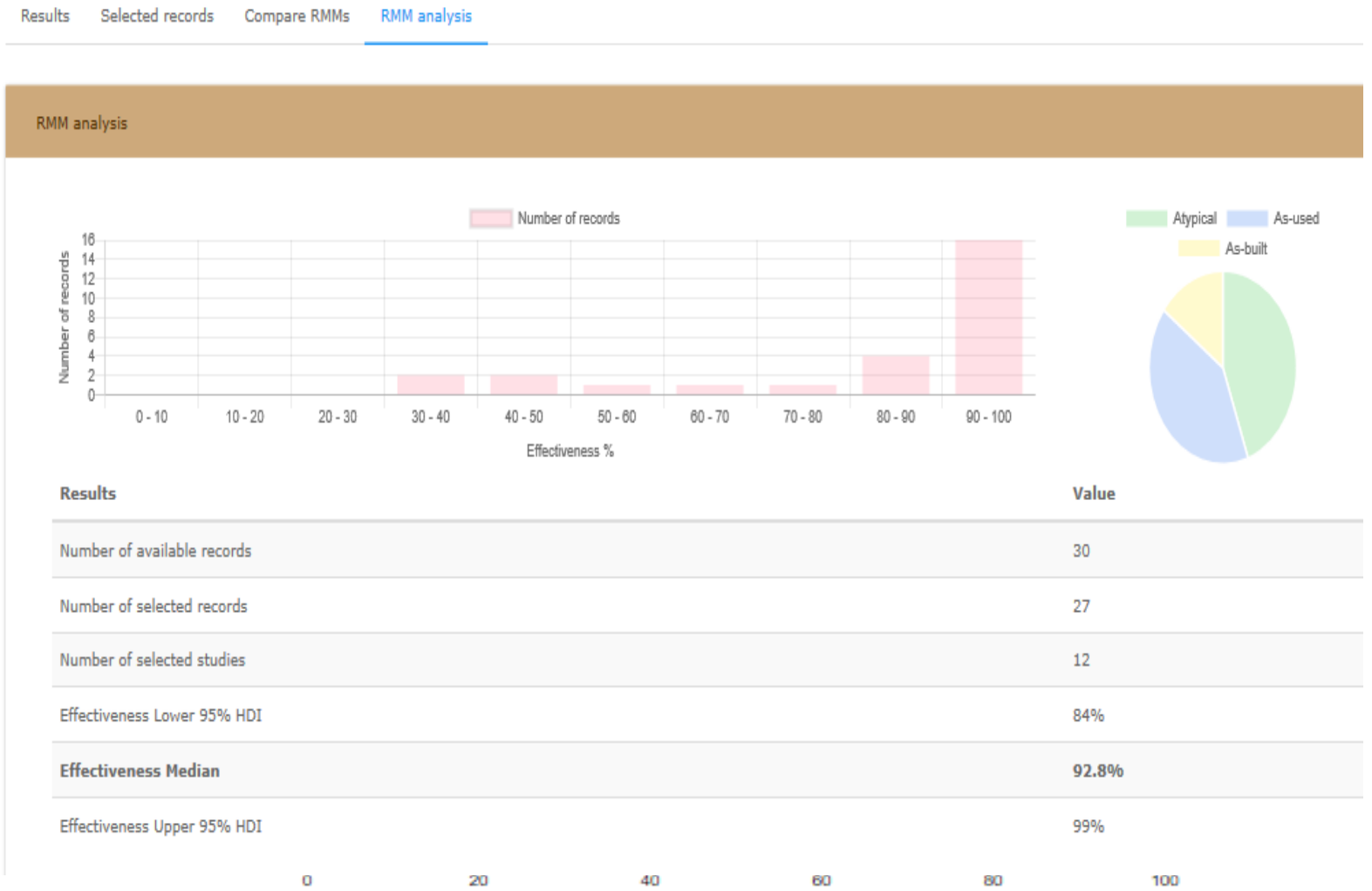
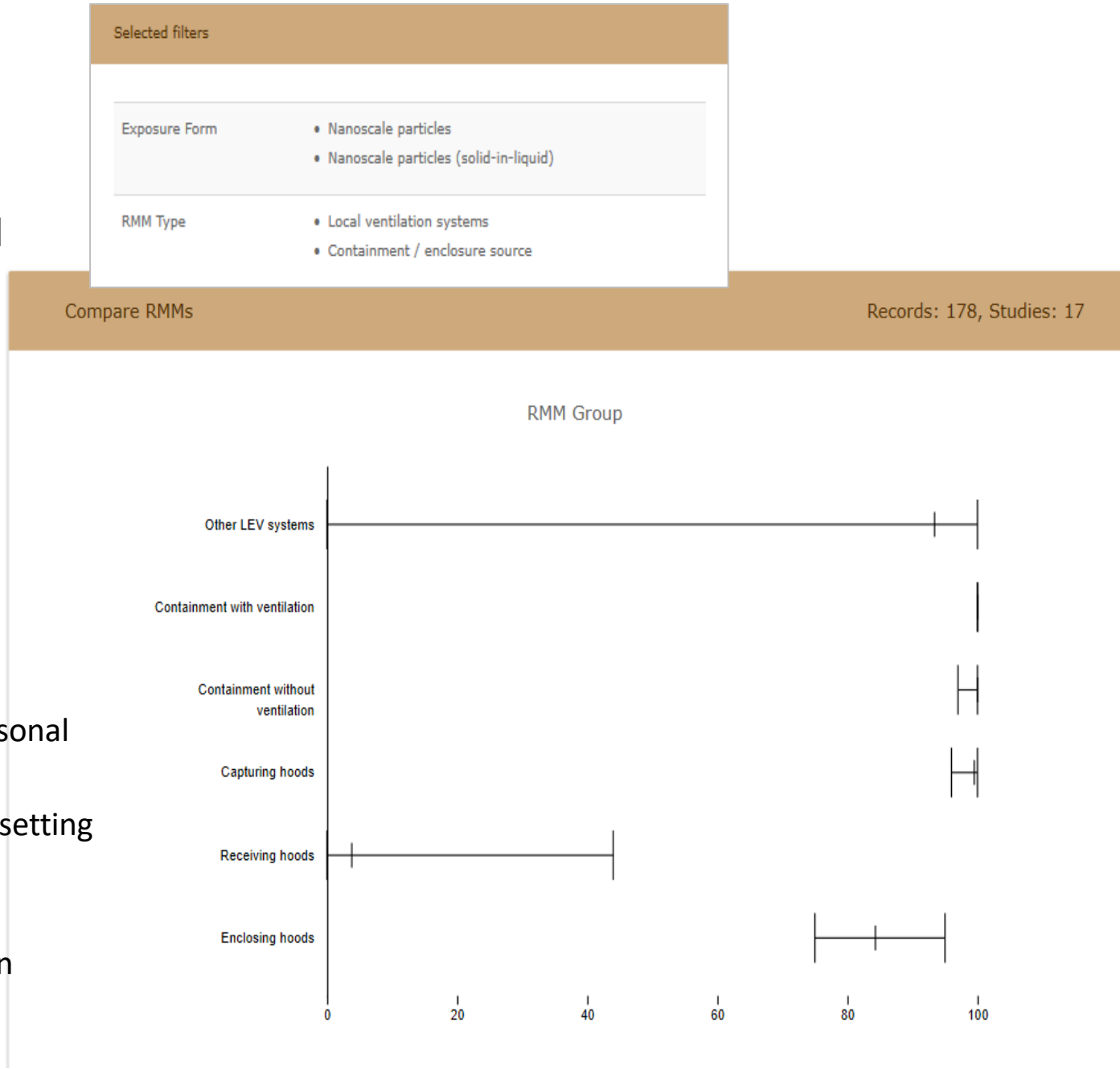


RMM EFFECTIVENESS

- Ongoing research to populate databases and analyse RMM effectiveness

- RMM testing
  - Single RMM (e.g. wetting system only)
  - Multiple RMM (combination of more than one RMM)
  - Improved RMM (or optimized RMM)

- Study types
  - As-used: field study data of single RMM based on personal exposures
  - As-built: manufacturer's data in (semi-) experimental setting during optimal conditions
  - Atypical: other relevant studies using 'atypical' test conditions (experimental) or work practices with often extreme outliers



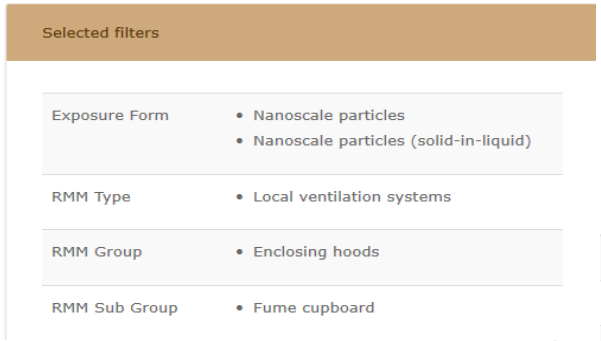
VARIABILITY IN RMM EFFECTIVENESS

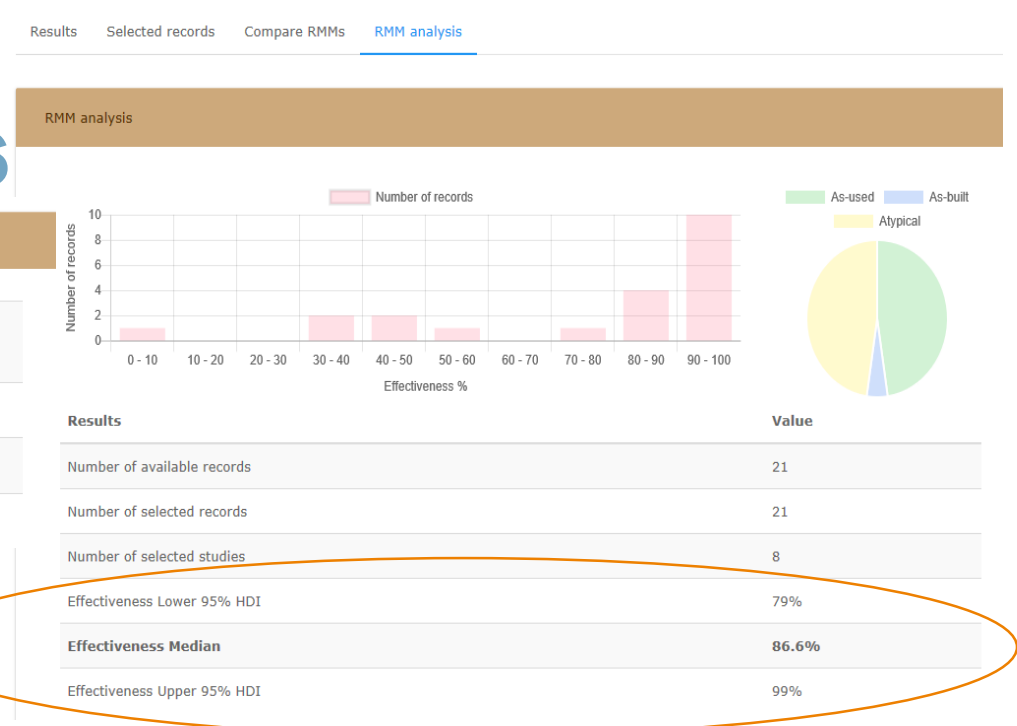
- Dependent on:

(Technical) specifications & design

Maintenance (incl. periodic testing, repair, cleaning, storage)

Use in practice (how is the RMM used?, work practices, respirator fit, etc)

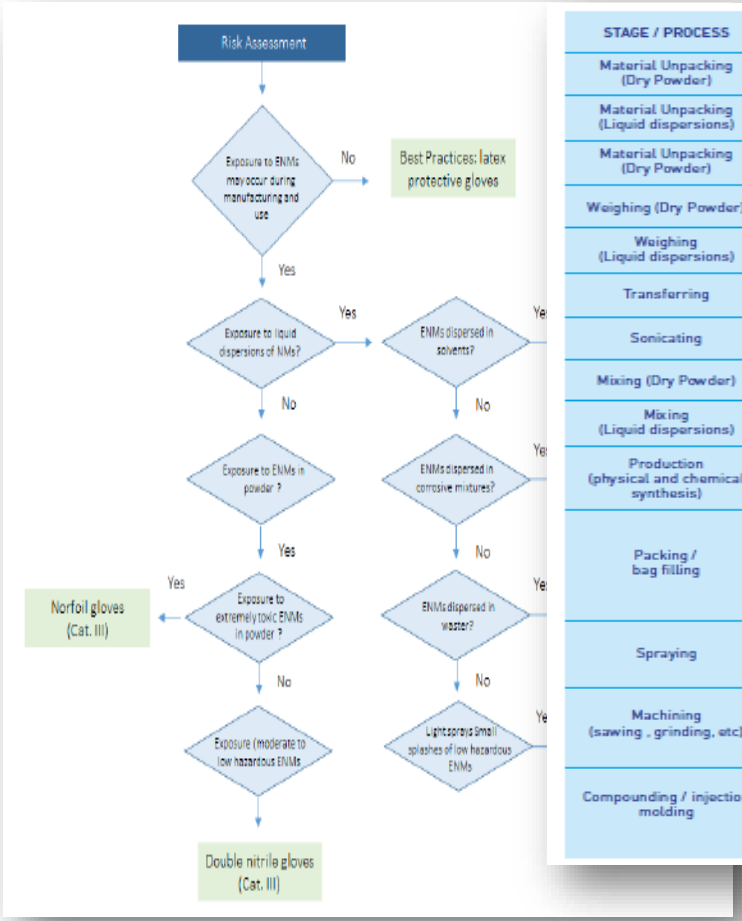




- Manufactured nanoparticles are known to coagulate rapidly during emission from the source and transport to the receptor – affecting actual effectiveness of a PSD bin

- A wide range of determinants associated with the substance-, activity/process- and ambient/environmental conditions may contribute to variability in effectiveness

RELEVANCE OF RMM FOR NANOMATERIALS



STAGE / PROCESS	LABORATORY	PILOT PLANTS	INDUSTRIAL SETTINGS (MEDIUM SCALE PRODUCTION)	INDUSTRIAL SETTINGS (LARGE SCALE PRODUCTION)
Material Unpacking (Dry Powder)	Ventilated Laboratory Hood (partial enclosure) Local exhaust enclosure (Glove Box)	HEPA filtered down flow booth	Custom-fabricated enclosures HEPA filtered down flow booth	Custom-fabricated enclosures HEPA filtered down flow room
Material Unpacking (Liquid dispersions)				
Material Unpacking (Dry Powder)	Ventilated Laboratory Hood (partial enclosure)	Ventilated Laboratory Hood (partial enclosure)	HEPA filtered down flow booth (or rooms) / Non ventilated	
Weighing (Dry Powder)	Ventilated Laboratory Hood (partial enclosure) Local exhaust enclosure (Glove Box) Biological safety cabinet	HEPA filtered down flow boo Walk-in hood		
Weighing (Liquid dispersions)				
Transferring				
Sonicating	Ventilated Laboratory Hood (partial enclosure)	Ventilated Laboratory Hoo (partial enclosure)		
Mixing (Dry Powder)	Ventilated Laboratory Hood (partial enclosure) Local exhaust enclosure (Glove Box)	HEPA filtered down flow boo		
Mixing (Liquid dispersions)		Movable LEV systems (extendable arms)		
Production (physical and chemical synthesis)	Ventilated Laboratory Hood (partial enclosure)	Ventilated enclosure locate inside a downflow room Receiving hood (hot proces		
Packing / bag filling	Ventilated Laboratory Hood (partial enclosure)	HEPA filtered down flow boo Ventilated collar-type exhaust hoods Continuous liner product off-loading system		
Spraying	Ventilated Laboratory Hood + built-in water wash down systems	Walk-in hood		
Machining (sawing , grinding, etc)	Ventilated Laboratory Hood (partial enclosure) Movable LEV systems (extendable arms)	Custom-fabricated Movable LEV systems (extendable arms)		
Compounding / injection molding	Custom-fabricated Movable LEV systems	Canopy hood - Receiving ho (hot process)		

	VENTILATED TECHNICAL MEASURES									NON VENTILATED TECHNICAL MEASURES	
	Laboratory fume hood or cupboard	Local exhaust enclosure (Glove Box)	Receiving hood (hot process)	Movable LEV systems	Walk-in hood / booth	HEPA filtered down flow booth	Ventilated collar-type exhaust hoods	HEPA filtered down flow rooms	Custom-fabricated enclosures (fully – partial)	Continuous liner product off-loading system*	Inflatable seals
Material Unpacking	X	X				X		X	X		
Weighing (Dry Powder and liquid dispersions)	X	X			X	X	X	X			
Transferring	X				X				X		
Sonicating	X								X		
Mixing (Dry Powder and liquid dispersion)	X	X		X	X			X			
Synthesis (Dry/ liquid)	X		X						X		
Packing / bag filling	X					X	X	X	X	X	X
Spraying					X	X				X	
Machining	X			X	X				X		
Compounding / injection molding			X								

GUIDEnano

NANORISK

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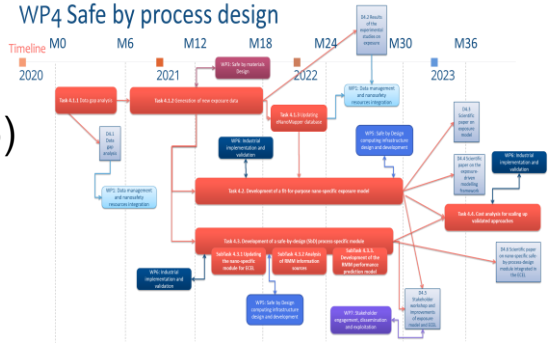
GUIDANCE ON RISK MANAGEMENT MEASURES

WAY FORWARD?

- Bring together information on RMM applications for NMs and their effectiveness – for improved guidance and implementation

- Development of a safe-by-process design module in SbD4Nano (WP4)
  - Integrate a safe-by-material design (WP3)
  - Development of a RMM performance prediction model (WP4)
  - Link will be made between RMM and exposure model (WP4) and e-infrastructure (WP5)



- More nano-specific studies required that evaluate the effectiveness of RMMs
  - Frequency analysis of ECEL and data gap analysis underway

- Further population and analysis of libraries such as ECEL
  - Examine the variability in RMM effectiveness values (to identify the drivers of effective & sustainable RMMs)
  - Investigate ways to include PSD bins in extracting RMM effectiveness values

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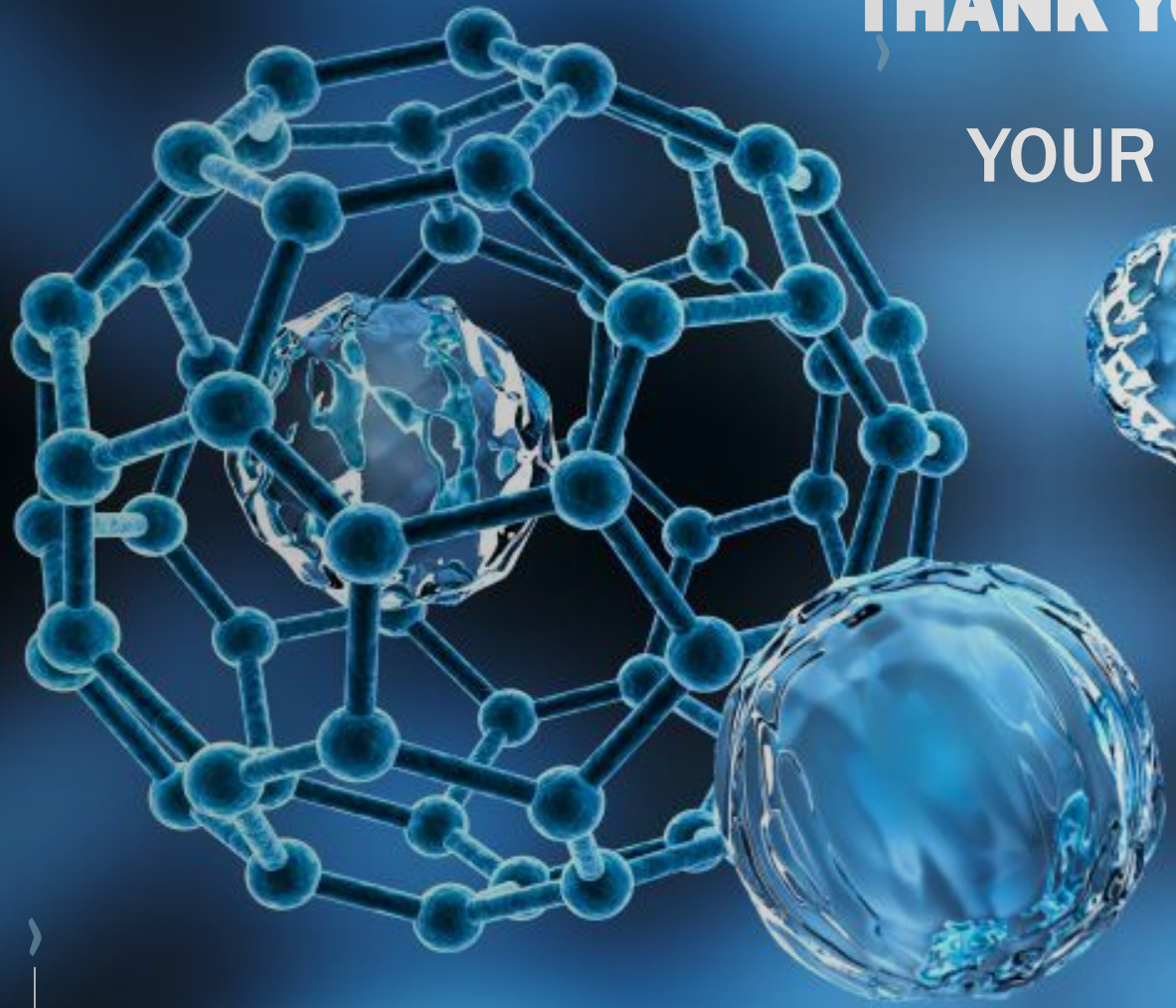
THANK YOU FOR

YOUR TIME



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