# Smart sensors for a healthy and safe working environment

Eelco Kuijpers, PhD | Stockholm, PEROSH

# About me

- Background in Occupational & Environmental health
- Living and working in Utrecht
- Since 2012 at TNO
- Finished PhD in 2018 at Utrecht University

- Focus: The use of new technologies for the prevention of occupational diseases.

# Agenda

1. The start of a journey....
2. 10 years of applied research
   a. From concept
   b. To vision
   c. Realising the vision by developing tooling
   d. Guidelines
   e. Involving stakeholders for implementing
3. How the journey continues.....

Relevance

# The start of a journey....

- **Henk**
- 45 years old
- Works at a construction site
  - **Silica exposure, wood dust, welding fumes, diesel**
  - Some older colleagues are sick
- Employer:
  - All exposures well **below limits** (according to yearly measurements)
  - Believes **behaviour** of workers causing high exposures

Relevance

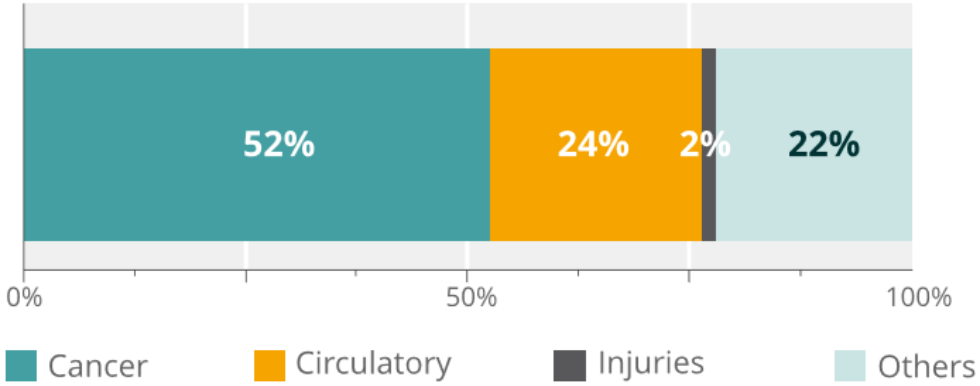
# Henk is one of many workers at risk

- **Occupational diseases** in EU countries have a large impact:
  - Deaths: 5-7% related to work circumstances
  - Loss of total work-years: 3.3%
  - Costs: 2-6% GDP

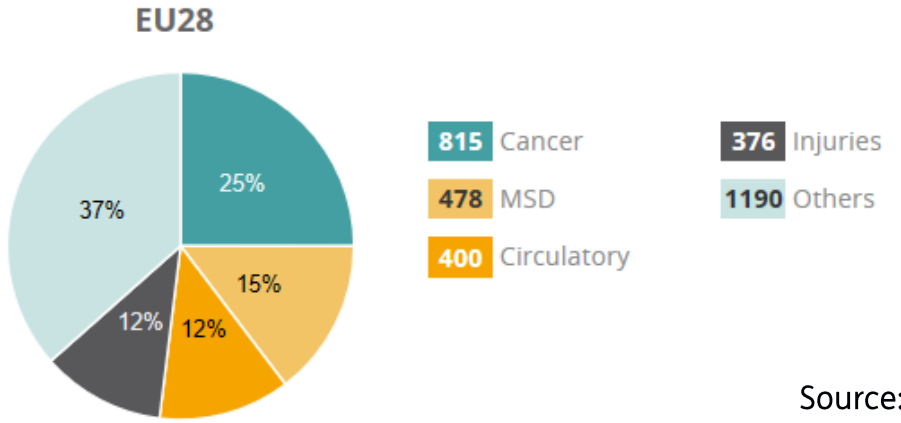
- **Ongoing new challenges:**
  - Ageing workforce
  - Changing nature of work
  - Dealing with lower and lower exposure limits

- **More effective prevention** still much needed.

- Percentage of all work-related deaths:




- Percentage of all work-related DALY per 100,000 workers:




Source: ILO, 2017

Relevance

# What is hampering more effective prevention?

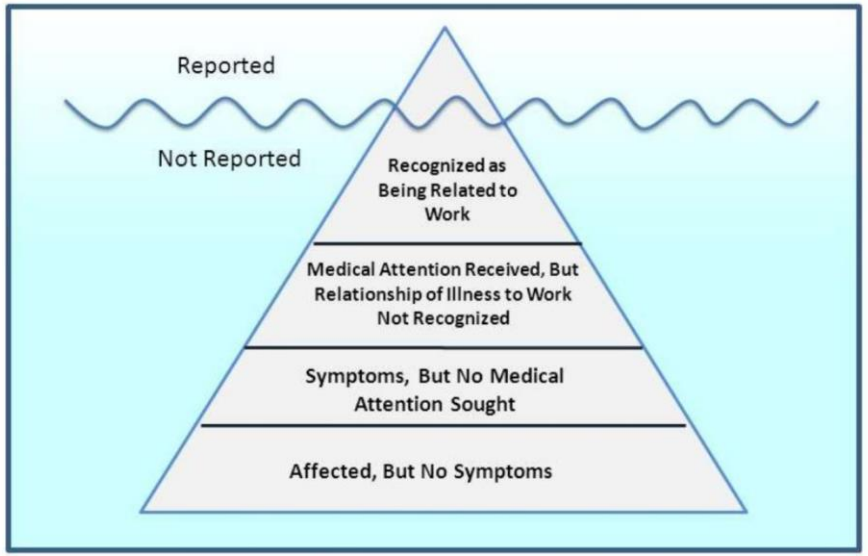
- **Occupational diseases are underrepresented** in statistics due to:
  - Poor diagnosis
  - Lack of acknowledgement and understanding relationship disease and working conditions (latency time often 10 - 30 years)
  - Lack of historical personal exposure data

- As a consequence, **awareness** by employers and employees is often relatively low.

- **Occupational hygiene:**
  - Regulatory driven
  - Limited amount of measurements
  - Often focus on average concentrations
  - Information becomes available long after exposures occured

- **Data driven insights collected with new technology** help e.g. HSE managers, employers and occupational physicians to focus more and earlier on prevention of occupational diseases.

The "iceberg" of Occupational Diseases




Source: Braeckman et al. 2012

**The start of our research.**

# 10 years of applied research


idewe
OPTIMISING WORK ENVIRONMENTS

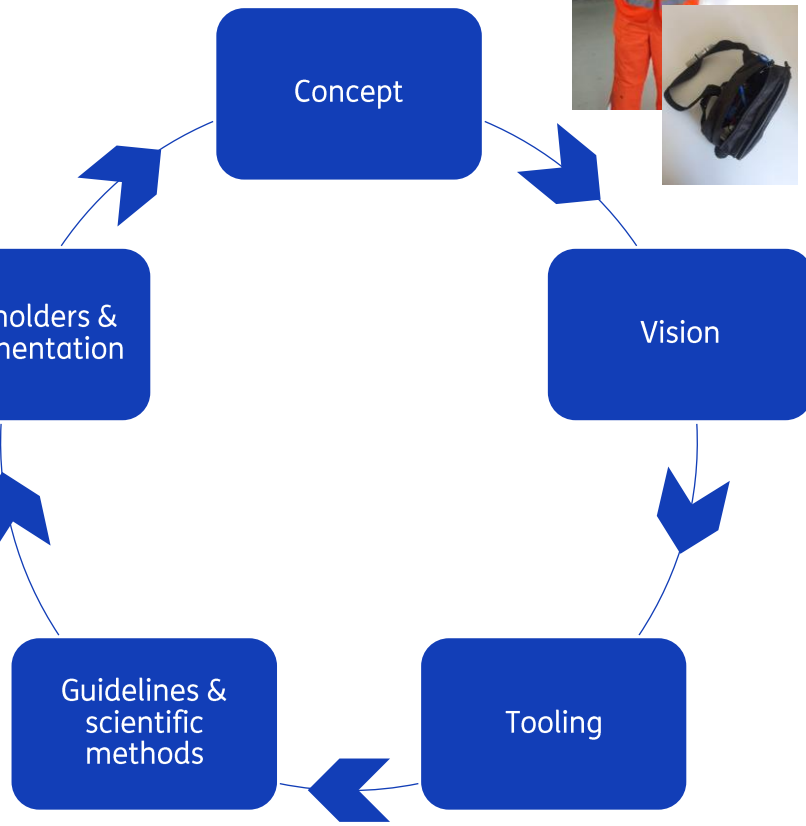
GCG
health safety hygiene

*NVVA
Nederlandse Vereniging van Arbeidsdeskundigen

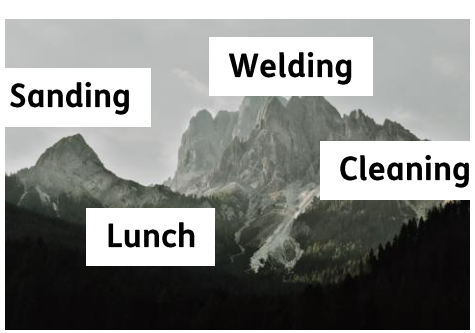
HSE
Health & Safety Executive

NIOSH

cen







VOHA

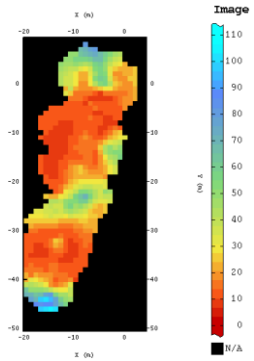
Ann Work Expo Health 2021 Apr 22;65(3):246-254. doi: 10.1093/annweh/wxaa102

**Future Prospects of Occupational Exposure Modelling of Substances in the Context of Time-Resolved Sensor Data**

Henk Goede [1], Eelco Kuijpers [1], Tanja Krone [1], Maaike le Feber [1], Remy Franken [1], Wouter Fransman [1], Jan Duyzer [2], Anjoeka Pronk [1]

EXCITE

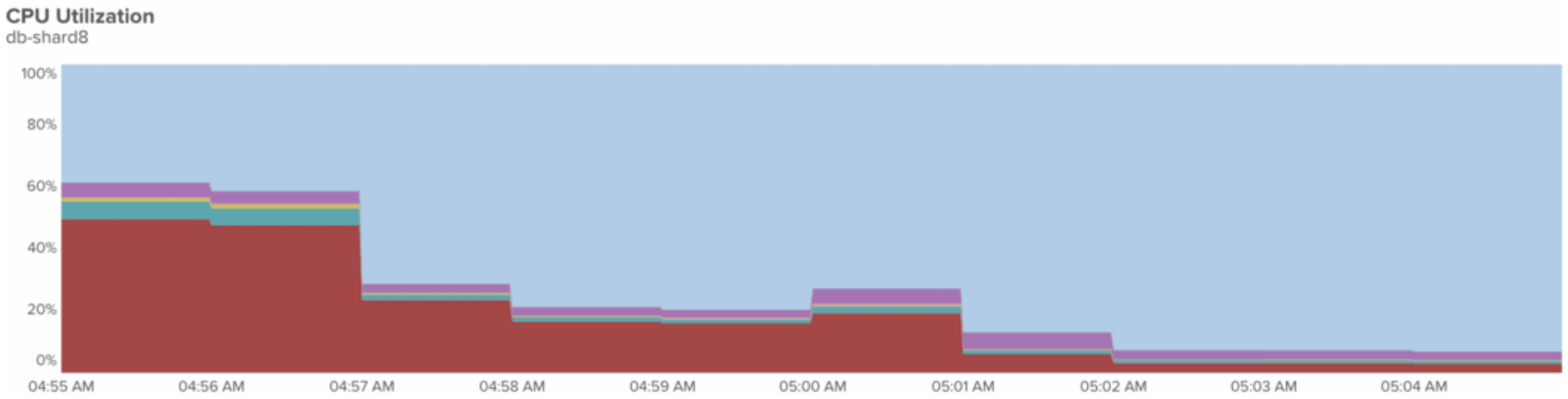

CID




KRIGING

Concept

# Why low-cost sensors?




- **Advantages** low-cost sensors:
  - Relatively cheap
  - Easy-to-use
  - More (high-resolution) data
  - Data directly available (direct feedback)

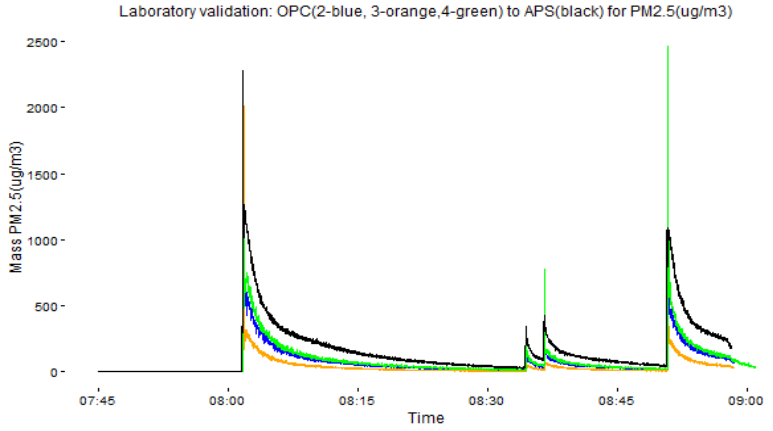

Concept

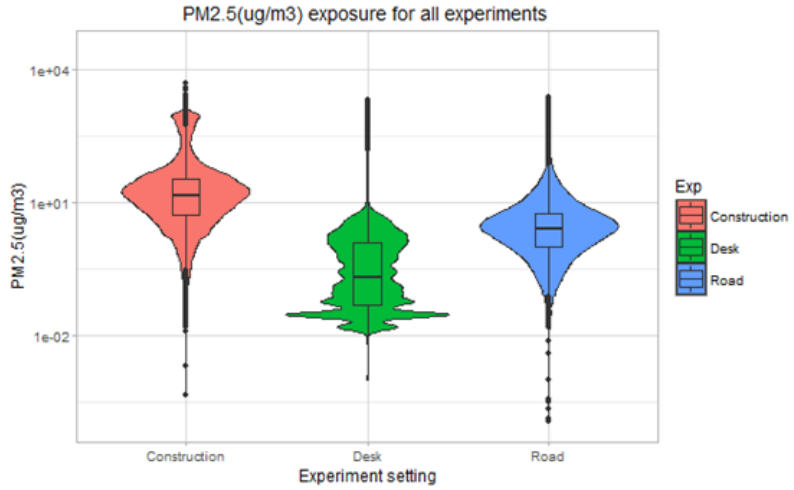
# The first testing (2014)

- **Aim:** to evaluate low cost PM sensors in laboratory conditions and at industrial workplaces.
- Laboratory: $R^2$ = 0.38 - 0.84 (variation between and within sensors)
- **In field:**

| Experiment/population | Number of measurement days | Activities |
|---|---|---|
| Road workers | 13 | Cutting grass in cabins, commuting along locations |
| Desk workers | 8 | Desk work, meeting, lunch |
| Construction workers | 9 | Drilling, welding, working with bitumen, concrete, rockwool, installations |

- **Conclusions:**
  - Low-cost sensors have **large potential** and given the costs do relatively well compared to traditional methods.
  - Data can be used for **indicative purposes.**
  - **More technology is needed** to translate real-time data into meaningful (near)real-time feedback.




Source: Cserbik et al. 2015

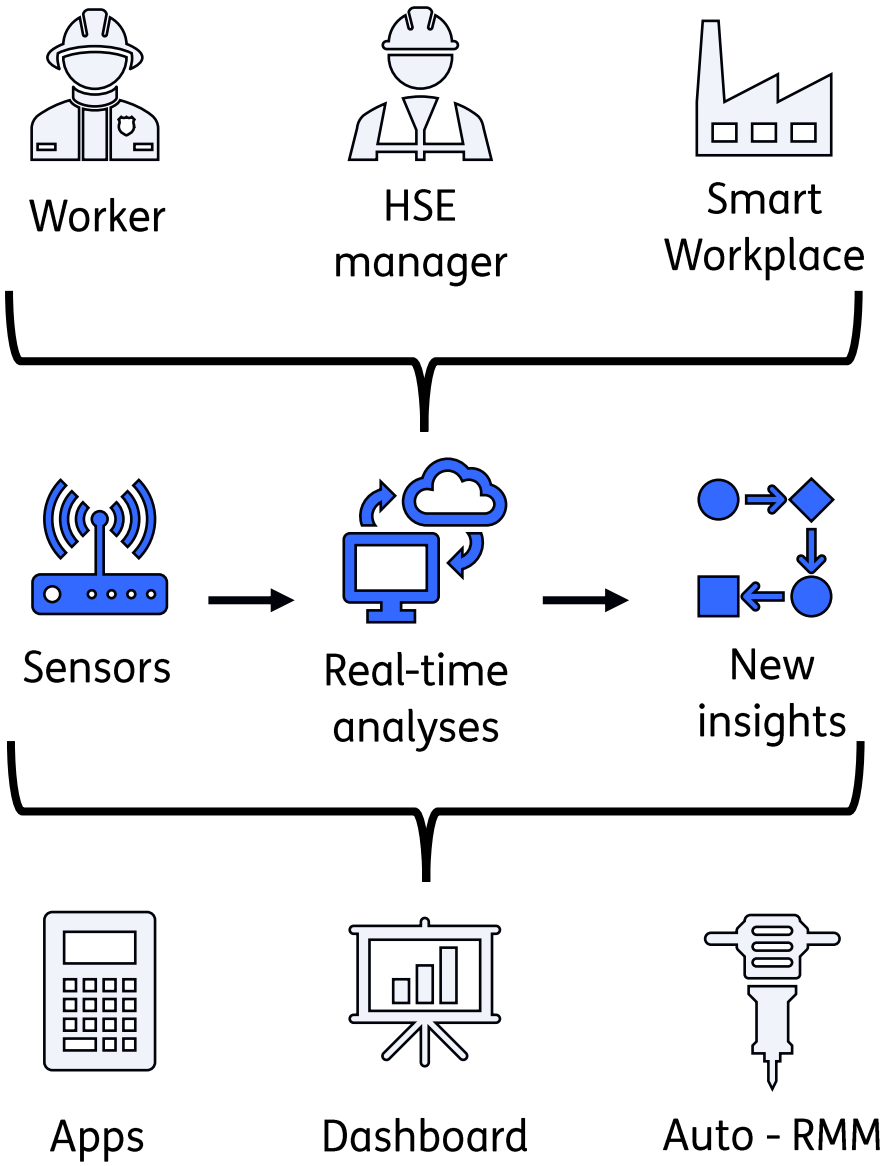
Vision

# The start of VOHA

- **The virtual occupational hygiene assistant (VOHA)** is a digital real time system for monitoring and management of occupational risks/exposures, that can assist workers, HSE manager and occupational hygienists in improving workplace conditions and reducing the workplace related burden of disease.

- VOHA is not a (single) product/method but a **vision** on how to realise more effective prevention of occupational diseases.

- **VOHA elements:**
  - Flexible and modular system for sensors and other non-invasive technologies
  - Focused on individual workers or a group of workers
  - Real time risk management
  - Stimulating behavioural changes
  - Dummy proof interventions
  - Data protection/privacy



# Vision to inspire

- VOHA video
- Two peer-reviewed articles on **modelling** (making use of sensor data) and **ethics/privacy considerations**
- ~ 15 articles in applied journals, newsletters, websites etc.
- Wide range of organisations, companies and individuals showed their interest, which is still ongoing.


*Annals of Work Exposures and Health*, 2021, Vol. 65, No. 3, 246–254
doi: 10.1093/annweh/wxaa102
Advance Access publication 20 November 2020
Commentary

Commentary

## Future Prospects of Occupational Exposure Modelling of Substances in the Context of Time-Resolved Sensor Data

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[1]Netherlands Organisation for Applied Scientific Research (TNO), Risk Assessment for Products in Development (RAPID), Princetonlaan 6, 3584 CB Utrecht, The Netherlands; [2]Netherlands Organisation for ...nalysis (EMSA), Princetonlaan 6,

*Annals of Work Exposures and Health*, 2021, Vol. 65, No. 1, 3–10
doi: 10.1093/annweh/wxaa093
Advance Access publication 15 October 2020
Commentary

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...on accepted 1 October 2020.

Commentary

## Ethics and Privacy Considerations Before Deploying Sensor Technologies for Exposure Assessment in the Workplace: Results of a Structured Discussion Amongst Dutch Stakeholders

**Maaike le Feber*, Trishala Jadoenathmisier, Henk Goede, Eelco Kuijpers and Anjoeka Pronk**

Dutch Institution of Applied Science, TNO, Department Risk Analysis (RAPID) – Team Exposure Assessment and Risk Management, Princetonlaan 6, 3584 CB Utrecht, Netherlands

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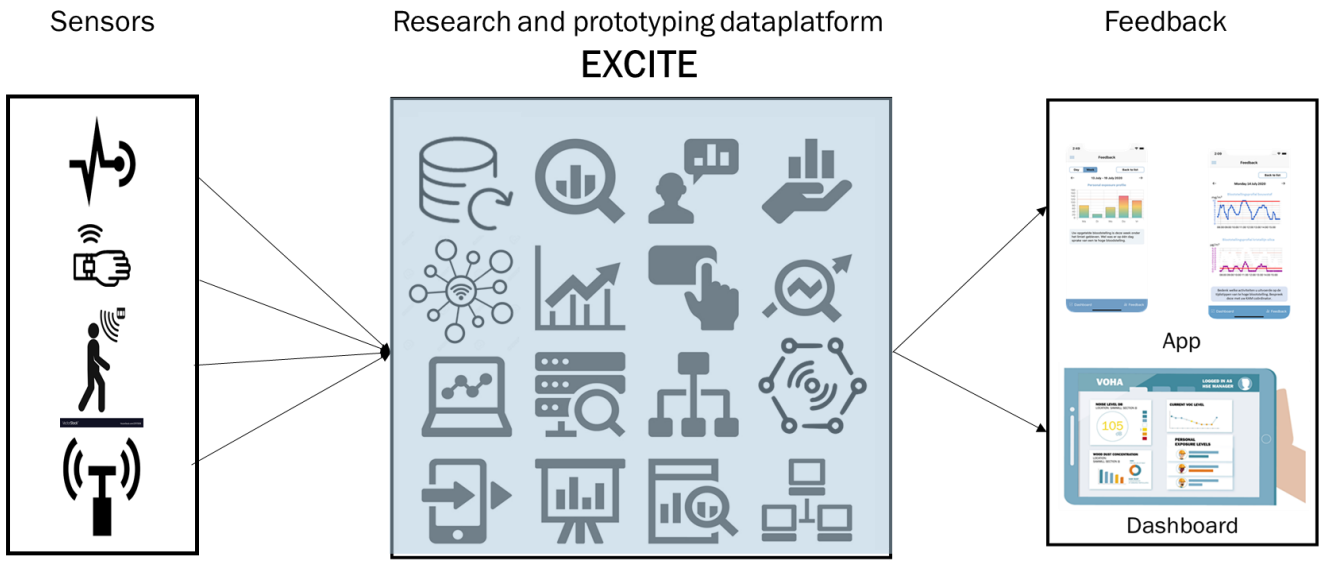
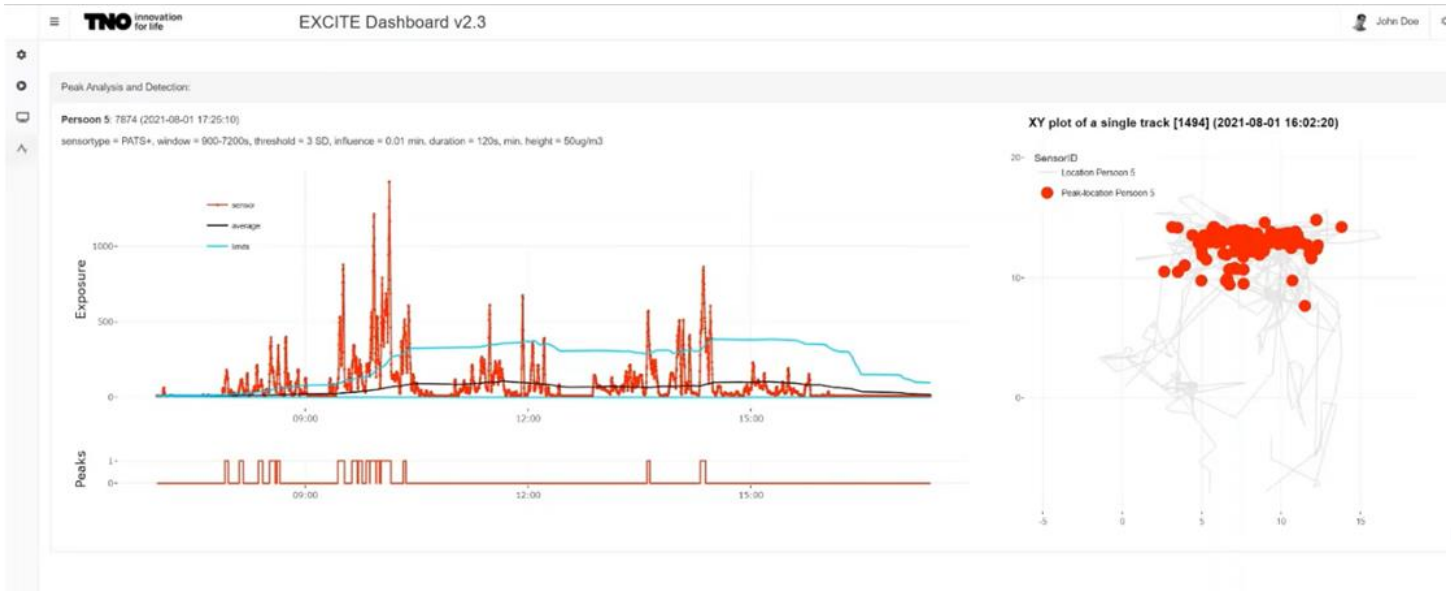
Submitted 7 April 2020; revised 16 July 2020; editorial decision 26 August 2020; revised version accepted 3 September 2020.

Tooling

# EXCITE



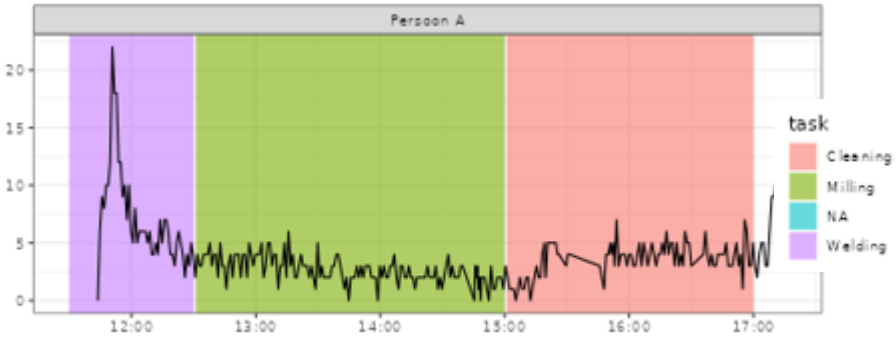

## EXCITE

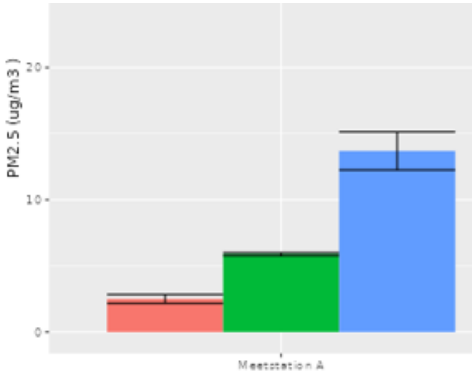
- **Data infrastructure** for in (near) real time collection, storage, interpretation and feedback of high resolution digital data.
- For research and prototyping to optimize **real-time risk management**
- Algorithms to automate:
  - Cleaning data
  - Peak detection
  - Comparison with limit values
  - Location tracking
  - Interpretation contextual information

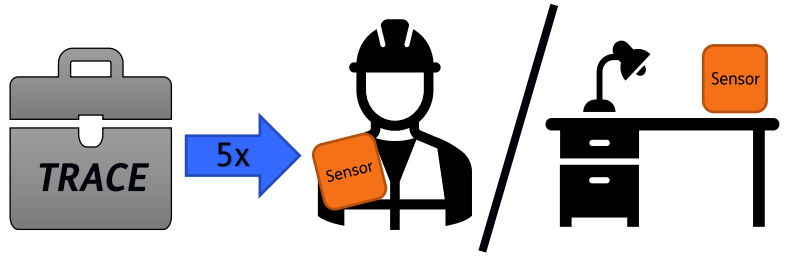
Tooling

# Toolbox for research and characterizing exposure (TRACE)

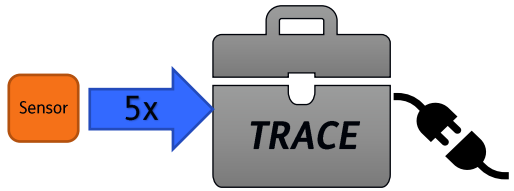
- Applying low-cost sensors can be **technically difficult.**
- Researchers often can overcome these challenges and appreciate the technical flexibility of the technology.
- But, **end-users** (workers, HSE managers) usually need a simple and ‘plug and play’ system.
- **TRACE** was developed:
  - To identify exposure sources and improve working processes
  - Cannot be compared with limit values or to validate control measures.



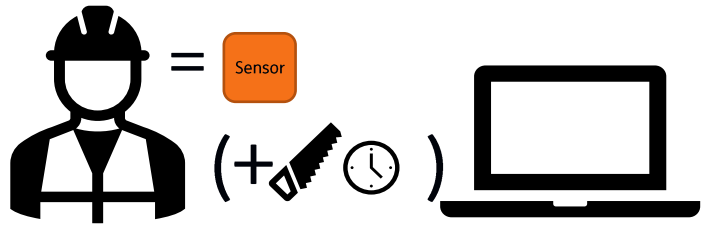




1. Measure using sensors




2. Connect sensors (end of workday)



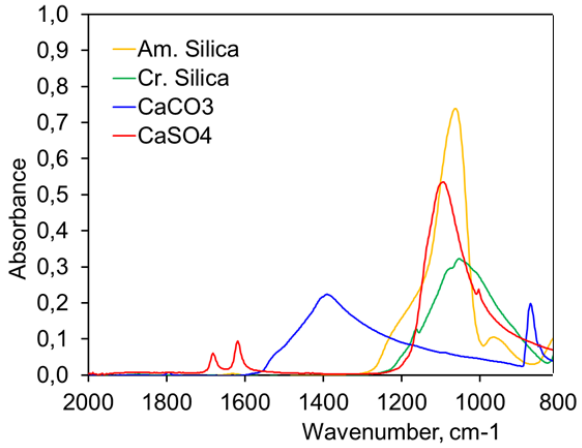

3. Register employee (code)s & Tasks/workplaces

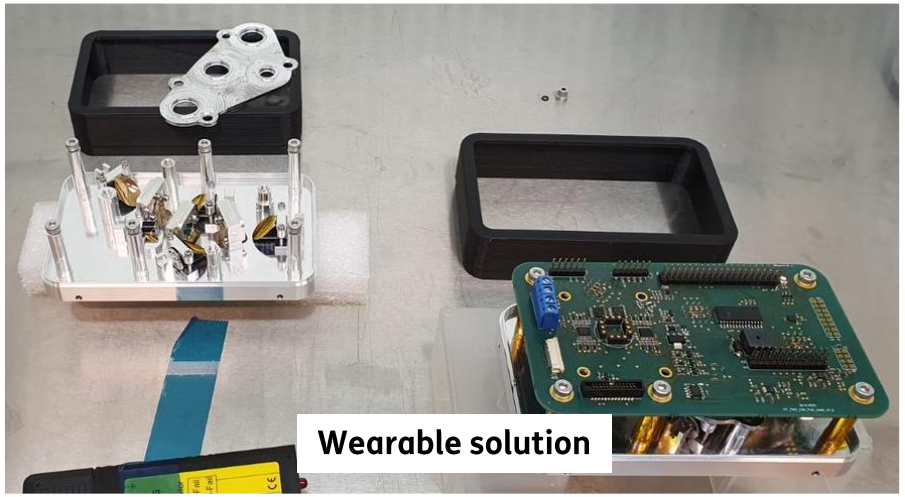
4. Visualization & analysis

# Chemical identifier (CID) – crystalline silica

- Most low-cost sensors are **not specific** for a chemical, while regulation often is specific when comparing to a limit value.
- To enhance implementation **specific methods** with the advantages of low-cost sensors are much needed.
- **Ambition:** Develop a specific sensor for crystalline silica.
- **Portable solution:**
  - 3 components: micro-cyclone, hollow waveguide (IR), IR analyser.
  - Specific for crystalline silica but technology can be adapted to other materials.
- **Wearable solution:**
  - Specific for crystalline silica (prototype)
- Application of prototype illustrated in a video.

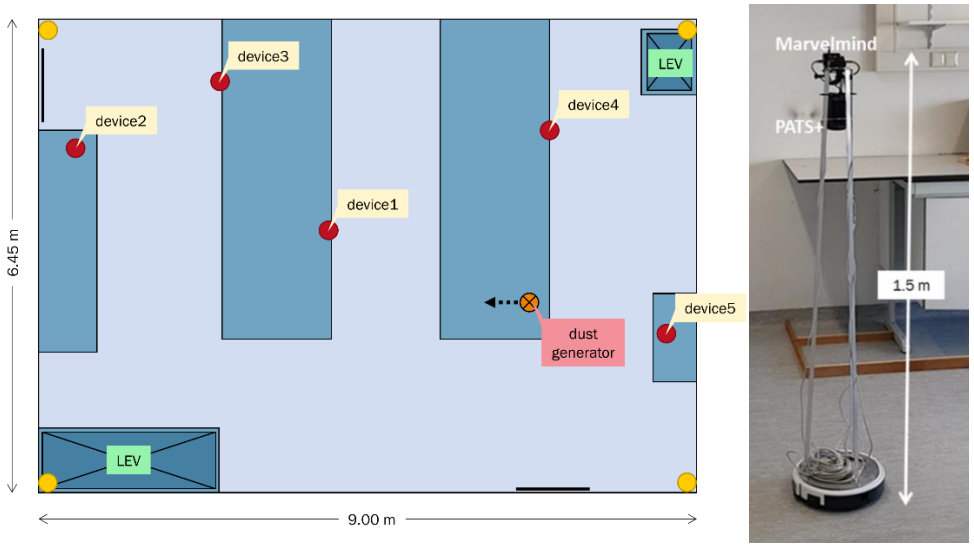
Portable solution



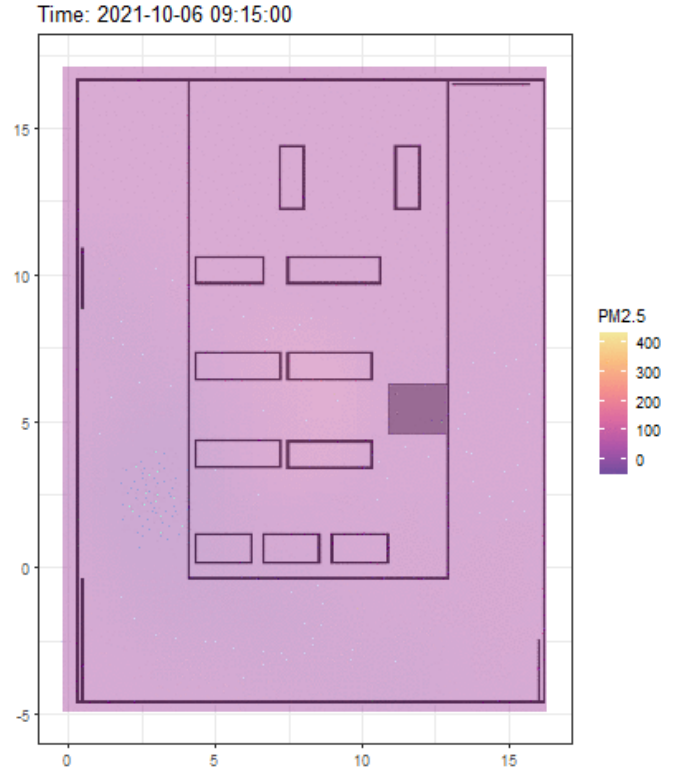


Wearable solution

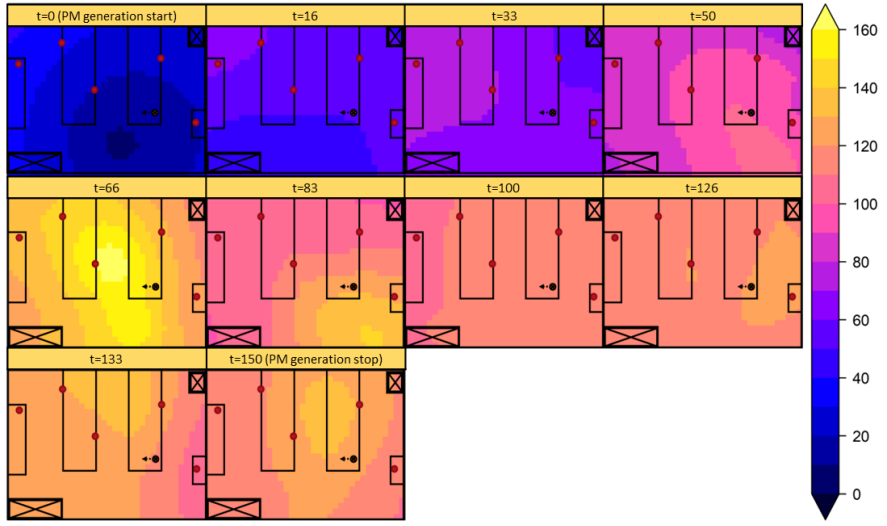
Tooling

# KRIGING







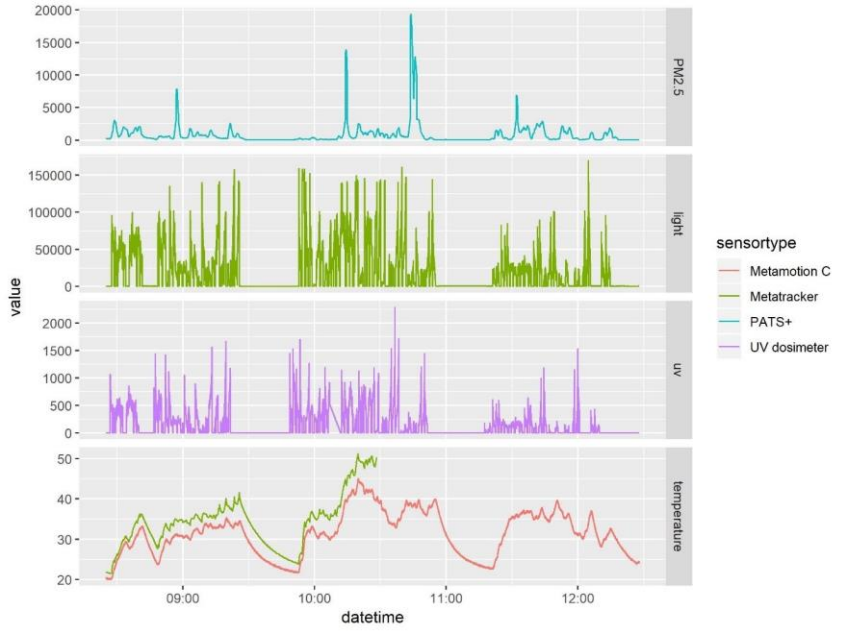



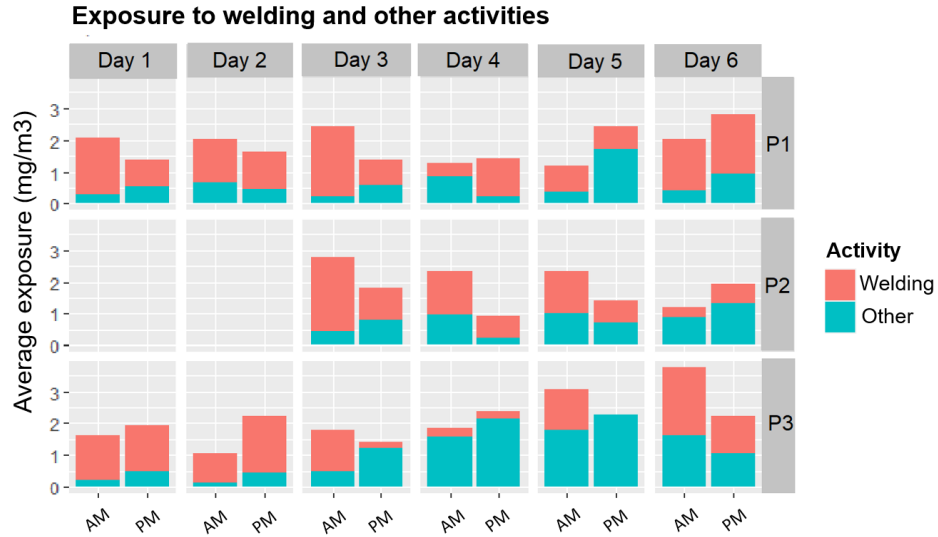

- Sensor data can be overwhelming. **Visualisation and modelling** can help translation the data into useful information.
- **Kriging** in time and place was explored to help users to identify exposure sources and locations with the highest exposures.

Tooling

# PM exposure and tasks

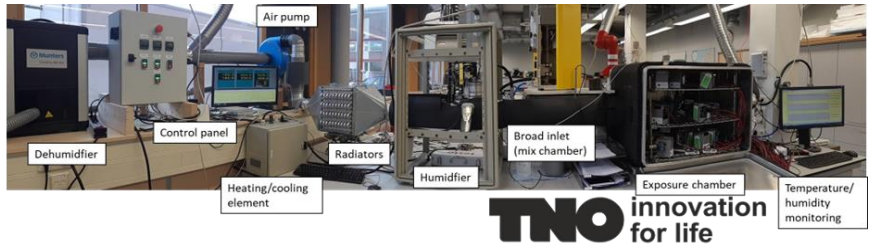
- **Contextual information** relevant for the interpretation of exposure data is often collected with observations or questionnaires.
- **UV sensor** estimated welding activities most accurate compared to the traditional method
- As an exploration, we showed the contribution of welding(fumes) to the total exposure measured.

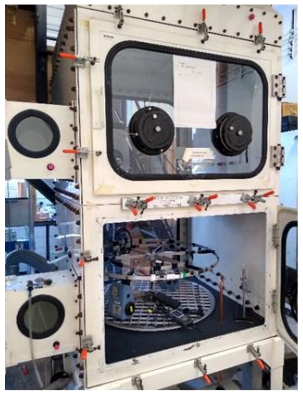


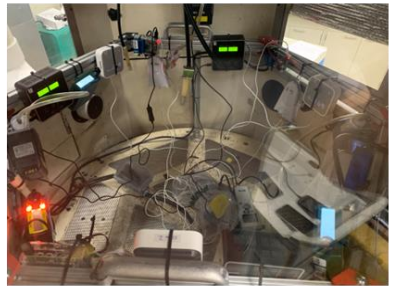
# Evaluation of sensors

- Before using low-cost sensors in the field, a proper **evaluation** is needed to ensure their successful and correct use.
- **Guidelines** are needed for:
  - Variables and criteria to be tested
  - Experimental conditions and environment
  - Inter-comparability between test locations
  - Calibration
  - Validation



HSE Health & Safety Executive



NIOSH

- Draft guidelines for lab evaluation based on a **round-robin study** (together with NIOSH/HSE)
- **CEN standard** (in preparation) on the use of low-cost sensors for NOAA

Int J Environ Res Public Health. 2020 Nov 19;17(22):8602. doi: 10.3390/ijerph17228602.

**Exploring Evaluation Variables for Low-Cost Particulate Matter Monitors to Assess Occupational Exposure**

Sander Ruiter [1], Eelco Kuijpers [1], John Saunders [2], John Snawder [3], Nick Warren [2], Jean-Philippe Gorce [2], Marcus Blom [1], Tanja Krone [1], Delphine Bard [2], Anjoeka Pronk [1], Emanuele Cauda [3]

Guidelines

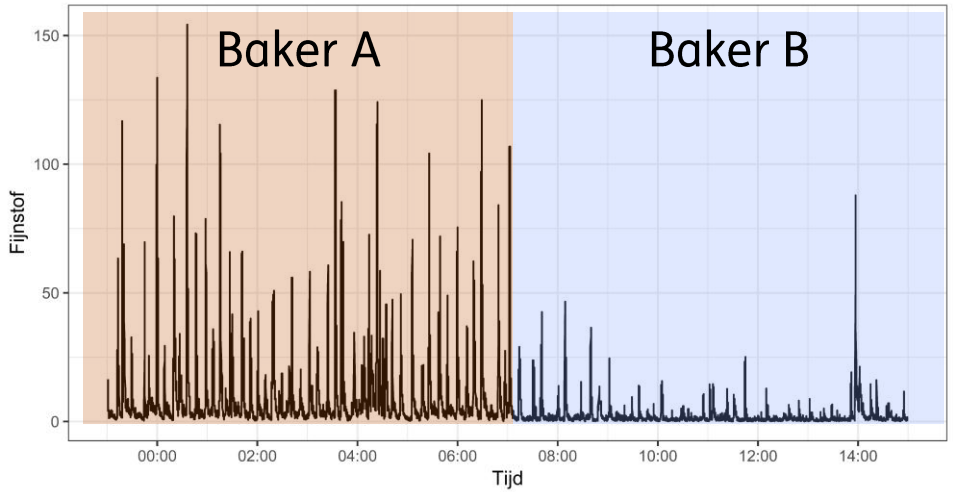
# In-field testing (1/2)

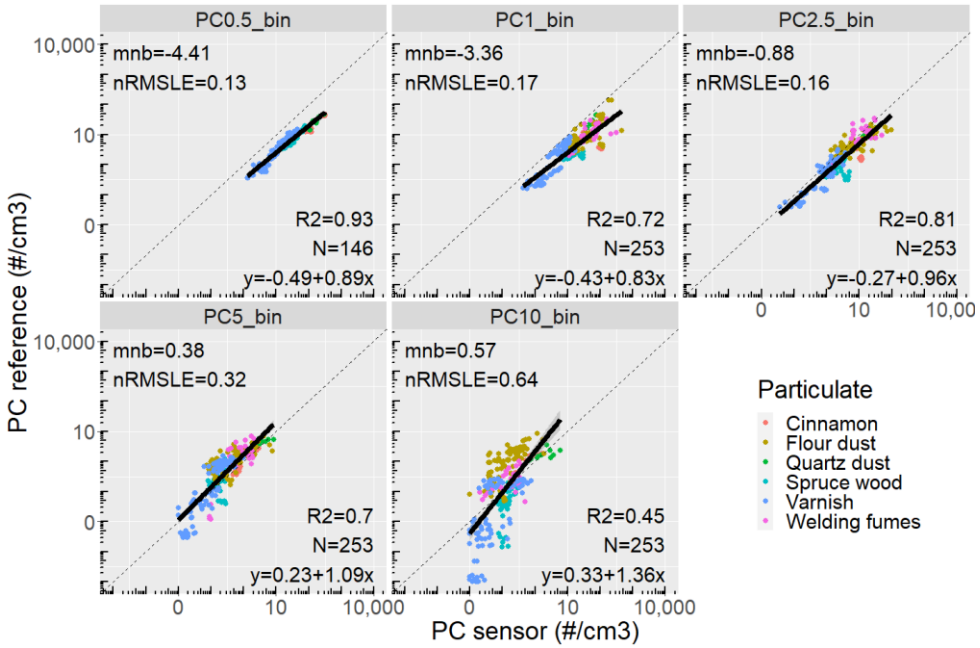
- Measurement campaigns in **wide variety of industries**:
  - Industrial bakeries, welding shops, wood processing industry, tile manufactory, construction industry, spice processing
  - Average study population size per industry: 8 - 10
- **Particulate Matter (PM)**
  - Personal and stationary measurements
  - Low-cost sensors, high-end monitors and gravimetric samples
  - Total measurement duration: sensors 200 hr, gravimetrical 431 hr
- **Contextual information** (also high resolution data):
  - Location
  - Temperature/UV/light

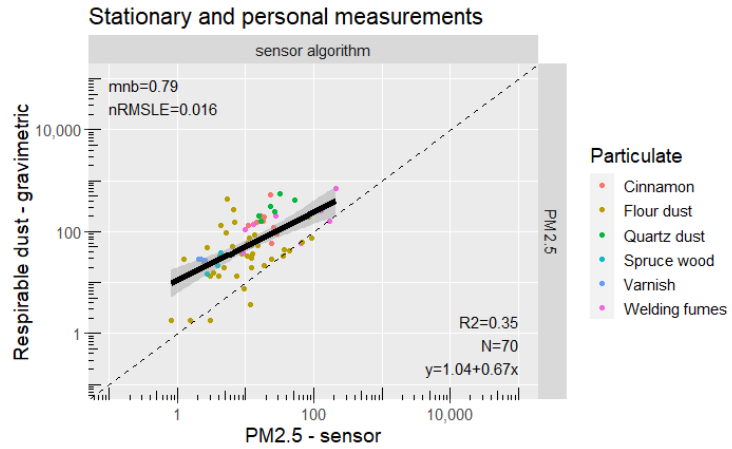
Guidelines

# In-field testing (2/2)

- **Results**
  - Low cost sensors **perform reasonably** well compared to APS and gravimetric (calibrations enhance performance).
  - Semi quantitative assessments also possible: rank correlations exposure levels tasks or individuals.
  - Identification of exposure sources and **good (and bad) working procedures** possible.
  - **Calibration** of low-cost sensors for quantitative use is being explored.
  - **'Playbook'** in preparation for correct application of sensors.

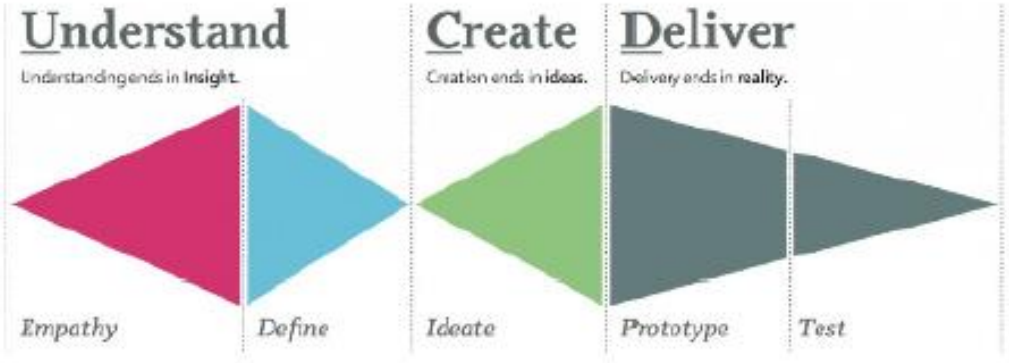


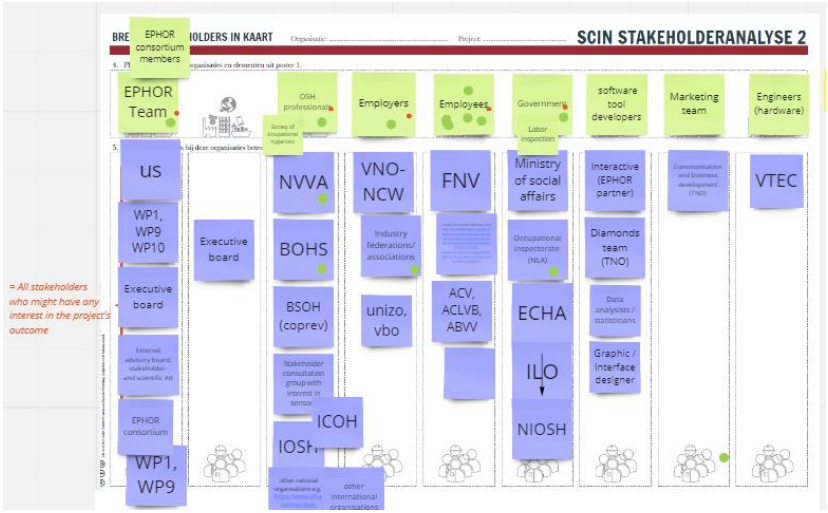



# Co-creation

- Step 1: Stakeholder mapping and understanding the needs
- Step 2: Validate needs and prioritize
- Step 3: Generate new ideas
- Step 4: Designing a prototype
- Step 5: Testing and refining
- Step 6: implementation




EPHOR Exposome tools for a healthy working life

# Ongoing co-creation

1. Construction companies on the CID development for crystalline silica.
2. Dutch labour inspection on how low-cost sensors will change their work (and needs).
3. Dutch branch organisation for occupational hygiene on the use of low-cost sensors in their daily work (which is often regulatory driven).
4. EPHOR project on the development of a toolbox to stimulate the use of low-cost sensors by OSH professionals.
5. Together with IDEWE on the link between exposures and health outcomes.

**Hardware**

**Evaluation**

**Video**

**Guidance**

**Exposome passport**

- **General conclusions:**
  - Sensors are more and more a welcome addition for awareness and early warning.
  - People tend to prefer to use sensors for campaigns (short periods with clear goals), not continuously.
  - Decide together about the goals and which info to share with whom and how to prevent negative side effects from the low-cost sensor data.

idewe

KU LEUVEN

IOM

NVVA Nederlandse Vereniging van Arbeidsdeskundigen

Nederlandse Arbeidsinspectie Ministerie van Sociale Zaken en Werkgelegenheid

TNO innovation for life

Closure

# Next steps

- Low-cost sensors have **large potential** but wide **implementation** is still far from realized.
- **More research** is needed in the following directions:
  - **Sharing and discussion on good practices using low-cost sensors**: we currently explore the start of a community of practice together with NIOSH, HSE and IOHA. Join us in our journey.
  - **Calibration of low-cost sensors:** explore the quantitative use of data becoming an alternative for traditional methods.
  - **Exploring the use of sensors in different contexts:**
    - Within EPHOR we explore the use of these sensors in the epidemiological context (respiratory diseases and shift work)
    - Other stressors like heat
    - Combining with other new technologies like ChatGPT and ML.
- Altogether, sensors **empower workers** and should ensure **Henk and many other colleagues** can do their work in a more healthy environment.

Acknowledgement

# It is a team effort


- Special thanks to my **TNO colleagues:**
  - Anjoeka Pronk
  - Henk Goede
  - Jody Schinkel
  - Joe Trimboli
  - Maaike le Feber
  - Paulien Bongers
  - Sander Ruiter
  - Wouter Fransman
- **Our partners** for collaborating and **funding** organisations;
- And **PEROSH** for inviting me.


- The findings and conclusions in this presentation are those of the author and do not necessarily represent the official position of the Netherlands Organisation for Applied Scientific Research (TNO).
- The author declares no conflict of interest.

# Thank you
FOR YOUR ATTENTION

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