Job Exposure Matrix, a fascinating way to learn about occupational and environmental exposures and their health effects

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Occupational exposure assessment: Why? and How?

- Regulatory reasons
  - To demonstrate compliance with standards and recommendations
- To inform and adapt risk management
- OSH & epidemiological research
  - Exposure or Dose-response relation
  - To develop and test sampling methods and devices
- Policy and public health decisions
  - To assess health impact
  - To assess the effectiveness of prevention measures

- Routine Vs Control measurements
  - Stationary
  - Personal (Breathing Zone)
  - Biomonitoring (Regular Vs Punctual)

- Contemporary, prospective, retrospective

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Quality of dose approximation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual measurement of <strong>body or organ-specific burden/dose</strong> for all workers</td>
<td></td>
</tr>
<tr>
<td>Individual measurement of the <strong>external concentration</strong> in PBZ for all workers</td>
<td></td>
</tr>
<tr>
<td>Measurement of <strong>external concentration at workstations</strong> or in specific industrial areas</td>
<td></td>
</tr>
<tr>
<td><strong>Ordinal / relative classification of jobs</strong> or tasks by exposure level</td>
<td></td>
</tr>
<tr>
<td><strong>Duration of employment</strong> in industry</td>
<td></td>
</tr>
<tr>
<td><strong>Binary ranking (yes/no)</strong> by industry job</td>
<td></td>
</tr>
</tbody>
</table>

JEM
# Job Exposure Matrix: What is it?

- One of the methods of exposure assessment
- Based on **OH expertise**, **Exposure measurement data**, and/or **Stat. Modelling**
- Database or a program associating data on occupational exposure to a hazard(s) with jobs

### Exposure estimates

*Presence, Probability, Frequency, Intensity of exposure...*

- Qualitative, **Semi-quantitative** or **Quantitative**

<table>
<thead>
<tr>
<th>Jobs \ Exposures</th>
<th>Hazard 1</th>
<th>Hazard 2</th>
<th>Hazard 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job 1</td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>Job 2</td>
<td>x</td>
<td>y</td>
<td></td>
</tr>
<tr>
<td>Job i</td>
<td>x</td>
<td>y</td>
<td></td>
</tr>
</tbody>
</table>

### Jobs | Exposures | Hazard 1 | Hazard 2 | Hazard 3 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Job 1</td>
<td>yes</td>
<td>1</td>
<td>5 (\mu\text{g/m}^3)</td>
<td></td>
</tr>
<tr>
<td>Job 2</td>
<td>no</td>
<td>0</td>
<td>0,0001 (\mu\text{g/m}^3)</td>
<td></td>
</tr>
<tr>
<td>Job i</td>
<td>yes</td>
<td>3</td>
<td>15 (\mu\text{g/m}^3)</td>
<td></td>
</tr>
</tbody>
</table>
Job Exposure Matrix: How does it work?

<table>
<thead>
<tr>
<th>Jobs \ Exposures</th>
<th>Asbestos</th>
<th>RCS</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job 1</td>
<td>yes</td>
<td>1</td>
<td>5 µg/m³</td>
</tr>
<tr>
<td>Job 2</td>
<td>no</td>
<td>0</td>
<td>0,0001 µg/m³</td>
</tr>
<tr>
<td>Job 3</td>
<td>yes</td>
<td>3</td>
<td>15 µg/m³</td>
</tr>
</tbody>
</table>

Mr. X
Occupational History
Job 1: 10y
Job 2: 25y
Job 3: 5y

Cumulative exposure
1*10 + 0 + 3*5=25 5*10+0+15*5=125 µg/m³

Cum. exposure duration 10 + 5 = 15 y
## Job Exposure Matrix: Which type?

<table>
<thead>
<tr>
<th>Company/plant specific</th>
<th>Industry-specific</th>
<th>Generic (general population)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREVA Pierrelatte nuclear plant</td>
<td>Chemical industry &amp; TiO2 Agriculture &amp; PPP</td>
<td>SYN-JEM, FIN-JEM</td>
</tr>
<tr>
<td>Parisian subway PM JEM</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Occupational cohort study
- Industrial cohort study
- Case-control studies nested within cohorts
- Case-control studies
How to create a JEM?

1st example: semi-quantitative JEM for AREVA Pierrelatte plant

- mining
- milling
- reprocessing
- conversion
- enrichment
- fuel fabrication
- reactor operations, maintenance
- MOX fuel fabrication
How to create a JEM?

1st exemple: semi-quantitative JEM for AREVA Pierrelatte plant

Calendar year

Gaseous diffusion prototype facilities

$^{235}\text{U} - 2\% \text{UF}_6$ enrichment

$^{235}\text{U} - 8\% \text{UF}_6$ enrichment

$^{235}\text{U} - 25\% \text{UF}_6$ enrichment

$^{235}\text{U} - 90\% \text{UF}_6$ enrichment

$^{235}\text{U} - 90\%$ enrichment of UF$_6$ derived from reprocessed uranium

Uranium metal fabrication from UF$_6$ derived from different processes; Waste recovery, decontamination, and recycling

Conversion of UF$_6$ in UF$_4$

Conversion of UF$_6$ derived from depleted uranium in U$_3$O$_8$

Production and marketing of hydrofluoric acide

Production of UF$_4$ and U$_3$O$_8$

General control, repairing and maintenance; Sampling; Physicochemical sample analyses; Maintenance, translocating and storage of containers

Gaseous diffusion facilities dismantling

Cleansing
How to create a JEM?

1st example: semi-quantitative JEM for AREVA Pierrelatte plant

**Jobs**: homogeneous occupational categories defined according to function, task, facility, and time-period from 1960 through 2006.

**Exposures**: 6 categories of uranium compounds and 16 categories of chemicals known as being carcinogenic, mutagenic or toxic that have been ever in use at the plant.

**Assessment procedure**

- **Expert committee**: 23 experts (occupational hygienist, security and radioprotection engineers, occupational physician, toxicologists, chemists, nuclear physicist, dosimetrist, epidemiologists) for defining JEM components
- **Evaluator committee**: 353 evaluators (171 retired workers and 182 active AREVA NC Pierrelatte workers) with a good knowledge of occupational conditions for a period 1960-2006.

**JEM ELABORATION**

- Definition of types of exposure ($A$), jobs ($j$), and periods ($p$) of stable exposure by experts
- Assessment of exposure indicators (frequency ($F_{Ajp}$) and quantity ($Q_{Ajp}$) of handled pollutant) by active and retired workers
- Keyboarding of assessment results
- Statistical examination of $Q_{Ajp}$ and $F_{Ajp}$ scores
- Experts’ arbitration on a final score for each job-period ($jp$) pair
- Final JEM with 232 job-periods and 2 exposure indicators ($Q_{Ajp}$ and $F_{Ajp}$) for 22 exposure agents ($A$)

**JEM VALIDATION**

- Examination of internal consistency of JEM by experts
- Examination of JEM sensitivity and specificity and its agreement with data from medical records

**COMPUTING OF INDIVIDUAL CUMULATIVE EXPOSURE SCORE ($E_A$)**

\[ E_A = \sum_{j=1}^{73} \sum_{p_j} F_{Ajp} \times Q_{Ajp} \times D_{pj} \]

**RECONSTRUCTION OF INDIVIDUAL JOB HISTORIES**

- Computing of employment duration for each job-period ($D_{pj}$) on the basis of personnel records

**EXAMINATION OF CORRELATION BETWEEN CO-EXPOSURES**

- Guseva Canu et al. RESP (2009)
- Guseva Canu et al. IJHEH (2010)
- Guseva Canu et al. IJHEH (2011)
Before this JEM

Cohort study of mortality among AREVA Pierrelatte workers (n=2897)
Average cumulative external dose 17.5 [0.05–217.2] mSv over 20-y dosimetry surveillance

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Obs</th>
<th>Lag</th>
<th>RR100mSv</th>
<th>IC-95%</th>
<th>P trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancereous diseases</td>
<td>214</td>
<td>10y</td>
<td>0.93</td>
<td>0.85</td>
<td>1.08</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>53</td>
<td>10y</td>
<td>0.89</td>
<td>0.79</td>
<td>1.23</td>
</tr>
<tr>
<td>Hemato-lymphopoetic cancer</td>
<td>21</td>
<td>2y</td>
<td>1.05</td>
<td>0.78</td>
<td>3.36</td>
</tr>
<tr>
<td><strong>Cardiovascular diseases</strong></td>
<td>111</td>
<td>5y</td>
<td>1.11</td>
<td>0.90</td>
<td>1.75</td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>47</td>
<td>5y</td>
<td>1.06</td>
<td>0.78</td>
<td>2.32</td>
</tr>
<tr>
<td>Cerebro-vascular disease</td>
<td>31</td>
<td>5y</td>
<td>0.92</td>
<td>0.70</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Obs – observed deaths; Lag – latency time (years); RR100MSv – Risque relatif per 100 Sv; IC-95%– confidence interval. *(Guseva Canu et al, 2014)*

Conclusion?
Absence of association?
Inappropriate exposure metric?
**JEM application in the dose – response analysis**

**Mortality due to cardiovascular diseases (111 cases)**

Cox proportional hazards model; Adjustment for attained age, calendar period, SES, sex, TCE, aromatic solvents, heat, shift work  
_Guseva Canu et al, 2013_

<table>
<thead>
<tr>
<th>Exposure variables</th>
<th>Uranium naturel (UN)</th>
<th>Uranium de retraitement (URT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type-F</td>
<td>Type-M</td>
</tr>
<tr>
<td><strong>Statut d’exposition annuelle (Binaire)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposé Vs Non-exposé</td>
<td>2.00 (1,00-4,02)</td>
<td>1.65 (1,06-2,56)</td>
</tr>
<tr>
<td><strong>Niveau d’exposition (catégorielle, 3 classes)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modérée</td>
<td>2.01 (1,01-4,03)</td>
<td>1.45 (0,76-2,04)</td>
</tr>
<tr>
<td>Forte</td>
<td>1.88 (0,83-4,29)</td>
<td>2.04 (1,14-3,49)</td>
</tr>
</tbody>
</table>

**Zhivin et al, 2018**

- Dose-response relationship with exposure duration and intensity
- Effect of isotopic composition (URT >>> UN)
- Effect of solubility (inverse relationship)
- Important for Hazard identification
- Time and cost-friendly
- Widely used: EURODIF JEM (FR), Sellafield JEM (UK), NIOSH (USA)

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**Table 5  Relationship between CSD mortality risk and uranium lung dose**

<table>
<thead>
<tr>
<th>Model</th>
<th>EOR/mGy (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unadjusted†</td>
<td>0.2 (0.02 to 0.6)</td>
</tr>
<tr>
<td>Adjusted for smoking†</td>
<td>0.2 (0.01 to 0.6)</td>
</tr>
<tr>
<td>Adjusted for BMI†</td>
<td>0.2 (0.01 to 0.5)</td>
</tr>
<tr>
<td>Adjusted for BP†</td>
<td>0.2 (0.01 to 0.6)</td>
</tr>
<tr>
<td>Adjusted for total cholesterol†</td>
<td>0.2 (0.01 to 0.6)</td>
</tr>
<tr>
<td>Adjusted for glycaemia†</td>
<td>0.2 (0.02 to 0.6)</td>
</tr>
<tr>
<td>Adjusted for external γ-radiation dose†</td>
<td>0.2 (0.02 to 0.6)</td>
</tr>
<tr>
<td>Fully adjusted††</td>
<td>0.2 (0.004 to 0.5)</td>
</tr>
</tbody>
</table>

**Note:**
- †Dose-effect relationship with exposure duration and intensity
- ††Effect of isotopic composition (URT >>> UN)
- †Effect of solubility (inverse relationship)
- †Important for Hazard identification
- †Time and cost-friendly
- ††Widely used: EURODIF JEM (FR), Sellafield JEM (UK), NIOSH (USA)
How to create a JEM?

2nd exemple: generic JEM «MatPUF» for Ultrafine Particle (UFP) exposure

Methods (Audignon-Durand et al. 2021)

1 - Literature review
   57 work processes and chemical composition of UFPs emitted

2 - Expert panel
   Probability and frequency of UFP exposure were assessed for each combination of occupational code and process.
   Occupational codes defined by the ISCO 1968 classification.

- UFP & lung cancer (OR = 1.51; 95% CI: 1.22–1.86)
- UFP & brain tumors (OR = 1.69; 95% CI: 1.17–2.44)
- UFP & pleural mesothelioma (OR = 0.78; 95% CI: 0.46–1.33)

Method used in MATGENE and MATPHITO programs (France)

- Estimation of PAF and DALYs
- Analytical epi-studies

Manangama et al. Env Res
How to create a JEM?

3rd exemple: «SYN-JEM» country-, job-, and time period-specific quantitative JEM for 5 lung carcinogens *(Peters et al. 2016)*

Data used

1 - ExpoSYN database

- 356,551 measurements from 19 countries: 140,666 personal and 215,885 stationary data points
- RCS (42%), asbestos (20%), chromium (16%), nickel (15%), and PAH (7%), covering a time period of >50 years
- Only personal measurement data used

2 - General population JEM (DOMJEM): no, low, or high exposure levels to all job titles listed in ISCO-68 *(Peters et al., 2011)*

Statistical method

A linear mixed-effects model, using the same structure for all five agents.

- Random effects terms: region/country and job title, for which best linear unbiased predictors (BLUP)
- Fixed effect terms: Sampling duration, Year, Measurement strategy, Analytical method
- Model predictions provides an annual geometric mean (GM) exposure level to any agents for a given job, region, year
- Approaches allows to combine individual-/subgroup-level and group-level exposure information using shrinkage
- estimators to maximize accuracy and precision of the final JEM
- Prior exposure rating allows calibration of exposure levels by a weighted mean of exposure measurements
- Inspired by Friesen at al 2012 and Bayesian calculations *(Verbeke and Molenberghs, 2000)*

Application

Assessment of cancer risks associated with low levels of occupational exposure and the joint effects of smoking *(IARC)*
How to create a JEM in Switzerland?

Data available
1 – SUVA database of occupational exposure measurements (no access for researchers)
2 – Data on UV environmental exposure and radon
3 – Survey of active population and Suisse health survey by Swiss Federal Statistical Office (SFSO)
   • Irregular working hours, psychosocial risk factors, physical activity, smoking
   • Prevalence of exposure, frequency, sometimes intensity
   • Since 1990
4 – Cohorts:
   • One industrial cohort (Swiss railway employees, (Röösli et al 2007))
   • No occupational cohort
   • Many general population cohorts: SNC, SAPALDIA, SKIPOGH, CoLaus/PsyCoLaus, SHeS
     • Occupation history completeness ± satisfactory, ± possible to reconstruct
     • Few exposure data
5 – Disease registries (cancer, ORTS, …):
   • Quality of occupational data deemed insufficient (Plys et al, submitted)

⇒ Need of case-control studies with detailed occupation history and JEMs
⇒ Suisse solution: use available JEMs
   • Directly by applying the region-specific EU or international JEMs
   • As prior for creating Swiss-specific JEMs
Exemple: How to create a Swiss-specific JEM for smoking?

Rational:
Given the frequent lack of smoking status data in Swiss datasets, a Swiss Smoking JEM could provide the tool to reconstruct such data when not available.

Datasets:
1. Swiss Health Survey (SHS) by SFSO
2. Job-Exposure matrix (DJEM) constructed by the Department of Occupational and Environmental Medicine (DOEM), Bispebjerg Hospital, Denmark
   - Jobs coded using ISCO 88
   - Smoking probability and intensity per Job, Sex, Age, and Calendar Year
Exemple: How to create a Swiss-specific JEM for smoking?

1. Retrieve estimated smoking status probabilities from DJEM, stratified by age group, gender, and occupation (ISCO-88) and compute log of odds.
2. Use the Swiss Health Survey (SHS), stratified similarly to DJEM, to estimate via a mixed logistic regression the probabilities of being a smoker. Compute the log of odds.
3. Estimate the Pearson’s correlation between the log of odds computed from DJEM and SHS
4. Estimate means and variances of log-odds
5. Use information from step 4 to build a prior for the Bayesian logistic regression (covariates: age group, gender, ISCO-88) to estimate smoking status probabilities
6. Same for smoking intensity
7. Check empirically the reliability of the Swiss JEM, by comparing the estimated probabilities given by the Swiss JEM and a different Swiss dataset that contains smoking status data.

Need of coding and recoding occupations from Swiss nomenclature into ISCO (88, 68) or national ones

Funding: SECO & FOPH

**Procode: A Machine-Learning Tool to Support (Re-)coding of Free-Texts of Occupations and Industries.**

Savic N., Bovio N, Gilbert F, Paz J, Guseva Canu I.
**Take-home messages**

- JEM is often the only method for retrospective exposure assessment.
- It is particularly appropriate:
  - for analytical epi-studies of diseases with long latency
  - for rare diseases (using case-control study design)
- JEM quality depends on the quality of the data and resources available.
- Even a semi-quantitative JEM can be more relevant than an individual quantitative measure if it correctly reflects:
  - the complexity of the exposure
  - the appropriate exposure metric
- Relevant for hazard identification and emergent risk assessment (e.g., nano)
- Very useful in research in OSH
Thank you for your attention!

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