

50 years of estimating exposures for different jobs: the past, present and future of developing and using job exposure matrices (JEM)

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Objectives Obtaining valid estimates of occupational exposures is an important objective of epidemiological studies involving the work exposome. Job-exposure matrices (JEM) link coded job titles to estimates of workplace exposures. This paper reviews their development over the past 50 years and provides practical guidance on their construction, selection, and use.

Methods We synthesized published literature and examples of existing JEM in a narrative overview of their historical development, construction, validation, and application. We organized practical considerations for developing and selecting JEM around exposure metrics, occupational classifications, temporal and geographical coverage, and validity.

Results JEM frameworks include exposure components and metrics; timing or location; whether exposures are based on direct measurements, expert opinion, or both; differentiation of qualitative, semi-quantitative, and quantitative matrices; type of job classification used; incorporation of sex and other variables; and validity testing. Investigators seeking to use a JEM must assess several important features: existing JEM and their availability, compatibility of job coding systems (or existence of a correspondence table), relevant components and exposure metrics, and JEM limitations.

Conclusions Awareness of the strengths and limitations of JEM is important for their effective use. To date, JEM have been mostly used in large general population studies though future applications in research, exposome evaluation and for other public health and policy issues are likely.

Key terms epidemiology; exposome; occupation; public health; worker.

Preventing disabling chronic diseases – such as cancer and cardiovascular, respiratory, neurodegenerative, mental, and musculoskeletal diseases – is a major global public health concern (1, 2). The many determinants of chronic disease make prevention complex, especially since most conditions are affected by factors present throughout the lifespan. At the population level, identifying the complex relationships among multiple determinants of health is essential for improving population

health and identifying relevant targets for prevention intervention (3–5). A wide range of workplace exposures, including chemical exposures, physical activities, long working hours, and psychosocial factors are important determinants of diseases such as cancers, respiratory and cardiovascular diseases, and musculoskeletal disorders (6). Population-level studies in industrialized countries have estimated that 2–8% of cancers and over 20% of upper-limb musculoskeletal disorders can be attributed

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to workplace exposures (7, 8). However, most population health studies do not account for occupational exposures. Similarly, most public health databases used for research contain little-to-no information on work (9).

Workplace exposures are difficult to assess and, although a substantial body of epidemiological work has analyzed occupational exposures in general population studies, they are not routinely assessed in the majority of epidemiological studies. Studies on occupational exposures often focus on specific populations of high-risk workers rather than on more common exposures affecting the millions of workers at a general population level (10–11). Obtaining valid estimates of occupational exposures should be an important objective of all epidemiological studies involving current or former working populations, though obtaining these estimates can be quite difficult. Direct in-situ measurement of occupational exposures and observation of workers at an individual level are precise and accurate methods, but they are costly and time-consuming to implement in a general population study and not feasible for assessing exposure retrospectively (12, 13).

Expert assessments allow evaluators to incorporate general knowledge about the exposure domain. However, they are also time-consuming. Questionnaires are easier to administer to large populations, but self-reported exposures may be inaccurate or biased, for example by the respondent's current or past health status (14). Job-exposure matrices (JEM) can be a useful approach to providing valid exposure estimates to general population studies.

In this paper, after offering a short definition of JEM, we present a 50-year history of the approach. We also describe the present use of JEM to provide a guide for using and developing JEM, their limitations, some examples, and thoughts on the future of JEM in research, public health, and other settings. This paper is not intended as a state-of-the-art methodological contribution nor as a comprehensive overview of existing JEM, but rather as a concise, practical guide for the wider readership of occupational and environmental health: epidemiologists working on other exposures, public health researchers, and clinicians who have never used a JEM. We discuss both the development and the use of JEM because readers must understand how matrices are built and validated in order to judge whether an existing matrix is fit for a given research question.

What is a job-exposure matrix?

A JEM is a table (matrix) that links coded job titles with indices of workplace exposure to provide exposure estimates for different jobs. Typically, all workers within the same job group are assigned the same exposure estimate (11).

JEM are developed based on several sources of data including direct measures of exposure, expert exposure assessment and modeling, exposures reported by potentially exposed subjects, surveillance data, administrative records, or a combination of these methods. JEM vary considerably depending on the type of exposures assessed and the exposure indices used, which may express the probability, frequency, duration, or intensity of exposure. Exposures may be expressed as a continuous exposure index (quantitative JEM) or as categorical variables (semi-quantitative and qualitative JEM) (15). In the construction of JEM, both variance between and within job groups are considered in order to optimize the contrast between groups (16). In some cases, further differentiation (eg, by industry) may be needed if exposures vary substantially within the same job groups. JEM can cover the general population, industry-specific settings (such as chemical and radiation industries), or specific occupations (such as nurses or welders).

The history of job-exposure matrices

Emergence of the JEM concept (<1980). Classifying jobs according to the potentially harmful agents to which they expose workers, whether in the general population or in specific industrial sectors, is a long-standing approach in occupational health studies reporting the risks associated with exposure to specific workplace hazards. As early as 1941, an occupational health textbook presented a “Chart of Potential Industrial Health Hazards” listing the presence or absence of 79 different hazards within each of 108 different “industrial classifications” (17).

The first author to coin the term “job exposure matrix” is likely SK Hoar. In 1980, she published an article with colleagues from the National Cancer Institute (USA), in which she presented the principle of the method without using the term JEM (18). In 1983–1984, she named a database linking different jobs to potential exposure to carcinogenic agents as a “job exposure matrix” (19).

She explained why a JEM approach is useful, especially for the study of potential long-term effects of substances, mainly carcinogens, as assessing past exposure is difficult or impossible with approaches such as questionnaires, and historical direct measures may not reflect workers' actual exposures. Historical exposure measures may reflect worst-case conditions, be collected for compliance purposes, or made as static (area level) measures rather than as personal measurements. Two years later, in their paper describing the development of a matrix for population-based studies, Pannett et al (20) explained that the alternatives, such as asking experts to assign past exposure at an individual level, were expensive and presented limitations and practical difficulties.

Years of chemical JEM (1980–2010). In the 1980s, several JEM estimating exposures to potentially carcinogenic chemical agents were published, originating primarily from England (20, 21), Italy (22, 23) and the USA (24–26).

A publication from the European Concerted Action on retrospective evaluation of occupational exposures (1990–1992) presented an overview of the available JEM, with a focus on the methodological aspects of performance and validity (27).

Until the early 2010s, JEM focused mainly on chemical substances, especially potential carcinogens. For example, a PubMed search covering the period prior to 2010 using the keyword “JEM” yields 83 articles on lung cancer. The agents most frequently studied were those investigated for their carcinogenicity: asbestos with 65 articles, also magnetic fields (56 articles) and ionizing radiations (47 articles), the majority of which were conducted in industry-based cohorts rather than in general population studies.

Other JEM years (>2010s). Since 2010, an important increase in the number of articles dealing with JEM occurred as indicated in figure 1. JEM are now being used to assess exposure to a wide variety of occupational and work-related factors, including: biological, ergonomic, psychosocial, nanoparticles, electromagnetic fields, heat, cold, noise, ultraviolet (UV) radiation, SARS-Cov-2, second-hand smoke, precarious employment, and lifestyle factors. In 2020, Peters (28) stated

that, despite their limitations, “job-exposure matrices are a common method for exposure assessment in occupational epidemiology” and that they “represent a highly efficient and reproducible methodology”.

A review of the Network on the Coordination and Harmonization of European Occupational Cohorts (OMEGA-NET) inventory of occupational exposure tools identifies nearly 50 JEM (29). Some cover a single agent (there are many possible examples, particularly in Matgéné or EuroJEM), while others cover multiple exposures, such as “Hoar JEM” (334 chemical agents), FinJEM (84 agents), or CanJEM (258 agents). Many of these JEM were developed for a specific project and study or, conversely, as part of a general JEM development program (Matgéné, EuroJEM). The extent to which individual matrices are actually used varies widely: a Scopus search retrieves 46 articles for FINJEM, 18 for CANJEM, 11 for both Matgéné and SYN-JEM, indicating that some general population matrices are widely used.

Two categories of exposures are examples of recent development of JEM. The first is musculoskeletal exposures, with only 2 articles prior to 2010 and 26 from 2011 to 2026. The second is psychosocial exposures, with 20 articles prior to 2020 and 63 from 2020 to date.

Design and use of job exposure matrices

How to develop a JEM. JEM vary considerably depending on the type of exposure being assessed, whether the

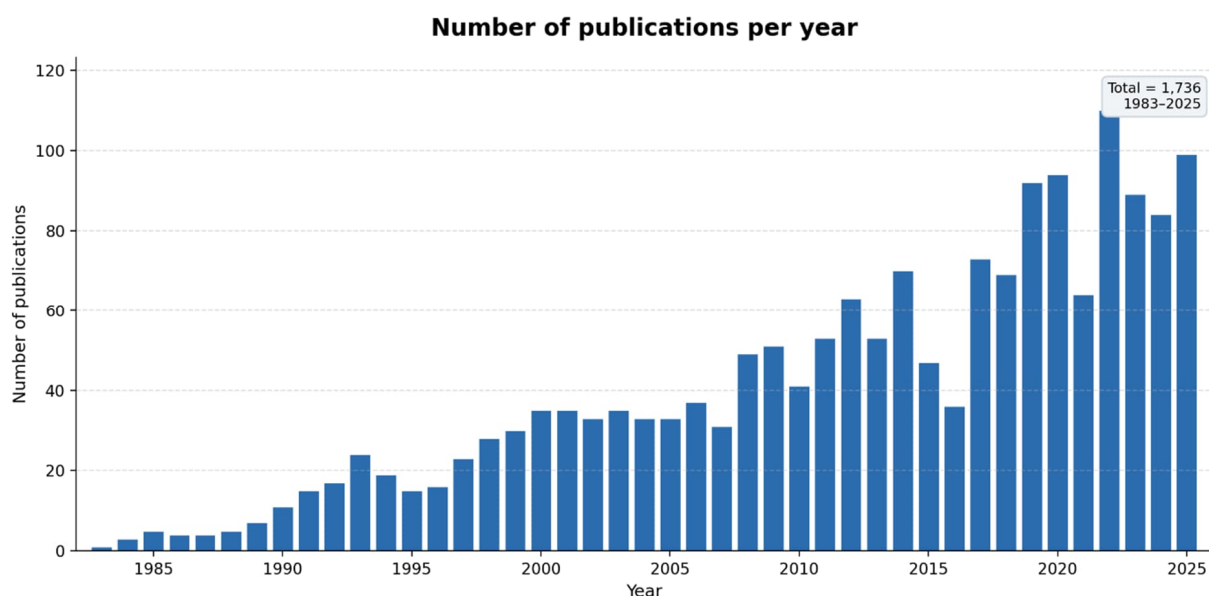


Figure 1. Number of articles published in Scopus based on job exposure matrix (JEM) in the title or abstract.

exposure index is continuous or categorical, and the exposure metrics used, which may include probability, frequency, duration, or level of exposure (15). The choice of these indices often depends on the available data. By design, a JEM assigns the same exposure estimate to all workers holding the same job title or belonging to the same job group; job groups should therefore be defined to maximize the contrast in exposure between groups relative to the variability that actually exists within groups (16). The choice of a JEM depends on the exposures of interest, the temporal and spatial patterns of these exposures, the population, and the research question and health outcome under study. It also depends heavily on the study design: a relatively crude general population matrix, such as the original “Hoar JEM” (18), may be adequate in a population-based study, where contrasts between occupations are large, while being of little value in an industry-based cohort in which all participants share broadly similar exposures. The choice also depends on the job title coding system used in the population under study, and in some cases, the economic sector or industry coding system.

Before developing a JEM, it is necessary to establish its framework by answering certain questions.

(i) Will the JEM be based on measured exposure data, reports from potentially exposed individuals, or expert assessments of exposure? Each of these methods has its advantages. Direct measurements of airborne chemicals are often used to develop JEM for chemical exposures, frequently supplemented by expert assessments of exposures among different groups of workers at different times. When sufficient direct measurements are not available – which is often the case – expert-based assessments can be used alone (30–32). These JEM models rely on experts (occupational physicians, ergonomists, hygienists, engineers, etc) with detailed knowledge of the jobs being assessed, including past working conditions if long-term exposure is being investigated. For general population JEM, knowledge of many different jobs is necessary. The use of self-reported exposures is less common in the construction of JEM, but for some exposures (eg, psychosocial job demands) it may be the only feasible option because they are not directly observable or known to external experts. This method also has certain advantages. JEM based on self-reported exposures rely on workers’ knowledge of their usual occupational exposures. By aggregating information and assigning exposures based on group-level responses rather than individual-level responses, JEM models reduce reporting biases due to individual variations in reporting that may be influenced by symptoms or disease status. A number of JEM models use a mixed approach, such as expert assessment supplemented by direct measurements, or the use of worker-reported exposures

combined with evaluation by experts (15, 33). A more recent development is the statistical modelling of exposure, in which expert or self-reported JEM ratings are combined with measurement data to produce quantitative estimates; early illustrations of this approach (34, 35) have since been adopted by a number of matrices (36) and it underlies several of the quantitative JEM described below.

(ii) What type of job classification should be used?

Occupational coding systems vary from one country to another. Although most of them can be linked via a cross-walk to the International Standard Classification of Occupations (ISCO), multiple ISCO versions exist, and the conversion between systems can lead to classification errors (37, 38). The choice of job classification depends on the intended use of the JEM, the type of job classification available, the time periods and populations under study, and technical aspects such as the availability of data for developing the JEM and its validation. For example, the 1968 and 1988 ISCO classifications were used to assess past exposures in the context of delayed-onset diseases such as cancer in multiple countries (39), while a study conducted in one country examined the risks associated with occupations using a country-specific occupational classification (40). The rationale underlying these classifications has itself changed over time, which matters for exposure assessment: ISCO-68 was organized partly by industry, with jobs nested within industries, whereas more recent ISCO versions classify jobs more by education and competencies, so that the same job title now occurs across many industries. This is one reason why combining job title with industrial sector can be necessary in a JEM.

Translating reported free-text job titles or descriptions into existing job coding systems can be complex. Job coding should engage experienced coding professionals who are unaware of the disease status of participants. Various automated tools are also available, from decision-support systems to fully automatic coding tools, some of which have been tested and shown good concordance with coding by professional coders (41).

In addition to job titles, it may also be important to include further differentiation based on industrial sector, often classified by the International Standard Industrial Classification of All Economic Activities (ISIC; version 4 currently in effect) (42). Such differentiation may be necessary for a JEM for chemical agents, for example, where all workers in a given area may be exposed to an inhaled toxin (15). Industrial sector is less relevant for JEM on biomechanical factors (43). This makes sense because the job title better summarizes biomechanical exposure than the sector: for example, an administrative staff member will infrequently lift heavy loads, regardless of the industrial sector. Furthermore, JEM can be

used as a risk assessment tool by occupational healthcare professionals; in this case, the classifications follow the coding used by the occupational health service (44). Finally, JEM specific to a company or sector may use a job or task classification specific to their sector.

(iii) Which components of exposure should be taken into account: level (intensity), duration, frequency, or probability? The choice of exposure component often depends on the data used to construct the matrix (eg, historical exposure records or exposure questionnaires) and may also be influenced by the hypotheses one wishes to test. For example, chemical or noise exposure may be described by several components, such as probability, frequency, intensity, peak levels, or the time-weighted average of exposures. Thus, some JEM provide an overall assessment of the exposure in question and its magnitude (43, 45) while other JEM provide data on the intensity of exposure as well as on frequency and duration (46). When the underlying data are sufficiently precise, these components are complementary and can be combined into a cumulative exposure metric, typically as intensity multiplied by duration of exposure or employment, often weighted by the probability of exposure (15, 47, 48). The exposure component can be expressed as a continuous exposure index, an ordinal measure (eg, low, medium, high) or a binary indicator (exposed versus not exposed). Similar to the choice of exposure component, the choice of scale/metric depends on the exposure, data availability, and the research hypothesis. To test for any association of exposure with a health outcome, a binary JEM may be appropriate, whereas assessing exposure–response relationships generally requires a continuous exposure metric.

Continuous exposure metrics are provided by quantitative JEM, in which entries are estimates of exposure level expressed in measurement units rather than in ordinal ranks. Such matrices are built from collated measurement databases, generally combined with expert judgement within a statistical model accounting for determinants such as calendar period, industry, and region (35, 36). SYN-JEM, which provides quantitative estimates for five lung carcinogens across jobs, periods and regions, is the most widely used example (47); CANJEM provides intensity, frequency and reliability estimates for 258 agents (48); FINJEM provides quantitative estimates for a large number of agents in the Finnish population (49); and a quantitative solar UV radiation JEM has recently been developed for Europe (50). Quantitative matrices are demanding in terms of data and of modelling effort, but they support exposure–response analyses that ordinal or binary matrices cannot, and they make results more comparable across studies and countries (11).

(iv) Should time and/or location (date/year, region) be taken into account? When exposure varies from one period to another or one geographic area to another, additional parameters should be added to provide separate exposure estimates for each job by period and region. For example, a JEM model estimating past asbestos exposure took into account the temporal evolution of government regulations that reduced and ultimately banned the use of asbestos (15). Time trends in exposure are well documented for many agents but remain frequently overlooked when a JEM is applied; as a general rule, the exposure period covered by the matrix should be relevant to the induction period and latency of the disease under study. While most JEM are specific to the country in which they were developed, cross-national use may be feasible and useful, particularly when no relevant country-specific JEM exist for the population of interest. This cross-national use of JEM is likely to become more common in the future, despite two challenges. First, each country has its own systems for classifying occupations and economic sectors. Unless ISCO has been used, it is necessary to transcode the occupation and economic sector codes to align the JEM with the population under study. Second, exposure in the same job can vary from country to country. This is very evident in certain situations: working outdoors involves exposure to cold or heat, depending on the country. Government regulations and industry practices may also differ. For these reasons, efforts to create and use transnational or international JEM systems must account for differences in exposure across countries, as well as for different job classification systems (49, 51), or even latitude for UV specific exposure (50). Such applications exist; for example, the US O*NET JEM has been linked to UK job titles by cross-coding the two job coding systems and has since been used to estimate occupational exposures related to SARS-CoV-2 and shoulder conditions in the large UK Biobank cohort (52).

(v) Are other variables relevant? Other factors may need to be considered. For example, specifying gender may be important as exposures within the same job may differ between men and women, which has led some recent JEM to provide separate values by gender. Similarly, exposure within the same job may vary by other characteristics, and JEM have been developed for specific groups, (eg, pregnant workers (53)). Company size may also be a factor to consider (54, 55). Preventive measures that reduce exposure levels are also sometimes important and must be incorporated into the development or use of JEM, such as mask-wearing and COVID-19 vaccination rates (56).

Assessing the validity of JEM. Assessing the validity of a JEM is an important step. This involves two aspects: (i) internal validity, which concerns the reliability of the JEM and whose assessment varies depending on the methodology used to develop the JEM, and (ii) external validity, which concerns the generalizability of the JEM to other contexts (eg, different time periods and different workplaces).

Regardless of the methodology used to construct the JEM, internal validity can be assessed by comparing the exposures estimated by the JEM to a gold standard of exposure, when it exists. In this case, sensitivity estimates the JEM's ability to correctly identify exposed subjects, specificity estimates the JEM's ability to correctly identify unexposed subjects, and the area under the ROC curve (AUC) evaluates the JEM's performance in distinguishing between exposed and unexposed subjects. Other methods for assessing validity include the ability of the JEM to identify known associations between exposure and health outcomes and the measurement of agreement among exposure estimates derived from different JEM (57, 58). Such comparisons are informative: applying three different JEM to the same population showed only modest agreement between them (59). The performance of a JEM also depends strongly on the prevalence of exposure in the population studied (60).

Regarding external validity, it can be assessed in various ways depending on the available data. It is possible, for example, to compare exposure results from the JEM with exposure data available in similar populations or to apply the JEM in another population to estimate its performance in that population (eg, by detecting known exposure–response relationships). It is also possible to compare JEM exposure results with available epidemiological data (for example, comparing the prevalence of exposure calculated using the JEM with national prevalence).

How to use job exposure matrices

Strengths of using a JEM. There are many good reasons for using JEM to assess workplace exposure. Though creating a JEM is a long, complex and costly process, its application is typically simple and low cost. Several JEM covering different exposures can be applied at the same time, increasing the number of work-related exposures that can be assessed in a general population study. Use of a JEM allows the conversion of each study participant's job history into cumulative individual exposure estimates. Importantly, because exposure is assigned from the job title alone, JEM exposure assignments are not influenced by the participant's disease status or by differential recall so that the resulting exposure misclassification is non-differential with respect to the

outcome. Finally, JEM allow work exposure data to be assigned to individual workers based only on job titles. This feature is particularly valuable for assessing past exposures, where workers' recall may be biased, and retroactive measurement of exposures is impossible.

Limitations of using job exposure matrices

Users should be aware of the limitations associated with the use of JEM. Because the same exposure is assigned to all workers in a given job, JEM cannot account for the individual variability in exposure among workers in the same job. This results in non-differential misclassification of individual exposures since the variations within a job due to individual behaviors and other factors are not taken into account (28). Depending on the exposure metric, this misclassification may reduce statistical power and attenuate estimates of risk. In the case of JEM, measurement errors are typically of the Berkson type rather than classical, since the JEM assigns a group mean rather than an individual value; this may reduce statistical precision and power. When the variability of exposure within a job is large relative to the variability between jobs, grouping may result in attenuation of the exposure–response relationship (61). Whether grouping helps or harms therefore depends on the structure of exposure variability and the contrast between the job groups retained. JEM models perform better when there are large differences in exposures across different occupations, as in general population studies, and are less able to distinguish between groups of workers with similar exposures. Furthermore, users should bear in mind that occupational classification systems were developed primarily from a socioeconomic perspective and may not accurately reflect exposure categories; this particularly applies to recent classifications based on education and competencies, compared with ISCO-68, whose industry-based structure lends itself well to exposure grouping. Furthermore, exposures must be reasonably estimable at the occupational group level. Some heterogeneity in exposure can be accounted for by adding more detail, such as increasing the number of variables in JEM. For example, estimating exposure specific to sex and age can help account for some heterogeneity in exposure within occupations. Assessing exposure with a JEM sets within-job variability to zero by construction; it therefore implies that this variability is small relative to the differences between jobs or that an average exposure is the relevant quantity for the outcome under study. This can be a limitation, for example, for psychosocial work exposures such as perceived social support that may vary more by workplace than job title. In such cases, individual-level exposure data are preferable (62). For certain health issues, the effects

of high short-term exposures may be more relevant than average levels over time. JEM models should also be used with caution given the limitations of their design, which is based either on expert assessments or on data collected at the individual level, including directly measured exposures of air contaminants or postures that are then aggregated. Coding occupations based on job titles and industry sector can be time-consuming and may influence the exposures assigned to individual workers.

Steps to using job exposure matrices

Investigators wishing to apply an existing JEM to their own data should work through the following six questions before starting: (i) *Is there an existing JEM for the exposure of interest?* In addition to common research databases (Pubmed, Scopus, Web of Sciences), researchers can look at online repositories of available tools, such as the OMEGA-NET inventory of occupational exposure tools (29); (ii) *Is the JEM available?* Although most JEM were publicly funded, are intended to be used widely, and are available through public websites or from their developers, restrictions of use and availability should be checked; (iii) *What job coding system is used (and is there a correspondence table)?* Job title information in the source data must be linked to the exposure data in the JEM. Ideally, the JEM uses the same job coding system as the source data – if these do not match, then transcoding of job titles will be needed to link to the JEM directly, typically by using an existing “cross-walk” or creating a new one. Even within the same coding system, attention must be paid to which version of standard occupational codes was used, as job and industry codes change over time; (iv) *Does the JEM contain relevant exposure metric(s)?* JEM vary widely on what exposure data are included, and at what level of detail; the hypothesis under study will drive the choice of the JEM. The analytic plan must consider which exposure(s) will be used, and how to define exposure levels (dichotomous or continuous) and exposure periods; (v) *Does the JEM have any limitations, including development validation?* The limitations set out above apply to every matrix, but each JEM also has limitations of its own: the way it was built, the population and the period it was built for, and the validation it has or has not undergone should be checked in the original publication and reported in the methods section of the study; and (v) *Has validation in the context of the proposed study been considered?* Additional external validation of a JEM may be possible within the context of a new population by checking known exposure–disease associations as positive and negative controls.

Examples of job exposure matrices

There are many examples of JEM, as mentioned above (29). In addition, existing correspondence tables between occupational classification systems are readily available [eg, ISCO-08/88 (63), the 2010 Standard Occupational Classification (SOC) to ISCO-08 crosswalk (64) or more general transcoding resources (65)], and indirectly by contacting researchers who have built one, eg, EuroJEM (66). Finally, web resources are available to support (automated) recoding of job titles (65).

Future of job exposure matrices and perspectives

Research. Beyond using JEM to study associations between workplace exposures and work related health outcomes, it is becoming increasingly clear that population health research should include all relevant factors in the exposome, including workplace-related factors (3). Indeed, given the significant amount of time people spend at work, workplace exposures and behaviors should be taken into account when describing risk factors for disease. There is growing interest in assessing the role of workplace-related factors in chronic and acute diseases that are not traditionally considered “occupational diseases.” For example, JEM have been used to study biomechanical exposures in relation to aging, and fetal death and preterm birth (67, 68). During the COVID-19 pandemic, the risk of SARS-CoV-2 infection based on protective measures implemented in the workplace led to the development of JEM related to workplace exposures (56, 60, 69). These examples illustrate the importance of accounting for occupational exposures in studies of combined risk factors, and show how JEM offer public health researchers a practical way to integrate workplace exposures into analyses. JEM have also been developed for “new” and emerging occupational exposures such as artificial intelligence (AI) use, and for broader working populations (called “workingers” to include volunteers, apprentices, family members who provide unpaid home care, and other work situations that occur outside of formal employment) (70). Increasing attention has also been given to activity–exposure matrices that link occupational exposures to specific work tasks or activities (71). By aggregating the task-specific exposures, activity–exposure matrices can extend the JEM concept to capture the entire occupational exposome. Their use will be particularly beneficial when work history data includes information on tasks or activities.

Methodological research on JEM is still ongoing, including statistical methods for their development and validation, such as Bayesian or machine learning approaches. Several research initiatives are also working to improve the use of JEM, including international JEM and adaptations of JEM to local contexts that may

expand the global reach of JEM. For example, the Euro-JEM aims to provide JEM applicable across different European countries (62), and the JEMINI initiative (*Job Exposure Matrix InterNational*) explores the possibility of developing international/European JEM (51). Finally, since manual occupational coding by trained coders is a time-consuming and costly task, automated job coding systems exist, and new systems are being developed using AI on several national classification systems. With the emergence of large language models, these tools may continue to improve further, though automated coding will likely still be supplemented by manual coding by experienced coders (41, 72), and the validity of AI outputs must be examined closely. Recent developments of big data in occupational health, such as administrative databases, routinely collected data, and large cohorts, also favors the use of JEM which are well suited to add valuable work exposure data to large datasets.

Other public and occupational health applications

In addition to research applications, JEM can play a role in monitoring population-level risk factors and other public health activities and may be helpful in clinical management. JEM could contribute to the clinical care of workers, return-to-work assessments, and workers' compensation or other social benefit processes by providing a baseline estimate of relevant exposures in various occupations. The value and the limits of using a JEM to estimate an individual's exposure for compensation purposes have recently been discussed (73). Since occupational diseases are often underdiagnosed, another practical application is to use the JEM to screen for occupational exposures as part of health surveillance and routine medical care. By summarizing multiple exposures at the job level, the JEM can also help policymakers set priorities regarding occupational risk prevention, job retention, and retirement. Likely, JEM can help identify workers who need health monitoring following significant past exposure to carcinogens like asbestos.

JEM can also assist occupational health practitioners. For example, a JEM was developed using data from the medical surveillance survey of employee exposures to provide occupational physicians with a tool to identify high-exposed jobs and help target prevention efforts (44). While JEM should be used with caution in this setting as it cannot replace individual exposure assessment by professionals, it can provide workers and employers an overview of exposure and prevention potential (11). JEM may also be useful when occupational health practitioners are scarce or nonexistent to improve occupational health culture and literacy among employers; use of a JEM can also help occupational health professionals focus their efforts and expertise when they are dealing with complex situations. Finally, JEM represent

an opportunity to more widely study occupational exposures in the broader field of epidemiology. Most large-scale epidemiology studies incorporate little-to-no data on occupational exposures, making work-related risk factors a largely ignored aspect of the exposome. Wider use of JEM should allow better estimates of multiple risk factors within large population studies.

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References

1. Vos T, Lim SS, Abbafati C, Abbas KM, Abbasi M, Abbasifard M, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*. 2020 Oct 17;396(10258):1204–22. [https://doi.org/10.1016/S0140-6736\(20\)30925-9](https://doi.org/10.1016/S0140-6736(20)30925-9).
2. Takala J, Hämäläinen P, Sauni R, Nygård CH, Gagliardi D, Neupane S. Global-, regional- and country-level estimates of the work-related burden of diseases and accidents in 2019. *Scand J Work Environ Health* 2024 Mar;50(2):73–82. <https://doi.org/10.5271/sjweh.4132>.
3. Rappaport SM. Implications of the exposome for exposure science. *J Expo Sci Environ Epidemiol* 2011;21(1):5–9. <https://doi.org/10.1038/jes.2010.50>.
4. Roquelaure Y, Luce D, Descatha A, Bonvallot N, Porro B, Coutarel F. [Occupational exposome: An organisational model] [Article in French]. *Med Sci (Paris)* 2022 Mar;38(3):288–93. <https://doi.org/10.1051/medsci/2022022>.
5. Wild CP. The exposome: from concept to utility. *Int J Epidemiol* 2012 Feb;41(1):24–32. <https://doi.org/10.1093/ije/dyr236>.
6. Pega F, Hamzaoui H, Náfrádi B, Momen NC. Global, regional and national burden of disease attributable to 19 selected occupational risk factors for 183 countries, 2000–2016: A systematic analysis from the WHO/ILO Joint Estimates of the Work-related Burden of Disease and Injury. *Scand J Work Environ Health* 2022 Mar;48(2):158–68. <https://doi.org/10.5271/sjweh.4001>.
7. Purdue MP, Hutchings SJ, Rushton L, Silverman DT. The proportion of cancer attributable to occupational exposures. *Ann Epidemiol* 2015 Mar;25(3):188–92. <https://doi.org/10.1016/j.annepidem.2014.11.009>.
8. Nambiema A, Bodin J, Fouquet N, Bertrais S, Stock S, Aublet-Cuvelier A et al. Upper-extremity musculoskeletal

- disorders: how many cases can be prevented? Estimates from the COSALI cohort. *Scand J Work Environ Health* 2020 Nov;46(6):618–29. <https://doi.org/10.5271/sjweh.3911>.
9. Modernizing the Coding of Occupational Health Data | Blogs | CDC [Internet]. [cited 2026 Sep 22]. Available from: <https://www.cdc.gov/nndss/in-action/health-data.html>.
 10. Kauppinen TP. Assessment of exposure in occupational epidemiology. *Scand J Work Environ Health* 1994;20(Spec No):19–29.
 11. Descatha A, Fadel M, Sembajwe G, Peters S, Evanoff BA. Job-Exposure Matrix: A Useful Tool for Incorporating Workplace Exposure Data Into Population Health Research and Practice. *Front Epidemiol* 2022 Apr;2:857316. <https://doi.org/10.3389/fepid.2022.857316>.
 12. Seixas NS, Checkoway H. Exposure assessment in industry specific retrospective occupational epidemiology studies. *Occup Environ Med* 1995 Oct;52(10):625–33. <https://doi.org/10.1136/oem.52.10.625>.
 13. van der Beek AJ, Frings-Dresen MH. Assessment of mechanical exposure in ergonomic epidemiology. *Occup Environ Med* 1998 May;55(5):291–9. <https://doi.org/10.1136/oem.55.5.291>.
 14. Leclerc A. Exposure assessment in ergonomic epidemiology: is there something specific to the assessment of biomechanical exposures? *Occup Environ Med* 2005 Mar;62(3):143–4. <https://doi.org/10.1136/oem.2004.017889>.
 15. Févotte J, Dananché B, Delabre L, Ducamp S, Garras L, Houot M et al. Matgéné: a program to develop job-exposure matrices in the general population in France. *Ann Occup Hyg* 2011 Oct;55(8):865–78.
 16. Choi B. Developing a job exposure matrix of work organization hazards in the United States: A review on methodological issues and research protocol. *Saf Health Work* 2020 Dec;11(4):397–404. <https://doi.org/10.1016/j.shaw.2020.05.007>.
 17. Reed JV, Harcourt AK. *The Essentials of Occupational Diseases*. Baltimore (MD): CC Thomas. 1941
 18. Hoar SK, Morrison AS, Cole P, Silverman DT. An occupation and exposure linkage system for the study of occupational carcinogenesis. *J Occup Med* 1980 Nov;22(11):722–6.
 19. Hoar S. Job exposure matrix methodology. *J Toxicol Clin Toxicol*. 1983 1984;21(1–2):9–26. <https://doi.org/10.3109/15563658308990408>.
 20. Pannett B, Coggon D, Acheson ED. A job-exposure matrix for use in population based studies in England and Wales. *Br J Ind Med* 1985 Nov;42(11):777–83. <https://doi.org/10.1136/oem.42.11.777>.
 21. Coggon D, Pannett B, Acheson ED. Use of job-exposure matrix in an occupational analysis of lung and bladder cancers on the basis of death certificates. *J Natl Cancer Inst* 1984 Jan;72(1):61–5. <https://doi.org/10.1093/jnci/72.1.61>.
 22. Vineis P, Magnani C. Occupation and bladder cancer in males: a case-control study. *Int J Cancer* 1985 May;35(5):599–606. <https://doi.org/10.1002/ijc.2910350506>.
 23. Magnani C, Coggon D, Osmond C, Acheson ED. Occupation and five cancers: a case-control study using death certificates. *Br J Ind Med* 1987 Nov;44(11):769–76. <https://doi.org/10.1136/oem.44.11.769>.
 24. Hinds MW, Kolonel LN, Lee J. Application of a job-exposure matrix to a case-control study of lung cancer. *J Natl Cancer Inst* 1985 Aug;75(2):193–7.
 25. Vaughan TL, Strader C, Davis S, Daling JR. Formaldehyde and cancers of the pharynx, sinus and nasal cavity: I. Occupational exposures. *Int J Cancer* 1986 Nov;38(5):677–83. <https://doi.org/10.1002/ijc.2910380510>.
 26. Linet MS, Stewart WF, Van Natta ML, McCaffrey LD, Szklo M. Comparison of methods for determining occupational exposure in a case-control interview study of chronic lymphocytic leukemia. *J Occup Med* 1987 Feb;29(2):136–41.
 27. Goldberg M, Hémon D. Occupational epidemiology and assessment of exposure. *Int J Epidemiol* 1993;22 Suppl 2:S5–9. https://doi.org/10.1093/ije/22.Supplement_2.S5.
 28. Peters S. Although a valuable method in occupational epidemiology, job-exposure matrices are no magic fix. *Scand J Work Environ Health* 2020 May;46(3):231–4. <https://doi.org/10.5271/sjweh.3894>.
 29. Job-Exposure Matrix Complete [Internet]. *Occup. Expo. Tools*. [cited 2026 Sept 22]. Available from: <https://occupationalexposuretools.net/inventory/job-exposure-matrix-complete/>.
 30. Svendsen SW, Dalbøge A, Andersen JH, Thomsen JF, Frost P. Risk of surgery for subacromial impingement syndrome in relation to neck-shoulder complaints and occupational biomechanical exposures: a longitudinal study. *Scand J Work Environ Health* 2013 Nov;39(6):568–77. <https://doi.org/10.5271/sjweh.3374>.
 31. Rubak TS, Svendsen SW, Andersen JH, Haahr JP, Kryger A, Jensen LD et al. An expert-based job exposure matrix for large scale epidemiologic studies of primary hip and knee osteoarthritis: the Lower Body JEM. *BMC Musculoskelet Disord* 2014 Jun;15:204. <https://doi.org/10.1186/1471-2474-15-204>.
 32. Descatha A, Despréaux T, Petit A, Bodin J, Andersen JH, Dale A-M, et al. [Development of “MADE”, a French Job exposure matrix for evaluation of biomechanical exposure] [Article in French]. *Sante Publique*. 2018 June;30(3):333–7. <https://doi.org/10.3917/pub.183.0333>.
 33. Dalbøge A, Hansson GÅ, Frost P, Andersen JH, Heilskov-Hansen T, Svendsen SW. Upper arm elevation and repetitive shoulder movements: a general population job exposure matrix based on expert ratings and technical measurements. *Occup Environ Med* 2016 Aug;73(8):553–60. <https://doi.org/10.1136/oemed-2015-103415>.
 34. Heederik D, Attfield M. Characterization of dust exposure for the study of chronic occupational lung disease: a comparison of different exposure assessment strategies. *Am J Epidemiol* 2000 May;151(10):982–90. <https://doi.org/10.1093/oxfordjournals.aje.a010142>.

35. Friesen MC, Coble JB, Lu W, Shu XO, Ji BT, Xue S et al. Combining a job-exposure matrix with exposure measurements to assess occupational exposure to benzene in a population cohort in Shanghai, China. *Ann Occup Hyg* 2012 Jan;56(1):80–91. <https://doi.org/10.1093/annhyg/mer080>.
36. Vested A, Schlünssen V, Burdorf A, Andersen JH, Christoffersen J, Daugaard S et al. A Quantitative General Population Job Exposure Matrix for Occupational Daytime Light Exposure. *Ann Work Expo Health* 2019 Jul;63(6):666–78. <https://doi.org/10.1093/annweh/wxz031>.
37. Rémen T, Richardson L, Pilorget C, Palmer G, Siemiatycki J, Lavoué J. Development of a coding and crosswalk tool for occupations and industries. *Ann Work Expo Health* 2018 Aug;62(7):796–807. <https://doi.org/10.1093/annweh/wxy052>.
38. Evanoff B, Yung M, Buckner-Petty S, Baca M, Andersen JH, Roquelaure Y et al. Cross-national comparison of two general population job exposure matrices for physical work exposures. *Occup Environ Med* 2019 Aug;76(8):567–72. <https://doi.org/10.1136/oemed-2018-105408>.
39. Olsson AC, Gustavsson P, Kromhout H, Peters S, Vermeulen R, Brüske I et al. Exposure to diesel motor exhaust and lung cancer risk in a pooled analysis from case-control studies in Europe and Canada. *Am J Respir Crit Care Med* 2011 Apr;183(7):941–8. <https://doi.org/10.1164/rccm.201006-0940OC>.
40. Kerbrat J, Descatha A. Pénibilité au travail en France et utilisation de l'outil matrice emplois-expositions pour son évaluation. [The recognition of health consequences of difficult working conditions in France and its evaluation with the use of a job-exposure matrix]. *Arch Mal Prof Environ* 2018 Sep;79(4):493–500. <https://doi.org/10.1016/j.admp.2017.12.001>.
41. Langezaal MA, Goldberg M, Rey G, Wang S, van den Broek EL, Vermeulen R et al. AI-induced occupational health assessment. *Stud Health Technol Inform* 2025 Oct;330:479–508.
42. UNSD — ISIC [Internet]. [cited 2026 Sep 22]. Available from: <https://unstats.un.org/unsd/classifications/Econ/isic#:~:text=The%20International%20Standard%20Industrial%20Classification,statistics%20according%20to%20such%20activities>.
43. Evanoff BA, Yung M, Buckner-Petty S, Andersen JH, Roquelaure Y, Descatha A et al. The CONSTANCES job exposure matrix based on self-reported exposure to physical risk factors: development and evaluation. *Occup Environ Med* 2019 Jun;76(6):398–406. <https://doi.org/10.1136/oemed-2018-105287>.
44. Guéguen A, Goldberg M, Bonenfant S, Martin JC. Using a representative sample of workers for constructing the SUMEX French general population based job-exposure matrix. *Occup Environ Med* 2004 Jul;61(7):586–93. <https://doi.org/10.1136/oem.2003.010660>.
45. Kauppinen T, Toikkanen J, Pukkala E. From cross-tabulations to multipurpose exposure information systems: a new job-exposure matrix. *Am J Ind Med* 1998 Apr;33(4):409–17. [https://doi.org/10.1002/\(SICI\)1097-0274\(199804\)33:4<409::AID-AJIM12>3.0.CO;2-2](https://doi.org/10.1002/(SICI)1097-0274(199804)33:4<409::AID-AJIM12>3.0.CO;2-2).
46. Cifuentes M, Boyer J, Lombardi DA, Punnett L. Use of O*NET as a job exposure matrix: A literature review. *Am J Ind Med* 2010 Sep;53(9):898–914. <https://doi.org/10.1002/ajim.20846>.
47. Peters S, Vermeulen R, Portengen L, Olsson A, Kendzia B, Vincent R et al. SYN-JEM: A Quantitative Job-Exposure Matrix for Five Lung Carcinogens. *Ann Occup Hyg* 2016 Aug;60(7):795–811. <https://doi.org/10.1093/annhyg/mew034>.
48. Siemiatycki J, Lavoué J. Availability of a new job-exposure matrix (CANJEM) for epidemiologic and occupational medicine purposes. *J Occup Environ Med* 2018 Jul;60(7):e324–8. <https://doi.org/10.1097/JOM.0000000000001335>.
49. Lavoué J, Pintos J, Van Tongeren M, Kincl L, Richardson L, Kauppinen T et al. Comparison of exposure estimates in the Finnish job-exposure matrix FINJEM with a JEM derived from expert assessments performed in Montreal. *Occup Environ Med* 2012 Jul;69(7):465–71. <https://doi.org/10.1136/oemed-2011-100154>.
50. Würtz ET, Pugdahl K, Fenger-Grøn M, Berglund IA, Cherrie MP, Dahlman-Höglund A et al. A quantitative solar ultraviolet radiation job-exposure matrix for Europe. *Ann Work Expo Health* 2025 Apr;69(4):415–28. <https://doi.org/10.1093/annweh/wxaf011>.
51. Descatha A, Evanoff BA, Andersen JH, Fadel M, Ngabirano L, Leclerc A et al. JEMINI (Job Exposure Matrix InterNational) initiative: a utopian possibility for helping occupational exposure assessment all around the world? *J Occup Environ Med* 2019 Jul;61(7):e320–1. <https://doi.org/10.1097/JOM.0000000000001631>.
52. Yanik EL, Stevens MJ, Harris EC, Walker-Bone KE, Dale AM, Ma Y et al. Physical work exposure matrix for use in the UK Biobank. *Occup Med (Lond)* 2022 Feb;72(2):132–41. <https://doi.org/10.1093/occmed/kqab173>.
53. Frankel HN, Flachs EM, Sejbaek CS, Petersen JA, Bonde JP, Mehlum IS et al. Development of a quantitative job exposure matrix for standing, walking, and forward bending among pregnant workers - The PRECISE JEM. *Scand J Work Environ Health* 2025 Nov;51(6):526–36. <https://doi.org/10.5271/sjweh.4252>.
54. Singier A, Fadel M, Gilbert F, Soignances group; Ester-MESuRS collaboration on occupational risks; Temime L, et al. Development and validation of a French job-exposure matrix for healthcare workers: JEM Soignances. *Scand J Work Environ Health*. 2024 Dec ;50(8):653-664. <https://doi.org/10.5271/sjweh.4194>.
55. Niedhammer I, Milner A, Coutrot T, Geoffroy-Perez B, LaMontagne AD, Chastang JF. Psychosocial Work Factors of the Job Strain Model and All-Cause Mortality: The STRESSJEM Prospective Cohort Study. *Psychosom Med* 2021 Jan;83(1):62–70. <https://doi.org/10.1097>

- PSY.0000000000000878.
56. Descatha A, Fadel M, Pitet S, Verdun-Esquer C, Esquirol Y, Legeay C et al. SARS-CoV-2 (COVID-19) Job Exposure Matrix: “Mat-O-Covid” Creation (COVID-Mate in French), accuracy study, and perspectives. *Arch. Mal. Prof. Environ.* [Internet]. 2021;82(5):487-93 Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8321772>
 57. Yung M, Dale AM, Buckner-Petty S, Roquelaure Y, Descatha A, Evanoff BA. Musculoskeletal symptoms associated with workplace physical exposures estimated by a job exposure matrix and by self-report. *Am J Ind Med* 2020 Jan;63(1):51–9. <https://doi.org/10.1002/ajim.23064>.
 58. Yung M, Evanoff BA, Buckner-Petty S, Roquelaure Y, Descatha A, Dale AM. Applying two general population job exposure matrices to predict incident carpal tunnel syndrome: A cross-national approach to improve estimation of workplace physical exposures. *Scand J Work Environ Health*. 2020 May 1;46(3):248–58. <https://doi.org/10.5271/sjweh.3855>.
 59. Offermans NS, Vermeulen R, Burdorf A, Peters S, Goldbohm RA, Koeman T et al. Comparison of expert and job-exposure matrix-based retrospective exposure assessment of occupational carcinogens in The Netherlands Cohort Study. *Occup Environ Med* 2012 Oct;69(10):745–51. <https://doi.org/10.1136/oemed-2011-100556>.
 60. van Veldhoven K, Basinas I, Hengel KO, Burdorf A, Pronk A, Peters S et al. 1510Development and validation of a Job Exposure Matrix for work related risk factors for COVID-19 [Internet]. *Int J Epidemiol* 2021 Sep;50 Supplement 1: [cited 2021 Nov 10] <https://doi.org/10.1093/ije/dyab168.678>.
 61. Kromhout H, Heederik D, Dalderup LM, Kromhout D. Performance of two general job-exposure matrices in a study of lung cancer morbidity in the Zutphen cohort. *Am J Epidemiol* 1992 Sep;136(6):698–711. <https://doi.org/10.1093/oxfordjournals.aje.a116549>.
 62. Solovieva S, Pensola T, Kausto J, Shiri R, Heliövaara M, Burdorf A et al. Evaluation of the validity of job exposure matrix for psychosocial factors at work. *PLoS One* 2014 Sep;9(9):e108987. <https://doi.org/10.1371/journal.pone.0108987>.
 63. ILO [Internet]. [cited 2026 Sep 22]. Available from: <https://www.ilo.org/publications/international-standard-classification-occupations-2008-isco-08-structure>.
 64. ISCO-SOC [Internet]. [cited 2026 Sep 22]. Available from: https://www.bls.gov/soc/isco_soc_crosswalk.xls.
 65. Exppro [Internet]. [cited 2026 Sep 22]. Available from: <https://exppro.santepubliquefrance.fr/transcodage-accueil>
 66. EuroJem [Internet]. [cited 2026 Sep 22]. Available from: <https://ki.se/en/imm/eurojem>.
 67. Møller A, Reventlow S, Hansen ÅM, Andersen LL, Siersma V, Lund R et al. Does physical exposure throughout working life influence chair-rise performance in midlife? A retrospective cohort study of associations between work and physical function in Denmark. *BMJ Open* 2015 Nov;5(11):e009873. <https://doi.org/10.1136/bmjopen-2015-009873>.
 68. Mocevic E, Svendsen SW, Jørgensen KT, Frost P, Bonde JP. Occupational lifting, fetal death and preterm birth: findings from the Danish National Birth Cohort using a job exposure matrix. *PLoS One* 2014 Mar;9(3):e90550. <https://doi.org/10.1371/journal.pone.0090550>.
 69. Fadel M, Salomon J, Descatha A. COVID-19 Job Exposure Matrix: From the Mat-O-Covid Design to Its Execution. *J Occup Environ Med* 2021 Mar;63(3):e168. <https://doi.org/10.1097/JOM.0000000000002148>.
 70. Descatha A. Travail(lant) (es): concept utile entre santé, exposition et prévention[“Workers”: A useful concept for health, exposure, and prevention]. *Arch Mal Prof Environ* 2026 Apr;87(2):103120. <https://doi.org/10.1016/j.admp.2026.103120>.
 71. Dumas O, Varraso R, Boggs KM, Quinot C, Zock JP, Henneberger PK et al. Association of Occupational Exposure to Disinfectants With Incidence of Chronic Obstructive Pulmonary Disease Among US Female Nurses. *JAMA Netw Open* 2019 Oct;2(10):e1913563. <https://doi.org/10.1001/jamanetworkopen.2019.13563>.
 72. Davis J, Peek-Asa C, Dale AM, Zhang L, Casteel C, Hamann C et al. Determining occupation for National Violent Death Reporting System records: an evaluation of autocoding programs. *Am J Ind Med* 2021 Dec;64(12):1018–27. <https://doi.org/10.1002/ajim.23292>.
 73. Kromhout H, Heederik DJ. Using job exposure matrices to estimate an individual’s exposure for compensation? *Occup Environ Med* 2026 Apr;83(1):58–60. <https://doi.org/10.1136/oemed-2025-110290>.

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