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Scand J Work Environ Health 2007;33(1):1-53

Status report on Swedish work environment research—history, context and international evaluation

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Refers to the following text of the Journal: 2005;31(1):30-35

Key terms: health; history; international evaluation; occupational health research; psychosocial factor; public health research; status report; Sweden; work conditions; work environment; work environment research

Print ISSN: 0355-3140 Electronic ISSN: 1795-990X Copyright (c) Scandinavian Journal of Work, Environment & Health

Scand J Work Environ Health 2007;33 suppl 1:1–53

Status report on Swedish work environment research—history, context and international evaluation

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Funded by

FORSKNINGSRÅDET FÖR ARBETSLIV
OCH SOCIALVETENSKAP
SWEDISH COUNCIL FOR WORKING LIFE AND SOCIAL RESEARCH

Single copies of this issue (volume 33, supplement 1) can be obtained from the following address: Scandinavian Journal of Work, Environment & Health, Topeliuksenkatu 41 a A, FI-00250 Helsinki, Finland (telephone: 358-30-474 2694; telefax: 358-9-878 3326; email: johanna.parviainen@ttl.fi). The price of supplement 1 of volume 33 is EUR 34.00 (plus postage and handling charges).

Foreword

by Rune Åberg, PhD,[1] & Kenneth Abrahamsson, PhD[1]

The Swedish Council for Working Life and Social Research (FAS) would like to thank the International Evaluation Group, the Swedish reference group, and all of the participating researchers for their contributions to the successful completion of this evaluation. We are also very pleased with the opportunity to present the bulk of this inventory and evaluation, the historical overviews, and some concluding remarks as a supplement of the *Scandinavian Journal of Work, Environment & Health* and thereby to an international audience.

The report has been submitted to the relevant ministries in the Swedish government, and the results have been presented at several seminars for researchers and practitioners. The latter have, in general, been very appreciative of the evaluation. The evaluation provides solid ground for future initiatives from the Council and, hopefully, also from the Swedish government. Work environment research in Sweden is in organizational transition due to the abolition of the National Institute for Working Life and the demographic transitions within the relevant sciences. Thus strong decisions need to be made to secure financial support for its future development. We are faced with major challenges—the need to facilitate response to demographic changes, to continue to support research of high international standard, and to promote dissemination and user dialogue. Finally, the report will be useful for the research strategy that the Council has to present as background material for the next bill of research, to be expected in 2008.

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Introduction

by David H Wegman, MD,[1] & Christer Hogstedt, MD[2]

In an amendment to the government assignments for 2005, the Swedish Council for Working Life and Social Research (FAS) was commissioned to:

". . . analyse Swedish research in the area of occupational health, primarily chemical, physical and biological health risks, and research on musculoskeletal strain injuries and disorders including the interaction with mental stress. The task includes an inventory as well as an evaluation of carried out research. The evaluation will consider scientific quality of the research as well as its relevance to society. The task should also shed light and comment upon the future needs of national research within this area."

The aim of this evaluation was to assess the scientific quality and to identify gaps, weaknesses, and strengths of parts of Swedish work environment research—in accordance with the aforementioned assignment—from an international perspective. The charge did not include the individual evaluation of psychosocial research on the work environment by researchers or research groups. Since most Swedish experts in this field were included in the evaluation themselves, international experts were required for an unbiased evaluation. Hence an international evaluation group (IEG) was appointed.

The group of international experts was appointed by the Swedish Council for Working life and Social Research in 2006. The group included Professor David H Wegman (Chair), Professor and Dean, School of Health and Environment, University of Massachusetts Lowell, USA; associate professor Alex Burdorf, University Medical Center Rotterdam, Netherlands; Paul Oldershaw, PhD, UK Health and Safety Executive, Great Britain; Professor Brigitte Schulte-Fortkamp, Institute for Fluid Mechanic and Technical Acoustics of TU Berlin (ISTA), Germany; and Professor Eira Viikari-Juntura, Musculoskeletal Centre, Finnish Institute of Occupational Health, Helsinki, Finland.

A secretariat in support of the evaluation was organized by the Council. This effort was coordinated by Professor Christer Hogstedt, National Institute of Public Health, together with Professor Kenneth Abrahamsson, Ms Carin Håkansta, and Ms Elisabeth Birke from the Council. An inventory of work environment research was based on a survey managed by the National Institute for Working Life [Arbetslivsinstitutet (NIWL)]. The library at the Institute also provided a listing of all relevant Swedish doctoral dissertations since 1941.

Professor Olle Persson, Umeå University, assisted the international group with a bibliometric analysis of published reports. Mr Svante Sjöberg provided information on the history and present situation of Swedish funding in work environment research. Professors Staffan Skerfving and Hans Welinder, Lund University, submitted reviews of the history of Swedish occupational medicine and hygiene research, and Professor Töres Theorell provided a discussion on the history of psychosocial research in Sweden.

In order to prepare for the evaluation, an initial meeting was held to determine what types of information would prove the most useful to the effort. Decisions were made on the selection criteria for research groups or projects to be included in the evaluation, the division of labor, whom to invite for interviews, the interview questions, the design of a bibliometric study, and the like. It was decided that the Council would send a letter to approximately 70 research groups that, in a previous survey, had reported performing research in the relevant areas. A letter of inquiry to each identified research group sought documentation on peer-reviewed scientific papers in English (published since 1 January 2001) that were judged to be of the highest scientific quality with respect to filling gaps in knowledge or enhancing current understanding in the relevant scientific area: (i) 1–2 papers for groups of less than 5 fulltime equivalent researchers, (ii) 1–5 papers for groups of 5–20 fulltime equivalent researchers, and (iii) 1–10 papers for groups with more than 20 fulltime equivalent researchers. Each group was also asked to give 1–3 examples of the application of or communication in scientific knowledge designed to bring such knowledge to the broader community of stakeholders (developed or produced since 2000). Examples of such products could include those related to the focus of this evaluation and that (i) could provide evidence of implementation for prevention or the control of occupational hazards, (ii) were designed

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to communicate scientific information to occupational professionals or other stakeholders, (iii) could lead to guidelines or regulations for occupational health, (iv) could lead to product development for the protection or promotion of the health of the workforce.

The evaluation group also met with representatives of various stakeholder groups and representatives of the research groups. The participants in these meetings were asked to consider a set of questions for the meetings (see the appendix). The Council secretariat received research material from approximately 60 research groups; this material was subsequently dispatched to the International Evaluation Group for its assessment in advance of its final meeting.

The International Evaluation Group met over a 5-day period to review all of the material submitted, interview stakeholders and researchers, and prepare a draft of the final report. In the subsequent month, this report was completed by correspondence and presented in a seminar for the work environment research community. Thereafter the report was finalized and submitted to the Council for its consideration.

This supplement provides, for the first time, the history of Swedish work environment and occupational psychosocial research. The timing is appropriate as it is exactly 100 years since the Section for Occupational and Environmental Health of the Swedish Medical Society was inaugurated, and many of its members have been given due credit in the texts. The supplement also provides a summary on the context of the Swedish work environment, actors, and researchers and the final report of the International Evaluation Group (somewhat abbreviated). In addition, a commentary has been provided on the lessons learned from this evaluation and from a similar exercise concerning Swedish public health research that was completed 2 years earlier.

Broad overview of the history of Swedish occupational health research

by Staffan Skerfving, MD,[1] Christer Hogstedt, MD,[2] & Hans Welinder, PhD[1]

In this section, different aspects of Swedish occupational health research are presented, generally according to the following organization: (i) the underlying structure of Swedish research, development, and education (ie, institutes, university departments, and hospital clinics), (ii) major research areas, and (iii) the influential researchers associated with this work.

Research in a particular area is understood to have been initiated in a certain time period, after which continued success evolved over time. In this description, the full account for the different major research developments have been placed in the decade when each accelerated with subsequent follow-up to the present, in order to give continuity to the evolution of the area being described.

To select "influential" researchers in a certain area is, to say the least, a difficult task. This description does not aspire to completeness. Many other researchers have made important contributions, but completeness would have gone far beyond the aim, which was to give a short overview of the strengths and weaknesses of Swedish research in occupational health.

In addition, the potential number of original articles that can be quoted is enormous, which is why only the names of the research group leaders have been included, omitting graduate students and other researchers who appeared originally. The interested reader is thus urged to look for the original papers, in which case the name of the senior scientist can be used as an entrance into the database.

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The evolution of research on the psychosocial work environment is addressed in a separate section of this supplement.

Pre-1960s

Structure

"Generator gas clinics". During World War II, many drivers were chronically exposed to carbon monoxide from gas generators attached to vehicles and fueled by wood (gasoline was in short supply and a substitute was needed). As a consequence, many suffered from persistent damage to the central nervous system. In order to examine such cases on an individual basis, a "generator gas clinic" was founded in the Sabbatsberg Hospital in Stockholm in 1941.

In 1945, an occupational medicine clinic was established in the Karolinska Hospital in Solna, close to Stockholm, and an outpatient clinic for occupational diseases (for the city of Stockholm) was established in the Southern Hospital (Södersjukhuset) in Stockholm at the same time. These units can be considered the beginning of Swedish occupational medicine.

In 1958, the first unit outside Stockholm was established, a clinic of occupational medicine in the University Hospital in Lund. It was characterized by the integration of competence and resources in medicine and occupational hygiene, advanced in an international perspective with great impact, with respect to both the examination of patients and research. The Örebro Regional Hospital established its clinic a little later.

National Swedish Institute of Public Health. The National Swedish Institute of Public Health (Statens Institut för Folkhälsa) was founded in 1937. It had a department of occupational hygiene, which did research in occupational health.

University departments of hygiene. The National Swedish Institute of Public Health was located on the campus of the Karolinska Institute in Solna, and it had close connections with the Department of Hygiene of the Karolinska Institute. The other three universities (in Lund, Uppsala, and Göteborg) also had a department of hygiene. But none of these was, at that time, carrying out research in the area of occupational health. Instead, their main activities were in general bacteriology. However, later, these departments also took up research in the area of occupational health.

Research

Chronic poisoning by generator gas—an unsolved enigma. Acute exposure to high concentrations of carbon monoxide can cause symptoms and signs of poisoning that can persist for a long period. Experimental studies established that even low-level exposure, for example, from generator gas-driven vehicles, caused effects that could be registered by sensitive tests (S Åke Lindgren). Whether low-level exposure during prolonged periods causes chronic toxic effects in the central nervous system with clinical symptoms of a neuropsychiatric nature is unresolved to this day.

Sweden—a very strong position in metal toxicology. During the 1950s, exposure to toxic metals was common and sometimes very high in Swedish workplaces. Workers were exposed in the chloralkali industry to vapors of elemental mercury, in seed treatment to organic mercury compounds (mainly methyl mercury, later also methoxyethyl mercury), in the paper and pulp industry to phenyl mercury, in mines and metal smelters to lead and arsenic, in storage battery production to cadmium, in the hard-metal industry to cobalt and tungsten, and in welding to iron, manganese, nickel, and chromium.

In the 1950s and 1960s, Swedish research explored the risks of mercury in a systematic way using animal experiments, hygiene measurements, and clinical and epidemiologic studies on workers (Axel Ahlmark, Maths Berlin, Åke Swensson, Stig Tejning, Ulf Ulfvarsson, Harry Öhman). This knowledge became important when, in the late 1960s, it was discovered that seed-eating and prey birds, and later fish, had high concentrations of mercury due to emissions from the aforementioned activities. Swedish research took a leading position in handling health problems related to exposure to methyl mercury in fish (Staffan Skerfving). Successful research on elemental mercury and methyl mercury is still on-going (Lars Barregård, Gerd Sällsten).

Extensive preventive activities, including a change from mercury to alternative agents, led to a decrease in occupational exposure in the Swedish chloralkali industry. This development resulted in a major export of metallic mercury from Sweden to the world market. The change caused a decrease in mercury prices and probably an increase in exposure to mercury in other areas. At the international level, use was seen especially in connection with gold mining in South America, Africa, and Asia, where mercury was used for extraction and then burned off, leading to inhalation exposure. Swedish researchers have been involved in studies of such toxic effects. The activities also cause contamination of the general environment, leading to methyl mercury accumulation in fish, both locally and in the oceans.

Swedish research had a profound impact regarding other metals (eg, lead). The important discovery that lead inhibited heme synthesis was an initial side-observation in studies of inborn errors of heme metabolism in the 1950s and 1960s. Such disturbances were traced

to lead workers, first in mines (in Lapland) and later in battery workers (Birgitta Haeger-Aronsen). Animal experiments helped elucidate the problem. Extensive studies of the metabolism and effects of lead were later carried out in Sweden, in particular in Lund (Andrejs Schütz, Staffan Skerfving, Ingvar Bergdahl).

Cadmium was shown early to cause kidney damage in workers producing nickel and cadmium batteries (Lars Friberg). Swedish research on cadmium toxicity has been successful ever since (Magnus Piscator, Gunnar Nordberg, Tord Kjellström, Carl-Gustaf Elinder, Lars Järup, Marie Vahter). A method of great importance to determining the toxicity of lead and cadmium was the development of methods for quantifying lead in the skeleton and cadmium in the kidney by in vivo X-ray fluorescence (Lars Ahlgren, Sören Mattsson). Such methods now have extensive national and international use.

Swedish experimental and epidemiologic studies resulted in the prohibition of cadmium use in the Swedish work environment. This step has recently been challenged at the European Union (EU) level, as a potential barrier to trade. However, studies in susceptible strata in the general Swedish population, without particular exposure to cadmium, have indicated effects on the kidney and skeleton at exposures far below the occupational threshold limit, a finding that supports the relevance of the prohibition.

Sweden played a dominant role in metal toxicology even after metal exposure decreased in its metal industries. Research on mercury, lead, and cadmium are good examples of positive interaction between occupational and environmental medicine.

A special note should be made of the pioneer work done by Swedish researchers in the field of risk assessment during the 1960s and 1970s (Lars Friberg, Staffan Skerfving, Gunnar Nordberg). The assessments of metals were at the international forefront for a long time. The methods developed for risk assessment had great importance with respect to exposure limits, both at work and in the general environment.

"Rönnskär disease". One particular workplace had great importance in the early development of Swedish occupational medicine. In the smelter Rönnskärsverken in Skelleftehamn in northern Sweden, workers developed chronic obstructive bronchitis ("Rönnskär disease") (Torgny Sjöstrand, Karl-David Lundgren). High concentrations of sulfur dioxide and arsenic were found to be important with respect to the complicated mixture of exposures in the smelter. Epidemiologic studies of smelter workers in the 1970s showed an increased risk of lung cancer in association with this arsenic exposure (Olav Axelson, Göran Pershagen, Stig Wall). These studies were the starting point for extensive research on arsenic metabolism (Marie Vahter).

Silicosis—an almost eradicated disease. In the 1950s, 1960s, and 1970s, Swedish researchers made contributions to the clinical description of pulmonary fibrosis induced by crystalline silicon dioxide (quartz, etc), which was a major problem in many workplaces (Åke Bruce, Axel Ahlmark, Carl-Johan Göthe, Gideon Gerhardsson). These contributions formed the basis for a major preventive campaign (Silikosprojektet), which systematically surveyed the risk in all quartz-exposing activities in Sweden. Although the campaign was successful, single cases of silicosis are still being diagnosed.

Noise—sufficient medical knowledge for prevention, but too little action. Hearing deficiency caused by noise in the workplace has been recognized as a problem since the time of Ramazzini. In Sweden, particular attention was paid to the problem in the 1940s, especially in the shipyards and the engineering industry. Swedish researchers made important contributions in the 1950s and 1960s, particularly with respect to the exposure–response relationships between noise and the temporary hearing threshold shift (Bengt Kylin). Another problem explored at the same time concerned measurements and risk assessments for impulse noise (P Voigt).

Much of the Swedish research on noise and hearing has been performed at the divisions of otology within the departments of otorhinolaryngology at the university hospitals. An important contribution was the development of a protocol for a systematic evaluation of hearing loss (Ingemar Klockhoff), which has later been widely adopted in other countries. Furthermore, the development of miniaturized equipment for the personal measurement of noise in the 1980s in combination with records on hearing losses, supplied useful "field" information for target interventions (Alf Ivarsson).

These studies were important for the early establishment of an occupational threshold limit of 85 dBA. This limit has later been adopted in many countries. However, preventive work has only been successful to a limited degree since there has not been full compliance with the action limit and since a considerable fraction of the workers develops hearing loss even at that level of noise. Furthermore, occupational noise can induce problems at levels far below those damaging the hearing [eg, fatigue (Anders Kjellberg, Ulf Landström)].

1960s

Structure

National Swedish Institute of Occupational Medicine. In 1966, the Department of Occupational Hygiene within the Institute of Public Health was merged with the Institute of Work Physiology and units of occupational

medicine and dermatology at the Karolinska Institute into the National Swedish Institute of Occupational Medicine (Arbetsmedicinska Institutet). This merger meant a considerable enhancement of the structure for research in the field of occupational health.

Clinic of occupational medicine. The Clinic of Occupational Medicine was started at the Regional Hospital in Örebro in the 1960s (Lennart Sundell), leading to better resources for the examination of patients but also for research aiming at prevention. The combination of medicine and occupational hygiene expertise in conjunction with an occupational hygiene laboratory was particularly important.

Research

Swedish occupational dermatology takes a unique world position. A successful Swedish line of research was initiated in the field of occupational dermatology in the 1960s. The combination of competence in medicine coupled with analytical chemistry and occupational hygiene was unusual and has only rarely occurred in other countries. It meant that associations between chemical risk factors and allergic contact eczema could be explored in detail. The development of the epicutaneous (patch) test method was also important as it made it possible to test people with a series of common allergens, as well as with suspected compounds from the workplace. Swedish occupational dermatology research had a profound impact (Sigfrid Fregert, Jan Wahlberg). An important achievement was the development of the guinea-pig maximization test, which enabled controlled testing of the sensitizing properties of chemicals.

Many work-related contact allergens have been identified throughout the years. In particular, the identification of a series of allergens in epoxy-resins systems should be mentioned (Sigfrid Fregert). It was the starting point for successful primary prevention efforts, emphasizing technical changes of the systems, along with changes in workplace practices, which have significantly reduced the risk.

Swedish research in occupational dermatology was also influential regarding other resins [eg, phenol formaldehyde (Magnus Bruce, Erik Zimerson)], which, in addition to the importance for individual patients, has supplied important basic information on the relationship between chemical structure and the potency of sensitization. The same is true for the systematic studies of colophony and terpenes and their derivatives (Ann-Thérèse Karlberg). Allergenic rubber chemicals have been studied, including their binding to peptides serving as full antigens (Christer Hansson)

Other important concerns of occupational dermatology during the 1970s to the 1990s were related to sensitizing metals. Allergic eczema caused by chromium was earlier a very significant problem among construction workers due to the presence of chromates in cement. An important Swedish invention was the risk reduction shown by adding iron salt to cement (Sigfrid Fregert, Birgitta Gruvberger). The method was simple and relatively cheap and has thus achieved wide application in several parts of the world. Other protection methods were also studied (Anders Boman). Swedish research on the risk of sensitization to nickel [eg, in coins (Carola Lidén)] was important.

An additional achievement in the 1980s and 1990s was the description of contact allergy to preservatives, some of which were potent sensitizers (Bert Björkner). The epidemiologic description of hand eczemas and their determinants (occupational and others) in the general population has also been valuable (Birgitta Meding).

Improved assessment of skin exposure resulted from the development of biomarkers with which to quantify exposures (Per Brunmark, Gunnar Johansson, Bengt Åkesson) or from direct analysis of the skin (Ingrid Liljelind).

Chlorinated hydrocarbon and hexavalent chromium. The production of chlorinated hydrocarbons in Sweden called for special interest in these chemicals. Swedish studies led to an occupational threshold value for trichloroethylene that was set lower than that used in other countries (30 ppm) (Bengt Kylin). Studies of the thermal decomposition of chlorinated hydrocarbons caused wide interest (JA Dahlberg). Studies on dermal lesions caused by hexavalent chromium were of great practical importance.

1970s

Structure

In the early 1970s, Sweden experienced several large strikes that resulted in an increased focus on work conditions and work environment issues. This occurrence strengthened the interest of society in work environment problems and was followed by a series of significant changes.

Swedish Work Environment Fund. In 1972, the Swedish Work Environment Fund was created. Up to then, research funding in this area had been scarce, especially since the Medical Research Council felt limited responsibility for the area. The importance of the Fund cannot be overestimated. It supplied economic resources that enabled the establishment of fairly large research teams in many parts of Sweden, as well as networking

nationally and internationally. The Fund mainly supported projects of direct relevance to improve different work environments. To some extent, in particular in the early period, it also funded more basic research bearing on exposures in the workplace.

National Swedish Occupational Safety and Health Agency. The National Swedish Institute of Occupational Medicine was transformed into a department within the National Swedish Occupational Safety and Health Agency (itself established in 1949), which meant that research was brought into close connection with the labor inspectorate. This was an advantage for the practical relevance of research, but it also had a tendency to make research more superficial. Due to the increased political interest in work environment issues in the 1970s, the department staff more than doubled to 300 persons. Furthermore, initiatives were taken to start a Swedish and a Nordic criteria group for documenting the scientific basis for occupational exposure limits and methods for their exposure measurements. The groups still exist and have published more than 250 documents in Swedish and English (Johan Högberg, Gunnar Johansson, Jan-Olov Levin).

Clinics of occupational medicine. A center for occupational medicine was started in Göteborg with a clinic of occupational medicine and a network of other occupationally related activities. Furthermore, a clinic of occupational medicine was founded in Linköping; it was linked to the first university department and professorship in the discipline.

Research

Further development of occupational hygiene. Occupational health research expanded throughout the 1970s due to the increased resources, the introduction of and partnering with epidemiology, and the availability of new and sensitive analytical instruments [eg, gas chromatographs (GC), high-performance liquid chromatographs (HPLC), and atomic absorption spectrophotometers (AAS)]. New analytical methods with lower limits of detection made it possible to develop improved air-sampling methods. There resulted an explosion of investigations for a wide range of exposures, including welding and the use of organic solvents, pesticides [including phenoxy acid herbicides and DDT (dichlorodiphenyltrichloroethane)], polychlorinated biphenyls (PCB), asbestos, synthetic mineral fibers, jet fuel, cadmium and lead, metal smelting plants, and diesel exhaust in the mining industry. Occupational hygiene research was also directed at improving the assessment of dermal exposures (especially those caused by epoxy compounds), approaches to characterizing exposure to molds, asphalt work, electromagnetic fields, vibration, polyester-resin lamination, and ventilation. Thus almost the whole spectrum of the occupational environment was illuminated from the perspective of exposure assessment and control.

Occupational epidemiology—a Swedish flagship. Sweden has had a unique potential for advanced register epidemiology; similar conditions are only present in the other Nordic countries. The basis for this potential is the combination of reliable population registries (with a unique "personal registration number" for every Swedish citizen), coupled with well-functioning registries of deaths (since 1958), tumors, births, malformations, and diagnoses for in-patients from hospitals.

These basic preconditions began to be widely used in a creative way by Swedish occupational epidemiologists at the beginning of the 1970s. The most valuable research has derived from combinations of epidemiologic methods with advanced records of exposure to work environment agents that look at intensity and duration.

Swedish researchers played an international role in the development of epidemiologic methods (Olav Axelson, Anders Ahlbom). In particular, the possibilities and limitations of the case–referent design were explored. In addition, multivariate modeling was developed. Theoretical aspects of confounding, effect modification, and other co-variation were explored, for example, the demonstration of the limited importance of confounding from smoking habits with respect to the risk for lung cancer in occupational groups (Olav Axelson). Later, methodological efforts to enhance the application of exposure assessment in epidemiologic studies have been a major contribution to occupational health research, to which Swedish researchers have contributed significantly.

A wealth of occupational epidemiology studies on cancer and causes of death has been carried out by Swedish research groups. A few examples of interesting projects follow.

One of the first occupational cohort studies in Sweden concerned workers exposed to trichloroethylene in degreasing metal in the metal manufacturing industry (Olav Axelson). A large register measuring metabolite trichloroacetic acid (TCA) in urine from exposed workers was used. There were findings of increased risks of several types of tumors. Later, in the 1990s, similar studies were made in cohorts of dry cleaners. The risks were confirmed in animal experiments elsewhere.

It has long been known that workers in uranium mining and processing experience an increased risk of lung cancer. In the 1970s, scattered observations indicated the possibility of an increased risk of lung cancer in Swedish nonuranium miners. A cohort study of Swedish zinc miners showed a 10-fold increase in the risk of

lung cancer (Olav Axelson). The cause turned out to be inhalation exposure to radon daughters formed through the decomposition of uranium in the ore. The observation induced a series of still on-going investigations in the iron mines of northern Sweden (Christer Edling, Bengt Järvholm). A twofold increase in the risk of lung cancer was also found in the mines. These observations have not only contributed to preventive work to reduce the exposure, but also to a wider understanding of exposure–response relationships for alpha radiation. The risk in iron mines is higher than can be explained by the levels of radon daughters, and it is probably due to an interaction with silica in the mine dust, which has been shown independently to induce lung cancer (Peter Westerholm).

The radon studies in mines subsequently led to the problems of radon in private homes. A series of studies showed that homes with significant radon levels caused about 500 cases of lung cancer each year in Sweden, mostly among smokers (Olav Axelson, Christer Edling, Göran Pershagen). Slowly, actions have been taken to eliminate the problem. The radon story again illustrates the often fruitful interaction between occupational and environmental medicine.

Many other Swedish accomplishments in occupational epidemiology are noteworthy. For example, the high risk of liver cancer for those exposed to vinyl chloride was verified among workers in a polyvinyl chloride plant after the risk had been reported in experimentally exposed animals (Anders Englund). Research also contributed to the growing evidence that certain rubber chemicals are carcinogenic. In addition, 200 years after Sir Percival Pott's report that chimney sweepers had an increased risk of cancer due to exposure to soot, a Swedish study showed increased risks of several types of cancer (Christer Hogstedt). Cancer risks were also shown for glass workers (Gun Wingren).

Pesticides—cancer in relation to herbicides. Sweden is a country with a more limited need for pesticides than many other countries. However, Swedish researchers have contributed to the knowledge on insecticide exposures in the forestry industry (Birgitta Kolmodin-Hedman) and have reported tumors (case–referent studies of lymphomas and sarcomas) associated with herbicides (in particular phenoxyacetic acids) in forestry and agricultural work (Olav Axelson). The latter has attracted intense international attention. There has also been fairly extensive pesticide research in cooperation with researchers in Central America. (See the later discussion.)

Asbestos—a major problem that was finally penetrated and eliminated. In the beginning of the 1970s, single cases of pulmonary fibrosis induced by asbestos (asbestosis) were not unusual in the daily life of Swedish occupational medicine, in spite of the fact that the risk had first been reported in the beginning of the 1900s and in Sweden in the 1930s. There were regulations for health examinations of asbestos-exposed workers, but they had not been very effective from a preventive point of view.

In the 1970s, there was a dramatic change in the concept of acceptable risk, including the risks associated with asbestos. The clinics of occupational medicine performed large surveys in several asbestos-cement factories and other industries that used asbestos for insulation purposes, primarily shipyards and railway-coach factories. A significant fraction of the workers were found to have radiographic changes in the lung and pleura (pleural plaques). Many were also shown to have decreased lung function in spirometry, and some had symptoms and signs indicating respiratory failure, which sometimes caused death. Many workers received workers' compensation, including a large group who had X-ray evidence of pleural plaques, in spite of no diagnosed effect on their physical health status.

The great attention focused on asbestos in Sweden led to almost total prohibition of its use. This early leadership led to several other nations following the Swedish example, even though asbestos is, today, still used in too many countries. Despite this very early action in Sweden, the on-going use of asbestos in the developing world is partly assisted by equipment exported from closed Swedish industries; this situation indicates a need for increased international cooperation to eliminate exposures in all countries.

A series of epidemiologic studies was made on the association between asbestos exposure and cancer risk (Maria Albin, Kristina Jakobsson, Carl-Göran Olson, Hans Welinder). The risk among heavily exposed workers was approximately doubled for bronchial cancer, with a particularly increased risk among smokers. There was also a high risk of pleural cancer (mesothelioma), but, because this is an uncommon tumor, the number of cases was much smaller.

Extensive efforts were made to estimate the intensity of the asbestos exposure, and two important facts became evident. First, while risk was earlier mainly detected for blue asbestos (crocidolite), a clear increase in the risk among workers mainly exposed to white asbestos (chrysotile) was also found. Second, the exposure associated with risk was lower than earlier reported. Recent data indicate cancer risk at extremely low exposure levels (Per Gustavsson). These results attracted great international interest and were instrumental in changing the view of the risk, including new occupational exposure limits.

Mesothelioma may develop after low-intensity exposure, and there may be an extremely long latency

time between exposure and the onset of disease. This is probably the reason why the rate of mesotheliomas is still high in Sweden (Bengt Järvholm), despite the fact that exposures—in principle—disappeared decades ago. However, asbestos exposures still occur in the destruction and renovation of old buildings.

Organic solvents—another risk that was explored and solved. It has long been known that organic solvents may cause acute intoxication, with accompanying symptoms of the central nervous system. In the 1970s, painters and styrene-exposed boatbuilders with chronic neurasthenic symptoms began to be seen in Swedish occupational medicine clinics.

This occurrence was the beginning of one of Sweden's research areas in which Swedish contributions were the most prominent. In a series of investigations of cohorts of painters and other groups (carpet layers, printers, etc) with high exposure to organic solvents (white spirit, toluene, styrene, jet fuel, etc), increased frequencies of symptoms and neuropsychological deviations were found and supported by case–control studies (Kerstin Ekberg, Christer Hogstedt, Palle Ørbæk, Bengt Knave, Arne Wennberg, Göran Struwe, Ingvar Lundberg, Olav Axelson).

The great concern for the exposure to organic solvents and other volatile compounds in the 1970s called for the development and establishment of new sampling methods. Up until 1970, available methods had been midget impinger (bubbler) sampling and sampling in various kinds of airtight ampules. After 1970, solid sorbent sampling was developed in combination with new, sensitive gas chromatographic methods (Kurt Andersson, Jan-Olov Levin). A spectrum of solid sorbents was tested for various pollutants (Bo Jönsson). A further development was the introduction of simple and practical methods for passive sampling (Jan-Olov Levin, Anna-Lena Sunesson).

Even rather low-level exposure to organic solvents caused toxicity. The results caused initial skepticism in other parts of the world, where it was believed that the disorders were due to inherent nonoccupational factors or to confounding agents (eg, alcohol). For quite some time, Swedish researchers stood rather alone (together with a few other Scandinavian or Nordic groups). The problem was even known as the "Scandinavian disease". Accordingly, there was some initial hesitation to compensate injured workers. However, studies performed later in other countries confirmed the presence of the effects. The new knowledge led to an intense campaign to reduce exposures to organic solvents in the work environment, including the lowering of occupational exposure limits and the development of appropriate inorganic substitutes. These activities were remarkably successful, and nowadays cases of organic solvent encephalopathy are rarely seen in Swedish occupational medicine clinics.

Activities around the "solvent syndrome" also included testing for the early effects of chemicals on the central nervous system, in which Swedish psychologists played important roles (Kerstin Ekberg, Francesco Gamberale, Monica Hane, Anders Iregren, Björn Karlson, Kai Österberg). Neuropsychological test batteries were developed, now widely used throughout the world. The interest in organic solvents also caused a general focus on the neurotoxic effects of other agents (eg, lead and mercury).

Parallel to the studies of toxicity among solvent-exposed workers, extensive Swedish research was carried out on the metabolism of organic solvents. The uptake, distribution, and elimination of a long series of compounds were explored in human volunteers in exposure chambers (Irma Åstrand, Gunnar Johansson). Through these activities, a profound understanding was obtained regarding the relationship between chemical structure or physical properties and the metabolism of solvents. In particular, the accumulation in, and release from, fat tissue was understood.

A tangent to the studies of chronic toxic encephalopathy with respect to exposure to organic solvents was an interest in the dramatic reactions to exposure at extremely low intensities of chemicals when smelled, which is sometimes called multiple chemical sensitivity (Lena Hillert, Björn Karlson, Palle Ørbæk, Kai Österberg).

Research on cardiovascular disease. In addition to assessments of cancer risks, Swedish researchers have contributed to the understanding of relationships between occupational factors and cardiovascular disease. Swedish facilities for population-based epidemiology (hospital registries) have been useful. In particular, the WOLF (work, lipids, fibrinogen) and SHEEP (Stockholm Heart Epidemiology Program) studies should be mentioned. These efforts have focused primarily on physical workload (Christina Reuterwall), shift work (Anders Knutsson, Lars Alfredsson, Torbjörn Åkerstedt), and the psychosocial work environment factors (Anders Ahlbom, Töres Theorell), which will be described elsewhere. Excess risks of cardiovascular disease have also been found for several occupations [eg, dynamite workers and chimney sweeps (Christer Hogstedt)].

Research on occupational accidents. The Work Environment Fund and its predecessor had put considerable resources into creating a center for research on occupational accidents at the Royal Institute of Technology (Kungliga Tekniska Högskolan) in Stockholm. Although the center produced interesting studies, when the funding ended, it was not supported by the Institute and

the research team split up There was another group concerned with studying occupational accidents within the Swedish National Institute of Occupational Health, but this research area has remained surprisingly small in Sweden. On the other hand, Sweden has an effective prevention record and has reduced fatal accidents from around 400 per year in the 1950s to about 50 annually today.

1980s

Structure

Swedish National Institute of Occupational Health. In 1987, the research department within the National Swedish Occupational Safety and Health Agency was reorganized into the Swedish National Institute of Occupational Health (Arbetsmiljöinstitutet). The headquarters of the Institute were located in Solna close to Stockholm, and a large detachment in Umeå was included.

As a result of continued interest in the work environment and health in the 1980s, the Institute obtained increased resources, reaching a total staff number of about 400 and a yearly budget of about 300 million Swedish crowns per year. The institute covered all aspects of the work environment, including the chemical, physical, physiological, biological, psychosocial, and organizational; only radiation was excluded. The Institute had a close association with the clinics of occupational medicine and dermatology at the Karolinska Hospital.

More clinics of occupational medicine and occupational dermatology. In the late 1970s and 1980s, more departments of occupational medicine and occupational dermatology were founded at the university and regional hospitals. In the end, every hospital region in Sweden had such units. The units varied in size, some having a staff of up to 50 persons and others having only a few. In addition, there were large differences in the structure. In some cases (Lund and Örebro), the units had laboratories with advanced competence in analytical chemistry and occupational hygiene, while, in others, staff consisted of physicians, nurses, and secretaries only. The strongest units are unique from the international perspective.

An important development, which started in 1980 and was gradually introduced in all of Sweden, was the assignment of clinic responsibilities to all people in the hospital regions (for instance, the southern Swedish hospitals cover 1.5 million inhabitants). The clinics had support from all of the county councils in the region, in relation to their population. Most of the counties maintained that the clinics not only held the responsibility for examining individual patients, but also for "science-like" activities in order to gather knowledge, as a basis for prevention.

These developments also meant that clinic personnel had the responsibility and possibility to visit workplaces to investigate patient disorders and promote preventive activities. This situation was of the utmost importance for creative research on the association between exposures and disease, which became the hallmark of much of the successful work environment research, a fairly unusual aspect of Swedish research. Such field work was, and is, not possible in most countries. This evolving system resulted from the combination of union interest in work environment issues and the willingness of employers to cooperate in addressing these issues. Examples would be "the solvent story" (introduced in one the previous sections), reported cancer clusters that became the starting point for important epidemiologic studies [eg, leukemia in workers exposed to ethylene oxide (Christer Hogstedt)], soft tissue sarcoma and phenoxy acid compounds (Olav Axelson), rhino-conjunctivitis and asthma and organic acid anhydrides (Staffan Skerfving), ischemic heart disease among dynamite workers (Christer Hogstedt), and eczema among rubber workers (Sigfrid Fregert).

University departments of occupational and environmental medicine. In the 1980s and 1990s, all of the Swedish universities (Lund, Göteborg, Karolinska Institute in Stockholm, Uppsala, and Umeå, in addition to Linköping) formed university departments of occupational medicine, which were combined with the clinics of occupational medicine in the university hospitals. Each university appointed at least one professor of occupational medicine, who was also the senior consultant and head of the clinical unit. This situation meant a definite strengthening of the structure for research (and education).

In the 1980s and 1990s, several of the departments of hygiene at the Swedish universities were too weak to be sustained as separate units. Accordingly, they were fused with the departments of occupational medicine to form departments of occupational and environmental medicine. Such a fusion was constructive since the departments had similar work areas, competencies, and resources and resulted in stronger organizations. In addition, it facilitated interaction in the training of students. At the same time, corresponding clinics of occupational and environmental medicine were established in close association. This development has not yet occurred everywhere, but will probably take place soon.

Occupational and environmental dermatology. A similar development occurred in some of the clinics of occupational dermatology at the university hospitals (Lund, Malmö, and the Karolinska Hospital). Most of the units changed their name to occupational and environmental dermatology, but, in several cases, occupational dermatology remained within the clinics of dermatology.

Research

Markers of damage to genetic material and susceptibility. Theories that an important component in the development of cancer would be damage to genetic material existed from the beginning of the 20th century. Considering the long latency between exposure and the onset of a tumor, there was much interest in finding ways to detect such DNA (deoxyribonucleic acid) damage in humans in connection with exposure, long before the cancer caused symptoms and signs.

In the 1960s, reports revealed that patients who had X-ray therapy developed microscopic aberrations in chromosomes in peripheral blood lymphocytes. This finding offered the possibility also to study chemicals with suspected genotoxic effects. An early discovery was chromosome aberrations detected in fishermen exposed to methyl mercury through fish (Staffan Skerfving). From 1980 on, several groups of workers were studied, and Swedish researchers played important roles in this work. Lead and ethylene oxide (in the sterilization of medical equipment) were found to cause chromosome breaks (Benkt Högstedt). For styrene, such effects were even used as a criterion for the occupational exposure limit. Studies of chromosome aberrations were time-consuming; hence, alternatives were explored, for example, micronuclei and sister chromatid exchanges in peripheral lymphocytes.

Early on, there was some doubt whether chromosome aberrations really indicated risk of later cancer. Most of the agents that caused chromosome aberrations were carcinogens, but some chemicals that caused aberrations did not seem to induce cancer. Furthermore, it was not obvious that changes in lymphocytes, cells only rarely involved in cancer, were relevant (though easy to sample). However, in a large Swedish project, which was gradually widened to include Nordic and EU partners, it was shown that those who had a record of a high frequency of chromosome aberrations ran a higher risk of later cancer than those with a low rate of aberrations (Lars Hagmar, Benkt Högstedt, Felix Mitelman, Ulf Strömberg, Christina Reuterwall, Staffan Skerfving, Håkan Tinnerberg). Hence the work and conclusions in the earlier studies seemed justified.

Microscopic changes in the chromosomes are a blunt index of genotoxicity. Through the explosive development of molecular biology, a series of other methods became available and was applied to problems in occupational medicine. Swedish research has constantly been in the forefront of this work. Methods to measure point mutations in single genes [eg, the GPRT gene] were used (Bo Lambert). An important forward step taken in the 1990s was the development of the postlabeling method to assess the binding of chemicals to DNA. This method allowed the use of adducts in peripheral lymphocytes as an index of exposure to genotoxic agents and mutagen damage (Kari Hemminki). These methods have been applied in assessments of risk from exposure to polycyclic aromatic hydrocarbons (PAH) (eg, in aluminum smelters), as well as for other exposures.

The developments in molecular biology also enabled the characterization of some of the background of variations in sensitivity between persons with similar exposure. An intense search for individual susceptibility factors started. In particular, polymorphisms in genes (*N*-acetyl transferases, cytochrome P450s, glutathione transferases, etc) involved in the metabolism of chemicals have been investigated. Several Swedish groups have been deeply engaged in this work. For example, workers exposed to several groups of chemicals [eg, PAH and isocyanates] were examined (Agneta Rannug). In addition, according to recent studies, it seems that selected genetic traits are involved in the metabolism of mercury and lead (Karin Broberg).

This research area is promising but extremely complicated; meaningful engagement requires a combination of a wide range of competencies and resources (eg, in molecular biology, biostatistics and bioinformatics, epidemiology, biomedicine, occupational hygiene, and analytical chemistry). In cases when such competencies have not been available in a single research environment, Swedish research scientists have developed or participated in networks in Sweden and internationally. In addition, the ability to make field investigations and the willingness of the Swedish workforce to participate in these studies have been important success factors.

Occupational musculoskeletal disease—still a major challenge for prevention. Musculoskeletal disorders are a major cause of suffering and a burden to worklife, the health system, and society. There is consensus that a large fraction of these disorders is caused by work environment factors, but much has long been unclear, in particular as regards the pathomechanisms and the relationship between physical and other risk factors. Swedish researchers are very active in these areas.

As to the pathomechanisms, a few contributions should be highlighted. The Cinderella hypothesis is one positing an uneven load on different motor units with recruitment of the same ones first in every contraction (Göran Hägg). This hypothesis has some experimental support but is, for methodological reasons, very difficult to test. In basic research, studies on nervous system function should be mentioned (Håkan Johansson). In addition, important contributions have been made to experimental measurements of pressures in vertebral discs and in tendons in connection with varying positions and movements (Alf Nachemsson, Tommy Hansson).

As in many occupational studies, one of the crucial elements in describing the relationship between exposure

and risk is the proper recording of exposure. In this field, Swedish researchers have, during the 1980s and 1990s, contributed widely to the study of musculoskeletal disorders. These efforts have included methods for recording exposure though the use of questionnaires (Istvan Balogh) and observations (Åsa Kilbom, Jörgen Winkel, Christina Wiktorin), the use of mechanical, electro-optical, and microelectronic equipment (Gert-Åke Hansson), and also developments in study design for the assessment of physical workload (Svend Erik Mathiassen). Swedish research groups have also contributed to the development of electromyographic (EMG) methods (Roland Kadefors, Roland Örtengren). However, except for the microelectronic devices, the methods have only been used to a limited extent in epidemiologic studies of musculoskeletal diseases.

Regarding the medical endpoint—musculoskeletal diseases—Swedish research groups have supplied important information on risks and risk determinants of arthrosis (Eva Vingård, Helen Sandmark), upper-limb disorders (Kerstina Ohlsson, Catarina Nordander, Staffan Skerfving, Ewa Wigaeus Tornqvist), and back pain (Eva Vingård). Several studies have been devoted to risks associated with computer work (Ewa Wigaeus Tornqvist, Mats Hagberg).

In addition, studies on rehabilitation and secondary prevention have been carried out with respect to musculoskeletal disorders (Kerstin Ekberg), but the success in terms of return to work has been limited. Primary prevention seems to be the only feasible way forward. However, primary prevention has not yet been impressively successful. Heavy lifting has certainly been reduced, but other types of physical workload seem to be unaffected, and it is doubtful whether the prevalence of musculoskeletal disorders has really decreased. This uncertainty may have several explanations, for example, first, a lack of sufficient scientific evidence for adequate actions, second, insufficient interaction between biomedical research and technological process design, and, third, an unwillingness in society to accept the high costs that efficient preventive actions sometimes would mean for the individual company. Hence this is a field that requires much more research.

Vibration from handheld tools—a sufficiently well-defined risk waiting for prevention. Hand–arm vibration may cause damage to blood vessels, nerves, and bones in hands. Swedish research has contributed to the understanding of the relationship between exposure and response. Methods for measurement have been developed and applied (Ronny Landström, Lage Burström), and risk patterns at various intensities and durations of exposure and pathomechanisms have been defined (Lena Ekenvall, Mats Hagberg, Ulf Hjortsberg, Göran Lundborg, Thor Nilsson, Ingrid Åkesson).

There is now, as a result of Swedish and other research, a sufficient base of knowledge so that primary prevention can be undertaken against local vibration. However, established limits for occupational exposure do not protect a significant fraction of the workers, and the enforcement of these measures has therefore not been sufficiently effective.

Whole-body vibration has also been studied (Jan-Erik Hansson, Ronny Lundström), although its association with health problems is less well established.

1990s

Structure

Swedish National Institute for Working Life. In 1995, the Swedish National Institute of Occupational Health was merged with the Work Life Centre (Arbetslivscentrum), into the Swedish National Institute for Working Life [Arbetslivsinstitutet (NIWL)]. The focus of the research activities of the Work Life Centre had been in the field of work organization and the labor market. The new institute was instructed to focus more on these areas and on issues concerning the psychosocial work environment than on chemical and physical factors. In addition, the new institute was ordered to reduce its volume, which caused several years of turbulence, resulting in partial deviation from the focus from research.

Eventually, many of its research groups in the areas of chemical, physical, and ergonomic risk factors were relocated to universities in different parts of Sweden, altogether about half of the former resources for this kind of classical occupational health within the Institute. Although they received a "backpack" with basic funding for several years, they still had to build up infrastructures in new research environments, which temporarily reduced their scientific productivity. The dispersed group had a formal responsibility to supply advice in their respective fields of competence, but the new national institute had problems in adequately and rapidly handling emerging risks in chemical, physical and ergonomic areas [eg, when the problems of acryl amide appeared (see the later discussion)].

The structure of the present Swedish institute therefore differed from that of the other Nordic central institutes, which still have major competence and resources in the field of chemical, physical, and biological risk factors. Now, even the centralized research focus of the Institute has been terminated and it closed in mid-2007 due to a decision made by the new government that took office in 2006.

Swedish Council for Work Life Research. Simultaneously with the emergence of the Swedish National Institute

for Working Life, the Work Environment Fund was transformed into the Swedish Council for Work Life Research [Rådet för Arbetslivsforskning (RALF)]. There was also a reduction in the resources available for work environment research, but, at least initially, still reasonable funding for well-established and productive groups.

International cooperation and European Union funding. In the late 1990s, many Swedish research groups in biomedicine started to seriously compete for resources within the European Union's framework programs 4, 5 and 6 for research and technical development. Research groups in the work and general environment fields have been successful (in relation to the size of the country and its research structure). The main reason is the strength of the groups, which makes them attractive to international research networks.

Hence a long series of concerted actions, strategic targeted research projects, integrated projects, and networks of excellence have been, or are, coordinated by Swedish researchers in the work environment area. In addition, many Swedish groups have been partners in projects coordinated from other parts of Europe.

EU project activities have widened the networks of the Swedish groups, and research has become more international. Within projects, many objectives have been tackled that would not have been possible to solve on a local or even national level, for example, studies on the relationship between chromosome aberrations and later cancer (Lars Hagmar), and investigations on the toxic effects of persistent organic pollutants (Helène Håkansson) and metals (Staffan Skerfving).

On the other hand, EU activities have major drawbacks. One problem has been the limited and rigidly formulated scopes of the European Union's research programs. In addition, the necessity to raise matching funds from national or local Swedish research-funding agencies can be an obstacle. Furthermore, the activities of many senior researchers within these collaborative projects have been refocused to administration, instead of to practical research. Thus it may be questioned whether the resources spent in EU projects are really in parity with the achieved results. At least there is a need for substantial national funding, which can support creative research not fitting into the narrow EU perspectives.

To address a different objective of international research collaboration, Swedish researchers have, from the 1990s on, been active in Central and South America and also in Africa and Asia. Senior Swedish scientists have been principal investigators or co-workers in studies on the effects of climate conditions (Ingvar Holmér), exposure to pesticides (Christer Hogstedt, Olav Axelson, Ingvar Lundberg) and toxic metals (Lars Gerhardsson, Kristina Jakobsson, Maria Albin), as well as tutors for successful doctoral students (Catharina Wesseling, Jamileth Miranda, Aurora Aragon, Patricia Monge).

Research

Occupational asthma, rhinitis and alveolitis. It had long been known that farmers have a highly increased risk of asthma and rhinitis, caused by the inhalation of proteins and sensitization mediated by immunoglobulin (Ig) E. Swedish research in the 1990s showed that such problems were still very common. For cohorts of farmers (Marianne van Hage Hamsten) and millers or bakers (Jonas Brisman, Linnea Lillienberg), patterns of sensitization were defined, and methods of diagnosis were improved. Laboratory animal allergy has been a useful model for protein-induced sensitization (Per Malmberg, Anne Renström).

In some work environments, exposure to microbial agents may cause allergic alveolitis induced by a type-3 allergic response. Swedish researchers have been active in this area, for example, in the evaluation of respiratory disorders among farmers (Anna Rask Andersson) and wood trimmers (Lars Belin). In addition, the practically important and theoretically interesting acute respiratory disease, which is very prevalent among personnel in swine confinement buildings, has been fruitfully explored (Per Malmberg, Kjell Larsson). Through field and experimental studies with bronchial lavage, the nature of the inflammatory reaction has been described. The studies have attracted much interest internationally.

Basic research on the pathomechanisms (biochemical and immunologic events) of obstructive lung disease has been performed in Sweden (Christer Tagesson).

There has also been great interest in airway sensitization by low-molecular-weight organic chemicals. One of the most interesting families of compounds is the organic acid anhydrides, which are used in the production of polyester and epoxy resins. A long series of studies of these compounds was launched in the 1990s. Some of these compounds turned out to cause the development of specific IgE and IgG antibodies in up to one-third of workers, even when exposed to extremely low concentrations. This finding indicates that these compounds form one of the most sensitizing groups of compounds ever encountered.

This finding was of practical importance for the examination of exposed workers and the understanding of the exposure–response relationship, as a basis for occupational exposure limits and prevention (Jörn Nielsen, Hans Welinder). For example, practical methods for the biomonitoring of the compounds through the analysis of metabolites in urine and protein adducts in blood were developed and employed in the workplace (Bo Jönsson, Christian Lind). However, the research also resulted in a wealth of basic knowledge on the process

of sensitization. The quantitative structure–activity relationship for organic acid anhydride was explored, and such an undertaking had never been attempted before for a type-1 allergen (Hans Welinder). The formation of the full antigen through reaction with hapten proteins was shown, and the exact binding of the allergens to the protein was demonstrated (Monika Kristiansson). This is a unique basis for the understanding of allergenic epitopes and the process of antibody formation. In addition, it was possible to describe the kinetics of IgE and IgG antibodies after the end of exposure. Research following up the findings on organic acid anhydrides is still on-going in 2007.

Similar progress in the understanding of risks associated with exposure to heterocyclic and tertiary amines was made possible by improved chromatographic methods (Kurt Andersson, Jan-Olov Levin, Gunnar Skarping, Bengt Ståhlbom) and should also be mentioned (Lars Hagmar, Bengt Åkesson, Staffan Skerfving).

Respiratory disorders in workers exposed to isocyanates were described as early as the 1950s. Swedish researchers have made major contributions in this area. Precise and sensitive analytical methods for air monitoring were developed during the 1980s (Carsten Sangö) and 1990s (Gunnar Skarping), as were means for biomonitoring isocyanate metabolites and protein adducts as indices of exposure and risk (Gunnar Skarping, Margareta Littorin).

The development of these sampling methods was facilitated by increasingly advanced chromatographic methods (Marianne Dalene), to be combined with mass spectrometers. Special focus was given to the complex products formed when polyurethanes were heated (Dan Karlsson). New and sensitive methods have been used for intensive monitoring of exposure at workplaces (Carl-Johan Sennbro, Håkan Tinnerberg, Håkan Westberg). This is one of many examples of the extreme importance of the development of advanced analytical techniques for the possibility to assess risk.

One major remaining problem is the lack of reliable information on the relationship between exposure, as measured by adequate methods, and risk. The gathering of such information has only just started. In addition, the explanation for the intriguing variation in sensitivity between workers with similar exposures has not been solved. It seems likely that polymorphisms in genes for enzymes involved specifically in the metabolism of isocyanates and generally in the development of respiratory disease are important factors. Even after decades of research, the pathomechanisms behind isocyanate-induced disease is still largely unclear; classical, specific IgE and IgG antibodies are certainly not the answer. Swedish groups have been active in these areas from the 1990s on.

In addition to the allergically induced respiratory disorders, the work on bronchitis in association with welding fumes and diesel exhaust (Ulf Ulfvarsson, Bengt Sjögren, Thomas Sandström) and construction dust (Bengt Järvholm) should be mentioned, as well as population-based surveys of asthma (Kjell Torén).

Advances in occupational hygiene. This period was characterized by improved analytical methods and an accessibility to advanced instruments, such as mass spectrometers. The development of sensitive methods for the biological monitoring of exposure is notable. This development included studies on exposure to cytostatic drugs and acrylamide. Advanced instruments facilitated the increasing use of protein adducts as biomarkers of exposure. New findings on the exposure to aromatic and aliphatic isocyanates in "hot" environments were reported (Gunnar Skarping). Methods for studies on skin adsorption and natural allergens were developed.

The biological monitoring of exposure has increasingly been introduced for a variety of chemicals. Among the metals, methods were developed especially for cadmium (Hans Welinder, Staffan Skerfving) and chromium (Gun Nise) in parallel with the continuous development of the methods for lead and mercury. With respect to biomarkers for organic compounds, the studies on amines, isocyanates, and organic acid anhydrides have already been discussed. The wood industry in Sweden is important, and thus the studies on metabolites of terpenes should be mentioned (Kåre Eriksson). Biological monitoring development for toluene is another good example (Gun Nise).

An interesting and important development has been the introduction of biomarkers with different "time windows" in relation to exposure. For cadmium, analysis in the blood, urine, and kidney reflects different compartments with biological half-times from hours to years. The determination of lead in bone is another example of a very long-lived biomarker (Lars Gerhardsson, Andrejs Schütz, Staffan Skerfving). Kidney cadmium and bone lead can be analyzed by in-vivo X-ray fluorescence techniques. Metabolites in the form of stable adducts to proteins like albumin and hemoglobin have been shown to indicate long-term exposure due to the long half-time of the protein adducts. Such albumin adducts have been found for toluene diisocyanate (Pernilla Lindh) and hexahydrophthalic anhydride (Monika Kristiansson), along with hemoglobin adducts for hexahydro- and methylhexahydrophthalic anhydride (Christian Lind, Bo Jönsson).

Methods for retrospective exposure assessment were developed over the years (Tom Bellander, Gun Nise, Nils Plato, Håkan Westberg,) and applied in many epidemiologic studies.

Sick building syndrome—still an intriguing problem. In the 1990s, Sweden became interested in the mucosal and

cutaneous symptoms of people who worked or lived in damp buildings. Swedish research contributed to methods for measuring possible causative agents, including fungi and their volatile metabolites (Göran Blomqvist, Kurt Andersson, Barbro Andersson, Jan-Olof Levin).

In addition, extensive Swedish studies were performed with the aim of linking microbiological and chemical [volatile organic compounds (VOC)] exposure factors to symptoms and objective findings among people dwelling in the buildings (Carl-Gustaf Bornehag, Birgitta Kolmodin-Hedman, Dan Norbäck, Bernt Stenberg, Jan Sundell, Gunilla Wieslander). However, in spite of all the efforts, most of the links between moisture and symptoms still remain unclear.

Visual display terminals and electromagnetic fields—illness, skin symptoms and cancer. The perception of light is very complex (Rickard Küller, Lennart Wetterberg). Exposure from visual display terminals (Carola Lidén, Ulf Bergkvist, Bengt Knave) and flickering light (Rickard Küller) have received special attention in Swedish research, and this research has led to the improved construction of visual display terminals.

During the late 1980s and the 1990s, a significant number of Swedes claimed that they developed nonspecific symptoms (fatigue, tiredness, headache, vertigo, nausea, etc) and cutaneous irritation of the face when exposed to electromagnetic fields from video display terminals or other electric equipment. The phenomena were investigated epidemiologically (Bengt Knave, Lena Hillert, Bengt Arnetz, Sture Lidén, Kjell Hansson-Mild) and by double-blind provocations in supposedly sensitive persons. It was not possible to link, in a conclusive manner, the exposure to the symptoms. Instead, it is likely that the symptoms were mainly due to psychological and ophthalmological stress in sensitive persons. However, this conclusion has never been accepted by some of the affected persons.

In addition, the question was raised of whether electromagnetic fields induce cancer (in particular, leukemia and brain and breast tumors). The possibilities offered by the Swedish registries were used to study the risk in occupations with high exposure to electromagnetic fields (welders, engine drivers) (Birgitta Floderus), but conclusive associations could never be established. The interaction between occupational and environmental research led to studies of leukemia in children living close to power lines (Anders Ahlbom, Maria Feychting).

2000–2005

Structure

The Council for Work Life Research was transformed into the Swedish Council for Working Life and Social Science [Forskningsrådet för Arbetsliv och Socialvetenskap (FAS)] at the same time that some of the resources aimed at technical development were transferred to The Swedish Governmental Agency for Innovation Systems (VINNOVA).

Research

Occupation and reproduction—great possibilities for the future. That exposure to certain chemical agents (lead, mercury, etc) in the work environment may cause reproductive effects is not new. Sweden offers good possibilities to perform studies in this area because of its well-kept birth and malformation registries. In addition, the willingness of the Swedish population to participate in studies is a great advantage. These fortunate preconditions have not yet been fully utilized, but they offer great possibilities for the future.

A series of different kinds of reproductive effects have been published from the 1990s on. Examples are indications of prolonged time to pregnancy, decreased birthweight, and malformations in female medical personnel exposed to anesthetic gases (Gunnar Ahlborg Jr), although the effects remain to be firmly established. Studies have also been carried out among female laboratory staff, hairdressers, and fishermen's wives exposed to persistent organic pollutants, polychlorinated biphenyls, and the like (Lars Hagmar, Lars Rylander, Anna Axmon).

Studies of disturbances in male reproduction are far rarer. Indications of effects on sperm, including data on the FISH (fluorescence in situ hybridization) analysis for fishermen consuming high amounts of fish contaminated with persistent organic pollutants have been reported (Lars Hagmar, Anna Rignell-Hydbom, Aleksander Giwercman). Another example is formed from studies of time to pregnancy in association with paternal occupational exposure to phthalates (Gösta Axelsson).

Acrylamide—occupational exposure and ingestion via food. In the 1980s, advanced gas chromatography–mass spectrometry methods were developed to assess the concentration of hemoglobin adducts of alkylating agents, initially ethylene oxide (Lars Ehrenberg, Margareta Törnqvist). The methods proved valuable in the biomonitoring of workers, but also as tools for the assessment of cancer risks, by extrapolation from data on radiation risks to chemical carcinogens. Stable adducts for albumin have been demonstrated for toluene diisocyanate (Pernilla Lindh) and hexahydrophthalic anhydride (Monika Kristiansson).

An investigation of an outbreak in the late 1990s showed that Swedish tunnel builders (and cows) exposed to acrylamide developed signs of toxicity of the peripheral nervous system. This finding started a fruitful

sequence of studies in which determinations of the hemoglobin adducts of acrylamide were the key to describing the relationship between exposure and toxic effects (Lars Hagmar, Margareta Törnqvist). The outbreak was also used for detailed investigations into the metabolism of acrylamide. The results attracted much international interest, since the exposure was fairly widespread.

These methods and metabolic data became unexpectedly useful once the discovery (Margareta Törnqvist) that acryl amide can be formed in foods with the heating of carbohydrates. In this case, the issue was not nervous system disorders but the risk of cancer in large population exposures to low doses. Again, the acryl amide story illustrates the usefulness of the close interaction between occupational and environmental health, and it is also a good example of the advantages of interaction between analytical chemistry, occupational hygiene, toxicology, epidemiology, and clinical and environmental medicine.

The history as illustrated by doctoral dissertations

It has been possible to identify the names of the authors of all doctoral dissertations in occupational health defended at Swedish universities, including those concerning the psychosocial work environment, from 1940 on (table 1). We have classified the dissertations into the following four main categories: chemical (including biological), physical, ergonomic risks, and psychosocial medicine. Furthermore, subcategories of the main aspects of epidemiology, occupational hygiene, physical risks, and ergonomics have been listed, although many dissertations combine several of the subcategories.

For the whole period, 148 of the 324 theses concerned chemical hazards, 85 dealt with ergonomic aspects (musculoskeletal), 46 focused on psychosocial factors, and 46 concerned physical risks (when accident research is included). About half of the dissertations had an epidemiologic character, while about 60 mainly concerned occupational hygiene methods. Another 43 theses covered physiology and ergonomic exposure methods. Many dissertations classified as epidemiologic had a strong component of exposure measurements, for natural reasons. The large number of epidemiologic dissertations supports our opinion that Sweden has had a leading role in occupational epidemiology in all categories of occupational health research.

During the first 30 years, fewer than 10 dissertations where published per decade. The number of dissertations increased to 20 during the 1970s and to more than 80 during the 1980s, with a further increase during the 1990s (118 theses), and almost 80 during the first half of the 2000s. The increasing number of doctoral dissertations in occupational health corresponds with the general development of Swedish academia; exceptional resources made available during the late 1970s and 1980s paid off in a dramatic increase in doctoral students.

Time trends show no striking differences concerning the number of dissertations per category, except an increase in psychosocial dissertations during the last 5-year period, and possibly a decrease in dissertations on chemical risks during the last 10-year period when compared with the period 1986–1995.

Table 1. Swedish doctoral dissertations in the work environment sciences, 1941–2005. [Chem = chemical and biological risks; Ergo = ergonomics; Ph = physical risks; epi = epidemiology or registers, clinical, intervention; oh = occupational hygiene, toxicology; derm = skin exposures or dermatitis; exposure = ergonomic exposures; rad = radiation and electromagnetic fields; Phys = physiology, biomechanics; psychosoc = psychosocial and rehabilitation; + Dev= developing country (included in decade columns)]

	1942–1950	1951–1960	1961–1970	1971–1980	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	+Dev
$Chem_{epi}$	4	2	4	6	11	16	19	12	11	2
$Chem_{oh}$	–	–	–	1	8	13	10	11	9	–
$Chem_{derm}$	–	–	1	–	1	4	2	1	2	–
$Phys_{noise,\ epi}$	–	1	–	1	1	–	–	2	3	–
$Phys_{noise,\ oh}$	–	–	–	–	–	–	1	–	–	–
$Phys_{vibration,\ epi}$	–	–	–	1	–	2	1	2	4	–
$Ph_{vibration,\ oh}$	–	–	–	–	–	–	2	1	–	–
$Phys_{light,\ epi}$	–	–	–	1	–	–	1	–	–	–
$Phys_{light,\ oh}$	–	–	–	–	–	–	2	–	–	–
$Phys_{climate,\ epi}$	–	–	–	–	–	1	–	–	4	2
$Phys_{rad,\ epi}$	–	–	–	–	–	1	–	–	1	–
$Phys_{rad,\ oh}$	–	–	–	–	–	–	–	–	1	–
$Ergo_{epi}$	–	1	–	1	4	3	13	7	13	–
$Ergo_{exposure}$	1	–	–	–	1	1	2	5	6	1
$Ergo_{physiology}$	2	4	3	5	3	2	6	–	2	–
Psychosoc	–	1	1	4	–	8	7	5	20	1
Accidents	–	–	–	–	–	2	4	2	3	1
Total	7	9	9	20	29	53	70	48	79	

Psychosocial factors in research on work conditions and health in Sweden

by Töres Theorell, PhD [1]

Psychosocial factors could be defined as social conditions influencing individual psychological factors and vice versa. Another way of defining psychosocial factors is to say that they represent the interplay between social (environmental) and psychological (individual) factors. This interplay is the core of psychosocial research.

The psychosocial concept has been criticized for being too vague and too extensive. In practice, however, psychosocial researchers in the field of work conditions have defined certain subjects as their working area. This is a broad spectrum of subjects relevant to work organization in relation to health, for example, workhours (including shift work, which is a good example since shift work must be organized by a group and many individuals are affected both psychologically and socially by the resulting conditions), work organization, leadership in organizations, as well as questions related to work democracy and work demands. An umbrella name is psychosocial occupational health research.

How Swedish psychosocial occupational health research arose

Compared with the situation in most other countries, psychosocial occupational health research has had a strong position in Sweden. Two factors may have been of particular importance in this respect. First of all, the importance of democracy at work has been emphasized for a long time in our country. One of the roots of this democratic orientation has been the labor movement with its strong position since the beginning of the 20th century in Sweden. The labor movement has had long-lasting support from the social democratic governments that have ruled Sweden for several decades. The emphasis on democracy has, in turn, triggered an interest in how participation in decision making can influence employee health. Secondly, biological stress research started early in Sweden, partly due to the fact that biomedical research in general had a strong position in Sweden after World War II—which our country did not participate in. A Swedish Nobel Prize (for Ulf von Euler) was important to work stress research. Euler got his prize for the discovery of noradrenaline, which is the transmitter substance of the sympathetic nervous system. This event was the basis for a vital stress research tradition that was founded during the 1950s and was very soon applied to worklife. In several ways the societal interest in work democracy and biological stress research were tied together because successful researchers were engaged and collaborated in these fields.

The Council of Personnel Administration [Personaladministrativa Rådet (PA-rådet)], a group of psychologist counselors, started as a unit emphasizing, among other things, instruments for identifying psychological individual suitability for jobs (1). However, the leading researchers there became actively interested in exploring group psychological processes at work and believed that there could be a different phenomenon for scientific inquiry than that for individual processes. The group has had great long-term importance to the academic research into and teaching of psychosocial factors at work. The Council also interacted intensively as a consulting body with physicians in charge of health issues related to the work environment in labor market negotiations, for instance, the National Board of Occupational Health and Safety, the Confederation of Employers, and the Trade Union Confederation.

Bertil Gardell was the psychologist in this group who had the most widespread international reputation. He and his co-workers were convinced that worker participation was of central importance to the work environment. Extensive epidemiologic studies confirmed the hypothesis that worker participation was also important to employee health. Gardell's basic reasoning was founded in the alienation concept—that industrialization alienates the worker from the work process. This alienation, in turn, has a negative impact on the relationship between the worker and the employer, as well as on employee health. Logically this situation would lead to increased needs for worker participation in decisions. But, first of all, there was a need for more basic research supporting or refuting such arguments. This research included evaluations of the effects of psychosocial job interventions during the latter part of Gardell's career, the 1980s (2, 3).

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Examples of branches that were studied in this manner were mail distribution and car production (4). His overall aim was really to examine whether there were any scientific arguments for increased worker participation. He also initiated collaboration with biological stress researchers, above all, Marianne Frankenhaeuser and her group. That collaboration has had great importance with respect to psychosocial work environment research. The alienation research findings appealed not only to the general working population and mass media, but also to some of the important industrial leaders of the time, for instance, Volvo's chief executive officer.

During the 1980s a close link was created between the University of Stockholm and the Swedish National Institute of Occupational Health (NIOH) [later the National Institute for Working Life (NIWL)]. Some of the most influential researchers with links to the previous Council for Personnel Administration had affiliations both to the university and to the National Institute.

At the University of Stockholm, Marianne Frankenhaeuser was the researcher who brought biological stress research into frontier psychological research, and a close collaboration was established with the work environment researchers there. It was shown that the urinary excretion of catecholamines was significantly associated with exposure to different kinds of work stressors. This was particularly clear when the increase in excretion during workhours was compared with the excretion of catecholamines during the same hours during work-free days. It was possible to follow processes, for instance, in relation to changes in workhours, by means of repeated observations. This work made it possible to verify or falsify hypotheses regarding different kinds of stressors, and it stimulated many researchers to do real-life explorations of the effects of work organization changes (5).

Lennart Levi started his stress research program at the same time as Marianne Frankenhaeuser. He is a physician and has had experience in rehabilitation, internal medicine, and psychiatry. Levi started the Clinical Stress Research Laboratory, in which urinary catecholamine excretion was an important outcome variable. Levi had a more medical profile in his research than the aforementioned psychologists. His group studied several other biological stress markers, such as thyroid hormones, electrolyte balance, and white blood cell counts. As the other Swedish stress researchers, this group has been interested in and oriented towards society. For Levi, good research is characterized as being useful and needed in society, but it is also performed in such a way that basic research can be part of it. Biological stress reactions were described in studies of shift work, assembly-line work, starvation, and cold temperatures, for instance (6). Unemployment—using a broad approach—was studied according to these principles (7). He has always recommended evaluations of interventions in his research.

Another input to psychosocial occupational health research during this time was the results from studies of critical life changes that had been introduced by the American psychiatrists Holmes and Rahe in 1968. This field was popular in psychosomatic medicine during the late 1960s and early 1970s. In Sweden, Richard Rahe spent 2 years as a guest researcher, and he initiated life event research in Sweden. Theorell and his co-workers performed one of the first epidemiologic prospective studies on the relationship between critical life changes and the risk of subsequent myocardial infarction. This study was done with male middle-aged construction workers, and it showed that critical life changes at work (eg, increased responsibility or conflicts) during 1 year had a statistically significant predictive value in relation to the risk of myocardial infarction during the subsequent 2-year period (8). This was a stimulus to psychosocial occupational health research during the 1980s.

In 1980, Lennart Levi founded the National Institute for Psychosocial Factors and Health [Institutet för Psykosocial Medicin (IPM)], which has since been a state agency under the Ministry for Health and Social Welfare. During the 1980s and 1990s, two areas of psychosocial occupational health research were focused on, namely, work organization and shift work or night work. Åkerstedt and his co-workers initially focused on night (shift) work and developed unique methods for recording fatigue and sleep during and after workhours, as well as in a sleep laboratory. This research has stimulated a large number of basic science studies on psychobiological sleep and fatigue correlates, as well as field studies including evaluations of improvements in shift cycles (9).

The National Institute of Occupational Health started more actively and permanently to incorporate psychosocial occupational health research into work environment research during the 1980s. A wide range of research areas has been established, for instance, qualitative research questions exploring the possibilities and limitations of quantitative approaches in evaluations of interventions (10), and not only research on the relationship between psychosocial work conditions and sick leave, but also between psychosocial work conditions and work presenteeism (presence at work despite illness), which has been a neglected research area (11).

Work psychology research at the Department of Psychology in the University of Stockholm became very psychosocially oriented during the 1970s and 1980s and has continued to be so (12). Ulf Lundberg, who collaborated with Marianne Frankenhaeuser for many years, has also expanded the psychosocial work research field. His group has introduced several psychophysiological assessments, such as saliva cortisol and electromyography in psychological work stress research (13, 14). A

parallel development has taken place at the University of Göteborg, where psychosocial occupational health research spread both to the Department of Psychology at the University (15) and to the Lindholmen Institute, a research institute that specializes on muscle ergonomics but has also included psychosocial factors in its model building (16). Physiological measures of stress became an important integrated part of this work. It soon became clear that biological observations made it easier to convince the surrounding society of the importance of psychosocial factors. Thus the typical studies in this area combined biological and psychosocial assessments.

For a long time, the departments of occupational medicine hesitated to incorporate the psychosocial factors into occupational medicine. During the 1980s, however, Christer Hogstedt and his co-workers started actively to incorporate psychosocial factors at the Department of Occupational Medicine in the Karolinska Hospital in Stockholm. Fairly soon, all of the departments of occupational medicine in the country had employed experts in psychosocial factors. This action was paralleled by rapid international development. Psychosocial factors have become a major subject in occupational medicine since the 1990s. Clinically relevant research on cardiovascular disease, exhaustion syndromes, and musculoskeletal disorders is necessary for correct assessments in work compensation cases and in preventive work. Hogstedt, who was also the Professor of Occupational Medicine at the National Institute of Occupational Health, had great importance because his group started several large epidemiologic studies with a broad approach, including etiologic research on psychosocial, ergonomic, and physical and chemical exposures in relation to cardiovascular and musculoskeletal disorders. Similar developments occurred soon thereafter in Göteborg (17), Lund, Malmö (18), Linköping (19), Örebro (20), Umeå (21), and Uppsala (22, 23). Today, all of the Swedish university departments have regional large-scale cohort studies that include psychosocial work conditions. This is a valuable supplement to the national studies in a field that has been very important both to Sweden and to the other Nordic countries. The Institute for Social Research at the University of Stockholm and Statistics Sweden have been hosts of the national studies.

Epidemiologic research was developing earlier and more intensively in Göteborg than in other Swedish university cities, since Göteborg was the city where the first population-based studies of cardiovascular disease and its risk factors started in Sweden. However, epidemiologic research in psychosocial occupational health was greatly stimulated in Stockholm during the 1990s when several studies were started, such as the Stockholm heart epidemiologic program (SHEEP) and the work, lipids and fibrinogen study (WOLF) (both of which were studies on cardiovascular disease) and the musculoskeletal intervention center studies in Norrtälje (MUSIC). Several scientific publications and extensive information to lay people about cardiovascular and musculoskeletal conditions were published from these studies (24–26)

Theoretical models particularly important to the Swedish situation

During the 1960s and 1970s the dominating model for work stress research was the one introduced by the Michigan school with its leaders Robert Kahn and James House. They had identified some psychosocial "stressors", such as overload, role ambiguity, lack of social support, and misfit between the person and the environment (27, 28). The latter factor corresponded to the dimension "person–environment fit" (PE fit), which has had great importance in both theoretical and practical work in this area. A very different school that gained influence during these years was "critical psychology", which had been introduced in East Germany by the two psychology professors, Hacker (1978) and Volpert (1974). They emphasized the importance of objectively recorded psychosocial conditions and introduced techniques for the systematic observation of such conditions. Such techniques have been further developed in Sweden by researchers at several institutions. The critical psychology tradition in East Germany also emphasized the importance of regarding employees as active participants rather than as passive objects.

Marianne Frankenhaeuser (1980) and her co-workers developed a theory that focused on the individual's psychophysiological reaction to stressors as the outcome variable. According to this theory, two dimensions could be identified, one that had to do with the amount of arousal that the stressor incurred and one that corresponded to negative and positive feelings. These were combined in a two-dimensional model. When the arousal level was high, two conditions could arise. One was labeled eustress ("positive stress") and the other as distress ("negative stress"). In laboratory experiments, eustress correlated with an elevated secretion of catecholamines only, whereas distress was associated with a joint increase in both cortisol and catecholamine excretion.

Bertil Gardell and his co-workers developed theories regarding the importance of alienating work and stimulating work. Lennart Levi and his co-workers, on the other hand, emphasized the importance of the integration of a whole web of social and psychological etiologic factors and were, at this stage, more involved in epidemiologic research than the university group was.

At this stage, the demand–control model was introduced. Karasek started as an architect. He came to

Sweden in the early 1970s and was impressed by the Swedish society's social emphasis. His experiences influenced him to start a new career as a sociologist. His background as an architect was important since he could illustrate his ideas in three-dimensional drawings. He also represented the rapidly growing field of social epidemiology, which, at this time, was represented in our country mainly by the Institute for Social Research at the University of Stockholm, which Karasek collaborated with in the late 1970s. Karasek combined general stress theory (the general adaptation syndrome according to Selye) with the alienation theory, which, in our country, had been introduced by Gardell. This work resulted in the theory that high external psychological demands result in stress reactions that are dangerous to health only when the employees have little influence over their situation (low decision latitude). This theory is intended to be a stressor model in the sense that the dimensions are related to work organization and could be changed by means of work design and redesign. The model does not intend to explain interactions between individual characteristics and the environment. Karasek and Theorell (who had a background in internal medicine and physiological stress research) jointly developed "translations" of the demand–control model into a psychophysiological theory. This work stimulated several empirical studies on endocrine, immunologic, and cardiovascular reactions to variations in demands and decision latitude at work. It also stimulated national and international research on the demand–control model in relation to cardiovascular, musculoskeletal, and mental disorders. During the 1980s, the American sociologists Jeffrey Johnson and Ellen Hall stimulated researchers to expand the demand–control model to include social support at work. The demand–control support model has been widely utilized in the Nordic countries, both in research and in practical work, particularly as an educational model in intervention work in the 1980s and 1990s (29).

During the late 1990s an alternative model was introduced by the German sociologist Johannes Siegrist—the effort–reward model. This model (30), which is theoretically in a position between the psychological Frankenhaeuser "reaction" model and the demand–control "stressor" model, rapidly gained importance in our country from the early 1990s on. The theory builds upon the hypothesis that great effort has to be balanced by great reward—reciprocity. The model includes both extrinsic "stressor" and intrinsic "response" components. The intrinsic component has been labeled overcommitment. According to this theory, people with particular previous (at work and outside work) experiences and individual characteristics are overcommitted and run a greater risk than others of developing poor health when they are subjected to a high external stressor level. In the model, rewards could be material, psychological, or sociological. During later years, the effort–reward model has been utilized in numerous studies in our country, as well as in other countries.

The two dominating psychosocial work-stress models may seem to be alike, but, in fact, epidemiologic research in which both models have been used concomitantly show that they supplement each other. It is evident that such broad general models have, however, to be supplemented with more-detailed explorations of the particular conditions at a given worksite and also that they have to be adapted to a constantly changing worklife (31). This circumstance was particularly true in Sweden during the period after the early 1990s when many changes occurred in Swedish worklife.

Gender has been an important topic in Swedish research in psychosocial occupational health, not the least since female participation in the workforce has been among the highest in the world in our country for at least 30 years. Marianne Frankenhaeuser has been an important promoter in this field. Her position was manifested in the publication of an international conference that took place in Stockholm and which summarized gender-specific stress research at the time (32). Psychosocial stressor patterns for female cardiovascular risk have been studied extensively by Kristina Orth-Gomér and her co-workers. The general conclusion has been that family conflicts are more important in such risk patterns for women than they are for men (33).

An important debate in Swedish psychosocial occupational health research has concerned scientific methods. This discussion has initiated a pluralistic approach that means that both qualitative and quantitative methods are being used. Qualitative approaches may be of particular importance during periods of dramatic change since quantitative methods may not be sensitive enough during such periods, and qualitative research may provide a good basis for redesigning large-scale questionnaire-based epidemiologic explorations. Examinations of biological stress markers have been used extensively, not only in research, but also, for instance, in practical evaluations of the health effects of psychosocial interventions.

In many ways Sweden has been a good country for psychosocial occupational health research. There has been a relatively high level of willingness to collaborate with researchers, both among employers and among employees. The population has a high level of education and is accustomed to population studies. This situation has resulted in high participation rates in work environment studies. Contrary to the situation in some other countries, Swedish employees have also hitherto accepted examinations using biological stress markers. There has been a long tradition of biological stress research in our country that may have contributed to the credibility of the field. In international evaluations of

Swedish occupational health research, there has been criticism because there is insufficient emphasis on the evaluation of interventions.

Swedish researchers in the field of psychosocial occupational health have had a relatively friendly climate during the period since the 1970s. There have been no big academic fights, and there are many examples of research endeavors that were undertaken in collaborative national and international (34) networks, as well as interdisciplinary ones (35). There has also been interdisciplinary work across national borders, such as that between southern Sweden and Denmark (14) and that between Finland, Sweden, Germany, and Great Britain in cardiovascular psychosocial occupational epidemiology (36).

An important factor in the high activity in this field during the past few decades has been the stability that was created through permanent government support to the National Institute for Working Life and the National Institute for Psychosocial Factors and Health. This support has created stability and good possibilities to develop methodologies and networks of scientists.

Since Sweden went through a financial crisis during the early 1990s, unemployment increased dramatically during this period. At the same time, resources for rehabilitation and prevention decreased. This combination was unfortunate, and there has been a related rapid increase in work-related mental ill health during the late 1990s. Long-term sick leave increased dramatically during the later part of the 1990s, and this increase was shown to be related to structural changes (37). Despite these alarming changes, research on long-term sick leave started relatively late. However, in biological stress research, knowledge regarding long-term stress mechanisms of relevance to "burnout" has grown rapidly, and therefore research in psychosocial occupational health in Sweden is contributing to this field. Since the changes were so dramatic in our country, interest in such mechanisms is pronounced.

During the late 1990s, interest in psychosocial occupational health research rapidly increased internationally. At the same time, the financial crisis in Sweden during the 1990s contributed to a somewhat weaker position for this field nationally. Therefore, Sweden's high position in psychosocial occupational health research is threatened internationally.

Financial framework for psychosocial occupational health research

Financial support to research in psychosocial occupational health (psychosocial occupational health research) has been relatively generous if an international perspective is used. The Research Council for Worker Protection (Arbetarskyddsfonden) was founded in 1972. In the beginning, research supported by this council focused primarily on chemical and physical hazards, but psychosocial factors slowly gained ground, particularly after the new law on co-determination [Medbestämmandelagen (MBL)] was introduced in 1976. This was a debated law, and societal discussions stimulated research. Two driving forces in this respect were the extensive educational program that was started in worksites for the introduction of the law and the Centre for Work Life Research (Arbetslivscentrum) that was devoted to the study of work organizations and their functions. It was financed by the Council. The support to research and developmental work grew to approximately 300 million Swedish crowns in the mid-1990s (approximately 40 million United States dollars for a population of 8 million). For a more-detailed description see the report by Oscarsson (38).

Special characteristics of Swedish development

The ground gained in the psychosocial aspects of the work environment early in Sweden may be due to many reasons. As pointed out earlier, there may be historical reasons, such as the strong position of the labor movement and the fact that Sweden has had a long-lasting tradition in mortality statistics—not only did Sweden have the world's first census in the mid-18th century, the results were made public (39). The fact that the labor movement has been strong indicates that the Swedish society has created a basis for inquiries into the establishment, mechanisms, and consequences of citizen participation in worklife. And there was basic agreement between employers and employees that these factors were important, this situation made it politically possible to create a financial basis for work environment research. By international standards, the Swedish laws on co-determination (1976) and the work environment (1978) were very radical regulation systems at the time. They enforced the fact that workers should be able to influence their work situation. Similar laws have been instituted in the other Nordic countries.

The strong position of public health statistics over a long period in our country has facilitated the creation of high-quality population surveys on life circumstances at an earlier stage than in most other countries. In particular, the Level of Living Survey (LNU) was started by the Institute for Social Research in 1968 and the Survey of Living Conditions (ULF) was initiated in 1972 by Statistics Sweden. Later (from 1989 on) Statistics Sweden, in collaboration with the Board of Occupational Safety and Health, started to collect more-detailed

survey information regarding work conditions among the working population [Work Environment Investigation (AMU)], and this work produced fairly extensive information regarding psychosocial factors. These high-quality surveys are repeated at regular intervals. A strong feature of these registers is that they can be linked to national registers of mortality, cancer incidence, hospitalization, and several other health outcomes. This linkage has provided an important basis for psychosocial work environment research. A high participation rate in these surveys was a hallmark during the initial years. Similar developments have taken place in the other Nordic countries. Concomitant information regarding outcomes in the psychosocial work environment and health in the population was attractive for foreign researchers, who saw Sweden and other Nordic countries as important "population laboratories" that stimulated international exchange in the field of psychosocial factors. Of course this aspect has been of major benefit to the research field in Sweden. An international network has created joint ventures with researchers in the psychosocial field in the other Nordic countries, Great Britain, the United States, Canada, France, Germany, and many other countries.

During these periods, the other Nordic countries have not had institutes similar to the National Institute for Psychosocial Factors and Health, and it has proved to be unusual internationally. The activities at the Institute have been cross-disciplinary in the following two ways:

1. Biological, psychological, and social research traditions have been mixed, and this joint collaborative work has been going on for several decades in a government institute. This long-lasting cross-disciplinarity has, in itself, been of importance, not only to the Institute itself, but also to other national institutions.

2. Borders between work and nonwork activities have been of less importance than in many other institutions. This situation allowed researchers to carry knowledge between work and nonwork activities in a fruitful way.

The National Institute for Psychosocial Factors and Health has been a small institute, and it has depended heavily on collaboration with the National Institute for Working Life, the National Institute of Public Health, the National Board for Health and Social Welfare, and many academic institutions. But the mere existence of a government "stress institute" with public health aspirations has stimulated other institutions to be attentive to these concerns.

While the Swedish society and its emphasis on public health and worker participation created a general basis for this kind of research, the theories and the underlying research techniques were often taken from other countries. As pointed out previously, the early years (1960s and 1970s) were characterized by group psychology theories with influence, for instance, from the Tavistock Institute in London. And the early theories formulated for Swedish research came from the Michigan school, the person–environment fit model (25) and the social support dimension (26), as well as from stress biology research founded by Selye. Other theories that gained ground during the 1980s were founded in East German "critical psychology" theory that emphasized the individual's right and the possibility to be in command of his or her situation at work (40, 41), which was in accordance with the Swedish societal discourse at the time.

The "Swedish model" for societal discourse has changed over the years. In the beginning, the central federations of the trade unions and employers used to have representation on the boards of many government agencies. However, during the early 1990s, the Federation of Employers decided that the organization did not want to participate in these boards with activities in the work environment field [eg, the National Institute for Psychosocial Factors and Health and the National Institute for Working Life].

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Characterization of the Swedish work environment and work environment research

by Carin Håkansta[1] & Elisabeth Birke[1]

Labor accidents, work-related disorders and complaints—data sources and statistics

Relevant statistics information is available from several sources, such as Statistics Sweden, the Swedish Work Environment Authority (SWEA), the Ministry of Industry, Employment and Communications, county councils, several research institutes, and the like. The most relevant are (i) the Swedish Information System for Occupational Accidents and Work-Related Disorders (ISA), a department in the Swedish Work Environment Authority that covers officially registered occupational injuries and work-related disorders and (ii) the Work Environment Survey, financed by the Swedish Work Environment Authority and conducted by Statistics Sweden. The latter is based on the respondents' own assessment of exposures, complaints, and disorders.

Accidents and disorders

The number of occupational deaths among men in Sweden is less than a sixth of what it was in 1965, as illustrated by figure 1. For the women, the low number of occupational deaths has remained constant, except for 1994, when the ferry Estonia sank and the hundreds of victims from the crew and conference participants created a peak in the death rate.

The number of self-reported occupational diseases has remained fairly constant over the past 15 years. The peak in 1993 and uncertain numbers in 2001–2003 (figure 2) are due to changes of the compensation rules.

The factors reported to be associated with occupational diseases in Sweden have not changed much over the past 5 years (figure 3). Ergonomic factors such as monotonous or unusually strenuous movements, manual materials handling, or awkward work postures cause close to 60% of the reports. Organizational and social factors cause between 20% and 25%. Chemical or biological substances or products, noise and vibration, and other factors all cause less than 10% of the reported occupational diseases. The leading diagnoses are musculoskeletal disorders, but psychosocially related diseases show the most rapid growth.

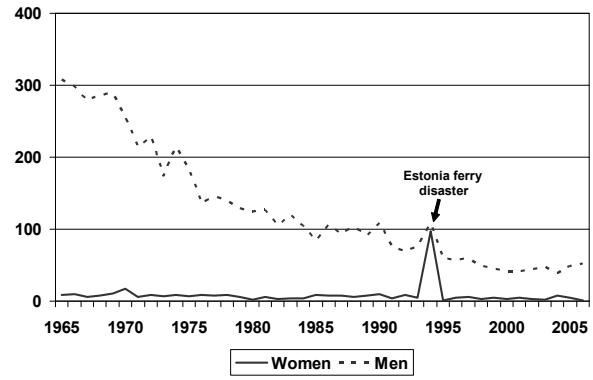

Figure 1. Occupational deaths in 1965–2005 (absolute numbers).

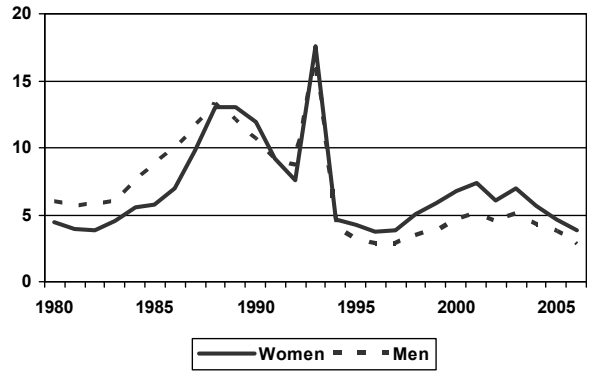

Figure 2. Number of self-reported occupational diseases in 1980–2005 (per 1000 employees).

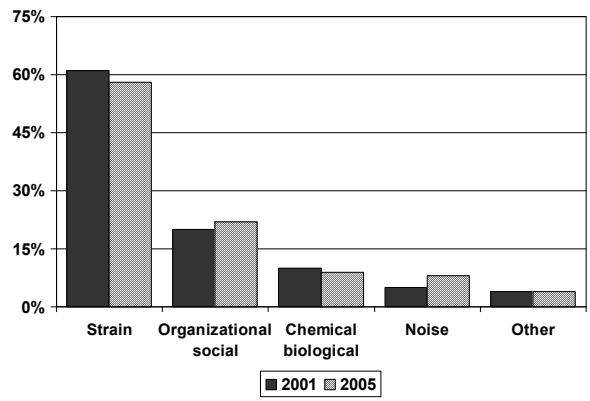

Figure 3. Underlying factors behind reported occupational diseases in 2001 and 2005 (men and women).

1 Swedish Council for Working Life and Social Research, Stockholm, Sweden.

Of the 20 787 occupational diseases reported in 2004, 56% affected women and 44% occurred among men. The rates of reported occupational diseases were 4% per 1000 gainfully employed men and 6% per 1000 gainfully employed women. A breakdown of occupational diseases reported in 2004 by branch of industry shows the highest frequency rate for men in the manufacturing of nonmetallic mineral products (12 cases per 1000 employed). Among women, the manufacturing of transport equipment showed the highest frequency (22 cases per 1000 employed).

Work environment survey and complaints

The Swedish Work Environment Survey, based on interviews with more than 14 000 Swedish employees, takes exposures and the determinants of the work environment into account from two different angles. One angle is based on questions regarding health complaints caused by work. Another angle is based on perceived exposure (ie, whether the interviewees experienced occupational exposures and determinants, such as noise, dust, vibration, or strenuous work positions) during at least one-fourth or half of their worktime during the past year.

The causes of work-related complaints show particularly high figures for strenuous work positions and stress. There has also been an increase in workers experiencing complaints caused by work in front of visual display screens. The numbers of complaints are, on the average, higher for women than for men. For instance, among workers experiencing stress, the complaints of women increased from 7% in 1997 to 12.1% in 2006, compared with 3.7% in 1997 and 7.4% in 2006 for men.

Regarding perceived occupational exposures in the work environment, few notable changes were detected in the 1990s except for the case of environmental tobacco smoke, which had a dramatic decline after 1998—partly due to new legislation.

On the question of whether workers can see or smell chemicals in the air one-fourth or more of the worktime, the overall number declined slightly from close to 30% in 1989 to around 20% in 2001, or 800 000 persons. About 370 000 persons reported such chemicals half their worktime or more. Exposures to detergents and disinfection liquids are especially common (8.3% of all men and 15.5% of all women in 2003, but as many as 66% of all female cleaners).

Dust exposure, or whether workers can see dust in the air, shows two trends. Around 1 million workers could see organic dust one-fourth or more of their worktime in 2003, and this level is no change over that of previous years. For inorganic dust, the number was 625 000 persons in 2001, while 240 000 did so during half or more of the worktime. These numbers show a slow overall improvement from 20% in 1989 to less than 20% in 2003.

Vibration from handheld machines is a problem area in certain branches. Around 825 000 persons reported such work one-fourth or more of the worktime in 2003, and around 185 000 persons did so one-half their worktime or more. Two of the most problematic sectors showed divergent trends. While such vibration seems to be decreasing among agricultural and forestry workers, there has been an increase among construction workers since 1989. From having had the same level of just under 30% in 1991, construction workers reached more than 40% in 2001.

Around a quarter of the workforce, or 15.8% of women and 30% of men in 2003, experienced noise too loud for normal conversation. This figure has remained stable among men, while women 30 to 49 years of age have experienced a 5% increase since the beginning of the 1990s. Women working as preschool teachers perceive the most noise, 54% in 2003. Among men working as process operators in the wood and paper industry, the corresponding figure was 78%.

Structure of work environment research in Sweden and its actors

Development of the structure for work environment research

The evolution of work environment research and its application has been irregular. The early period—during and after World War II—was characterized by research embedded within the Swedish National Institute for Public Health (SNIPH), and the evolution of regional occupational medicine clinics. Over the 1970s and 1980s there was further development of regional attention to occupational health concerns with the development of some occupational medicine clinics, as well as university institutions.

Since the beginning of the 1960s, the structure of government work environment institutions has undergone a series of changes. In 1965 certain units from the Swedish National Institute for Public Health and an institute of work physiology were combined into the National Swedish Institute of Occupational Medicine (NSIOM), which, in 1971, was integrated to become a research department in the National Board of Occupation Safety and Health (NBOSH today SWEA), which was responsible for enforcing workplace regulations. In 1987 this research department was separated from the Swedish National Institute for Public Health to become the Swedish National Institute of Occupational Health (SNIOH). In 1995 the Swedish National Institute of Occupational Health was merged with the Centre for Work

Life Research [Arbetslivscentrum (ALC)] and parts of the Work Environment Fund (AMFO) to form the National Institute for Working Life (NIWL). The much broader mandate for this institute somewhat disrupted the growth of traditional occupational health research. The National Institute for Working Life was closed on 1 July 2007 [See more about this institute below].

Current structure of Swedish occupational health

Swedish Work Environment Authority. The Swedish Work Environment Authority was formed in 2001 through the amalgamation of the 10 districts of the Labour Inspectorate and the National Board of Occupational Safety and Health. The objective of the Authority is to reduce the risks of ill health and accidents in the workplace and to ensure compliance with work environment and workhour legislation and also, in certain respects, with the Tobacco Act and the Environmental Code with regard to certain issues related to genetic engineering and pesticides. The Authority is also required to furnish advice, respond to inquiries, and publish information. It is also Sweden's "liaison office" with respect to citizens of other EU countries working in Sweden for a limited period (as a "posted worker"). Work environment inspections at workplaces in Sweden are carried out by inspectors from the Authority. Altogether 440 inspectors are stationed in 10 districts, and, between them, they carry out 38 000 inspections annually. However, this capacity has been dramatically weakened in 2007 as the budget of the Swedish Work Environment Authority was cut by almost a third, in line with the political priorities of the current Swedish government.

The lay board of the Swedish Work Environment Authority consists of the director general, as the chairperson, and six members representing general knowledge of worklife, all appointed by the government. The Swedish Work Environment Act is applicable to all areas of worklife, and, out of Sweden's almost 9 million inhabitants, approximately, 5.3 million come under this act. The Authority supplements and articulates stipulations of the Work Environment Act and attends to the transposition of EU legislation into Swedish law. To this end, the Authority issues regulatory amendments and new rules for the work environment. Today, there are some 130 provisions related to technical, chemical, organizational, and psychosocial factors.

National Institute for Working Life. The National Institute for Working Life (NIWL) was created in 1995 by a merger between the former National Institute of Occupational Health (NIOH), the Centre for Work Life Research (ALC), and parts of the Work Environment Fund (AMFO) as a national center of knowledge and research for issues concerning worklife. The Institute has since undergone several reorganizations, particularly when five new local branches were set up and major parts of the former research resources for chemistry, toxicology, aerosols, and lung disorders were outsourced, along with ergonomics, to different universities.

The Institute carries out research and development covering the whole field of worklife, on commission from the Ministry of Industry, Employment and Communications. The goals of the Institute are to contribute to (i) a good worklife with well-functioning work conditions and (ii) increased knowledge of and in worklife. Research and development are concentrated into the following three main areas: the labor market, work organization, and the work environment. Research is multidisciplinary and arises from problems and trends in worklife. The Institute collaborates with its social partners, industry, universities and university colleges, international partners, and with others active in the field of worklife.

The Institute head office is located in Stockholm and it has local branches in Göteborg, Malmö, Umeå, Norrköping, Östersund, and Visby. It has approximately 400 full-time employees and a total budget of 441 million Swedish crowns (2005). In 2001, 55 million were transferred from the Ministry of Industry, Employment and Communications to the Ministry of Education and Research and distributed to the universities that hosted the outsourced disciplines.

Note: In 2006, the newly elected government suggested to Parliament that the National Institute for Working Life be closed. The Parliament accepted this recommendation in December 2006, and the Institute ceased to exist on 1 July 2007.

Local safety work. "Employers and employees shall co-operate to establish a good working environment" (Work Environment Act, Chapter 3, Section 1). The law makes the employer ultimately responsible for the work environment. But cooperation is also a key factor, and some institutions exist to facilitate local safety work. One is the safety committee (skyddskommitté). Safety committees must be set up in workplaces with more than 50 employees. The unions elect representatives to the committee, which represents all groups at the workplace. The unions (blue- and white-collar unions together) have one representative more than the employer.

The safety committee takes part in the company's work environment activities in a broad sense and provides guidelines on how this work should be carried out. Safety delegates (skyddsombud) are the employees' representatives in health and safety matters. They are elected for a period of 3 years by the local unions at workplaces with five or more employees. If there is

no union at a workplace, a safety delegate is elected among the employees anyway. There are 96 000 safety delegates in Sweden. Large workplaces have several safety delegates, one of whom is elected to be the "chief safety delegate."

Safety delegates have a legal right of access to all information necessary to fulfill their duties. The employer must allow them the paid time needed for the job and also the necessary training. The local trade union organization may appoint a "regional safety delegate" with the main duty of stimulating safe work practices in small companies without safety committees. There are 2140 such regional delegates.

Occupational health services. No law demands that companies provide occupational health services (företagshälsovård). The employer and employees are jointly responsible. The coverage of the Swedish workforce is approximately 75%. Large companies mostly have their own built-in occupational health services, while joint occupational health centers provide services to small and medium-size companies. Traditionally, an occupational health team includes a physician, a nurse, a physiotherapist, an industrial hygienist or safety engineer, and, in some cases, a psychologist. A recent trend is towards larger companies through mergers and voluntary collaboration with local satellite units.

The conditions for Swedish occupational health services changed in the beginning of the 1990s when the subsidies from the government were abolished. For financing, occupational health services are dependent on renewed contracts with public and private enterprises. The former research facilities within some of the larger occupational health organizations have thereby disappeared, and the former involvement in research has more or less ended.

University institutions and hospital-based clinics of occupational medicine. The leading employer of occupational health researchers has been the National Institute for Working Life. Other important research centers are the Karolinska Institute (Stockholm), the universities in Gävle, Göteborg, Linköping, Lund, Stockholm, Umeå and Uppsala, the Royal Institute of Technology (Stockholm), and the Chalmers University of Technology (Göteborg). Some of the universities host outsourced groups from the National Institute for Working Life with, so far, guaranteed funding.

Work environment problems requiring expert studies are referred from occupational health services to clinics for occupational medicine at the regional hospitals (yrkesmedicinska kliniker). Most clinics collaborate closely with departments of occupational and environmental health at the local university. There are clinics for occupational medicine in Göteborg, Linköping, Lund, Malmö, Stockholm Sundsvall, Umeå, Uppsala, and Örebro

Private research institutes. There are also some private sector research organizations in the work environment field, for example, STFI-Packforsk AB, the Swedish Environmental Research Institute (IVL), and Industrial Research and Development AB (IVF).

Inventory of the Swedish work environment research workforce

The National Institute for Working Life carried out an inventory of Swedish worklife research in 2005–2006 on the assignment of the Swedish Council for Working Life and Social Research and the Swedish Governmental Agency for Innovation Systems. This inventory was based on a survey sent to all major research institutions involved in different areas of worklife. The National Institute for Working Life prepared questionnaires, which were filled out by 336 Swedish research leaders in worklife sciences. The evaluation of Swedish work environment research used the preliminary report from the exercise of the National Institute for Working Life, as well as computer files containing survey data from the inventory. This is a short overview of the data available from the inventory for the research evaluation.

First, the inventory helped the evaluation secretariat to identify which Swedish research groups were active in the relevant disciplines (ie, groups engaged in research on ergonomic, physical, biological, and chemical health risks). Out of the total 336 groups, 70 groups remained. The list of the 70 research leaders was subsequently used when a request for research material was sent out from the International Evaluation Group.

Second, data from the questionnaires of the selected 70 groups were analyzed. These data showed, for example, that the number of research personnel working in selected areas of work environment research represented about 570 full-time equivalents, out of the total 1500 in worklife research. When only postdoctoral researchers are counted, the approximate total was 250 full-time equivalents. Table 2 shows the division of research groups and full-time equivalents between the different

Table 2. Research groups and personnel distributed over the selected work environment research areas.

Research area	Full-time equivalents	Research groups
Physical health risks	92	16
Chemical and biological health risks	136	25
Strain ergonomics	166	15
Combinations	174	14
Total	568	70

areas of work environmental research. The "combination group" is comprised of those who carry out research in two or more of the selected areas.

The gender balance in the selected research areas proved to be even, 51% women and 49% men. However, when distributed over professional categories (figure 4), clear gender differences became visible with more women in the lower professional categories and a male dominance in the postdoctoral categories. Among the women in the postdoctoral categories almost 45% (40 of 93) were employed by the National Institute for Working Life, as were less than a third of the men in this category (45 of 152).

The most common faculty background of the research staff in the selected areas was health sciences, natural sciences, and technology studies. In the ergonomics groups and combination groups, it was also common to have a background in behavioral sciences or other social sciences.

A comparison of the research leaders' age structure showed that the average age was rather high. As illustrated by figure 5, only one of the research disciplines, chemical and biological health risks, had any research leader under 40 years of age. Most were between 55 and 59 years of age, and 23% was more than 60 years of age.

The largest research institutions, counted as the number of full-time equivalent research personnel, are listed in table 3. The National Institute for Working Life was clearly the largest institution, the Karolinska Institute being the second largest. After the National Institute for Working Life and Karolinska, the old traditional universities were the largest, with the exception of the Gävle University College, explained by the move of the musculoskeletal center from the National Institute for Working Life to Gävle in 2003.

A summary of the reported sources of funding shows that Swedish work environment research has relied, to a large extent, on public-sector funding. Around two-thirds of the total research funding has derived from different government institutions, and 40% of the total comes from state-funded research councils, such as the Swedish Council for Working Life and Social Research. Other public-sector sources are, for example, the National Institute for Working Life and the country councils. An insurance company owned by the labor market partners (Afa) has increased its support to work environment research. Different types of funding from the private sector and EU grants are small in comparison.

The survey also inquired about how the research groups saw the social benefits of their research. According to the responses to this open question, the benefits could be categorized into the following five categories: practice and exposure limit guidelines (23%), training and communication (20%), measurement methods

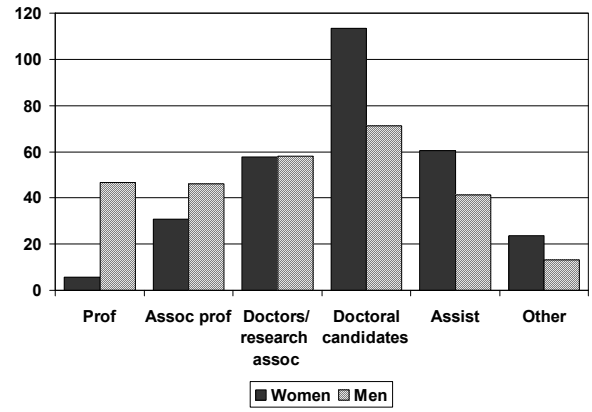

Figure 4. Distribution of professional categories according to gender in the selected research groups. (Prof = professors, Assoc = associates, Assist = assistants)

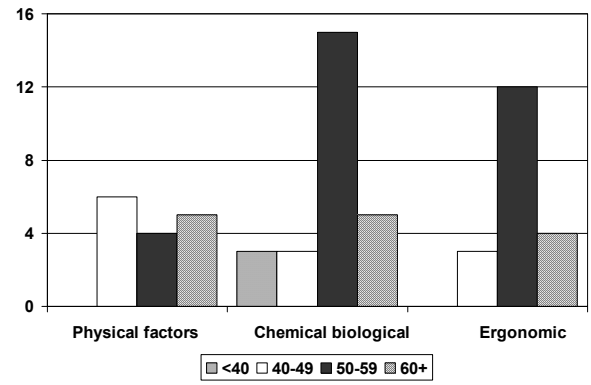

Figure 5. Age structure of Swedish research leaders in different work environment fields.

Table 3. Largest research environments according to the rank of the total research personnel and postdocoral personnel (full-time equivalents).

	Full-time equivalents
Total (including assisting staff)	
1 National Institute for Working Life	167
2 Karolinska Institute	57
3 Linköping University	39
4 Göteborg University	35
5 University College Gävle	31
6 Lund University	26
7 Swedish University of Agricultural Sciences	12
8 Örebro Country Council	11
9 Uppsala University	11
10 Umeå University	10
Postdocoral personnel	
1 National Institute for Working Life	85
2 Karolinska Institute	42
3 Lund University	33
4 Linköping University	15
5 Göteborg University	14
6 University College Gävle	7
7 Örebro Country Council	7
8 Swedish University of Agricultural Sciences	6
9 Umeå University	6
10 Uppsala University	5

and products (20%), prevention (20%), and scientific knowledge (14%).

The final survey questions looked into the researchers' views on future research and knowledge needs. As indicated by table 4, traditional work environment issues appeared to dominate. Consequences from societal changes in recent years also seem to have had an effect on priorities, as well as the relationship between work and leisure time. Contributions to improved work conditions and individual differences in sensitivity and vulnerability were also frequently mentioned. The researchers had a tendency to mention ideas for future research close to their on-going research.

Table 4. Prioritized research areas by work environment research groups (number of responses by priority area).

Priority area	Number of responses
Analysis of new risks or deeper knowledge of old risks	35
Consequences of combined exposures	7
Studies of differences in individual sensitivity (primarily of physical exposures)	4
Attitudes towards work and its consequences, along with the relation between work and leisure time and the significance of recovery, rest, and sleep	22
Limitations to work ability and possibilities to work, as well as rehabilitation and issues concerning return to work	8
Questions around the organization and design of occupational health activities	7
Consequences of national or international rules in the area of the work environment	3

International evaluation of Swedish work environment research

by David H Wegman, MD,[1] Alex Burdorf, PhD,[2] Paul Oldershaw, PhD,[3] Brigitte Schulte-Fortkamp, PhD[4] & Eira Viikari-Juntura, MD[5]

The evaluation of research on the work environment focused on evaluating whether Swedish contributions to work environment research met international standards in quality, quantity, and relevance. The approach to this evaluation was organized into seeking a response to the following questions:

- Does work environment research address gaps in international research and significantly enhance the knowledge base or mainly repeat research that has been carried out elsewhere?
- Does work environment research pay adequate attention to engaging with the international research community?
- Do efforts in work environment research include knowledge distribution and knowledge implementation in addition to knowledge development?
- Does the research and its transfer provide a good basis for policy decisions, strategies, and activities to promote a good work environment?
- Does the structure in the support of work environment research appear appropriate and optimal?

The original international evaluation report has been somewhat edited for this supplement to make it more accessible to an international readership. Most of the relevant background information has been provided

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5 Finnish Institute of Occupational Health, Helsinki, Finland.

earlier in this supplement. The entire report is available from the Swedish Council for Working Life and Social Research (FAS). Brief comment is offered here on the system for registering worklife risks and their consequences, as well as on the funding of work environment research in Sweden.

Sweden has a well-developed national system for registering and surveying worklife, the work environment, health, and safety. The information system is constant, well standardized, well organized, and available for research. In spite of the high quality and reasonable coverage of the data systems, the picture still remains somewhat fragmentary. A well-structured Swedish worklife profile presented in a user-friendly format is suggested.

The total amount of funding for work environment research is substantial and was 275 million Swedish crowns in 2005. However, the structure for funding work environment research has become decentralized. Previously, most of the investigator-initiated funding available for application in work environment research had been organized within the Worklife Research Council (RALF). The funding available for open competition through the Council (100 million Swedish crowns in 1996 and 68 million Swedish crowns in 2000) was reallocated to the Swedish Council for Working Life and Social Research and the Swedish Government Agency for Innovation Systems (VINNOVA) in 2001.

Moreover, there has been a substantial reduction in funding from the two latter-mentioned organizations in comparison with the funding available from the Worklife Research Council before the split. Currently only 32 million Swedish crowns is available for open competition. In the case of the Swedish Government Agency for Innovation Systems, it seems to be a conscious decision not to make this kind of research a priority and, for the Swedish Council for Working Life and Social Research, the number of applications has decreased proportionally to the awarded funding. The "success rate" for applications seems to be around 15% of all applications, and several of the interviewed researchers indicated that they found it easier to get funding from other sources (eg, insurance companies).

Work environment research is conducted in a variety of large and small units. Some of these units are integrated parts of normal university structures, while some are private organizations, and some are part of the regional structure of the National Institute for Working Life, and the remainder are outsourced from this institute with uncertainty about long-term circumstances. This structure is not optimal and could probably be better coordinated to identify areas in work environment research of the highest concern and emerging issues. The absence of a coordinated structure may reflect the lack of transparent priorities of stakeholder needs for work environment research.

The funding support for these units is also complex. A mix of support from core university funds, earmarked university funds, the National Institute for Working Life, competitive research funding, and, increasingly, contracts with the labor market insurance company (Afa) and private industry make for a diffuse and unclear system. There is little evidence of priority-driven research funding, some of which would be desirable.

The following provides the body of the evaluation report by the International Evaluation Group organized into three major sections—evaluation of scientific production, quality, and relevance. At the end of the evaluation is the Group's response to the five posed questions and, finally, a list of recommendations.

Scientific production in work environment research

A bibliometric analysis was undertaken to evaluate two core aspects of the scientific production in Swedish work environment research, the quantitative contribution of Swedish research to the international literature, and the relative impact of Swedish articles in the international literature.

This analysis was carried out using two databases, an inventory of publications as reported to the National Institute for Working Life in Stockholm by research groups and the Web of Science database on publications in selected journals included in the Science Citation Index. The first database was used to describe the overall productivity of Swedish research in different fields, as well as the contribution to top journals in medical research. The second database was used to evaluate the quantity and quality of Swedish research relative to those of other countries.

Publications from Swedish research groups

The database from the National Institute for Working Life contains 1166 publications by Swedish groups in work environment research during the period 2001–2005. It should be noted that this database relies on self-reports by the research groups and thus may not represent the complete scientific production. However, a cross-evaluation with the database PubMed showed a strong correlation for scientific articles published in the international literature.

In the 5-year period 2001–2005, primarily journal articles (71%) and reports (16%) were reported, but also 39 doctoral dissertations and 12 licentiate theses. About 78% (N=647) of all of the articles were published in English language scientific journals. The analysis of the most frequently used key words and major fields shows that, with respect to the total scientific output,

the areas of "chemical and biological health risks" and "ergonomics" were far more productive than the area of "physical health risks". Important subfields in the area of "chemical and biological health risks" were cancer, exposure assessment (including biological monitoring), respiratory disorders, and toxicologic studies. Important fields in the area of "ergonomics" were musculoskeletal disorders, psychosocial risk factors, physical load, and occupational physiology.

These 647 English publications were published in 215 different scientific journals, of which 10 journals in occupational health and ergonomics captured 36% of all the publications (table 6). These 10 journals were the ones thought best able to capture the most representative reports related to work environment research. It is worth noting that the researchers included in this evaluation also published in other well-known journals such as *The Lancet*, the *BMJ*, *Epidemiology*, *Spine*, the *American Journal of Epidemiology*, *Environmental Health Perspectives*, the *International Journal of Cancer*, *Allergy*, *Pain*, and the *Journal of the National Cancer Institute*.

Table 6. Journals selected for the bibliometric analysis (2005).

Journal	Impact factor	Rank
Subject category "public, environmental and occupational health"		
Occupational and Environmental Medicine	1.93	34 [a]
Journal of Occupational and Environmental Medicine	1.89	38 [a]
Scandinavian Journal of Work, Environment & Health	1.82	40 [a]
International Archives of Occupational and Environmental Health	1.48	52 [a]
American Journal of Industrial Medicine	1.31	57 [a]
Annals of Occupational Hygiene	1.14	61 [a]
American Industrial Hygiene Association Journal	0.83	79 [a]
Subject category "industrial engineering"		
Ergonomics	0.93	5 [b]
Applied Ergonomics	0.73	12 [b]
International Journal of Industrial Ergonomics	0.53	16 [b]

[a] Of 99.
[b] Of 33

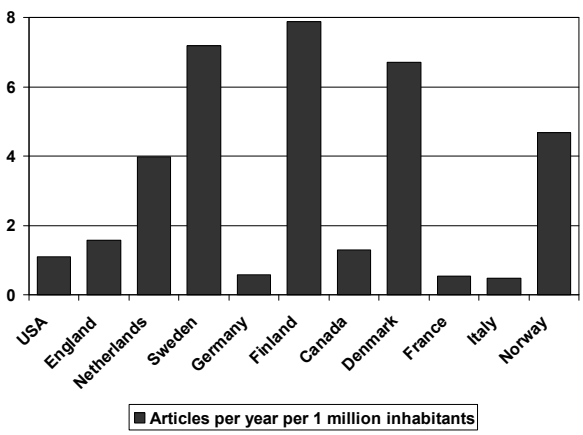

Figure 6. Productivity in occupational health journals by country in 2002–2005.

International comparison of the quantity of Swedish research

The Web of Science database on publications in the Science Citation Index was used to evaluate the relative contribution of Swedish authors to scientific articles published in peer-reviewed journals. According to the database from the National Institute for Working Life, 36% of all publications appear in seven occupational health journals with the highest impact factor in the subject category "public, environmental and occupational health" and three ergonomics journals with the highest impact factor in the subject category "industrial engineering" from the *Journal of Citation Reports*. It has to be kept in mind that these 10 journals do not reflect the position of Swedish research in some specialized fields, such as noise, indoor climate, cold environments, ionizing radiation, cancer, and respiratory disorders, since key publications in these fields often appear in specialist journals, where work-related issues compromise a small minority of the total publications.

This bibliometric analysis does not permit a structured evaluation according to the three areas distinguished in this evaluation (chemical and biological risks, ergonomics and musculoskeletal disorders, and physical factors). Physical factors will certainly be underrepresented in the selected 10 journals.

The impact factor and associated rank in the subject category illustrates that occupational health journals have a rather modest position relative to journals on epidemiology, environmental health, or public health (table 6). Within the subject category "industrial engineering", ergonomics journals have a much better rank although a lower impact factor. The impact factor is a strongly criticized measure of the overall quality of a journal, but it is used by many researchers to select journals for the submission of their scientific work. Hence the bibliometric analysis in the 10 journals does not capture any shift among research groups to publish in high-quality journals outside the domain of occupational health or ergonomics.

Articles with at least one Swedish author contributed about 8% to the world production in occupational health and in ergonomics. Figures 6 (occupational health) and 7 (ergonomics) show the relative contribution of articles with a Swedish author, expressed by the average number of articles per year per 1 million inhabitants) in the period 2002–2005. In occupational health, Sweden ranks number 2 in the world, and in ergonomics Sweden ranks number 1 in the world.

A trend analysis was performed on publications of Swedish research in occupational health and ergonomics.

Table 7 shows that, in the past 20 years, the market share of Sweden in the total scientific output has remained remarkably stable.

One metric for measuring the overall quality of scientific publications is their citation rate (the number of citations per article per year). Although this metric has attracted severe criticism, it is one of the few available metrics that allows a cross-country comparison. The comparison in this evaluation report is again based on the articles published in the selected journals as described earlier, but citations may be from other journals as well.

In the past 5 years, Swedish articles were cited an average of 3.5 times, which ranks Sweden among the top five countries (table 8). Thus Swedish articles attract an above-average number of citations, suggesting that the quality of Swedish research is above the world average.

The collaboration index shows that, on the average, 28% of the authors of Swedish articles are from another country. An additional analysis showed that 38% of all publications with at least one Swedish author have at least one author from another country, most often the United States (24%), Denmark (21%), Finland (21%), Germany (18%), France (16%), Norway (14%), or the Netherlands (13%). This is a clear illustration of the international collaboration of research in Sweden.

Conclusions

Swedish researchers contribute about 8% to the world production of scientific articles in occupational health and ergonomics. Adjusted for country population, Sweden ranks number 1 in the world in this area. In the past 20 years, the market share of Sweden in the total scientific output has remained stable, around 8%. As measured by citations, the quality of Swedish research is above the world average. There is considerable international collaboration in research, mostly focused on the Nordic countries.

Quality of Swedish work environment research

The International Evaluation Group (comprised of the authors of this section) was asked to review research contributions in a select subset of the work environment (chemical or biological factors, ergonomics and musculoskeletal disorders, and physical factors). These areas are, of course, not uniquely distinct from other workplace risks, but they are reasonably coherent and have a long history of attention in Sweden. The assessment was focused on a relatively limited time period (5 years), which, by necessity, was constrained by the fact

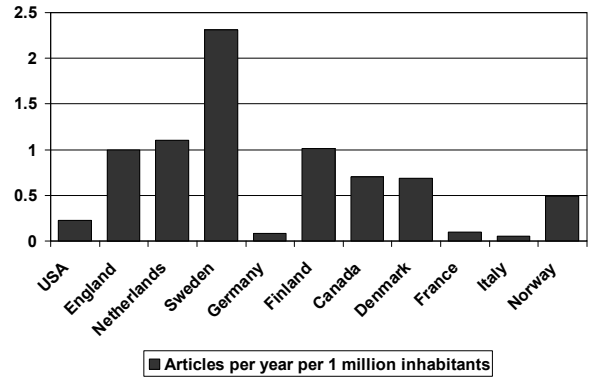

Figure 7. Productivity in ergonomics journals by country in 2002–2005.

Table 7. Proportion of Swedish and other countries represented in research published in the 10 selected occupational health and ergonomics journals over time (percentage of all papers in which a given country occurs).

Country	1986–1990 (%)	1991–1995 (%)	1996–2000 (%)	2001–2005 (%)
United States	38.5	38.4	37.8	35.7
England	10.8	9.7	10.7	12.3
Sweden	8.5	8.0	8.2	8.3
Canada	6.4	6.4	6.3	6.1
Netherlands	3.3	3.9	4.7	7.6
Finland	3.7	4.3	4.4	4.3
Japan	2.8	4.1	3.5	2.8
Germany	0.5	2.5	4.8	5.1
France	1.9	2.9	3.6	3.8
Italy	2.6	2.9	3.7	2.9
Denmark	2.2	2.2	2.8	3.6
Australia	1.5	2.0	2.2	3.3
Norway	1.1	1.8	2.1	2.3

Table 8. International collaboration and citation rate (impact) of publications in occupational health and ergonomics journals by country (2001–2005). (Note: citations to internationally co-authored papers have been fractionalized)

Country or territory	Collaboration index	Mean number of citations per article
United States	1.13	3.6
England	1.14	2.9
Sweden	1.28	3.5
Canada	1.24	2.8
Netherlands	1.27	3.8
Finland	1.30	3.1
Japan	1.19	3.3
Germany	1.34	3.1
France	1.29	2.4
Italy	1.24	2.5
Denmark	1.33	3.7
Australia	1.23	2.1
Norway	1.30	3.1

that many studies in process had not yet been published and that the published literature represents work undertaken over a rather broad time interval.

Most of the groups active in work environment research were asked to submit examples of their best research publications for direct inspection by the Evaluation Group. In response, the researchers submitted 2–10 research publications. The total number of submissions was 244, 103 of which addressed chemical or biological subjects, 91 concerned ergonomics and musculoskeletal disorders, and 50 dealt with physical factors. The evaluation was organized so that each paper was read by two members of the review team and assessed with respect to (i) the overall contribution and the degree to which the work filled critical gaps or were pioneering efforts, (ii) the contribution to methodology or the use of existing data or unique Swedish population resources, and (iii) attention to exposure assessment and applications (or potential) for intervention. Consideration was given to the standing of journals in which the research was published, as well as to publications that contributed through organized review or assessments of the published literature for an expanded understanding of the selected focus areas.

Chemical and biological risks

Description of the research area. Swedish work environment scientists continue to pay substantial attention to the study of chemical and biological risks. Advances in exposure assessment are considered important, and recent publications report on new metrics and approaches to exposure assessment for application in epidemiologic studies. In addition, notable are studies directed towards developing biomonitoring methods relevant to the guidance and evaluation of control efforts with special attention given to exposures related to dermatitis and dermal uptake. Attention is also focused on developing biomarkers for the noninvasive detection of outcomes, some of which could be useful in population studies. Population studies remain a strength, with studies presented that examine important work risks, particularly work-related respiratory conditions, cancer, and dermatitis. These efforts are enhanced by efforts to better characterize the background population incidence and prevalence of respiratory and skin conditions. Finally, there is evidence of attention to the study of the effectiveness of efforts to control work risks. These efforts have primarily been observation studies designed to assess the impacts of changes in work exposures systematically in a given industry, commonly examining change in exposure to carcinogens.

Members of the research community who responded to the survey of the National Institute for Working Life on Swedish worklife research (2005–2006) provided their vision of important future research areas. Highlighted were research on skin exposure (methods and knowledge), user-friendly methods for exposure control and assessment, biomarkers, nanotechnology, and cross-scientific research, particularly the combination of epidemiology with molecular biology and occupational hygiene.

Evaluation of the contributions. Among the scientific publications reviewed, the International Evaluation Group found particular importance in the developments concerning biomonitoring, dermal exposure to specific chemical substances, and attention to improvements in retrospective exposure assessment in epidemiologic studies. Important advances have been made in the understanding of exposures related to conditions important to the Swedish workforce, including attention to agricultural workers and those in the service industries. These efforts include investigations to identify biological risk factor(s) that cause farmer's lung, as well as to determine the agents that are most worrisome regarding dermatitis among hairdressers and dental technicians. The application of retrospective exposure assessment methodologies is state-of-the-art in studies of cancer and respiratory disease. Biomarker exploration was appreciated in several studies, and attention to the understanding of the mechanisms of airway disease in association with exposure to organic acid anhydrides is promising.

An epidemiologic examination of large Swedish cohorts was included in several submissions demonstrating high-quality work in general. These efforts ranged from primarily descriptive cross-sectional assessments to an extended follow-up of a unique Swedish cohort. A descriptive study of the relationship between type of disability and type of occupation contributes to a better understanding of disability and potentially of disability trends. The follow-up of the important cohort of persons exposed to organic solvents provides greater appreciation of the long-term neurocognitive effects of these historical exposures. In addition, the application of biomarkers in population studies begins to reveal a deeper understanding of risks for cancer and asthma.

Although no formal experimental studies of intervention were presented, there were valuable systematic examinations of settings in which exposure has been reduced, for example, asbestos and organic solvents. Technology has also been designed for innovative application in promoting intervention on a task-specific basis by using video exposure monitoring to reveal exposure sources and the impact of improved controls.

In addition to formal scientific investigations, there were valuable contributions of a different sort. For example, Swedish researchers have played an important role in developing an internationally relevant statement on the occupational burden of respiratory disease

(statement of the American Thoracic Society). On a different scale, Swedish investigators have shown innovation in working with investigators in developing countries to adapt advanced exposure assessment technology for use in local circumstances. Examples include the application of video exposure monitoring and an assessment of dermal exposure to pesticides.

International impact and collaboration. Swedish research on cancer risks has a high standing internationally, especially through the approach to exposure assessment in risk studies. In addition, the investigations on dermal exposure assessment methods and the study of the relationship of exposures to dermatitis are notable. The long-standing work on occupational asthma has been important, and the international collaboration in this area is well recognized. Continued attention to the impact of organic solvent exposure on neurological function not only demonstrates the specific value of this research beyond Sweden's borders, but also provides a model for the type of longitudinal cohort investigations for which Sweden is appropriately recognized as an international leader.

Summary assessment. The epidemiologic studies in this area have utilized exposure assessment effectively in a range of studies on chemical and biological exposures. Studies of cancer and asthma risks remain a successful area of attention and positive contribution. Experience in these epidemiologic investigations and related exposure assessment expertise has been less focused on the development of exposure modeling than on the application of existing models to epidemiologic research.

Ergonomics and musculoskeletal disorders

Description of the research area. The approaches to exposure characterization include the development of strategy and measurement techniques for the assessment of physical exposures, using instruments ranging from questionnaires to video recordings, specific posture measurement devices, and electromyography. Analyses have been carried out to describe the physical and psychosocial factors in traditional and modern occupations and by gender. Lately, a system approach has been applied to assess the exposure determinants to model the exposure. Traditional and new production systems have been evaluated with this approach.

The prevalence and incidence of local musculoskeletal pain were the most commonly used outcomes in epidemiologic studies in this area. A community-based sample was used to assess physical and psychosocial risk factors for neck and shoulder disorders. Other studies assessed individual and work-related factors associated with seeking medical advice due to low-back and neck disorders and factors affecting the course of symptoms and disability after a pain episode. A prospective study looked at risk factors for musculoskeletal pain among computer users.

Some groups explored the mechanisms of muscle pain by looking at inflammatory factors in work-related myalgia or the increase in such factors after various types of physical exercise in people with diagnosed work-related myalgia. Several research groups used electromyography to look at patterns of the recruitment of muscle fibers.

Rather few studies addressed sick leave and disability due to musculoskeletal disorders. They included a qualitative approach to factors that induce people to go on sick leave and, in turn, aid them to return to work. Other studies looked at the effects of musculoskeletal disorders on productivity and direct costs related to musculoskeletal disorders.

Among the few workplace intervention studies, a randomized study looked at the effects of giving feedback on workplace ergonomics and psychosocial data to workers and supervisors. Other trials assessed the effects of different types of exercises combined with cognitive approaches to neck and back disorders. Some studies compared worktasks and workload factors as a consequence of technical development and could be considered a description of the effects of a natural intervention.

In the survey conducted by the National Institute for Working Life, new areas that were emphasized included methods to be used in the assessment of the outcome of interventions, the development of tools to design better production systems, and the need for randomized controlled trials in workplace settings. A better understanding of pathophysiology in the development of disorders and better diagnostic tools were called for. A stronger connection between research in ergonomics and industry was considered beneficial.

Evaluation of the contributions. The measurement techniques developed for exposure are, in general, of high international quality. Research into the design of measurement strategies for postural load is of high international quality, and it utilizes a large international network. A promising area is production ergonomics, in which a production system is linked to the physical exposures of individual workers.

Although most cross-sectional studies on the determinants of musculoskeletal disorders among working populations had good quality, only a few prospective studies have been conducted that give new insight into the effects of physical and psychosocial risk factors and their combinations.

In research into the pathomechanisms of musculoskeletal disorders, research areas of high relevance for

occupational health included the effect of physical and psychosocial exposures and work patterns on motor recruitment. Methods for analyzing electromyographic signals have been developed to a high level. The role of inflammatory factors in muscle myalgia is a new area of research that has the potential to increase our understanding of the development of the disorders and provide insight for prevention. It also has the potential of providing methods for the early identification of musculoskeletal disorders. It is recognized that Sweden is one of the few countries in the world conducting research in this area.

The qualitative approach using the illness flexibility model to look at factors driving those with spinal pain to sick leave and back to work was assessed as highly innovative and methodologically qualified. An emerging research area was identified, namely, assessing direct and indirect costs of musculoskeletal disorders; this work is important with respect to evaluating the cost-effectiveness of interventions.

The few intervention studies that used a randomized design were, in general, of high quality. Most of them looked at the effects of various types of physical exercise and cognitive techniques on neck and low-back disorders. Among the few studies in workplace settings was a cluster-randomized trial that addressed the effects of a short feedback discussion of ergonomics and psychosocial work environment data to individual workers, supervisors, or the work group as a whole.

Interviews among the researchers in this area provided evidence of a lively debate concerning differing concepts of the proper design and nature of intervention studies. They ranged from the view that such studies should only be accepted if they were randomized controlled trials applying interventions decided in advance at one extreme to following and documenting a naturally occurring development in industry at the other extreme. The broad spectrum of methodologies appropriate to the range of study types seems to be well represented in the Swedish research community in this area.

International impact and collaboration. Research in the measurement and evaluation of physical loads is of high international quality, and an extensive international collaborating network has been established. Sweden has a strong tradition in research into the pathophysiology of musculoskeletal disorders and continues to produce research of internationally high quality.

Summary assessment. Strong areas of research include the measurement and evaluation of physical loads at the workplace and the application of this knowledge in the design of new workplaces. This research area is of great international importance and contributes to filling a gap in knowledge. The use of this knowledge has, however, been limited in observational epidemiologic and intervention studies. Sweden is internationally one of the few actors in research into the pathophysiology of musculoskeletal disorders. This area was assessed to have continuing high productivity and is extending to new approaches. The application of this knowledge into the prevention of work-related musculoskeletal disorders was, however, limited to relatively few areas.

Physical factors

Description of the research areas. In the area of physical risks, the papers broadly covered the key areas of temperature extremes, fatigue, sleeplessness and temperature, electromagnetic radiation (including potential health risks of mobile telephones as a major issue and of public concern), noise effects (ranging from physical health risk to annoyance, speech and noise), noise and performance, classroom acoustics, and low-frequency noise. Several papers addressed the health risks of vibration. There were also examples of scientific work being converted into guidance and other interventions, particularly in the area of electromagnetic radiation as a matter of public briefing.

In the survey of Swedish research on worklife conducted by the National Institute for Working Life in 2005–2006, noise was the most frequently mentioned area for future research with respect to physical factors. There was interest expressed in electromagnetic fields and the health effects of new technology. Several groups mentioned the problem of research on combined exposures, which requires cross-discipline cooperation. Among the cited examples were stress and physical exposures, stress injuries and heart disease, noise and vibration, and ultraviolet radiation and chemical exposures. Another area of importance is climate and vision.

Evaluation of the contributions. The overall quality of this work is of good standard, addressing continually important concerns and representing high scientific challenge. The studies use standard methodologies adapted to particular circumstances and related to current problems in modern societies. We did not note any innovative approaches, but established procedures were applied well.

Swedish expertise in the thermal environment has been developed over several years and was represented by several high-quality papers related to standards and worker protection. The assessment of possible cancer risks from the use of mobile telephones, a major health concern, has been a well-researched target in Sweden, as represented in the research reviewed by the International Evaluation Group. Research on the effects of low-frequency noise on the performance of sensitive persons

builds competently upon the strength of this Swedish work over several years.

The research on the health risks of cold environments and on the health risks of mobile telephones are clearly of high importance in Sweden, and the research is also well targeted towards international concerns about both. Many aspects of noise and its effects are being researched in Sweden, and they particularly address health risks and life quality. Classroom acoustics, a major international issue, is being well investigated. Work on understanding the effects of low-frequency noise fills important gaps in national and international knowledge. There was an effort to understand and control the risks in nontraditional workplaces, particularly in teaching and in call centers.

Health effects due to thermal environments, noise and vibration, and low-frequency noise are clearly important and were well investigated. Aspects on measurement strategies, whole-body and hand–arm vibration syndromes, including neurological effects, were well performed.

International impact and collaboration. An excellent example of international collaboration was observed between leading researchers from five countries (Sweden, the United Kingdom, the Netherlands, Belgium, and Finland) in developing temperature limit values for cold touchable surfaces. This contribution to international standard setting has had a high impact. Collaborations were noted between several research groups in exploring the hypothesis that there are patients with perceived electrical hypersensitivity. This joint work permitted the use of a range of investigative techniques.

In the interviews with work environment researchers, the International Evaluation Group was informed that the successful experiences of some researchers in obtaining EU funding was proving to be important with respect to the sustainability of the research. In one instance, this effort had been proceeding well for 10 years.

Summary assessment. There is a diversity of research in the field concerning physical factors, some of which was quite impressive. However, the research reviewed covered a wide range of topics, and it is difficult to determine how well aspects of the most relevant factors are being addressed as a whole. Much of the work had direct practical relevance. There was an appreciation of the need for effective knowledge transfer.

Relevance of the research on the Swedish work environment

Stakeholders

The evaluation of relevance is discussed from the point of view of funding and enforcement, ministries, trade unions, and employers, and it is based on data from and interviews with the stakeholders.

The Swedish Work Environment Authority (SWEA) continues to benefit from criteria documents that incorporate literature reviews and assessments of exposure–response for guidance in controlling work exposures. The Authority has identified, however, a need for more research in order to become more proactive (eg, epidemiologic studies on the effects of some common chemicals and, especially, mixed exposures). In addition, human factors and work organization were recognized as areas needing more research. The Authority has no official forum for the continued discussion of research priorities.

Both the trade unions' and employers' representatives clearly expressed the message that they are not well informed about on-going research projects. There is information in publications, brochures, and websites, but the social partners have difficulties in finding the essentials and how to use them in practice. They expressed a multitude of research needs, including the functioning of respiratory protective equipment in real work situations, how to deal with electrical sensitivity, how to handle the directive on electromagnetic fields, and the like. Practically oriented interactive workshops between researchers and workers to communicate research results were commended.

The assessment of relevance is affected by the notion that the different stakeholders use partly different sources of data to identify problems and follow trends in the work environment and health. There is no established mechanism through which stakeholders can organize and communicate with research scientists about what the needs for knowledge transfer are.

The unavailability of representatives from the government and the occupational health services prevented the assessment of the roles of these stakeholders in the setting of priorities.

Knowledge transfer

Work environment research addresses existing and potential future risks to the workforce in the rapidly changing world of work. It often provides knowledge that can be effectively extrapolated to be informative about the risks to the general population. It can have great relevance to human health and well-being and also to industrial development and economic growth. The wide "stakeholder" group needs to be considered in the prioritization and definition of research and in attempts to gain the greatest value from the activity. The International Evaluation Group sought examples from the research community on how these issues were being addressed. Effective means of ensuring that research activity led to practical outcomes was especially

searched for. It should be clearly pointed out that the Group could not refer to any evaluation of implementation or any end user's ranking. No such evaluations or rankings were received.

Research groups were asked to submit a maximum of three examples of the application or communication of knowledge. In the areas of ergonomics and musculoskeletal disorders, chemical and biological risks, and physical factors, several contributions were identified, for example, articles in vocational journals, brochures, leaflets, websites, conferences and workshops, education and training, standards, and guidelines.

Several products in the area of chemical and biological risks were brought to the Group's attention. Most of the products were designed for direct users (eg, risk assessment for hairdressers in magazines and as training tools for apprentices). Concerned with exposure assessment, some groups provided information through workshops addressing the indirect user (eg, companies and manufacturers). A statement of the American Thoracic Society on the burden of occupational factors was directed at professionals. A notable example of a high-impact product was the use of visualization techniques, in which measured exposure levels were superimposed on a video of work activity. Application of these techniques in work settings indicated effective communication to managers and workers concerning the source of risks, as well as the impact of controls.

In the area of ergonomics and musculoskeletal disorders, several useful products were submitted to illustrate the transfer of knowledge into practice. Most of the products were aimed at direct users and some at the general public. A website containing information on various areas in agriculture was considered to be well structured and to contain in-depth information on important technical, ergonomic, and environmental protection aspects. In collaboration with two research groups in production ergonomics, a tool was developed for designers that encompassed aspects of production and material flow together with physical risk factors for the worker. The development of a patented welding visor is an example of a product with producer(s) and end-users as target groups.

In the physical factors area, products were submitted with respect to direct and indirect users. The provided examples included international standards addressing the public input to the setting of regulations, electronic information about cold touchable surfaces, direct practical advice for the reduction of risks such as radiofrequency exposure, and brochures in voice training for teachers with respect to gender differences. The complex issue of health risks related to mobile phone use was helpfully described in a leaflet for a wider public audience.

The Evaluation Group recognized the many different approaches by the research community in disseminating the results of its work, but noted that clear performance indicators for societal impact were generally lacking.

Summary evaluation and recommendations

The evaluation of research on the work environment was focused on determining whether Swedish work environment research is of international standard in quantity and quality and of relevance for society. In undertaking this task the International Evaluation Group formulated several fundamental questions identified at the beginning of this chapter. Here these questions are answered.

Does work environment research address gaps in the international research, significantly enhance the knowledge base, or mainly repeat research carried out elsewhere?

Sweden plays a significant role in enhancing the international knowledge base for work environment research. The bibliometric analysis provided direct evidence of the high standing of research when compared with that of other leading nations in the major work environment journals. In the judgment of the Evaluation Group, Swedish work environment research is located among the top three in the world. In several areas, outstanding contributions were identified. Research in all three of the examined areas of work environment research was found to have good quality, relevance, and a sufficient balance between new areas and developments in existing areas of study.

Changes in the funding of work environment research and the structures of the research organizations may place this standing at some risk. The Evaluation Group has some concern that the current high level in the quantity and quality of work environment research cannot be maintained without recognition of its importance and continuing support. To guarantee the sustainability of the research community, it is of crucial importance to support the recruitment of young researchers and provide opportunities for career development.

Does work environment research pay adequate attention to engagement with the international research community?

The Swedish work environment research community has, for some time, been collaborating with international partners. This engagement is consistent with that of the other major contributors to work environment research in western Europe and North America. More international collaboration in some areas of work environment research would benefit the international community, as well as the Swedish work environment research community.

Do the efforts of work environment research include knowledge distribution and knowledge implementation in addition to knowledge development?

The evidence of knowledge transfer is uneven, both in terms of the translation of scientific research into information widely available to the public and other stakeholders and in terms of transferring the research findings into practice. Some researchers have made great efforts to engage in knowledge transfer, but the social partners expressed a greater need for such a transfer. There appears to be a gap between research and practice that needs further attention in Sweden.

Do work environment research and its transfer provide a good basis for policy decisions, strategies, and activities to promote a good work environment?

Work environment research is largely relevant to policy considerations but could be supplemented by more attention to research related to the surveillance of current work conditions in Sweden and to the identification of emerging risks. The communication of the research findings in a form useful with respect to the needs and actions of work environment policy could be improved.

Does the structure in support of work environment research appear appropriate and optimal?

The structure for work environment research has, in recent years, become decentralized. Now, work environment research is conducted in a variety of large and small units. Some of these units are integrated parts of the normal university structures, some are part of the regional structure of the National Institute for Working Life, and the remainder are outsourced from the National Institute for Working Life with uncertainty about long-term circumstances. This structure is not optimal and needs to be better coordinated. The absence of a coordinated structure suggests inadequate prioritization of research needs.

The funding support for these units is also complex. A mix of support from core university funds, earmarked university funds, the National Institute for Working Life, competitive research funding, and, increasingly, contracts with labor market partners (Afa), and private industry makes for a diffuse and unclear system. There is little evidence of priority-driven research funding, some of which would be desirable.

Summary assessment of strengths and weaknesses

The International Evaluation Group has evaluated the strengths and weaknesses of Swedish work environment research, and a summary follows, representing key issues identified and discussed during the evaluation.

Strengths

- Extensive well-kept registers and survey systems that provide data on trends in health outcomes for priority setting and a well-organized basis for epidemiologic studies
- Well-functioning networks between researchers, social partners, and authorities providing the opportunity for good access to workplaces and information on current and emerging problems
- Existence of funding organizations that clearly identify work environment research in their objectives
- Research covering a wide range of important work environment issues and providing depth in knowledge that appears relevant to the Swedish work environment
- A large contribution on the part of Sweden to the global knowledge base in work environment research, as demonstrated in the bibliometric analysis
- Excellent expertise with respect to respiratory disorders, cancer epidemiology ergonomics, climate, and electromagnetic field research providing international leadership in these areas
- Close collaboration between university departments and occupational medicine clinics presenting unique opportunities for relevant research
- Good opportunities for doctoral education with a constant high production of doctorates in work environment research
- Good access to an open research structure
- Strong competence in measuring exposures in all of the studied areas of work environment risks.

Weaknesses

- Clear priorities for work environment research not evident and effective priority setting not apparently in place
- Existing survey data on work environment issues not well utilized to drive priorities in funding work environment research
- Inadequately developed hazard surveillance systems and systematic horizon-scanning for emerging work environment risks of concern
- Insufficient multidisciplinary research and the need to better develop networks among and across work environment research disciplines, along with other disciplines of worklife

- Project funding covering 3 years or less limiting effective studies in some highly required areas, such as longitudinal epidemiologic and intervention studies
- Insufficient research funding mechanisms organized specifically to promote the development of the work of young scientists undertaking their own research
- Decreasing funds for open-call researcher-initiated projects that might threaten both innovation and the sustainability of research in this area
- Long evaluation processes of research applications inhibiting rapid response to emerging problems in work environment research
- Age structure of research leadership a threat to the sustainability of work environment research
- Insufficient attention to the study of intervention effectiveness
- Insufficient research directed towards exposure modeling and its role in understanding exposure–risk relationships
- Knowledge interchange between stakeholders and researchers needing strengthening

Recommendations

Funding

1. In order to maintain the current high quantity and quality of work environment research, it is essential to maintain funds specifically dedicated to this research area and open for applications to include both personnel and equipment. The amount of funds available through the Swedish Council for Work Environment Research (RALF), 6 years ago, should at least be re-established

The bibliometric analysis of Swedish work environment research demonstrated a high production of good quality. The evaluation of the quality of submitted research contributions by the International Evaluation Group confirmed the good quality of research in both established and new areas. This high profile of work environment research in Sweden can only be maintained with due recognition and visibility in the allocation of resources within research organizations.

There are several uncertainties about the future of funding for work environment research. The most important of these are the reduction in support of the National Institute for Working Life, as well as the stability of research funds that have been reallocated from this institute to the universities. The International Evaluation Group raises concern as to the absorption of support for work environment research into larger research structures [for example, The Swedish Governmental Agency for Innovation Systems (VINNOVA)] addressing all aspects of worklife or adjacent domains. The International Evaluation Group strongly recommends that the Swedish Council for Working Life and Social Research (FAS) continue and expand its program in work environment research.

The overview of the finances for work environment research shows that public funding through open calls by the Swedish Council for Working Life and Social Research accounts for only approximately 10% of the total budget available for work environment research. The International Evaluation Group is of the opinion that this small proportion of "free money" hampers the development of innovative, new research. Hence the Group strongly recommends a more appropriate level of funding be established through open calls with at least the amount of funds available through the Swedish Council for Work Environment Research, 6 years ago.

2. The duration of projects to be funded in open calls should provide options for funding up to 5 years. This change would greatly enhance the possibility to conduct longitudinal epidemiologic and intervention studies for which there is a high priority.

The current structure of funding has a large impact on the design and content of research projects. In some areas, projects cannot be carried out successfully within a time frame of 3 years. Epidemiologic studies to characterize exposure–response relationships generally require a longitudinal design, and the latency period between first exposure and the incidence of disease may dictate follow-up periods that exceed 3 years. Furthermore, with a 3-year maximum grant duration, intervention studies can only be carried out for risk factors with short-term effects. The International Evaluation Group recommends that the Swedish Council for Working Life and Social Research (FAS) consider more flexibility in the acceptable duration of projects eligible for funding.

3. Rapid assessment processes should be established for smaller project plans to facilitate pilot studies with novel approaches and rapidly emerging issues.

The current structure of funding agencies relies strongly on well-established procedures for the submission and appraisal of applications through extensive peer-review processing and prioritizing. Given the standard time interval between application and the final decision, strong consideration should be given to establishing a fast track procedure for projects of short-term duration. The International Evaluation Group notes that sometimes rapidly emerging issues require a rapid response of researchers that is not possible in the regular funding process. This mechanism could also be considered for seed grants that allow researchers to investigate the potential use of novel approaches in larger,

well-designed studies for a limited period of time or to develop pilot data for the early and conceptual stages of projects that address new hypotheses.

4. There is a need for a better integration of different domains of knowledge in order to address multifactorial work-related health problems. Interdisciplinary research projects should be encouraged through funding strategies.

Work-related health problems are often multifactorial in nature and call for input in research projects from different disciplines. The International Evaluation Group has noted that Swedish work environment research has established national and international collaborative networks, but collaboration across different disciplines should be improved. Funding agencies should actively encourage applications on interdisciplinary research and establish mechanisms to fund these collaborative proposals from different programs.

Commission to examine the work environment research structure

The complex state of the research structure and financial support related to and coupled with the apparent lack of a systematic priority setting scheme for identifying the areas of work environment research of highest concern lead to the recommendation to establish a high-level commission. Such a commission should examine the organizational structure in support of work environment research and the setting of priorities and suggest the best funding options to deliver the most appropriate research.

The examination of the extensive materials submitted, accompanied by interviews with both researchers and other interested parties, revealed a very complex state of the research structure and financial support related to work environment research. This fact, coupled with the apparent lack of a systematic priority setting scheme for identifying the work environment research areas of highest concern, make it uncertain how or whether the current structure and funding of work environment research are organized in the best way to serve the needs of Swedish worklife. We suggest that a full understanding of the priorities and the level of resources (both personnel and financing) necessary to address these priorities is essential. To achieve this understanding, the most efficient and effective way would be to establish a high-level commission with representatives from the government, the social partners, funding agencies, and members of the research community.

Sustainable resources

Research institutions should actively pursue the career development of competent work environment researchers in order to guarantee sustainability. Such activities could include support to attract recent postdoctoral scientists early in their careers and means to stimulate mid-career researchers. Funding mechanisms in support of such activities should be encouraged.

The demographic development in many research groups showed that most research leaders are over 55 years of age and will retire within the next decade.

The lack of possibilities for career development will not only affect research capacity but also discourage excellent students from considering a career in work environment research. This situation raises serious concerns about the sustainability of work environment research. During the interviews with research leaders, this problem was singled out as one of the most urgent to be addressed. An active approach is required to identify and recruit future research leaders and to support and supervise their personal development towards a senior position with full responsibility for the acquisition, research, and management of a research group. Funding agencies should establish appropriate means to support active career development (eg, grants for sabbaticals and study trips).

Important research areas to be developed

1. Research on exposure assessment modeling and related risk modeling needs to be strengthened. This recommendation includes research on exposure variability, which factors determine exposure patterns, and how this knowledge is applied in the design, conduct, and interpretation of epidemiologic studies and workplace interventions.

In all three areas of work environment research, the techniques and methods for the measurement and evaluation of exposure are well developed. However, the International Evaluation Group observed that, in epidemiologic and intervention studies, the focus is on the application of existing exposure assessment methods and that there is less attention being paid to methodological development in exposure strategies and exposure modeling. In recent years, statistical techniques have become available that allow a simultaneous evaluation of the magnitude of variance components, as well as determinants of this variability. These techniques are powerful instruments in the design of measurement strategies in epidemiologic studies and in the implementation of control and prevention strategies to reduce hazardous exposure. The incorporation of advances in biomarker research will benefit this work as well. The International Evaluation Group recommends targeted research in this area to improve further the quality of epidemiologic and intervention studies.

2. More systematic intervention studies are needed. There is a major need for the development of scientific methods for determining the efficacy and effectiveness of interventions. It is also recommended that more attention be paid to the use of appropriate study designs and methods for exposure and outcome assessment in intervention studies, along with economic evaluation techniques. Interdisciplinarity is likely to be important in achieving this objective.

The International Evaluation Group observed that research is mainly focused on risk identification, the occurrence of health problems in different occupational groups and workplaces, and the characterization of exposure–response associations. Research into the effectiveness of interventions is less well developed. The Evaluation Group acknowledges that intervention studies are difficult to conduct, but, with the growing understanding of exposure–response associations, a shift is needed towards intervention research. Therefore, we recommend a substantial increase in resources being allocated to intervention studies. Insight is needed into the use of appropriate study designs, varying from natural experiments to quasi-experimental designs and randomized controlled trials. Development is required in strategies to better characterize exposure patterns and health outcomes in intervention studies and methods embedded in intervention studies to evaluate whether the underlying etiologic hypotheses of their association can be corroborated. A special area of attention is the economic evaluation of workplace interventions designed to reduce work environment risks. Available economic evaluation techniques and methods should be adapted specifically for use in work settings, and, where necessary, appropriate new methodologies should be developed.

3. Research is needed on methods and strategies for the implementation of new scientific knowledge.

In the evaluation of the relevance of work environment research with respect to Swedish work environment practice, several interesting examples of knowledge transfer were presented. During interviews with researchers and stakeholders, various barriers and problems with the implementation of effective interventions were mentioned that exemplify the gap between research and practice. There is a great need for the communication of research findings and access to these findings. However, even when companies and stakeholders are reasonably well informed of effective interventions, the actual application of scientific knowledge to improve work conditions is strongly influenced by behavioral, organizational, economic, and technical constraints. The International Evaluation Group recommends initiating and funding research projects that develop generalizable methods and strategies for facilitating the implementation of interventions that have been effective in reducing work-related risks.

Basis for priority setting

1. Research is needed to develop hazard surveillance systems that identify and monitor exposures at the workplace. They should consider, as well, the use of early indicators of risk, for example, noninvasive biological techniques and self-assessment appropriate to the modern structure of Swedish work.

Systematic ongoing hazard surveillance has not been present for Swedish work environments for some period. At the same time, there has been dramatic evolution in the worklife of Sweden, many classical industries having been replaced by work environments more oriented towards service functions, many of these reliant on modern information technology and systems. The limited data describing risks from physical, chemical, biological, or ergonomic hazards in the current mix of Swedish work environments makes it difficult to target appropriate research and intervention activity. There is a variety of noninvasive methods, recently developed, that have potential in the application in surveillance systems. Research is needed into the most appropriate and cost-efficient systems that are sufficiently representative to provide necessary guidance for policy makers and practitioners, along with research on the best indicators to be used in these systems.

2. Using modern sampling methods, government agencies need to take advantage of existing health data and hazard surveillance data and consider the structure of Swedish worklife to prioritize the need for work environment research. Information available internationally should be used to advantage. Research leaders should be engaged in this effort as well.

There are data available from the Work Environment Survey and from the Swedish Information System for Occupational Accidents and Work-Related Disorders (ISA) that has been insufficiently used and could be further developed for priority setting. There is, however, a lack of regularly collected exposure data to be used for surveillance. Existing data have some limitations, but a better and more-complete analysis of these data has the potential to provide a first-order understanding of the distribution of risk and adverse health outcomes on a regional and national level. In spite of the high quality and reasonable coverage of the data systems, the picture still remains somewhat fragmentary. A well-structured Swedish worklife profile presented in a user-friendly format is suggested. For example, registry data could be complemented and strengthened by the appropriate

use of modern sampling methods. Well-targeted national and other surveys can be utilized to monitor problems and assess gaps in registration systems. This possibility applies particularly to the severe underreporting of accidents and diseases.

These surveys could be used, along with data available from other nations with a similar mix of industry types or relevant exposures, to develop an initial set of priorities for research. Continuous improvement of the systems is encouraged in order that the priorities be evidence-based at the best possible level. Care needs to be taken that the evidence informs the priority-setting process but that sufficient flexibility in funding is maintained to allow for new areas of research in the fast-changing work environment to be addressed.

3. Work environment research groups throughout Sweden should be encouraged to interact to minimize overlap and maximize the use of available national research expertise.

There is a variety of research groups in each of the research areas evaluated. The groups vary in size and are spread rather widely throughout Sweden. This situation brings benefits to the different regions but also presents challenges with respect to efficient and effective cross-group collaboration and the appropriate allocation of resources. Some of these groups have found effective ways to interact to identify priority research needs, to orient the leadership of the identified research targets and to promote effective combinations of specialized expertise. Platforms for interactions and methods to support the development and continuation of research networks should be facilitated, where necessary, by some targeted funds.

Interchange of knowledge

1. The interchange of knowledge from stakeholders to researchers and the reverse should be improved. Means and methods should be developed for collaboration between the social partners, other user groups, and the research community to design effective information transfer. Efforts in knowledge transfer need to be systematically assessed.

Evidence suggests that stakeholders' needs are not effectively communicated to the research community. Knowledge transfer requires specific structures and contents of different forms of communication that should depend, only in part, on the scientist responsible for the research. As a rule, research scientists are highly skilled in developing new knowledge and publishing this knowledge in scientific literature. However, scientists are not specifically trained in determining stakeholder needs or in translating their knowledge into forms that are the most useful for the social partners or specific user groups. It is essential to develop a structure that enables those who are experts in knowledge management and transfer specific to each of the interested user groups and stakeholders to collaborate with research scientists in order to design effective information transfer.

Social responsibility

1. Continued support for the training and education of professionals in work environment research in developing countries is encouraged.

Sweden has an enviable record of engagement with developing nations in research and research training relevant to the needs of these nations. Representative of this work are the doctoral dissertations presented to Swedish research faculties by students from such nations. Given the leadership of Sweden in work environment research, there is a social responsibility to continue these efforts.

Addendum

During the final preparation of this report, the International Evaluation Group was informed that the national budget proposal from the new government presented on 16 October 2006 suggests complete closure of the National Institute for Working Life on 1 July 2007 and that preparations have already started for dismantling the Institute, without any compensatory mechanisms or transfer of ongoing research projects. Although it was not the task of the Evaluation Group to evaluate separate groups or institutions, the Group has noted that the National Institute for Working Life, with a quarter of the total estimated budget for work environment research, represents the largest of all research centers and that its research is of the same quality and relevance as the rest of the evaluated Swedish work environment research. It has noted that the broad, multidisciplinary composition of researchers within the Institute offers excellent conditions for the type of new research areas suggested.

It is obvious that a decision from Parliament in line with the proposal will drastically diminish the resources for work environment research in Sweden unless earmarked compensation is given to the universities or to funding agencies [eg, the Swedish Council for Working Life and Social Research (FAS)] in time for the Institute's researchers to apply for funding or new university positions.

Lessons from the evaluations of Swedish work environment and public health research

by Christer Hogstedt [1] & David H Wegman [2]

The purpose of this contribution is to summarize some experiences that may be of value for consideration by those who determine there is need for a national evaluation of a field of applied public health research. We believe that efforts to assess a "national" body of research in any field is uncommon but that such efforts could prove highly relevant to public policy debate with respect to the intent and the success of research sponsored by public funds to address the public's need for an evidence base for action. These lessons are intended for the consideration of those who agree to undertake such an evaluation, those who accept participation as evaluators, and those who are the subject of the evaluation.

Our experiences are based upon evaluations that have been completed for a national assessment of research in occupational health (1) and in public health (2) in Sweden. The two Swedish government efforts were in response to a charge to undertake retrospective evaluations of mainly applied research from many units with large research activities in many disciplines at different sites and in a comparative international perspective. Reviews of the described evaluations are not necessarily relevant for those more commonly considered for the evaluation of research proposals or the evaluation of specific research programs. Therefore, some comment is provided on how the described Swedish evaluations differ from an evaluation of an institute's research portfolio (ie, the current evaluation of the National Institute for Occupational Safety and Health in the United States).

We have organized our presentation around a series of questions that we believe need to be answered in the process of undertaking such an evaluation.

Objectives and logistics of the evaluation

An evaluation of research can serve several purposes, including the ranking of different institutions versus each other for the priority of funding, the identification of weaknesses in a national research agenda in order to address any gaps that are determined, the international comparison of research contributions in one or several areas, the overall assessment of scientific quality, and the examination of the relevance of research to needs of the "consumers". Within the overall context of the objective, the purposes can also be specific and limited, for example, evaluating the knowledge base and monitoring the intended results of research strategies, findings from the assessment of the demographic composition of researchers, the attractiveness of the field for young researchers, and the like.

It is, however, fundamental for the scope and direction of the evaluation that the purpose be clearly stated from the directing agency. This is not always the case, and therefore we recommend that the evaluation coordinator and the secretariat interpret the purpose in writing and present this interpretation for formal acceptance or modification by the responsible body.

1. What units are included, how should they be categorized, and what is the basis for comparison?

The Swedish efforts showed that it is not self-evident which base unit(s) should be included in the request to submit material for an evaluation and how they are going to be identified and treated. Approaches to the base units could include their citation identification through funding agencies, through university or institute administrations, or through professional organizations.

In the evaluations of Swedish work environment research, the assessment was explicitly restricted to evaluations of chemical, biological, physical, and ergonomic research. Psychosocial research and research on occupational health systems were specifically excluded. Although there were no such constraints placed on what to include within "public health research", this body of research was determined to be best considered by organizing the wide range of efforts into a few appropriate subheadings. They were research on health outcomes, research on social and behavioral determinants, research on descriptive, analytical or interventive studies, and research on health systems and public health economics.

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In addition to specifying the appropriate units, it is important to recognize that increasingly many researchers belong to more than one research group or have changed research groups during the period of concern for the review. Measures must be taken to manage overlaps and identify researchers or research groups who might otherwise be missed.

In public and occupational health, researchers often do only a part of their research in the specific field, especially if the work is not undertaken within a department or unit that is wholly concerned with the field of interest. A restriction could be made to those belonging to a designated department of the discipline or a criterion that the researchers should work at least 25% or 50% of their time in the field. While there may be concern that important aspects of the field will be lost to the review if it is restricted, it will be difficult to evaluate productivity unless there is clarity about the person time available for research in the unit. It is also advised to get figures on the time spent on research, teaching, and the communication of research results.

In occupational health research, the major units to be evaluated were easily identified, but the more peripheral and smaller groups were less clearly specified, and some of them were particularly multifocused so that the research time allocated to the relevant occupational health research needed to be determined by appropriate interaction with the units.

In the evaluation of national research, as well as that of large, multicenter institutes, comparisons with other countries and large institutes are natural, although usually hard to do quantitatively, except for the use of bibliometric measurements. The purpose of an international evaluation group with participants from several countries is, in our judgment, a desirable qualitative approach that appropriately facilitates these international comparisons.

The content and quality of the relevant research policies and strategies should be scrutinized, as well as the knowledge base for them, the incitements to track the implementation of relevant research findings, and the ways of monitoring the implementation of the overall research strategy.

2. What period of work should be reviewed for the evaluation?

Research, by its nature, is an ever-evolving endeavor. As a result, there is no clear beginning or end to research, particularly when it relates to applications to broad public agendas. Therefore, it is important to decide, in advance, the period of time that will be targeted for the review. It is recognized that many of the intermediate and end outcomes of the completed research are the consequence of research outputs accomplished earlier in time. Concluded research is, of course, the most interesting in terms of direct relevance to application; however, research currently underway or in the planning stages is critical to the future. Whether this research is well organized and directed towards the highest priority needs is also important to know.

3. What should be the composition of the evaluation team and how should it function?

Obviously the size of the evaluation team depends on balancing the effectiveness and efficiency of the team, and an adequate balance of differing perspectives, with the amount of research that will be evaluated, the depth of the evaluation, the number of disciplines necessary, and the budget set up for the enterprise. For a comprehensive evaluation of larger institutes with several annexes or a whole nation, a minimum of five evaluators with broad experience in evaluation, as well as appropriate representation of research directions, seems to be a minimum, and perhaps ten is a maximum. It may be preferable for each evaluator to have more time rather than using a larger number of evaluators with shorter time. The average time spent by an evaluator in our experience has been around one full-time month and 50% more for the coordinator.

Public and occupational health are very multidisciplinary research areas, and it would be infeasible to have evaluators from all of the participating disciplines. Therefore, senior researchers with different backgrounds, long experience, and usually a leading role with responsibility for multidisciplinary research should be looked for.

To be effective and accepted, it is very important that the evaluation group be respected for its knowledge, as well as its integrity, by the community that will be evaluated, as well as by the consumers of the research. Therefore, we determined that the evaluation team needs to be complemented by one or two reference groups with representation from the scientific community of concern as well as the "consumers" (eg, ministries, government agencies, labor market partners, health care providers, research councils).

Reference groups may serve in an ad hoc capacity, meeting only once, or might follow the process, give advice on suitable evaluators and the best measures for collecting relevant material, and propose organizations to be interviewed by the evaluation team to gain perspective on research relevance. Reference groups can also serve in a limited quality-control role by reviewing report drafts from the evaluators to correct mistakes, point out unclear formulations, or identify missing information. However, it is essential that the organizing agency decide which evaluators to invite to comprise the team and that the agency also agree that the evaluation

group has the sole responsibility for the final report and its recommendations.

We recommend at least two face-to-face meetings with an international group of evaluators. One at the beginning of the exercise to agree upon procedures, what material to request from the researchers, which groups to meet, the evaluation categories and the division of labor. This process could take 2–3 days. It is relatively easy to determine the types of published research findings to be collected for assessment by the evaluation group. Less evident is what informal information can be collected about research organizations, functions, interactions across organizations, policy drivers, hidden constraints or determinants, and the like. The first meeting allows the evaluation team to identify the key areas to be surveyed from representative members of the evaluated groups or the consumers of the research. Taking time to structure the survey questions before the first meeting closes allows these surveys to be completed in a timely fashion.

Another meeting at the end is essential to clarify questions that have arisen, discuss discrepancies in the evaluation (if the same material is evaluated by more than one evaluator), discuss and agree upon the different aspects of the evaluated material, and finalize the written report, including the executive summary. Such a meeting usually takes 5 full days.

A meeting in between (eg, with site visits and hearings) could be warranted, if the budget and time allow, and certainly it could enhance the effort by resolving problems that have been identified through direct conversation and engagement. Only those who agree to participate in all of the meetings should be the final members of the evaluating group, as the mutual discussions are important. In any event, there is usually substantial correspondence between the secretariat and the evaluators, as well as within the group, throughout the process.

4. How might the secretariat function to provide context, background, history, and practical support?

A comprehensive evaluation needs a qualified secretariat that spends 6–12 full-time person months on the task, from the beginning to the end. The secretariat may provide, translate, and summarize background material on policy and strategy documents from the government, agencies and research councils, map the funding possibilities and the size of awarded grants, distribute and collect questionnaires, and compile descriptive data on the number and characteristics of researchers. In addition, the secreteriat handles all other practicalities around meetings, hearings, and seminars.

In addition to the scientific material to be evaluated, there is also other information that can be of value that would place the presented research into perspective (eg, the history of the organization of the research efforts of concern to the national scientific agenda). While it is possible that this information can be organized effectively by the secretariat, it is likely, and possibly preferable, that this work be undertaken by well-informed consultants.

5. Are site visits or interviews with researchers and stakeholders required?

Two different modes for face-to-face meetings between the evaluators and the researchers were employed in the evaluation of occupational health research and public health research, hearings in front of the occupational health evaluation group and site visits by the public health evaluation group. Site visits can obviously give more information and a sense of the research environment, but they are practically impossible if 50–100 research groups or units around a country are to be evaluated. Choosing which sites to visit or which groups to invite for a hearing is a sensitive issue, and visiting a very active site can be even overly impressive and lead to an unbalanced assessment of its relative importance or success. In any event we suggest taking gender, geographic, and disciplinary distribution into account, as well as the size of the group. Before site visits or the meetings with representatives for some of the evaluated groups, their submitted material should have been studied and questions preferably distributed to them in advance.

It is equally important to have interviews or hearings with the practitioners, stakeholders, and "consumers" of the research if relevance is to be considered. Again the selection of participants and the effort to provide a properly balanced representation is likely to prove to be a sensitive matter and should be done in a well thought out and transparent manner. As for meetings with researchers, questions should be submitted in advance to the stakeholder groups. [See the examples in the appendix.]

In order to listen to as many as possible, we chose to split the evaluation group into subgroups that allowed a sufficient number of interviews with groups of no more than 6–8 researchers or stakeholders. We believe this procedure allowed ample time for input by all of the invited participants.

Evaluation components and methods

6. How might the evaluation of innovativeness, scientific quality, productivity, and relevance be organized?

There is recognized literature on how to evaluate the quality of scientific publications, including bibliometric aspects like citation and impact indices. One important

limitation on most of these quantitative methods is that they constrain informed judgment about scientific quality. Rather they depend on the peer-review process and different aspects of the relative ranking of scientific journal importance. It is more difficult to assess the balance of individual contributions within a broad interdisciplinary team and to separate highly competent research contributions from highly innovative ones. We have practiced a few very simple methods in addition to bibliometric ones.

To make certain that the evaluation identified the best available evidence of high quality research, we asked the research group leaders to provide the evaluation group with their best publications with respect to originality and impact. The number of publications asked for was related to the size of the group, but never more than 10 publications from the last 5 years. The publications were read and scored independently by two evaluators according to the originality, scope, and presentation of the analyses and the discussion in grades of high, medium, and low. While these assessments were necessarily subjective, the purpose of identifying an appropriate international evaluation group is to bring together senior, experienced researchers precisely to obtain their professional judgments. Although the purposes were not the ranking of individuals or groups, the summary scoring indicated whether the subcategory of the research area was regarded as of average, higher, or lower international standard on the basis of the appreciation of the evaluators. In order for one person's perspective to not overly influence any assessment of this type, each submitted publication was reviewed by two evaluators. During the final meeting, these evaluations were painstakingly considered. When the two reviewers had scored the submitted research very differently, they were asked to discuss and revise or share the different opinions with the whole evaluation group. This is more of a semi-qualitative approach rather than a quantitative scoring, but, in our opinion, it provided an important balance to the quantitative assessments provided by the more formal bibliometric reviews.

Productivity, as opposed to quality, is a difficult area for examination in research evaluation. The simplest way to measure productivity between groups is to relate the number of published articles of different types and other relevant products to the researcher time available. This process is further elaborated under a later section on bibliometrics, as are possibilities to make a more quantitative analysis of international productivity or at least appearances in journals. In addition, published articles, such inputs as the organization of international research networks, conferences, and research courses should be taken into account.

The amount of external funding for a research group was of interest, although it will certainly depend on the amount of permanent funding otherwise available, as well as on the principles for awarding certain institutions funding from research councils and the like. For Scandinavian countries the amount of funding from the European Union is of special interest.

It might be tempting to ask for elaborate self-analyses of strengths, weaknesses, opportunities, and threats or other qualitative information from the research groups, plans for the future, and the like. It was our judgment, however, that these valuable undertakings are not appropriate or meaningful when the evaluation targets national research. Self-analyses of strengths, weaknesses, opportunities, and threats seem more relevant for the evaluation of research departments and groups. Even if such analyses from all of the research groups involved (77 in the occupational health review and 66 in the public health review) had been thought to be desirable, it was judged that they would be too difficult to summarize in an informative and fair manner.

We also urge that special attention be paid to the type and number of requests for information from the affected groups. When requesting information from all research groups in a country, one should be very restrictive with questions and be sure that they will give important information, as many person hours will be spent answering the questionnaires.

7. How is relevance taken into account?

Most research in occupational health, as well as Swedish public health research, is applied, and therefore the relevance for society has been a natural and necessary component of the evaluations. We employed two complementary methods, interviews with "consumers" and requests to the research groups to submit examples of studies or products that they regarded to be their best contributions of relevance [eg, conclusive analyses of preventable risks or interventions, new patents, and products (measuring device, personal protection equipment), manuals, basis for occupational exposure limits or standards, teaching material for practice webpages designed for the public]. The estimated value of these products of relevance were also scored as high, medium, or low and summarized for the subcategory.

There are alternative means with which to assess the societal impact of health research, such as measuring increased life expectancy, health-related quality of life, saved health care costs, and reduced sickness absence, but mostly suited for and applied in the evaluation of medical treatment. However, some of the methods (eg, an evaluation of the benefits of a healthy workforce to the economy through occupational health research) could possibly have been done but would be a separate agenda. As attractive as such measures are for the ultimate relevance of research, they are rarely, if ever, the

product of a single research finding or line of research investigation, nor is it likely that research alone can be attributed as the source of a positive impact on society.

One difficulty for an international group in assessing relevance properly may be that much of the material is in a language not known to all the evaluators. Therefore the interviews with stakeholders is of great importance.

8. What is the role for bibliometric analyses?

An essential basis for comparative research evaluation is the published literature focused on in the most appropriate international, peer-reviewed journals. Modern databases provide the possibility to compile all publications from specified researchers over many years, including citation and impact factors. Furthermore, the proportion of articles published in the most respected journals in the discipline can be compared with a look at national and international collaboration according to the institutional base for the authors and many more items. A reasonable time span for such analyses is the last 5 years, which can then be supplemented by the consideration of certain trends in productivity or within subcategories over a longer period. Longer time periods for a primary bibliometric analysis are not, however, necessarily representative of the research community today.

There is a great deal of controversy about the meaning and proper use of the citation and impact factors that are available for peer-reviewed journals. While it is important not to rely exclusively on these indicators, we believe that they provide value together with the other measures. Unless the knowledge of bibliometric methodologies is advanced among the evaluators, it may be wise to consult with an expert.

Evaluations should not overlook the importance of research or technical reports that can play an important role in practical applications despite not being published in peer-reviewed journals. They could be asked for in a limited number with English abstracts.

An unusual, possibly unique input in the Swedish evaluations resulted from the possibility to compile all doctoral dissertations from specified university departments that indicated time trends, the productivity from different universities, and, within subcategories as well, an illustration of the manpower base for future research. The quality of doctoral dissertations could also be an item for evaluation. However, in Scandinavian countries, practically all doctoral dissertations are based upon articles published or accepted for publication, and therefore their content has already been taken into account.

9. How is research capacity and sustainability evaluated?

In an assessment of any research program, national or otherwise, it is essential to consider the demographics of the research workforce. This consideration is important with respect to the following issues: (i) making certain that the necessary range of expertise is available to address the research objectives properly, (ii) making certain that a reasonable range of perspectives is represented (eg, a balance of gender and ethnicity when relevant), (iii) making certain that the workforce is sustainable and not inappropriately young or old, and (iv) making certain that research leadership is open to all qualified persons. Data with the necessary specificity to be useful are unlikely to be available from existing occupational census data that are routinely collected. We recommend that an appropriate survey be undertaken that is directed towards the research community engaged in the research to be evaluated in order to ascertain the necessary demographic information. Furthermore, if available, documentation on the nature of the emerging workforce, as seen through doctoral training programs, can provide a very useful understanding of how the reviewed fields are likely to progress as the established research scientists retire.

10. Should a draft be discussed with the research community before the report is finalized?

Consideration should be given to whether or not to provide an opportunity for comment on any draft report in advance of a formal release of the report. There are good reasons to distribute a draft to the reference groups and the research groups that have been evaluated in order for factual mistakes to be corrected, clarifications added, and perhaps judgments specified. However, there are also risks of attempts to lobby for more positive remarks. We still recommend feedback to the evaluated community before the report is finalized, preferably with a possibility to participate in a seminar, as well as submit written comments. Naturally all other stakeholders can be invited to the same seminar and participate in the discussion.

National versus institutional review

The evaluation of an entire nation's scientific research in any area is a challenging task. The described approach is intended to provide a reasonable balance between feasibility and comprehensiveness. As it is, each of the two efforts took a year to complete and required significant participation by the active research community that was the subject of the reviews.

This effort differs from that which may be appropriate for a single institute, even a fairly large one. For example, the National Institute for Occupational Safety

and Health (NIOSH) in the United States has recently engaged the National Academies in a systematic evaluation of its research and research accomplishments. The Institute is a large federal organization that has locations in six cities [Atlanta (GA), Washington (DC), Cincinnati (OH), Morgantown (WV), Pittsburgh (PA), and Spokane (WA)] and more than 1400 employees. The institute has the major national responsibility for research on occupational injury and illness and their prevention. This work is accomplished both through a large intramural research program organized into several major units and competitive awards of grants and contracts to the extramural research community. In addition, the Institute engages in direct services through information and education programs and through the assessment of workplace hazards, when invited.

At the request of the director of the Institute, the National Academies was invited to undertake a multiphase effort to assist the Institute in assessing the relevance and impact of its research to address the Institute's goal of reducing workplace illnesses and injuries and improving occupational safety and health. This evaluation began by having a multidisciplinary committee of experts develop an evaluation framework to serve as a guideline and structure for a series of 15 separate research program reviews to be carried out by appropriately constituted evaluation committees. The 15 evaluations are expected to be completed within 5 years.

This "Framework for the Review of Research Programs of the National Institute for Occupational Safety and Health" was prepared in 2005 as a draft document to be amended, as necessary, after the initial evaluation committees have applied it to specific work areas (3). The Framework was designed to provide a detailed structure and consistent approach for each of the 15 evaluation committees that are to be used in guiding the assessment of each of the research programs. Based on the logic model adopted by the Institute, the 35-page Framework describes how to assess program goals, inputs, activities, outputs, intermediate outcomes, and end outcomes. The document advises that close attention should be given to the external factors that constrain the impact of the Institute's research. It also presents specific guidance on scoring with special emphasis on the importance of a detailed qualitative description providing the basis for the final scores.

The first evaluation report (4) was published in 2006, and a second will be published in the first half of 2007 (5). Experience applying this framework illustrates some important differences from the approach to a national review of research by all relevant bodies.

- *Target of the review:* The Swedish reviews were charged to assess the entire scientific field for the country. The NIOSH evaluations are restricted to the research undertaken or sponsored by NIOSH. These evaluations, therefore, are more narrowly targeted and require a closer examination of a smaller body of work.
- *Scoring of the review:* In contrast to the Swedish reviews, the National Academies was asked to score each NIOSH research program on a scale of 1–5 for relevance and impact. Such scoring is familiar to most scientists when undertaking individual project reviews, but it has proved difficult for the committees to assess an entire research program in quantitative rather than qualitative terms.
- *Longer period for the evaluation:* The Framework document instructs the evaluators to begin by determining the time frame for the review. In general, this is about 15 years [ie, the time since the last strategic plan was developed (NORA 1) 1996 (6)]. Flexibility in the time period is, however, left for the evaluation committees to determine. For example, the mining review would be remiss if it ignored the major impact that NIOSH research had in the early 1970s in reducing coal workers' pneumoconiosis. The current research and research agenda for mining needed to be seen in this larger time context.
- *Appropriate inputs*: The Framework document suggests questions for programs and types of documentation that may prove useful to the evaluation committees. Since each program review was to be carried out in a very short period of time (4 months), the first meeting already needed substantial background data in hand rather than having time to develop a well-targeted request at the first meeting. Therefore, the generic requests of the Framework have had to be supplemented, and some of the preparatory work done by NIOSH has proved to be unnecessary.
- *Hearing from stakeholders:* There was no easy mechanism through which to receive stakeholder inputs other than including, as possible, one expert each from labor and from management on each committee. Public input at each meeting is possible, but unusual, and a stakeholder survey through the Internet has proved to be only moderately successful.
- *Input before the finalization:* Studies directed by the National Academies do not allow for public review before finalization. However, each study undergoes an external evaluation by reviewers selected to represent expertise relevant to the charge for each committee, but it also may include stakeholders as appropriate. This process may prove to have a more rigorous prepublication assessment, but it does not assure the correction of inadvertent errors or missing information.

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Appendix

Interview questions

Questions to funding agencies (the Swedish Council for Working Life and Social Research, etc)

1. What is the basis for setting priorities in funding, and is the process transparent?
2. What is the input of stakeholders?
3. Do you feel that there are substantial gaps in the knowledge needed to set these priorities, and how might these gaps be filled?
4. Over what time period do you establish priorities, and how are these priorities and long-term views communicated?
5. Is there communication between funding agencies in order to seek an adequate balance across all areas and different types of funding (projects, programs, personal grants)? How is the balance arrived at between areas and types?
6. How do you evaluate the outcome of funded research (quantity, quality, does the project meet the aims, dissemination, and relevance for science and society)?
7. How do you monitor the trends in occupational health and the benefits of research?
8. How do you identify strategic areas for continuing support (infrastructure)?

Questions for occupational health services

1. In what ways are you involved in setting priorities for work environment research in Sweden?
2. Do you feel that your scientific needs are met? If not, in what respect?
3. How well is the scientific output from the research community communicated in a way that meets your needs?
4. How does the research community bring emerging research concerns to your attention?

5. Are you actively engaged in conducting research?
6. Do you have sufficient resources to take full advantage of the output of the scientific community?
7. How do you monitor the trends in occupational health and the benefits of research?
8. What research developments in the past 5 years have you been able to use to enhance worker health or prevent work-related disease?

Questions for the ministries

1. Do you have the information you need for setting priorities in research in general and for emerging issues in particular?
2. Does your ministry have sufficient input in setting priorities?
3. How do you judge value for money?
4. How do you arrive at decisions about the available money for research?
5. Are you satisfied with the structures in place (with funding agencies) to determine priorities for research?
6. What concerns do you have about the infrastructure of research in occupational health?
7. What is your view about collaboration at the level of the European Union?

Questions to employers, trade unions and labor market partners

1. In what ways are you involved in setting priorities for work environment research in Sweden?
2. Do you feel that your scientific needs are met? If not, in what respect?
3. How well is the scientific output from the research community communicated in a way that meets your needs?
4. How does the research community bring emerging research concerns to your attention?

Questions for the researchers

1. Do you have a strategy for determining research needs? If so, how was this strategy developed?
2. Are you maximizing the knowledge base that your unit has in carrying out your research activities? Can you identify existing obstacles to your better utilizing your capacity and achieving your objectives?
3. Is your group or research environment sufficiently interdisciplinary to accomplish your research goals? If not, what is the expertise that you need and how might it be made available?
4. What methodological impediments exist for you to undertake research that you think is of high priority?
5. Are there serious problems in occupational health in your areas of expertise for which you have sought funding but have not been able to develop adequate interest in support from funding agencies?
6. What mechanisms do you use to recruit young researchers and promote their careers? How do you promote gender equity in this process?
7. What efforts have you made to translate your research findings into practical outputs? Have these been successful or what impediments have you encountered?
8. What opportunities have you had for international collaboration? In what way have these activities proved useful for your research or other outputs?
9. What opportunities have you had to seek international funding? What has been your experience with these efforts?