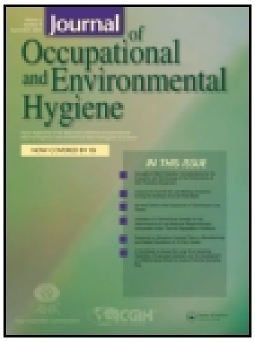

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Pollution Prevention—Occupational Safety and Health in Hospitals: Alternatives and Interventions

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An integrated pollution prevention (P^2) and occupational safety and health (OSH) worksite intervention and alternatives assessment strategy was developed in hospitals. It was called the Pollution Prevention-Occupational Safety and Health (P^2OSH) assessment for the "Sustainable Hospitals Project." Methods included (a) developing a participatory intervention model for introducing more environmentally sound, healthy, and safe materials and work practices for specific hospital procedures; (b) developing an integrated P^2OSH survey to evaluate environmental and occupational impacts of the intervention; and (c) conducting and evaluating interventions by applying the P^2OSH assessment pre- and post-intervention. Eleven interventions were performed in six hospitals: an aliphatic fixative replaced xylene in three histology laboratories; a mercury reduction plan was implemented in three clinical laboratories; digital imaging replaced wet chemical film processing in three radiology departments; a less toxic aldehyde replaced formaldehyde in one hospital histopathology laboratory; and conventional mopping was replaced by microfiber mopping in one hospital. Occupational and environmental health and safety impacts were observed for all interventions. The alternatives generally were beneficial, although each had limitations that resulted in process and task changes with potentially negative P^2 and/or OSH impacts. When these were identified in the pilot phase they could be addressed before full-scale implementation. The P^2OSH method shifts the focus of occupational and environmental hygiene from hazard control to substitution. Because few ideal alternatives exist, the emphasis is on a continuous process to identify, implement, and evaluate alternatives, rather than on a particular alternative. Occupational and environmental health and safety professionals have an important role as agents in hospital organizational change and in the search for healthier and safer alternatives. Through these activities they can become involved in the design/redesign of products, materials, and processes, thus expanding their traditional role.

Keywords alternatives assessment, hospital pollution prevention, occupational health in hospitals, substitution, worksite interventions

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The health care industry in the United States includes nearly 6000 hospitals[(1)] that employ approximately 5.3 million workers.[(2)] Hospitals have a significant impact on the environment through hazardous, solid, and medical waste; air and water emissions; and consumption of raw materials and energy. They produce about 1% of the U.S. municipal solid waste stream[(3)] and are, respectively, the third and the fourth largest source of pollution from dioxins and mercury in the United States.[(4,5)] Within the hospital, many workers routinely experience biological, chemical, physical, musculoskeletal, work organization, and safety hazards.[(6–8)]

Numerous government, industry, labor, and community-based initiatives have been established recently (e.g., by the U.S. Environmental Protection Agency [EPA], by the Joint Commission on Accreditation of Health Care Organizations, and by the government-industry-labor-community group collaboration Hospitals for a Healthy Environment) to foster pollution prevention in hospitals and other health care facilities. Thus far, many of these initiatives focus on replacing hazardous materials to reduce pollution without considering the work environment. However, occupational and environmental hazards arise from the same source—the production process and materials—so the development of comprehensive solutions to these problems requires an approach that integrates both.[(9)]

The goal of this work was to develop an integrated pollution prevention (P^2) and occupational safety and health (OSH) intervention and alternatives assessment strategy in hospitals. To accomplish this, it was necessary to draw on conceptual frameworks and methods from several disciplines, including industrial hygiene, ergonomics, process engineering, organizational management, and occupational safety and health intervention research. Specific objectives were to:

1. Develop a participatory intervention model for introducing more environmentally sound, healthy and safe materials and work practices (referred to as interventions

or alternatives in this article) for specific hospital procedures
2. Develop integrated P^2-OSH assessment methods to evaluate environmental and occupational impacts of the intervention, and
3. Implement and evaluate work site interventions using the integrated assessment methods.

The integrated intervention/alternatives assessment was called the Pollution Prevention-Occupational Safety and Health (P^2OSH, pronounced "POSH") work site assessment. The study was named the "Sustainable Hospitals Project." This article describes the P^2OSH methods and provides an overview of the study findings and lessons learned.

METHODS

Development of the Intervention/Alternatives Assessment Model

Developing a Multidisciplinary Framework and Language

Several disciplines offer methods to improve the work environment. Even though similar principles underlie all of them (assessing the current situation, introducing a change, and evaluating it), each has a different conceptual model and vocabulary. One challenge of this study was to develop a model and methods that integrates these. Additionally, most of the workplace change methods were developed in the manufacturing setting where the production process is organized around some type of an assembly line. In this study, "production process" is broadly defined to refer to the procedures involved in producing medical care.

Pollution prevention strategies to introduce a workplace change draw mainly on methods from two disciplines. The first is production process and materials characterization developed within the field of process engineering. It involves a systematic analysis of technical processes, with a focus on evaluating the steps required to make a product and the functions of the associated technologies and raw materials. The analysis often includes a process flow map[(10)] and materials and cost accounting.[(11)] In the vocabulary associated with this model, a workplace change is a technical "process or materials change" brought about by introducing an "alternative" or "innovation" that is initially evaluated using a "pilot process" and, after "full scale implementation," is evaluated as part of a "continuous improvement plan."[(11,12)] A second set of methods, developed in organizational management, pertains to the management of the production process and the workplace administrative structures that support it. These methods are used to promote "organizational change" that is guided by a social "change process" and motivated by a person called a "change agent."[(13,14)] These process engineering and organizational management frameworks are also used in industrial hygiene engineering and program management and are called "process hazard analysis,"[(15–17)] and "management of change" and "change analysis."[(18,19)]

Industrial hygiene and ergonomic work site assessments use job hazard analyses as well as process engineering to evaluate worker interactions with the production process. A workplace improvement is made by introducing a "control" or "substitution." These are usually technical but may be administrative.[(20,21)] The selection and implementation of a control may be conducted according to a "participatory model," that is, involving the workers affected by the change.[(22)] Methods developed for work site intervention research are also used to introduce workplace improvements in health and safety. In this context, the introduction of an alternative is usually called an "intervention." The work site intervention framework includes three major steps: identification and implementation of the intervention and evaluation of its effectiveness.[(23)] This framework can be applied at multiple work organization levels,[(24,25)] including the individual worker,[(26)] a particular production process,[(27,28)] the overall work site,[(29)] and national policies and regulations.[(30)] The model developed to conduct the P^2OSH interventions incorporates elements from all of these disciplines. Figure 1 shows the P^2OSH model along with the corresponding steps of OSH intervention research. The interventions/alternatives assessments performed in this study were conducted at the level of a specific production process or hospital department.

The P^2OSH intervention/alternatives assessment model was developed using three guiding principles:

1. A material or process cannot be changed successfully without understanding its function in the production process,[(11)] the associated job requirements and work practices, and the final product or service to which it contributes.
2. A material or process intervention cannot be implemented successfully in the long term without the participation of the people affected by the change because they understand the functions and work practices best and, ultimately, maintain the change.
3. Very few alternative products or processes can be categorized in absolutes of "good" or "bad" with respect to occupational safety and health or the environment. The P^2OSH model is used to assess the relative differences between a conventional material and one or more alternatives *for a particular application*. This is accomplished by characterizing products or processes from many aspects (e.g., human and environmental toxicity, cost, ergonomics, space requirements) and systematically comparing overall performance. Thus, the focus is on the *process* by which an alternative is evaluated and implemented rather than on a *particular alternative*. When a new alternative becomes available, the process to evaluate it is repeated.

Adapting the Model to the Hospital Setting

Literature reviews and open-ended interviews with hospital administrators, clinicians, and support staff from six hospitals, and hospital worker health and safety specialists from four health care unions were conducted to identify: (a) typical hospital organizational structures responsible for managing materials and environmental and occupational health and

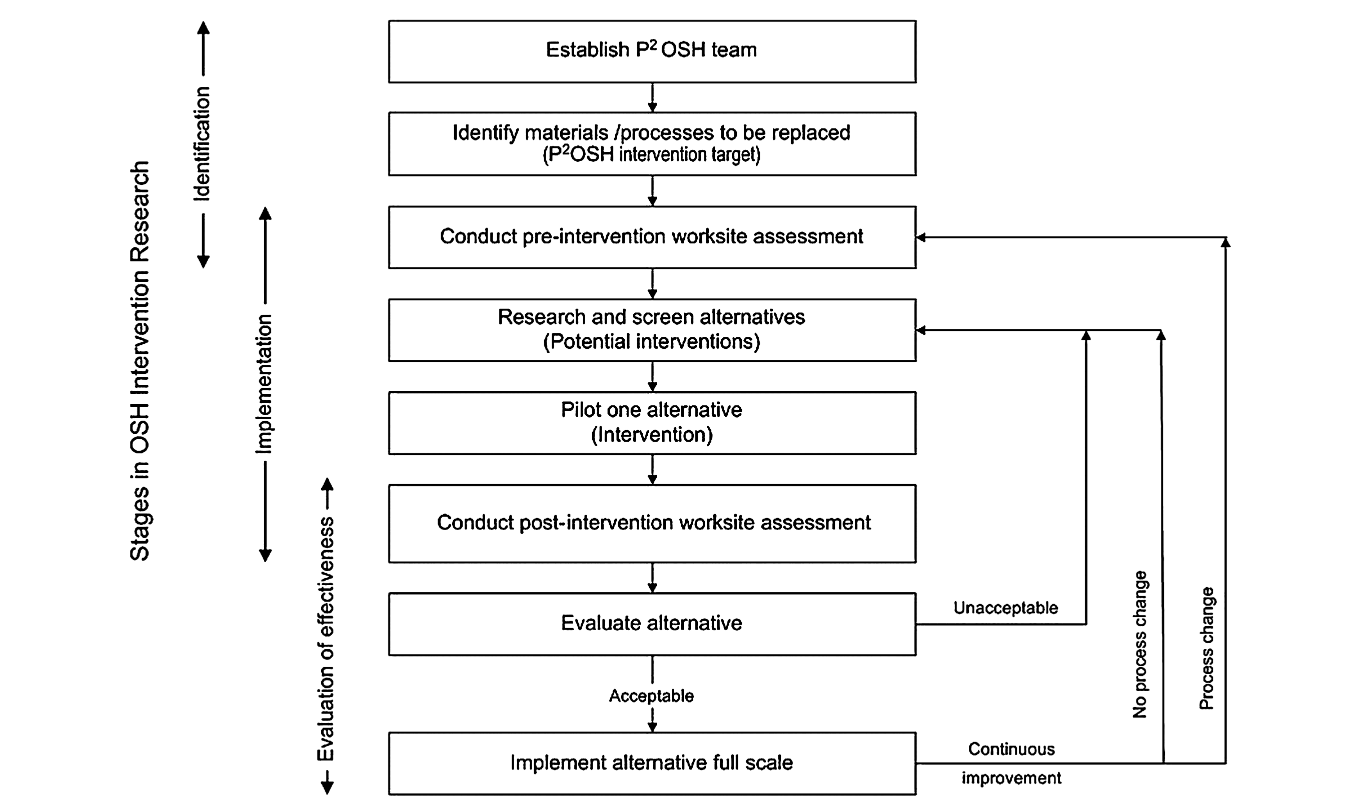


FIGURE 1. P^2OSH intervention/alternatives assessment model

safety, and (b) existing models for introducing environmental and occupational interventions in hospitals or other work sites.

Hospital Participation and Identification of Potential Intervention/Alternatives Targets

Site visits were conducted in 18 hospitals in the northeastern United States to present the P^2OSH method and to evaluate the potential for intervention projects. Open-ended interviews were conducted with hospital administrators and staff who expressed an interest in participating in the P^2OSH intervention study. The purpose of these interviews was to identify (a) P^2OSH intervention/alternatives assessment targets within specific hospitals; (b) environmental and OSH concerns among hospital employees; (c) how employees gather information needed for their work (e.g., internet, professional journals, colleagues); and (d) how changes are made in their workplace.

Six of the 18 hospitals were chosen because they represented a range of demographic characteristics and because they agreed to pilot an intervention for which there was a feasible alternative. Hospitals were eliminated primarily because they were undergoing mergers or other major organizational and economic restructuring, and it was decided that it would be difficult to obtain institutional commitment for the duration of the study. The P^2OSH interventions were not performed in urgent care areas for reasons of patient confidentiality and the potential for disrupting emergency procedures.

Development of the P^2OSH Work Site Assessment Survey

A P^2OSH work site assessment survey and the methods to implement it were developed to characterize existing process (pre-intervention work site assessment) and the process after the alternative was introduced (post-intervention work site assessment). The survey instrument consists of multiple, nested questionnaires that begin at the level of the entire hospital and progress to more specific levels of the organization concluding with a detailed analysis of health care workers' tasks associated with the use of a material or product targeted for the intervention. The questionnaires were administered onsite by the intervention study team. The information was collected by interviewing workers employed at various levels of the organization, by industrial hygiene walkthrough evaluations, and by observational evaluations based on industrial hygiene, ergonomic, and safety process, job and task hazard analyses. The survey instrument was developed and piloted in two hospitals that did not participate in the full intervention study. At least two industrial hygienists and ergonomists applied the area, process, and task surveys separately and compared their results. When there was disagreement, the survey instrument was modified and re-evaluated. Table I provides an overview of the P^2OSH worksite assessment survey instrument.

Linking Process and Tasks

The processes targeted for an intervention were evaluated using processes mapping (Figure 2). The task survey

TABLE I. Overview of the P^{2}OSH Worksite Assessment Survey Instrument

Type of Survey	Scope
Facility	Collects demographic data (e.g., location, number of beds, religious and public/private affiliation) and data on OSH and P^2 activities.
Area	Identifies all processes occurring in an area, the physical characteristics of the area, and the staffing (e.g., layout, equipment density and location, lighting, general ventilation, noise and employees, job titles, and basic duties).
Process	Analyzes the process targeted for intervention. The results are summarized in a process map highlighting the steps that use a material or technology targeted for intervention. An example of a process map is shown in Figure 2.
Materials Input/Output	Identifies materials going into and out of each process step. Effluents from the process step are also identified by type of waste stream, such as solid or hazardous waste, air, or water emissions. An example of the materials input/output map for 2 steps in histopathology is shown in the top portion of Figure 3.
Task	Determines the potential impact of changing materials or practices on the occupational safety and health of affected workers. Each task associated with the intervention is evaluated for frequency, duration, and potential occupational hazards in five categories: chemical, biological, physical, safety, and ergonomics. An example in the lower portion of Figure 3 shows how tasks are linked to process steps.
Employee	Assesses workers' perceptions of the intervention. Workers rate the intervention as neutral, favorable, or unfavorable. They also describe in an open-ended format any positive or negative changes in their jobs that resulted from the intervention.
Cost Analysis	Evaluates direct costs associated with a change (e.g., cost of materials or equipment, changes in staff time)[A] and tangible indirect costs related to OSH and P^2, such as worker training and hazard communication, personal protective equipment, installation and maintenance of engineering controls, air and water monitoring, surveillance and incident reporting, hazardous material handling and storage, waste handling and disposal, medical monitoring, emergency response preparedness, and regulatory fines for noncompliance.

[A] P2/FINANCE (Pollution Prevention Financial Analysis and Cost Evaluation system) developed for the U.S. EPA. Copyright 1996, Tellus Institute, Boston.

information was combined with the process survey data using a matrix, thus linking the workers, through their tasks and jobs, to the process steps. Conventionally, OSH focuses on jobs and tasks, whereas P^2 focuses on processes, materials, products, and waste streams. While these obviously overlap, the methods to link them in field studies have not been well developed and so it has been it difficult to study specific impacts of P^2 interventions on OSH and vice versa. An example of a process step-task linkage matrix is shown in the lower portion of Figure 3.

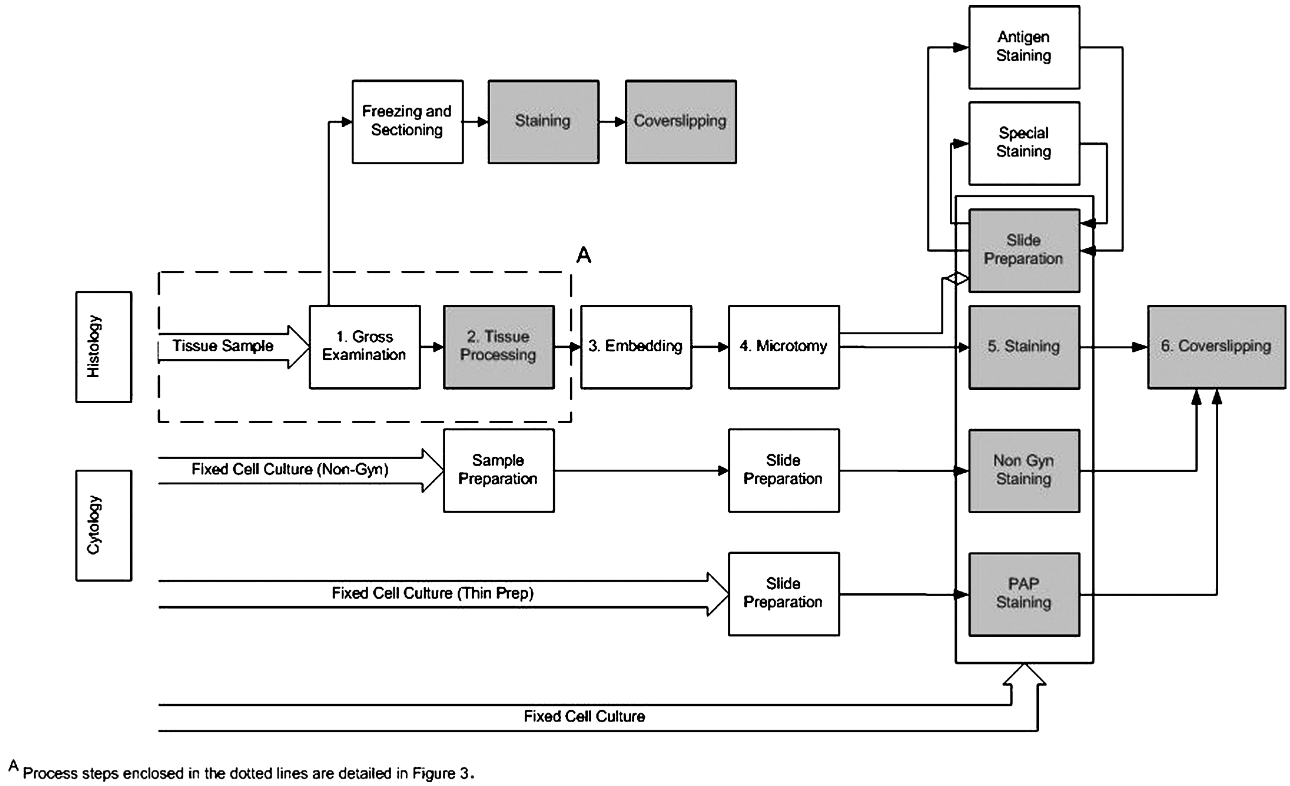
Application of the P^{2}OSH Model and Survey

Establish a Multidisciplinary Team and Identify the P^{2}OSH Intervention Target

At each participating hospital, a vice president or director of a division such as facilities and operations, made a commitment to the study. These high-level managers then identified a single contact within their hospitals, usually the manager of the clinical or support department where the intervention would be conducted, with whom the intervention researchers coordinated all on-site work. The hospital contact worked with the researchers to identify key hospital staff to participate in the intervention/alternatives assessment. These staff, called the P^{2}OSH team, were able to oversee the intervention because they had financial and organizational decision-making authority as well as technical knowledge relevant to procedures and jobs. The team included managers and staff performing the process targeted for the intervention, as well as representatives from related departments upstream (purchasing, materials distribution) and downstream (housekeeping, waste disposal). P^{2}OSH teams typically consisted of five or six members.

The P^{2}OSH team defined the scope of the problem targeted for intervention, including the current situation and its adverse impacts, the desired outcome, and measurable criteria by which the team would know when the intervention was successful. This detailed problem definition ensured that there was agreement on the scope of the problem and minimum criteria for recognizing when an alternative was viable.

Due to time constraints and understaffing, it was difficult for the entire P^{2}OSH team to meet regularly. Each P^{2}OSH team typically met as a full group only one or two times to define the problem and the criteria for accepting an alternative. The other steps in the P^{2}OSH intervention were conducted by subgroups of the team. The researchers served as staff to the P^{2}OSH team to identify the environmental and occupational issues related to the conventional product/process and to research possible alternatives.



[A] Process steps enclosed in the dotted lines are detailed in Figure 3.

FIGURE 2. P^{2}OSH process map for histopathology. Shaded boxes indicate process steps in which xylene was used.

Conduct P^{2}OSH Pre-intervention Work Site Assessment

The researchers characterized the conventional process and the function of the material targeted for intervention in the process and in creating the final product. This was done with the pre-intervention work site assessment surveys, particularly those for the area, process, materials input/output, and tasks. The results served as a baseline to compare worksite changes post-intervention and to evaluate the technical function of the intervention target in the process.

Research and Screen Alternatives

Potential alternatives were identified by a review of the scientific, engineering, and medical products manufacturing literature and websites; review of advertisements in professional journals; personal or telephone interviews with hospital personnel who were already using an alternative; inquiries on medical professions' listservs such as Histonet[31] and Hospitals for a Healthy Environment;[32] and a search of professional and regulatory standards and guidelines, such as those from the College of American Pathologists (CAP, a group that oversees an accreditation program for medical laboratories) and the NCCLS (formerly the National Committee for Clinical Laboratory Standards, an organization that develops and disseminates standards, guidelines, and best practices for medical testing).[33,34]

When technically feasible, alternatives were identified. They were reviewed for environmental and health impacts, including toxicity; biopersistence; irritant and sensitization properties; dermal uptake; odor; vapor pressure, flammability; and other physical properties related to safety, storage, handling, and disposal requirements; and the degree of workplace reorganization required to make the change. Financial feasibility was also considered using the cost analysis portion of the P^{2}OSH work site assessment. If an alternative appeared more favorable with respect to environment and health characteristics, then it was considered for pilot evaluation. The final decision regarding which alternatives to pilot was made by the hospital staff. It was deemed essential to the study's success that the affected hospital staff agree that the intervention would not interfere with patient care. This screening of alternatives was intended to identify one or two materials or processes for a comprehensive pilot evaluation.

Pilot Alternatives, Conduct P^{2}OSH Post-intervention Work Site Assessment

In collaboration with the hospital staff, the researchers developed pilot methods to introduce the alternative in a controlled manner under typical working conditions. The evaluation methods and time to completion differed depending on the application. The most complex intervention

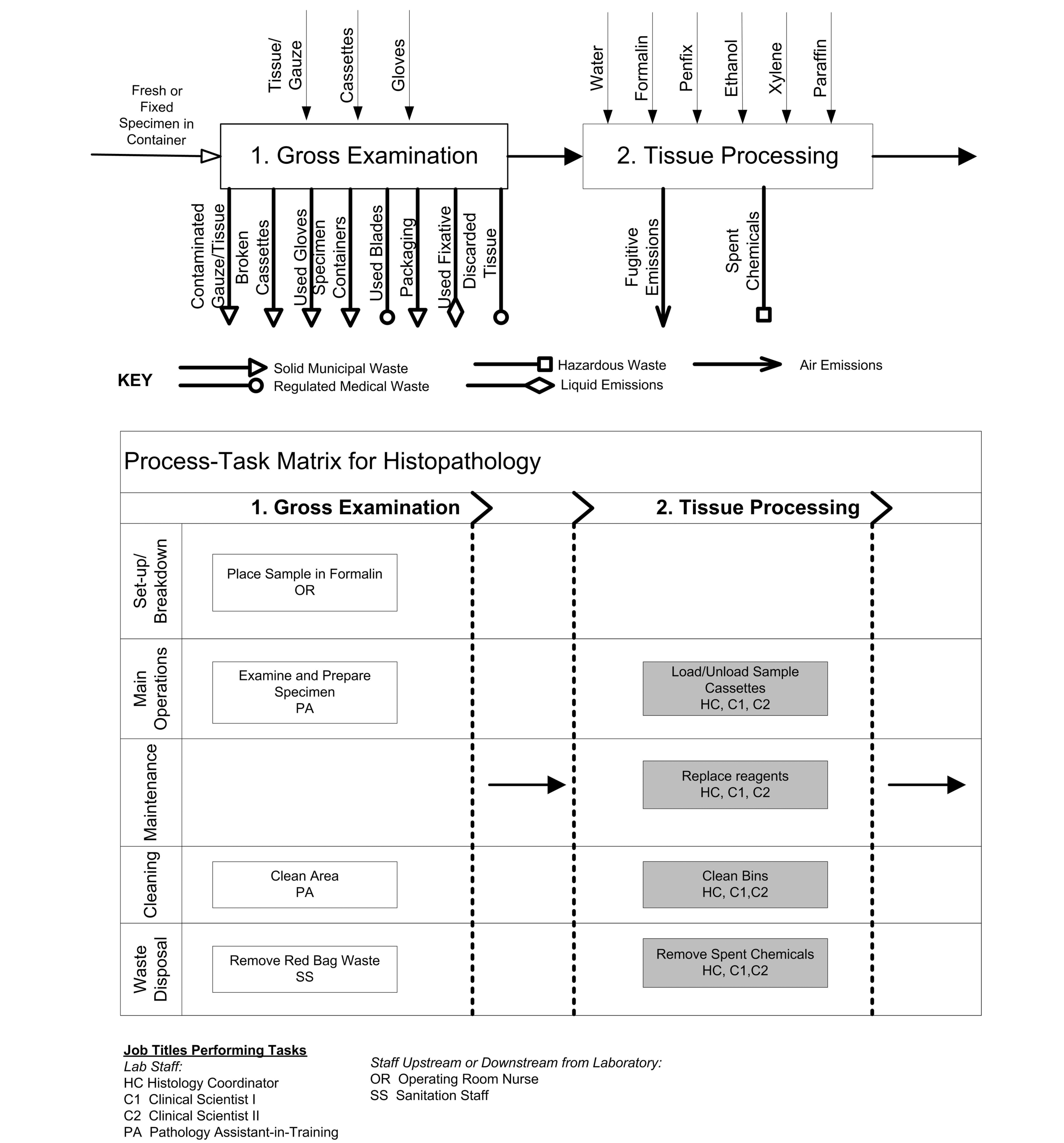


FIGURE 3. P^{2}OSH materials input/output map (upper portion) and process-task matrix (lower portion) for histopathology. Details of the first two process steps (Figure 2, dotted box) are shown. Shaded boxes indicate tasks that use xylene.

(formaldehyde replacement in histopathology, see below) required approximately 6 months to complete, whereas the least complex (conventional mopping replacement in housekeeping, see below) required approximately 6 weeks. A post-intervention P^{2}OSH work site assessment was conducted for each alternative piloted.

Evaluate the Intervention/Alternative

To assess comprehensively the impacts of the alternative on the tasks associated with each process step, the pre- and post-intervention survey results were compiled in a table with all tasks and hazard categories and tallied using a simple grading scale of positive (+), negative (−), mixed (+/−), or neutral (see the task survey description, Table I). Comparison of the pre- and post-intervention results allowed determination of: (a) whether the alternative met the acceptance criteria defined by the team; and (b) whether the alternative was preferable from an overall perspective of pollution prevention *and* occupational safety and health. Typically, the full-scale implementation of an alternative required multiple iterations of piloting and assessing alternatives.

RESULTS

Hospital Interventions

Eleven interventions were performed in six hospitals. A summary of the hospital interventions is given in Table II.

Xylene Replaced by an Aliphatic Fixative in Three Histology Laboratories

Xylene, a liquid aromatic hydrocarbon, is used in histology laboratories to fix tissue for the preparation of diagnostic slides. It is a neurotoxicant and suspected carcinogen regulated by the U.S. Occupational Safety and Health Administration (OSHA) and the EPA.[35–38] This intervention was motivated by both occupational and environmental considerations: the histology staff reported respiratory, mucous membrane, skin irritation, and headaches due to the strong odor. Two of the hospitals were located in a water resource district that strictly regulated xylene emitted to the sewer. The goal was to implement an alternative that was more benign to the workers and would conform to sewer regulations. The intervention researchers identified several chemical alternatives that could directly substitute the xylene, requiring little work reorganization. The final intervention was an alternative tissue fixative, a mixture of aliphatic hydrocarbons that does not include hexane (C9–C12). Samples of tissues from surgery and hospital clinics were prepared in parallel using xylene and the alternative. These were evaluated by the histologists and pathologists in blind comparisons. The alternative was judged acceptable by the hospital staff as a tissue fixative, and the P^2OSH work site assessment survey determined it to be less toxic. Six months after the interventions, all three hospitals were continuing to use the alternative. The overall result was that xylene was either completely or significantly reduced in these laboratories.

Mercury Reduction Policy in Three Clinical Laboratories

In three hospitals the intervention was a written policy and plan for the reduction and eventual elimination of mercury in the clinical laboratories. Mercury occurs in well-recognized sources, such as thermometers, sphygmomanometers, and thermostat switches, and it is also present in small quantities in many laboratory reagents as a preservative or as a contaminant (e.g., thimerosal, which contains mercury, is a widely used preservative in pharmaceuticals).[39] Most of these reagents are disposed in municipal sewers via laboratory sinks. Intervening on mercury use was motivated by both occupational and environmental concerns: it is a persistent bioaccumulative toxicant (PBT) that affects the nervous and reproductive systems and it is strictly regulated by the water resource district in which two of the hospitals were located. In addition, mercury has been targeted by the EPA as a priority PBT for reduction due to the significant adverse health and ecological effects.

TABLE II. Summary of Hospital Interventions

Intervention	Hospitals[A]	Motivation for Change	Main P^2 Impacts	Main OSH Impacts
Xylene → aliphatic fixative	1, 2, 3	Worker irritant symptoms	↓chemical waste	↓odor, headaches ↓skin irritation ↓toxicity
Mercury reduction policy and plan	1, 2, 3	Water pollution	↓water pollution	↓spill hazards ↓toxicity
Wet chemical film processing → digital imaging	4, 5, 6	New technology	↓ chemical waste ↓water use ↓plastic waste	↓ chemical exposures ↓repetitive motions ↓awkward postures ↓lifting ↑VDT hazards ↑job loss
Formaldehyde → glyoxal	3	Water pollution	↓water pollution	↓ toxicity ↓odor ↓skin irritation
Conventional → microfiber mopping	3	Water conservation, musculoskeletal strain	↓water use ↓chemical use	↓musculoskeletal strain ↓infection potential

Notes: ↓ = decrease; ↑ = increase.
[A]Hospital demographics: 1-urban, small, private; 2-suburban, large, public; 3-urban, medium, private teaching; 4-urban, very large, private teaching; 5-urban, large, private teaching; 6-suburban, medium, public.

From the hospitals' perspective, mercury spills are difficult to control and can lead to costly cleanup efforts[40] and/or environmental regulatory fines. The goal was to eliminate or minimize use of mercury to prevent both occupational and environmental exposure.

The P^2OSH work site assessment was used to identify sources of mercury in the laboratories, and then mercury reduction opportunities were researched. With input from the laboratory managers and staff, a mercury reduction policy was developed and a plan to meet the policy was implemented. The introduction of the mercury reduction plan required countering accepted dogma about the need for mercury-containing equipment. Many clinicians perceived that mercury thermometers and sphygmomanometers produce better clinical measurements and require less routine maintenance (or none at all) than nonmercury medical devices. However, for most applications, this is not supported by the scientific literature. More importantly in terms of convincing clinicians, the researchers compiled reports from credible health providers about their satisfaction with mercury free alternatives.[41]

Initially, laboratory staff were not satisfied with the intervention. Although some acknowledged that mercury reduction was ecologically favorable, the staff's work became more difficult because they had to adapt to new technologies and products. In one hospital, at the 6-month review, the laboratory staff still had not fully accepted the interventions and hoarded mercury thermometers. The mercury reduction effort was renewed and after an additional 6 months, the mercury reduction plan was determined to be functioning. The mercury policy was implemented hospital-wide in the two hospitals located in the water resource district that strictly regulated mercury. The third hospital was considering doing so.

Wet Chemical Film Processing Replaced by Digital Imaging in Three Radiology Departments

Three hospital radiology departments were in the process of upgrading their radiologic film processing from wet chemical methods to digital imaging. The intervention researchers recognized that this technological change could have significant impacts on OSH and P^2 and gained the hospitals' agreement to evaluate it using the P^2OSH intervention study methods. The staff and managers in the radiology departments had not considered the potential P^2OSH impacts of the change, even though these were likely to be beneficial and could thus add to the justifications for the technology upgrade.

Comparison of the pre- and post-intervention results showed that several process steps and tasks associated with film processing, storage, archiving, and retrieval were eliminated. This had positive impacts on hospital costs and the environment due to reduced space requirements for film storage. For example, two large, urban teaching hospitals rented off-site space for film archiving and transported films back on site when needed. Digital imaging eliminated the need for off-site storage and transportation. The materials input/output also changed because film processing chemicals, plastic film, and water were eliminated, resulting in significant positive impacts on the environment. There was increased demand for computers that will partially offset the reduced solid waste production, unless computer recycling is implemented.

The elimination of the film processing and handling tasks had mixed impacts on the workers. There were positive impacts related to the reduction of chemical exposures, repetitive motions, heavy lifting, and awkward postures for the film handlers. However, there was a potential for job elimination with the introduction of the less labor-intensive new technology. The study hospitals anticipated this and conducted retraining prior to the introduction of the new technology so workers could move to other areas of the hospital and possibly into higher skill jobs with greater job satisfaction. For example, one worker in this study received training to move from a job as a film filing clerk to a computer database manager.

Formaldehyde Replaced by a Less Toxic Chemical in One Hospital

The P^2OSH method was used to replace formaldehyde used for tissue preservation and fixation in a histopathology laboratory. Formaldehyde is a carcinogen and sensitizer regulated by OSHA, the EPA, and the water resource district in which the hospital was located.[42−45] The hospital's primary motivation for this intervention was financial. Repeated violations of their sewer permit for excessive formaldehyde in wastewater prompted the hospital to install a collection system to dispose all of the lab's liquid effluent as hazardous waste. However, even these costly engineering controls failed to eliminate the sewer violations, and the hospital's clinical lab manager and vice-president concluded that the best way to prevent the sewer discharges would be to replace the formaldehyde. The laboratory's chief pathologist did not fully agree with the hospital managers on the scope of the problem or its solution.

Several chemicals and a microwave oven were identified as technically feasible alternatives. The laboratory manager rejected the microwave alternative in favor of a direct chemical substitute that required less work reorganization, implementation time, and initial expenditures. The final alternative selected by the histopathology laboratory staff was a chemical containing glyoxal, a less toxic aldehyde than formaldehyde.[46] An influential factor for the chief pathologist was that another local, prestigious hospital was already successfully using this formaldehyde alternative in its lab. Glyoxal appealed to the laboratory staff because it does not have the irritating odor of formaldehyde.

To pilot the alternative, diagnostic slides were prepared with the alternative using 11 different tissues from surgery and the hospital clinics. The slides were read by six pathologists in a blind comparison. For diagnostic purposes, the results showed that the alternative performed as well as formaldehyde in the preparation of most, but not all, tissues. The lab considered establishing two tissue preparation lines, one using the alternative for most tissues and the other using formaldehyde for the few tissues that were not well fixed with the alternative. Although no additional staff time was needed, the two lines proved infeasible for the lab due to space limitations. Six months after the intervention commenced, the hospital returned to using formaldehyde. However, the laboratory manager acknowledged that it would likely be feasible to run separate lines in other clinical laboratories and through participation in the intervention she identified specifications for future lab renovations.

Conventional Mopping Replaced by a Microfiber Mopping System in One Hospital

A microfiber mop consists of a synthetic cloth fit on a plastic handle. Multiple mopping cloths are soaked in a pan that uses less water than the conventional bucket. Rather than rinsing the mopping cloths between room changes, the floor cleaner replaces the soiled cloth with a clean one from the soaking pan and stores the soiled cloth in a dry container. When the floor cleaning is completed, the dirty cloths are sent to the laundry. The hospital housekeeping staff were motivated to pilot the microfiber mop both for occupational and environmental reasons: the microfiber mop is much lighter and smaller than the conventional system that uses a cotton loop mop, bucket, and wringer and so had the potential to make their work easier. In addition, the microfiber mop uses less water and disinfecting chemicals. The initial capital expenditure was not high and it was calculated that this could be offset by savings on water and cleaning agents. The hospital's head of infection control supported the intervention pilot because a clean mop head could be used for each patient room or public area, thus reducing infection potential.

Although information on the environmental benefits of the microfiber mopping was available from the scientific literature and the manufacturer's material, nothing regarding the ergonomic and other worker health and safety impacts was found.[47] The intervention researchers expanded the musculoskeletal hazard assessment portion of the P^2OSH survey to include a detailed videotape analysis of floor mopping in hallways and patient rooms. This analysis showed that the wringing and squeezing of microfiber cloths before use introduced musculoskeletal strain. However, overall the microfiber mop was easier and more comfortable for workers to use, and musculoskeletal strain of the back and upper extremities was reduced. The use of water and cleaning and disinfecting chemicals also was reduced.

DISCUSSION

This article summarizes the P^2OSH method for work site implementation of alternative materials, technologies, work practices, and assessment of their impacts on pollution prevention and occupational health and safety. Typically, environmental and occupational impacts are assessed separately, if at all, when workplace changes are made. The P^2OSH method integrates occupational and environmental health and safety by focusing on the production process as the fundamental unit of analysis and then systematically assessing the hazards that emanate from it. Several lessons were learned that overarch all of the interventions.

Both occupational and environmental health and safety impacts were observed for all of the interventions. In general, it was concluded that the alternatives were beneficial, although each had limitations that resulted in process and task changes with potentially negative P^2 and/or OSH impacts. These changes varied in complexity but even for the chemical alternatives that were nearly direct substitutes for the conventional chemicals (xylene and formaldehyde), work practices had to be altered. These alterations included the elimination or addition of a task, a change in the frequency or duration of a task, a change in materials handling or storage practices, and changes in cleaning and maintenance tasks. Several of the interventions showed that there could be positive environmental impacts but negative OSH impacts if these were not considered simultaneously. For example, in radiology, the change to digital imaging had mostly positive impacts on the environment. It also had significant positive impacts on OSH, but one potentially serious negative impact was job loss. The pre- and post-intervention assessment identified this negative impact in the pilot phase so that it could be addressed before the full-scale implementation. When applied in this way, the P^2OSH method can be used to prevent shifting the risk of a hazard from the environment to the worker or vice versa when a workplace change is introduced.

Information about less hazardous alternatives does not exist in a form that is readily accessible to hospital staff. The researchers spent considerable time finding information that was sufficiently detailed to purchase and pilot an alternative. After obtaining the information, it had to be summarized in a form that could be understood and used by hospital staff. At the beginning of the study, hospital staff were reluctant to participate in the changes. When questioned about the reasons for this, in addition to the obvious difficulty of having another time demand on already overextended schedules, staff reported that they were not accustomed to being involved in workplace changes and they did not have easy access to information about alternatives and innovations in their field. To address this concern, the Sustainable Hospitals Project started a website listing more environmentally friendly and safe products, materials, technologies, and work practices for hospitals (www.sustainablehospitals.org). Because our survey found that not all hospital staff have access to the Internet, we prepared technical bulletins and fact sheets that could be downloaded or distributed in hardcopy. These have been distributed by hospital associations, hospital worker unions, state and federal government agencies, environmental and occupational health and safety nonprofits, universities, and law firms.

There is a need for safer and more environmentally sound alternatives for medical products and materials. The alternatives identified for xylene and formaldehyde were not ideal. Although the aliphatic and glyoxal mixtures did not appear to be as toxic, there was insufficient toxicologic information. The P^2OSH analysis identified specific characteristics of these products that need improvement. These shortcomings were communicated to the product manufacturers and, in some cases, led to discussions about how the product could be redesigned. The manufacturers had an incentive to engage in these discussions when the lab managers and hospital purchasing agents began requesting less hazardous products and materials.

The successful introduction and assessment of an alternative involved a social process as well as a technical one, and interventions were most successful when all parties impacted felt they were represented in the change. This was particularly evident in the formaldehyde intervention when it became clear that the chief pathologist did not have the same view of the problems of using formaldehyde as the hospital administrators. He piloted the alternative reluctantly and, ultimately, decided not to implement it.

The clinicians and clinical laboratory staff were most strongly influenced to change when they learned that their counterparts in another, well-respected hospital were already successfully using an alternative. This was found for every intervention in the study and it was especially important for physicians. Hospital staff tend to differ from manufacturers in this regard; often the manufacturer wants to be the first to innovate and then guard the new trade secret from other manufacturers. Because clinicians trusted the experience of their colleagues in other hospitals, even more than information on a proposed alternative from peer-reviewed, scientific journals, case studies describing the experience of hospital staff using a particular alternative were added to the Sustainable Hospitals Project website.

P^2OSH teams with flexible structures worked best. This was because regular, full group meetings were impossible due to time constraints, understaffing, unpredictability of urgent patient care needs, and shift work. The full P^2OSH team usually met only at the beginning and end of the intervention, whereas subgroups worked on specific steps and reported back to the team leader. The role that the intervention researchers played as team support staff and communication links helped to maintain team cohesion and move the work forward. If the P^2OSH method were used in other hospitals it is likely that occupational and environmental health and safety staff would be needed for this role.

The hospital staff preferred direct substitutes for conventional chemicals because they required less work reorganization. Unfortunately, these were not always the alternatives that the researchers judged to be the best with respect to protecting health and the environment and possibly even with respect to long-term cost savings for the hospital. For example, in the case of formaldehyde replacement in histopathology, microwave tissue fixation was identified as a possible alternative but the lab staff did not want to pilot it because of high initial costs and considerable work reorganization and process changes. One way to address short- versus long-term trade-offs is to use the P^2OSH assessment as a continual improvement process over a range of time frames.

Commitment at all levels of the organization involved in the change was needed to implement an alternative successfully. Top management commitment was needed for employees to understand that the work was a priority and how it could be used to improve the organization. The commitment needed most, however, was from the mid-level clinician/manager of the department where the alternative was introduced. The hospital departments in this study operated somewhat autonomously from the central administration, and work procedure and purchasing decisions were determined by department managers. The participation of laboratory and housekeeping staff also was important for the successful conduct of the intervention but was even more important to maintain the change. When the intervention status was reviewed 6 months after implementation at each of the hospitals, the staff had the most in-depth experience with the alternative and knew best how to maintain or stop it.

It is difficult to introduce a P^2OSH change in a worksite that is undergoing significant organizational restructuring. Several of the 18 hospitals originally contacted for study participation were involved in mergers or other major organizational and economic restructuring. These hospitals were not pursued for study enrollment because it was not possible to ensure management commitment or adequate hospital staff involvement for the duration of the study. This decision did not affect development of the intervention/alternatives assessment model or the survey instrument. However, these were applied in hospitals with relatively stable organizational structures.

Even though changing to less hazardous alternatives can obviate the need to comply with occupational and environmental regulations, legal standards remain important incentives for hospitals to reduce or eliminate hazards. In this study, environmental regulations provided a greater incentive than occupational safety and health regulations due to the higher cost of environmental fines and potential negative publicity in the hospitals' neighborhoods. Administrators in all of the hospitals reported that it was an organizational goal to be seen as good neighbors and as promoting health. Two of the hospitals that implemented mercury reduction and elimination policies in the labs and later extended the policy to the entire hospital. These two hospitals were in the water resource district that more strictly regulated mercury.

It was easier to engage managers in a process that focused on finding new, improved alternatives rather than one focused only on hazard identification and control. Although exposure assessment and control are important elements of the P^2OSH process, these are performed to assist the main objective: the identification and evaluation of improved alternatives. To managers, the search for alternatives represents innovation and solutions and is seen as building the organization, even if the change process requires extra work. Managers view hazard controls, such as engineering devices or personal protective equipment, as necessities but ones that constrain (control) productivity by taking resources and time away from the main production process. In addition, the hazard remains in the workplace with the potential to be "out of control." Product and/or process redesign remove or significantly reduce the *source* of the hazard while improving the production process and allowing it to develop in news ways.

CONCLUSIONS

Substitution/elimination is the top choice in the occupational hygiene hierarchy of workplace hazard controls.[21] The methods presented here are intended to turn this principle into practice. In reality, few truly harmless alternatives exist, but rather than allowing this to block improvement efforts, the P^2OSH method should be used as a continuous process to identify, implement, and evaluate substitutes as they become available. This means that rigorous exposure assessment must remain an essential part of the P^2OSH method. Another key aspect of the approach described here is that occupational hygienists have important roles to play as agents in hospital organizational change and in assessment and design of alternatives at the worksite. These activities represent an expansion of the conventional role of occupational hygienists, but it is a role for which they are already well prepared.

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