RISK REDUCTION IN THE CHEMICAL ENGINEERING CURRICULUM

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Since Bhopal, words such as hazard, risk, waste, and chemical seem to be synonymous to the public and the media. There is increasing public, government, and industry awareness and concern over a number of problems: hazardous and toxic chemicals in the workplace, the environment, and home; increasing quantities of waste and costs of disposal, along with limited treatment capacity; industrial and transportation spills and accidents involving chemicals; contamination of water supplies; etc.

These concerns are being manifested by more (and tighter) local, state, and federal regulations. At the same time there is public opposition to things such as siting of incinerators, landfills, and industrial operations involving hazardous materials.

In response to the problem, the US Environmental Protection Agency created the phrase *Risk Reduction Engineering* as part of a multimedia-based "Pollution Prevention" program. The goal is to minimize wastes that present current and future risks to human health and the environment.

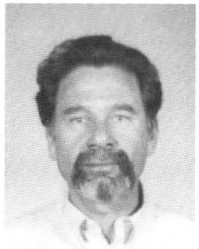
With regard to chemical engineering, the risk reduction concept encompasses a broader spectrum which includes safety, health, and loss prevention, as well as waste management and environmental controls. Risk reduction also deals with the technological/societal interface in the sense that management, regulations, and public relations are all components.

All of these concepts are implicit in chemical engineering education. However, despite the apparent job opportunities for chemical engineers in, for example, environmental engineering, risk reduction still seems to be largely ignored in the curriculum.

In particular, chemical engineering will play a major role in risk reduction by developing, assessing, and applying the technology that will predict, measure, control, and reduce risks from hazardous materials. It is thus timely (and perhaps mandatory) that, in the chemical engineering curriculum, greater emphasis be placed on topics such as waste reduction, safety, and health. While it is not necessary to make experts of all the students, the undergraduate program is a logical place to begin providing a background for recognition of potential hazards and an awareness of safe and clean process and product designs. Risk reduction can be addressed in most chemical engineering courses, from general chemistry to plant design, and the concepts should be easily understood by the students.[1]

I do not believe that new engineering programs in safety and health or waste-reduction engineering are needed, such as those that exist, for example, in environmental engineering. Much of the relevant knowledge and tools are implicit in the existing chemical engineering curricula. However, concepts such as hazardous materials, engineering controls, and materials substitution, are *not* usually covered, and could, at the least, be presented through example and homework problems such as those available from the AIChE Center for Chemical Process Safety.[2]

Risk reduction can be viewed as a unifying general concept that will provide an awareness, sensitivity, knowledge, and positive attitude for the students' future stewardship of health, safety, and the



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environment. Inclusion of these areas in the curriculum could be facilitated without adding numerous courses by incorporating them in the "Risk Reduction" spectrum. For example, in the materials and energy balances course, the properties, effects, and management of hazardous materials can be presented from the viewpoint of simultaneous concerns in the workplace, home, and environment.

In this paper, inclusion of risk reduction in the curriculum will be explored, and current related teaching efforts at the University of Louisville will be described. General principles and commonalities, synergies, and trade-offs between the components will be emphasized.

RISK REDUCTION COURSES AT LOUISVILLE

Several ideas for including safety and health in the chemical engineering curriculum have been previously presented.[1,3] These ideas can also be put into the general framework of risk reduction since many of them also pertain to environmental concerns. At the University of Louisville, risk reduction was incorporated into the material and energy balances course when I last taught it. A one-hour course entitled " Safety, Health, and Environment," will be mandatory for juniors in the spring 1991 term, and a two-course sequence, "Safety and Health" and "Industrial Waste Management," was developed as first-year graduate (500-level) electives. (These two courses would also be suitable as senior electives, but our seniors do not have electives.) Graduate students can also take elective courses in "Membrane Separations" and "Chemodynamics," which are both related to risk reduction. Graduate students at the University of Louisville include our fifth-year Master of Engineering (M.Eng.) students.

A common feature in the material and energy balances, safety and health, and industrial waste management courses is a segment we call "In the News." During the first five minutes of class, articles from the local newspaper, *Time* magazine, *Chemical & Engineering News, etc.,* which are related to either chemical safety and health or environmental issues are discussed. Since Louisville is a highly-industrialized city there is always some local or state news that the students can relate to, and this heightens their interest in the courses. In my opinion, the day-to-day real-world relevance of these courses is an important feature. In contrast to more traditional courses, students asked many questions. It is perhaps not so surprising to find that students *are* interested in risk reduction and that many have chosen chemical engineering as a career for that very reason.

In particular, chemical engineering will play a major role in risk reduction by developing, assessing, and applying the technology that will predict, measure, control, and reduce risks from hazardous materials.

Sophomore students interview for their first co-operative internship position while taking the material and energy balances course, and the M.Eng. students are interviewing for permanent positions at the same time. Both groups asked the interviewers about the company's health, safety, and environmental practices and opportunities. Feedback from the interviewers indicated that this helped to create a positive impression of our students. After their first co-op position, many of the sophomore students reported that they had dealt with risk reduction material covered in the material and energy balances course, *e.g.,* materials safety data sheets, oxygen demand of waste-waters.

Specifically, some of the teaching modules from the AIChE Center for Chemical Process Safety[2] were used in the material and energy balances course. The students were also required to fill out a materials safety data sheet. Next time I teach the course, problems developed from waste minimization assessments will be incorporated into the course, *e.g.,* recovery of nickel salts from electroplating rinse-waters.

COMMON FORMAT OF COURSES

"Safety and Health" and "Industrial Waste Management" are broad-based survey courses offered at the first-year graduate level in the fall and spring semesters, respectively. We attempt to describe these courses in a manner that emphasizes generic and common features. Some of the risk reduction concepts can be covered in either course or in both.

The course outlines by topic are shown in Table 1, and the textbooks used are listed in Table 2. The same generic topics are covered in both courses, including regulations and standards, properties, effects and characteristics of hazardous and toxic materials, modeling, heirarchy of management and control options , preventive measures such as substitution and inventory control, control technology, and risk assessment. By necessity, there is some overlap of specifics between the two courses, even though

repetition is minimized. For example, SARA Title III is discussed in both courses. However, OSHA regulations are discussed primarily in Safety and Health, and RCRA primarily in Industrial Waste Management. Threshold limit values, while referred to in Industrial Waste Management, is covered in depth in the safety and health course, while hazardous waste lists are discussed in Industrial Waste Management. Hazardous waste characteristics are discussed in both courses, but with different emphasis. However, in each course the commonalities and relationships between the different aspects of risk reduction are pointed out.

Both courses include student team audits and inspections. In Safety and Health, safety and health inspections of the chemical engineering laboratories were done, while in Industrial Waste Management the students did a waste minimization assessment at a local plant. The students found the inspections to be eye-opening, interesting, educational, and fun. Either of these courses is suitable for seniors, and to help meet accreditation guidelines they can easily be structured to include design and to enhance student communication skills. As an aside, student participation in safety, health, and waste reduction assessments is an excellent teaching tool. Several students

TABLE 1
Course Outline by Topics

Safety and Health Course	Generic and Common Topics	Industrial Waste Management Course
	Materials Properties: Effects and Hazards	
• Toxicology • Epidemiology • Fires and explosions • Reactivity	• Dose response • Risk	• Health/environmental effects of pollutants • State of the environment • Hazardous waste characteristics
	Regulations and Liability	
• OSHA, TSCA, HMTA, SARA (Worker right to know)		• RCRA, CWA, CAA, CERCLA, HMTA, TSCA, SARA (Community right to know, toxics release inventory)
	Emission Sources, Types, and Characteristics: Criteria and Definitions	
• Gases, vapors, particulates • Threshold limit values • Other hazard classifications, *e.g.*, NFPA	• Materials safety data sheets • DOT guidelines	• Hazardous/toxic waste lists and characteristics • Hazardous waste generator reports • Air toxics • Wastewater parameters
	Modeling	
• Source models for worker exposure	• Radioactivity concentration guide for water • Ambient carbon monoxide standard Coburn, Forster, Kane equation • Dispersion	• Air pollution: Smog 0_3, NO_x, VOCs
	Management, Hazards Identification, Inspections	
• Checklists, surveys, reviews, HAZOP • Accident investigations • Risk assessment fault and event trees, probability	• Hierarchy for prevention and control	• Environmental audits • Waste minimization assessments
	Prevention, Protection, Engineering Controls	
• Protective equipment and clothing, monitoring • Isolation, ventilation • Relief valves • Suppression of fires and explosions	• Materials substitution, product/process modification • Inventory control • Emergency response, spill prevention control	• Underground storage tanks • Transportation of wastes • Industrial wastewater pretreatment • Waste reduction, resource recovery, recycling • Thermal treatment • Landfill disposal • Chemical, physical, and biological treatment • Injection well disposal
	Site Remediation	
• Worker protection		• Hazard ranking system • Containment/treatment technologies • Financial considerations
	Student Team Project	
• Safety and health inspection of chemical engineering building		• Waste minimization assessment of local manufacturing facility

are participating in a funded waste minimization assessment program and are involved with the preparation of preliminary engineering feasibility studies for a variety of different manufacturing facilities. Two of these students have received job offers from major companies to work in waste reduction after graduation.

In general, the courses are more descriptive and qualitative than quantitative and theoretical, although a limited number of theoretical/calculational problems are assigned. Safety and Health is the more technical course, primarily because of the recent availability of a new chemical engineering textbook.[4] However, the students are made aware of the relevant principles and techniques from traditional courses and how to apply them. For example, material from *Transport Phenomena*[5] is used to estimate relative evaporation rates of solvents as a measure of fire and health hazards and to estimate solvent loss. With regard to risk reduction, the students already know much of the necessary technical content, but need to be shown where and how to use it. In this sense, the instructor serves as more of a facilitator than a subject-matter expert.

Since safety, health, waste management, etc., cover such a wide range of topics, it would be difficult for any one instructor to have sufficient overall expertise. Also, the available textbooks in these subjects do not cover many relevant topics. Therefore, quest speakers are used to lecture in areas that they work in, such as waste-water treatment, air-pollution control, and toxicology. The part-time students are an excellent classroom resource, and some of them also make presentations related to their work. They can often answer classroom questions better than I can, and they provide excellent input to classroom discussions. A partial listing of some of the topics presented by guest and student speakers in given in Table 3.

Field trips and plant visits are also part of both courses (see Table 4). During some field trips, in-plant lectures are given. The guest lectures and field trips were highly valued by the majority of the stu-

TABLE 2
Textbooks and Other Required Materials

Safety and Health
- Crowl and Louvar, *Chemical Process Safety: Fundamentals with Applications,* Prentice Hall, 1990
- Hammer, *Occupational Safety Management and Engineering,* Prentice-Hall, 1985
- ACGIH, *Threshold Limit Values and Biological Exposure Indices* (latest edition)
- *NIOSH Pocket Guide to Chemical Hazards*

Industrial Waste Management
- Wentz, *Hazardous Waste Management,* McGraw-Hill, 1989
- Martin and Johnson, *Hazardous Waste Management Engineering,* Van Nostrand-Reinhold, 1987
- Dawson and Mercer, *Hazardous Waste Management,* Wiley-Interscience, 1986 (not used in course, but recommended)

Other
- Hoover, Hancock, Hutton, Dickerson, and Harris, *Health, Safety and Environmental Control,* Van Nostrand-Reinhold, 1989

TABLE 3
Guest Lectures

Safety and Health
- "Applications of Toxicology Data to Chemical Operations," by Health and Safety Director, Rohm & Haas
- "Material Safety Data Sheets," by Occupational Health Consultant
- "Du Pont Philosophy and Management System for Safety and Health," by Maintenance Supervisor, Du Pont
- "Fire Safety and Industrial Hygiene," by Senior Loss Control Engineer, Travelers Insurance
- "Cleanup of Superfund Hazardous Waste Sites," by Emergency Response Engineer, EPA Contractor
- "Health Hazard Identification," by Field Inspector, Kentucky Department of Labor

Industrial Waste Management
- "Environmental Management in the Chemical Industry," by Environmental Affairs Manager, Du Pont
- "Environmental Regulations," by Environmental Attorney or Assistant Commissioner, Kentucky Department for Environmental Protection
- "Legal Liability for Environmental Practitioners," by Environmental Attorney
- "Industrial Waste-Water Pretreatment and the Morris Forman Waste-Water Treatment Plant," by the Director, Industrial Wastes Metropolitan Sewer District
- "Air Pollution Modeling and the Local Smog Situation," by Director, Jefferson County Air Pollution Control Board
- "Prevention, Containment and Response to Hazardous Materials Spills," by Spill Control Engineer, Metropolitan Sewer District
- "Leaking Underground Storage Tanks," by Consultant
- "Waste Incineration," by USEPA Speaker or Technical Operations Manager, Louisville Incinerator
- "EPA Programs in Waste Minimization," by Risk Reduction Engineer, USEPA
- "Environmental Audits for Property Acquisition," by Consultant
- "Remediation and Closure at a RCRA Landfill," by Environmental Manager, Du Pont
- "State of the Environment in Kentucky," by Environmental Activist Attorney
- "Transportation and Disposal of Hazardous Wastes and Waste Oils," by Hazardous Waste Management Broker
- "Solid Waste Disposal and Landfill Design: Engineering and the Decision Making Process," by Director, Division of Waste Management, Kentucky Department for Environmental Protection

dents, and they particularly appreciated the networking aspect, as did I.

Many useful movies and video tapes are available in safety, health, and environmental areas, and they are also used in class (see Table 5). The videos, many of which are excellent dramatizations, often depict things much better than the instructor or a text can. Study guides for the videos, in the form of assigned questions, are given to the students. Because of the deficiencies within the textbooks and the lack of breadth and currency of the topics, numerous additional materials are also given to the students (see Table 6).

PART-TIME STUDENTS ATTRACTED TO COURSE

The primary prerequisite for Safety and Health and Industrial Waste Management is a BS in science, math, engineering, or its equivalent. Thus, the courses are taken by first-year graduate and M.Eng students from other departments, along with part-time students from industry, consulting firms, and government agencies. Many part-time students come from as far as sixty miles away.

The courses are offered on a one night per week basis, 2-hours 45-minutes per class, so as to attract part-time students. Announcements of the courses are placed in newsletters of various regional and statewide professional organizations such as the Kentucky Waste Reduction Centers and the Air and Waste Management Association.

The first offering of Industrial Waste Management drew about thirty-five students, two-thirds of which were part-time students. Several of the part-time students also took Safety and Health which was taught the following year with fifteen students (nine of them part-time). In the second offering, Industrial Waste Management had eighteen students (fourteen of them part-time) and Safety and Health had ten students (nine of them part-time). These courses are being recommended to co-workers, and the part-time students have requested additional courses in risk reduction. In response, we plan to offer a course entitled Waste Reduction, Treatment, and Disposal in the future.

Many of the part-time students are not pursuing a degree and thus can register through Continuing Studies rather than through the usual, more tedious, routes. Students not applying the credits towards a degree, along with non-chemical engineering students (who may lack some of the technical

TABLE 4
Field Trips and Plant Visits

Safety and Health
- Safety Features in Emulsion Polymerization Process: Rohm & Haas
- Emergency Response Simulation: Jefferson County Hazardous Material Mutual Aid Group
- Hazardous Waste Incinerator Siting Hearing

Industrial Waste Management
- Waste-Water Treatment Plant: Metropolitan Sewer District
- Industrial Waste-Water Pretreatment Plant: General Electric
- Municipal Solid Waste Incinerator
- Industrial Landfill: Waste Management Company
- Waste Minimization Assessment: BASF

TABLE 5
Video Tapes and Films[1]

Safety and Health
- *Acceptable Risk,* ABC Television
- *Safety in the Chemical Process Industries,* AIChE-7 Tape Series
- *Safety and Loss Prevention, First Impressions,* BASF
- *Chemical Toxicity and How it Affects You and Your Job,* Celanese
- *MSDS: Cornerstone of Chemical Safety,* ITS
- *Health Hazard Evaluation: Environmental-Epidemiological Study of Workers Exposed to Toluene Diisocyanate,* West Virginia University
- *Dual Protection,* NIOSH, (Paints and Coatings)
- *First Considerations,* NIOSH (Pesticide Formulating Plants)
- *Case Studies—Flixborough, Bhopal*
- *BLEVE,* NFPA
- *Confined Space Entry,* NIOSH
- *Oxidizers: Identification, Properties, and Safe Handling,* CMA

Industrial Waste Management
- *Doing Something,* CMA
- *The Need to Know,* CMA
- *The Burial Ground,* (Hazardous Waste Dumping)
- *The Toxics Release Inventory: Meeting the Challenge,* EPA
- *In Your Own Back Yard,* NFPA (Underground Storage Tanks)
- *Tank Closure Without Tears: An Inspectors Guide*
- *Beyond Business as Usual,* EPA (Hazardous Waste Management)
- *Marine Shale Processor, Let's Clean Up America,* (Incineration/Recycling)
- *Pollution Prevention by Waste Minimization,* 3M Company
- *Less is More: Pollution Prevention Pays,* EPA (Waste Minimization)

Common to Both Courses
- *Carcinogens, Anti-Carcinogens, and Risk Assessment,* Council for Chemical Research
- *First on the Scene,* CMA (Emergency Response)
- *Teamwork,* CMA (Emergency Response)
- *Dry Paint Stripping,* Promaco/Schlick (Waste Reduction, Safety)

[1] Not all used in a given semester

background), can take the course on a pass/fail or audit basis to minimize the pressure of grades. The courses are taught on an informal, relaxed basis (similar to a workshop or seminar) which enhanced the students' enjoyment. For example, on some nights when movies or video tapes were being shown, popcorn was served. Because of the maturity of the students, it was a pleasure to be on a more collegial basis with them, and as pointed out earlier, the part-time students are an excellent classroom and networking resource.

SYNERGIES BETWEEN APPLICATIONS

Some examples of the unifying concepts of risk reduction, resultant synergies, and trade-offs are briefly explored. These approaches can be used in either of the two survey courses or as a component of any appropriate required course.

One example of synergy is in finishing operations such as paint and coating applications. The same properties that make wastes and emissions from these operations hazardous also contribute to exposure that endangers employee health and plant safety. Thus, waste reduction measures will simultaneously benefit employee safety and health, and vice versa. These measures include substitute materials and alternative methods, such as aqueous-based rather than solvent-based paints, powder coatings, and airless or electrostatic spray guns. Another synergy that occurs with waste reduction is conservation of raw materials. For example, increased recycling of plastics can simultaneously reduce dependence on foreign crude oil.

Trade-offs or conflicts can also be shown (for example) between waste minimization and quality management, and between safety and waste disposition considerations. Reworking of off-specification and waste solids from tank cleaning into useful products is a waste minimization technique. Spills on the one hand must be properly retained and disposed of so as not to damage the environment. On the other hand, a reactive (but improper) response to a hazardous materials spill might be to flush it immediately down the drain.

TABLE 6
Examples of Supplemental Handout Materials

Safety and Health
- Materials Safety Data Sheet and Glossary
- Carbon Monoxide Health Effects and Standards
- Health Hazard Classification, BASF
- *Safety and Hazards Evaluation Review—Protocol,* Rohm & Haas
- OSHA Hazards Communication Standards

Industrial Waste Management
- Glossary of Environmental Terms
- *Leaking Underground Storage Tanks: The New RCRA Requirements,* EPA
- *Understanding the Small Quantity Generator Hazardous Waste Rules: A Handbook for Small Business,* EPA
- Used Oil Fuel Classification Under RCRA
- Definitions, Important RCRA Dates (Land Bans), and TCLP Requirements
- Environmental Progress and Challenges: EPA's Update, 1989
- *Waste Minimization: Environmental Quality with Economic Benefits,* EPA
- 1988 SARA Title III Section 313 Summary Report (Kentucky), County Releases
- Estimating Releases and Waste-Treatment Efficiencies for the Toxic Chemical Release Inventory Form

Common to Both Courses
- *Emergency Response Guidebook,* DOT
- *Hazardous Materials Warning Placards,* DOT
- *Federal Statutes and the Control of Toxic Substances,* Kentucky Department for Environmental Protection
- *Hazardous Waste Sites and Hazardous Substance Emergencies,* NIOSH 1982
- *Explaining Environmental Risk,* EPA
- The 13 Commandments of Hazardous Materials Response

WHAT IT WILL TAKE

Some preliminary ideas concerning the inclusion of the risk reduction spectrum into the curriculum have been presented and exemplified in this paper. Because of the increasing importance of risk reduction to chemical engineers, further exploration of ways to incorporate these concepts seems mandatory. Availability of teaching materials such as the problem sets available from the AIChE Center for Chemical Process Safety can facilitate this process. Hopefully, such materials will be available from the newly-established AIChE Center for Waste Reduction Technology.

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