OCCUPATIONAL SAFETY AND HEALTH MATERIALS FOR INTEGRATION INTO ENGINEERING CURRICULA

Instructor's Resource Guide

Prepared by:

N. Bruce Hanes, Ph.D.
Annette M. Rossignol, Sc.D.
Tufts University
Department of Civil Engineering
Medford, Massachusetts 02155

ABSTRACT

This course package contains educational materials related to occupational health and safety developed by faculty of the Tufts University College of Engineering for incorporation into <u>existing</u> undergraduate courses for engineering students.

Five groups of educational materials were developed, each group by participating faculty members in the following departments:

> Chemical Engineering
> Civil Engineering
> Electrical Engineering
> Engineering Design
> Mechanical Engineering

The strategy of exposing a majority of undergraduate engineering students to pertinent information about occupational health and safety within existing departmental courses will reach virtually <u>all</u> undergraduate engineering students. It is hypothesized that engineers are more likely to think of safety at the critical time if the educational exposure is associated with basic engineering subject matter that is used in later practice. It is also anticipated that an introduction to occupational health and safety concerns in this setting will stimulate further study. Such a strategy can be effective only if participating faculty are willing to incorporate appropriate educational materials into required course work for undergraduate engineering students.

Unfortunately, appropriate course materials in the major undergraduate engineering areas are not readily available at this time. The purpose of this course package is to provide such materials and/or ideas that may be used by engineering faculty members where appropriate.

DISCLAIMER

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INTRODUCTION

BACKGROUND

"Engineers, and students of engineering, need to be cognizant of
their professional stature and the associated responsibilities. In
the eyes of the court, engineers, as professionals, are unlike an
ordinary employee and, hence, cannot simply carry out assignments
without giving some thought to the broad consequences of their
actions. For example, the courts understand that to carry out the
responsibilities described in The Professional Engineer's Code of
Ethics, 'to hold paramount the public safety, health, and welfare,'
the engineer must routinely make judgments as to whether the
overall effect of a proposed course of action may be harmful to the
public interest. Obviously, in order for engineers to make
accurate decisions, they must be capable of recognizing potential
hazards and have some familiarity with the various techniques for
eliminating or controlling them."

The above conclusion from Paustenbach's article entitled "The Need to Edu-
cate Engineers in Occupational Safety and Health and a Proposal for Schools
of Engineering" (1984)[1] summarizes the reasons why the Tufts University
College of Engineering proceeded with the development of its proposed occu-
pational safety and health engineering program. The strategy for this pro-
gram was described in a report dated September 1984 and included the develop-
ment of educational materials which integrate occupational safety and health
engineering concepts into required courses for undergraduate engineers.

The strategy was based on the results for a survey of 8 Engineering faculty,
64 Engineering students, and 53 Engineering alumni.[2] The survey asked
participants to rate the perceived relevance of 33 health and safety
engineering tasks to the practice of engineering. Table 1 summarizes the
survey findings.

TABLE I

Perceived Relevance of 33 Health and Safety Engineering Tasks

    1. represents topics with the highest relevance
    2. represents with mid-level to high relevance
    3. represents with mid-level to low relevance
    4. represents with the lowest relevance

	Average Rating		
Engineering Area	Faculty	Student	Alumni
Chemical	1.8	1.9	2.0
Civil	2.3	2.2	2.3
Design	2.9	-	-
Electrical	2.3	2.1	2.6
Mechanical	1.9	2.1	2.8

RATIONALE

The integration of occupational safety and health engineering resource materials into existing course work is an effective and practical method for reaching all undergraduate engineering students. Because diversified course materials in the major undergraduate engineering areas were not readily available, faculty members representing five engineering areas developed lecture, case study and/or laboratory materials. These materials will be presented in undergraduate courses for engineers during the 1985-86 academic year. The five engineering areas are:

1. Chemical Engineering
2. Civil Engineering
3. Electrical Engineering
4. Engineering Design
5. Mechanical Engineering

PLANNING PHASE

The plan to integrate occupational safety and health materials into the existing engineering curricula was reviewed with Frederick C. Nelson, Dean of the Tufts University College of Engineering. Dean Nelson expressed support for the program and offered to fund a fifth faculty member to provide a greater impact on existing course work. It was decided that the faculty members would be selected by the individual departments through the chairman. Dean Nelson also suggested that the University Safety and Health Engineering Work Group consist of the five participating faculty members, the Project Directors, and the Dean of Engineering, in addition to the outside consultants. This arrangement would assure direct interaction among the individuals most directly involved in the proposed program.

A letter was sent to each department chairman briefly outlining the project and requesting a meeting. In all cases, the engineering department chairmen expressed both interest and support for the proposed program. Faculty participants were identified, and individual meetings with the project directors were held to discuss appropriate topics for the course materials to be developed.

Dr. Melvin W. First, of the Harvard School of Public Health, and Mr. Wesley E. Straub, of NIOSH, agreed to provide advice to the faculty participants in the development of the course materials.

A meeting of the Tufts University Safety and Health Engineering Work Group was held to introduce participating faculty to the consultants and to identify topics for the development of course materials. The members of the work group are given in Appendix A.

DEVELOPMENT PHASE

The faculty participants and their course material topics as developed through the Tufts University Safety and Health Engineering Work Group are as follows:

1. Professor Jerry Meldon, Department of Chemical Engineering

    Professor Meldon developed materials that identify the health effects of chemicals, fate of chemicals within a plant, and the fate of effluents. Specifically, he addressed the following topics:

    a. Toxic Releases at Union Carbide Facilities in the Kanawha Valley of West Virginia.

    b. Necessity of Design for Possible Runaway Reactions.

    c. Liquified Natural Gas Stratification and Rollover.

2. Professor Lewis Edgers, Department of Civil Engineering

    Professor Edgers developed educational materials in the area of failure of constructed facilities. The topics selected are:

    a. Vaiont Dam Failure.

    b. Safety Evaluation of Existing Dams.

    c. Design Professional Failure and Loss Prevention Programs.

    d. Construction Machinery Safety.

3. Professor Arthur Uhlir, Department of Electrical Engineering

    Professor Uhlir developed materials related to the potential for microwaves to cause cataracts, and to the dangers and treatment of high-voltage exposure.

4. Professor John G. Kreifeldt, Department of Engineering Design

    Professor Kreifeldt developed materials related to back injuries from manual materials handling and to the failure to warn in consumer products liability cases.

5. Professor Anil Saigal, Department of Mechanical Engineering

    Professor Saigal developed materials related to occupational problems associated with noise and hazard control technology.

EDUCATIONAL MATERIALS

The Educational Materials are presented in five sections representing the five participating engineering areas. Each section consists of an introduction which indicates the form used for presentation of the course materials, for example lecture, case study, or laboratory exercise. Also included in the introduction is a catalog description of the course in which the materials will be integrated.

The body of each section contains the actual lecture, case study, laboratory and/or other course material. In general, the course material is divided into natural divisions for its presentation. For example, if three lectures were prepared, then this section is divided into three parts.

The educational materials are presented in the following order: chemical engineering, civil engineering, electrical engineering, engineering design, and mechanical engineering.

CONCLUDING REMARKS

The materials developed will be incorporated into existing courses for undergraduate engineering students during the 1985-86 academic year. This strategy is consistent with the NIOSH-sponsored report, "Comprehensive Occupational Safety and Health Engineering--Academic Program Development Strategy"[2].

SELECTED REFERENCES

(1) Paustenbach D.J., Occupational Safety, Mechanical Engineering, 106 (3), pp 76-82, March 1984.

(2) Hanes N.B., Rossignol A.M., Comprehensive Occupational Safety and Health Engineering--Academic Program Development Strategy. U.S. DHHS (NIOSH), Publ. No. 84-690, 1984.

Appendix A

Tufts University Safety and Health Engineering Work Group

Anthony D. Cortese   Center for Environmental Management

Lewis Edgers   Tufts/Civil Engineering

Melvin W. First   Harvard School of Public Health

N. Bruce Hanes   Tufts/Civil Engineering

John G. Kreifeldt   Tufts/Engineering Design

Jerry Meldon   Tufts/Chemical Engineering

Frederick C. Nelson   Tufts/Dean of Engineering

Annette M. Rossignol   Tufts/Civil Engineering

Anil Saigal   Tufts/Mechanical Engineering

Wesley E. Straub   USPHS/CDC/NIOSH

Arthur Uhlir   Tufts/Electrical Engineering

Health and Safety Course Material

in

Chemical Engineering

by

Jerry Meldon, Ph.D.
Chemical Engineering Department
Tufts University
Medford, MA 02155

UNIT OVERVIEW

METHODS: Case Studies and Lectures

PURPOSE: Introduction of chemical engineers to potentially dangerous
                consequences of plant design and operation decisions,
                particularly in the handling of volatile liquids.

OBJECTIVES: Upgrade the safety consciousness of graduating chemical
                engineering students.

RATIONALE: The practicing chemical engineer must develop an awareness of
                the sequences of events that may lead to explosions or the
                release of hazardous chemicals.

PRESENTATION: Case study material is designed for presentation and
                discussion in four one-hour classes. Substantial reading
                material is recommended.

INSTRUCTOR
MATERIAL: Chalkboard.

STUDENT
MATERIAL: Handouts, articles and monographs on library reserve.

INTRODUCTION

This report contains material suggested for introduction into the undergraduate chemical engineering curriculum, the goal of which is to upgrade the safety consciousness of graduating professionals. The material covers engineering as well as chemical aspects. Although chemical toxicology and industrial hygiene form part of the material, the emphasis is upon improving awareness of the hazards of breakdown of safety systems and rupturing of vessels. The material on safety in chemical engineering practice, consisting of lectures, readings and case studies, is appropriate for use in the following undergraduate courses:

A. Industrial Chemical Calculations (applications of material and energy balances to industrial processes).

ChE 10 Industrial Chemical Calculations. Applications of material and energy balances to industrial processes; engineering units of measurement; stoichiometric relationships. Use of digital computers is required. Prerequisites: Chemistry 31, Mathematics 6 or 7 or 12.

B. Unit Operations (fluid mechanics).

ChE 21, 22, 24 Unit Operations. Fluid mechanics, pumps, and meters; heat transfer in solids and fluids, heat-exchanger design; stagewise operations including distillation, absorption, humidification, extraction. A laboratory in the operation of chemical engineering equipment is a part of 22 and 24. Prerequisites: Chemical Engineering 10, Engineering Science 7. One course each semester.

C. Chemical Engineering Thermodynamics

ChE 42 Chemical Engineering Thermodynamics. An intermediate course dealing with relations among thermodynamic variables; equations of state; thermodynamics of composition change, chemical and phase equilibrium; the concepts of statistical thermodynamics. Prerequisite: Engineering Science 7.

In addition, the two case studies below are intended for use in the senior course on Chemical Plant Design.

ChE 60 Chemical Plant Design. Design of a commercial plant and its economic evaluation are undertaken. The students working in groups

on assigned or selected portions of the overall project are required to make integrated use of a wide variety of fundamentals and principles gained from previous courses. Work laboratories are supplemented by appropriate lectures. Opportunity for independent study is provided. Use of digital computers is required. Prerequisites: Chemical Engineering 22 and 42.

MATERIALS DESCRIPTION (CASE STUDIES)

CASE STUDY OF AUGUST 1985 TOXIC RELEASE AT UNION CARBIDE FACILITY AT INSTITUTE, WEST VIRGINIA

On August 11, 1985, within months of Union Carbide's declaration that a Bhopal-like disaster could not occur at its Institute, West Virginia plant, a cloud of toxic gas escaped from that facility. The chemical was not methyl isocyanate, which killed over 2,000 in Bhopal, India in December of 1984. Nonetheless, 135 local residents required treatment for eye, throat and lung irritation caused by some three thousand pounds of hazardous chemicals (see table).

As consequences of the Bhopal, Institute and other recent hazardous chemical releases, the chemical industry has been under fire, Senate hearings and legislation are anticipated, and one of America's largest corporations, Union Carbide, has been forced to undergo belt-tightening to cover major losses and prepare for the outcome of lawsuits.

Chemicals Released on 8/11/85 (> 10 lb) (1)

Compound	Amount (lb)	Threshold Limit Value (2)	
		ppm(a)	mg/m^3(b)
Methylene chloride	650	100	350
Methyl isopropyl sulfide	550		
Isobutyrobnitrile	500		
Aldicarb nitrile	400		
Dimethyl disulfide	300		
Methyl mercaptan	275	0.5	1
Aldicarb amide	250		
Trimethyl isocyanurate	150		
Isobutyramide	125		
Acetone	95	750	1780
Volatile polymers	90		
Acetoxime	90		
1,3,5-Trimethylbiuret	75		
1,3-Dimethylurea	75		
Dimethyl sulfide	70		
2,4 Dithiapentane	65		
2 Methylthiopropene	40		

(a) Parts of vapor or gas per million parts of contaminated air by volume at 25ºC and 1 torr.

(b) Approximate milligrams of substance per cubic meter of air.

In light of the potentially profound consequences of a toxic chemical release, it is of importance that chemical engineers adhere strictly to the dictates of safety requirements, in both day-to-day plant operations and chemical process design. To develop appreciation for factors that trigger such catastrophes, the comparatively minor incident at Institute, West Virginia will be reviewed.

According to Union Carbide investigators, the summary of events is as follows (1,3):

Ten days before the incident, methylene chloride was pumped into the "aldi-carb" reactor (in which aldicarb oxime, or -methylthioisobutyraldoxime, is converted ultimately into the pesticide Temik[R]). The aldicarb oxime was then introduced. However, a flowmeter malfunction resulted in too much addition. Engineers then pumped the solution, via a temporary pipeline, to a second, glass-lined reactor that had not been employed in nine months (see Figure 1).

During the first week of August, steam flowed through leaky valves into the reactor jacket. According to reports in Chemical & Engineering News and the New York Times (1,3), this went undetected by Union Carbide operators. It caused the methylene chloride (boiling point 104ºF) to volatilize from the much higher boiling aldicarb oxime, and thereby raised the oxime concentration from 38 to 81 weight percent. Apparently unaware of this change in composition, operators attempted to pump the contents from this second reactor back into the aldicarb reactor on August 7. When operators concluded that the pump had completed the removal after two-and-a-half hours, they shut it off, apparently unaware that 500 gallons remained as a "heel" in the tank's convex bottom.

Steam continued to flow into the jacket of the presumed empty tank, further raising the heel's temperature. The operators would have learned of the rising temperature had they consulted the display of reactor conditions provided by the control room computer. Reportedly unaware of either the steam leak or the heel, they did not refer to the display.

From simulations of the apparent chain of events, Carbide investigators concluded that on August 11, 1985 the reactor temperature reached 300ºF. At this point, the aldicarb oxime apparently decomposed exothermically. A pressure alarm went off at 9:25 AM, indicating the rupture of a safety valve and the consequent rapid flow of gas via a knock-out pot and scrubber to a flare tower.

An operator in the control room who heard the reactor rumble looked out toward the flare tower and saw a large cloud of smoke. Almost instantaneously, the pressure indicator registered a steep drop, indicating

Figure 1

Flowsheet of aldicarb reactor, adjoining vessels and
emergency relief systems at Union Carbide's Institute, West
Virginia facility. (Compiled from several sources)

Emergency Vent Header

Aldicarb
Reactor

Flare

Knock-
Out
Pot

Oxidation
Reactor

Steam

To
Storage

Crystallizer

Caustic
Solution

Scrubber

Normal Vent Header
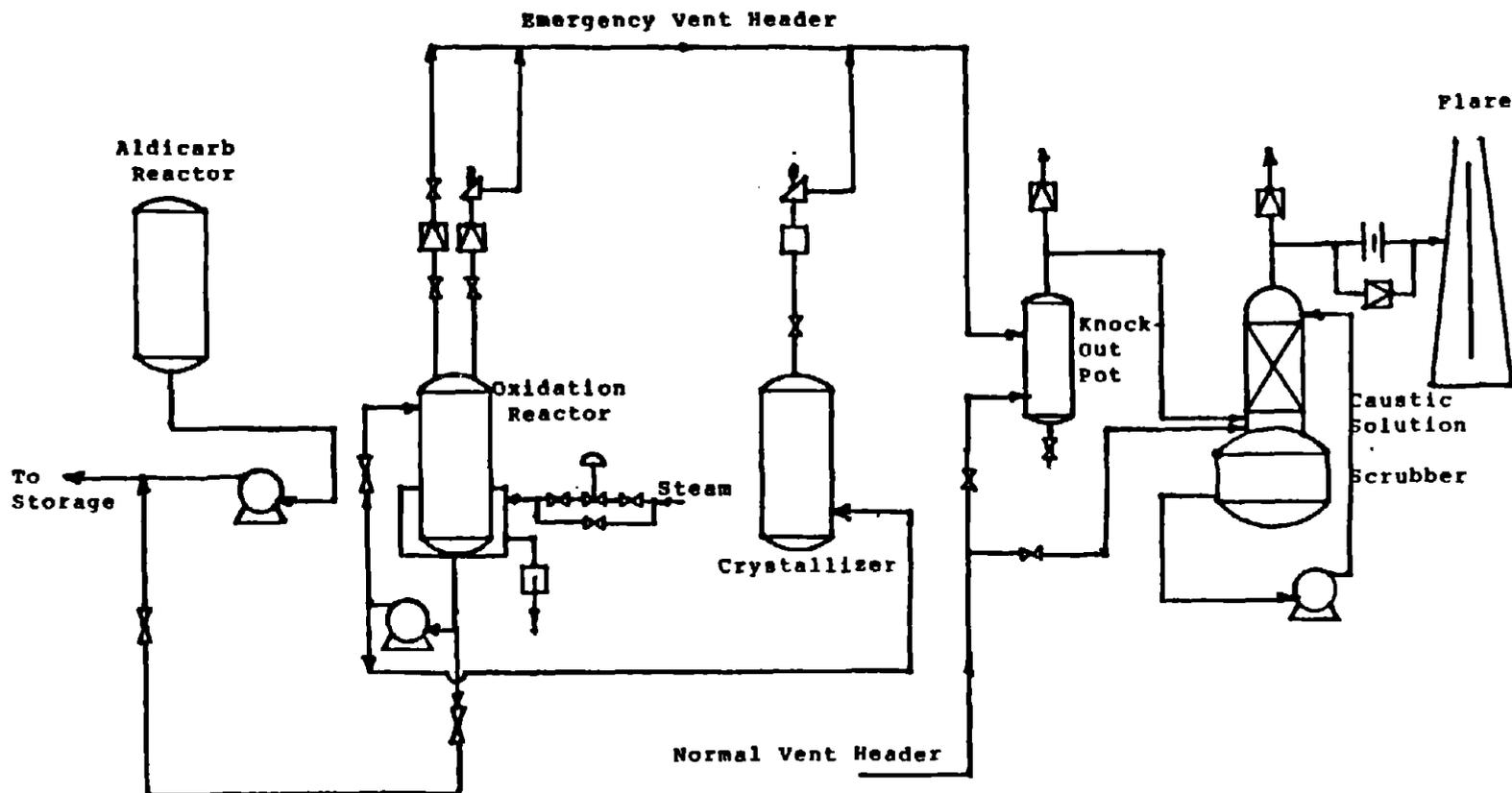
the opening of additional relief valves. The plant alarm was sounded at 9:26 AM. A thick white fume enclosed the yard and control room, trapping six operators who could not see the panels before their eyes. By 9:32 the eruption had ended, and the workers were quickly rescued. Although methyl isocyanate was not involved in the incident, a residue of MIC derivatives had lined the reactor's piping following its use as a MIC reactor the preceding November. Three hundred pounds of this solid residue were blown out together with the methylene chloride and aldicarb oxime breakdown products.

As pieced together in the New York Times reports (3), a chain of errors appeared to be responsible for the accident. Workers had reportedly not checked the temporary storage tank and associated instrumentation to ascertain whether they were in running condition. The data-logging computer was not programmed to print out the temperature, pressure and other conditions within the tank during its use. Workers were apparently aware that a dip stick, which might have indicated how much heel was left in the tank after pumping, was cracked.

It was known prior to the accident that heat could cause a runaway reaction involving aldicarb oxime. Nonetheless, the solution was stored in a tank with a steam jacket (installed for other reasons), and the operators reportedly had not insulated the tank from such heating.

The leakage of steam into the jacket caused slow temperature and pressure rises. This caused pressure alarms to sound repeatedly. Seemingly unaware of the alarms' significance, the operators reportedly shut them off and raised their set points repeatedly, ultimately to the maximum value of 20 psi (1,3).

Despite the fact that engineers had designed a safety system including a neutralizer and flare tower to treat escaped toxic chemicals, the chemicals escaped untreated. This was because high pressure blew out gaskets on three of the tank's portholes, two of which were large enough to accomodate workers assigned to clean the inside of the tank. Pressure also caused the rupture of a safety valve designed to open at 80 psig into the neutralizer and flare tower, and blew out a rupture disc on the piping leading to these treating units. Notably, the Bhopal disaster was caused in large part by temperatures and pressures in excess of design limits of valves and other pieces of equipment (3). Thus, the sizing of pipes and valves was a key aspect in both accidents.

CASE STUDY OF LIQUEFIED NATURAL GAS STRATIFICATION AND ROLLOVER

This study focuses on a phenomenon referred to in the natural gas industry as the "rollover" of the contents of huge LNG storage tanks (the diameter and height of which may each be in the hundreds of feet). Rollover is the culmination of a complex series of events, which manifests itself in the flashing of large amounts of LNG over a short period. The rapid generation of great amounts of vapor causes pressure relief valves to open, venting of huge clouds of gas, and thus an acute risk of flammability.

The most serious incident of rollover occurred at an Esso facility in La Spezia, Italy on August 21, 1971. Detailed analyses of the process dynamics leading to the venting of some 300,000 pounds of natural gas over a period of 75 minutes (creating a cloud that spanned the Italian peninsula), have elucidated the underlying causes and facilitated development of means to prevent it (4,5).

The incident appeared to commence when one of the La Spezia storage tanks (diameter 161 ft., height 88 ft., capacity 315,000 barrels, design pressure 500 mm H_2O at -260°F) experienced a sudden increase in pressure, causing discharge from the tank's safety valves and vent (6). The safety valves discharged for little over one hour, while the vent released at an unusually high rate for a total of three and one-quarter hours. The pressure rose to 710 mm H_2O at its peak. The pressure rise occurred some 18 hours after the tank had been filled by the LNG ship Esso Brega. Fortunately the tank remained fully intact throughout the incident.

As determined by Esso operators and engineers, the pressure rise had been spontaneous and uncontrollable. The cause was a "rollover" within the tank of a layer of high vapor pressure, ship's cargo that had lain at the bottom of the tank because it was denser than the tank's heel (what remained in the tank at the time of filling) and because the tank had been filled through a port at its bottom.

To understand what led to the sudden arrival of high vapor pressure liquid at the surface and consequent flashing, several factors had to be considered, most important the status of the tank at the time of filling and the compositions and conditions of the feed. Significantly, LNG is not a mixture of exactly defined composition.

When the storage tank began to be filled from the sea-going tanker Brega, it contained a heel of 60,000 barrels (16.5 ft.) of LNG. The heel was comparatively "light" and its effective vapor pressure was calculated to be 400 mm H_2O, as indicated in the table below. By comparison, the vapor pressure of the 210,000 barrels of comparatively heavy Brega LNG cargo was some 1660 mm H_2O and its composition as indicated in the table.

LNG STORAGE TANK AND SHIP CARGO COMPOSITIONS (5)

Component	Tank Heel	Brega Cargo
	(mole percents)	
Nitrogen	0.35	0.02
Methane	63.62	62.26
Ethane	24.16	21.85
Propane	9.36	12.66
n-Butane	1.45	1.94
i-Butane	0.90	1.20
n-Pentane	0.05	0.01
i-Pentane	0.11	0.06
Tank pressure (mm H_2O)	250	1100
Vapor pressure (mm H_2O)	400	1660
Density (lb/ft^3)	33.82	34.06
Quantity (Bbl)	60,000	210,000

The cargo from the tanker was not only denser than the tank heel, but hotter. This requires some explanation. LNG is kept at a cryogenic temperature of close to -260°F to minimize vaporization. Despite insulation, heat inevitably leaks through the walls of a storage facility - be it a land-based tank or the hull of a ship. During the Brega's voyage, in this case from a port in Libya, its cargo was continuously warming, which caused vaporization and venting. The lighter components were preferentially volatilized. Thus, the cargo was progressively enriched in the higher molecular weight components of natural gas, and so increased in density. At the same time, its temperature rose.

Because of the location of the filling port at the bottom of the storage tank, and its horizontal orientation, the entering cargo formed a stratified layer at the tank's bottom, lifting the cooler, less dense heel in the process. Consequently, a huge mass of liquid - the lower stratum, which filled the bottom 4/5 of the tank - was excluded from contact with the overhead gas phase (see Figure 2). Thus, a state of vapor-liquid disequilibrium prevailed.

Molecular diffusion and heat transfer between the two LNG layers was negligibly slow. Heat leakage through the tank's walls, however, promoted natural convection currents in each layer (see Figure 3). The increasing temperature of the lower stratum caused its density to decrease, while evaporation of lighter components from the upper stratum caused that layer's density to rise. Thus, the densities of the two layers converged. Ultimately, the density difference became so small that the convection pattern switched to the second of those illustrated. Bottom-to-top convection then promoted the flashing of a great quantity of previously unequilibrated liquid.

Despite its apparent complexity, the means to avoid rollover are quite simple. The fundamental cause is the incomplete mixing of heel and cargo LNG. It is of course possible to promote mixing by mechanical means. However, the energy thereby dissipated appears as heat, and therefore significant evaporative losses. On the other hand, if a heavy cargo is fed at the top of a tank, as it sinks it entrains a great quantity of heel and effectively mixes the tank. Correspondingly, introducing lighter cargo at the bottom of a tank produces a rising plume that similarly entrains the heel. All that remains is to predetermine the status of the cargo and feed LNG, and provide entry ports that ensure that gravitation and entrainment promote sufficient mixing without undue heat generation.

SELECTED MATERIAL FROM WHAT WENT WRONG? CASE HISTORIES OF PROCESS PLANT DISASTERS (7)

This recent monograph contains a wealth of material for safety curricula in chemical engineering. Chapters five and twelve include discussions that complement the material introduced above.

24 in. vapor outlet

Safety valve manifold

8 valves/tank

4 in. recycle
inlet

Carbon steel outer shell

Maximum normal level

2.5 in.

Insulation

88 ft

161 ft.

20 ft.

24 in.
inlet

16 in
outlet

Pile cap

Piles
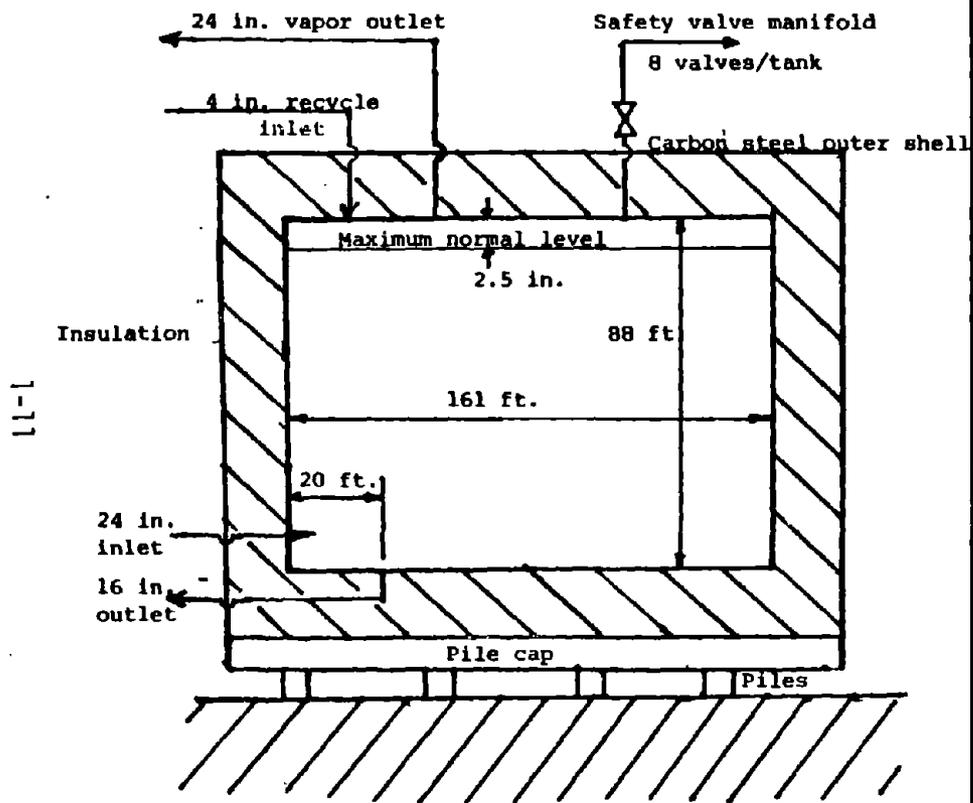
Figure 2
Schematic diagram of Esso La Spezia LNG Storage Tank S-1.
Gross 315,000 barrels/tank; design pressure = 500 mm H_2O @
-260°F. (Adapted from Esso Research & Engineering report)

Evaporation

Light layer

Heavy layer

(a)

Evaporation

(b)
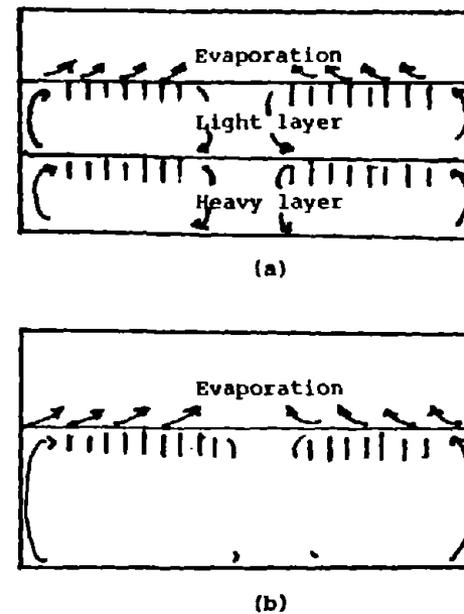
Figure 3
Schematic diagram of natural convection currents
a) with and b) without density stratification.
(Adapted from Drake et al., 1973).

MATERIALS DESCRIPTION (LECTURES)

LECTURE ON THE NECESSITY TO DESIGN FOR POSSIBLE RUNAWAY REACTIONS

According to conventional wisdom, there is low risk that design defects will
lead to health emergencies. This is because, generally, only a string of
human and equipment failures will lead to the release of hazardous materials
into the environment. Furthermore, weather conditions would have to be such
that the material were carried to populated areas. Nonetheless, as seen in
at least two recent disasters, the major catastrophe in Bhopal, India, and
the smaller and less tragic incident in West Virginia, such health
emergencies occur.

It was recently estimately (3) that as many as 50,000 processing units in
chemical plants around the United States have been inadequately designed for
the prevention of leakage of hazardous chemicals in the event the process
gets out of control. Although emergency systems have indeed been developed
to relieve potentially dangerous temperature and pressure increases, and
have been commercially available for at least five years, few companies have
installed such equipment. The reasons for this include high cost, lack of
technical know-how on-site, and the absence of a government regulatory
agency that requires such technology. An additional reason is that
undergraduate chemical engineering students have not been required to study
this subject.

As part of a ten-year study completed recently under the auspices of the
American Institute of Chemical Engineers, a check was made of some 100
emergency relief systems in assorted plants (3). All were deemed inadequate
to handle material flows that could result from the buildup of very high
temperatures and pressures during runaway reactions. The principal design
problems involve the sizing of valves and piping for relief of the pressure
rise engendered by such reactions. The reaction itself may be caused by
inadvertent addition of heat (as in the Institute, West Virginia incident)
or pressure, or of a reactive material (such as water, which triggered the
violent reaction leading to the Bhopal disaster).

Conventional relief systems are designed to handle single-phase flows.
Thus, boiling liquids have been presumed to be completely vaporized.
However, it was discovered over a decade ago that the boiling material
frequently exists through relief valves as a mixture of gas and liquid,
often a foam. This causes greater pressures (and therefore temperatures)
than anticipated, because of the partial blockage of safety valves and pipes

1-12

by liquid. Thus, by 1980, AIChE researchers discovered that relief systems anywhere from 2 to 10 times larger than those typically installed were necessary (3).

One reason for the improper design of such systems, besides general neglect of two-phase flow, was the improper scale-up of bench-top pilot studies. Preliminary experiments conducted with scaled-down vessels often underestimate the degree of temperature and pressure buildup during runaway reactions, because of the excessive heat capacity of the smaller vessels' walls. Larger tanks designed for use in chemical plants are characterized by smaller surface-to-volume ratios. Consequently, their walls absorb a smaller proportion of the heat generated by uncontrolled reactions. In Bhopal, the pressure and temperature far exceeded the specificiations of equipment installed in order to handle escaping gas. Few companies are reported to have added equipment necessary to handle two-phase flow. Even fewer have designed to account for the operating wall heat capacity.

The last and perhaps most obvious way of designing to minimize release of hazardous chemicals is to minimize the amount of such chemicals stored on site. Union Carbide came under sharp criticism for the 45,000 gallons of methyl isocyanate storage capacity at its Bhopal plant. Other firms have essentially no significant amount of highly toxic and reactive chemical stored on site.

SUGGESTED LECTURE TOPICS FOR UNDERGRADUATE COURSES

A) Industrial Chemical Calculations

A subject conventionally treated in this course is the purge line necessary to prevent accumulation within a plant of a feed component that is recycled and consequently does not leave in a primary effluent stream. The classic example is that of an ammonia synthesis plant. Nitrogen and hydrogen are fed in stoichiometric proportions to a reactor in which the two combine. Product ammonia is purified by partial condensation of the effluent. Unconsumed nitrogen and hydrogen remain in the gas, which is recycled to join the fresh feed, and are ultimately consumed. However, non-condensable, non-reactive trace feed components accumulate unless a purge or bleed line is affixed to the recycle piping.

The above situation, while not necessarily hazardous, suggests a related circumstance that is. In cryogenic air separation systems, feed air is liquefied at temperatures of close to -300°F. The liquefied air is distilled into oxygen and nitrogen. Argon, a minor component, is also produced. The danger arises from the natural occurrence of acetylene as a trace component of air or a product of the cracking of compressor lubricant. By virtue of the relative volatilities, acetylene tends to accumulate in the liquid oxygen reboiler. If not bled off, the acetylene may exceed its flammability limit, as realized from explosions in prototype systems.

The lecturer is encouraged to introduce this phenomenon in conjunction with a discussion of purge/bleed streams - and to consult the discussion of oxygen manufacturing in the Kirk-Othmer Encyclopedia of Chemical Technology.

B) Unit Operations - Fluid Mechanics

The lecturer is encouraged to read the above sections on problems encountered at Union Carbide's Institute, West Virginia chemical plant as a result of the improper design of safety valves and piping. Material should be developed on proper sizing to allow for unusually high fluid flows during runaway reactions. Material should also be introduced on two-phase flows which, as noted above, have frequently been responsible for catastrophic releases.

C) Chemical Engineering Thermodynamics

The lecturer is encouraged to read the above section on "rollover" in LNG storage tanks, which motivates extended discussion, in the context of vapor-liquid equilibria, of the flashing of disequilibrated liquids in storage tanks. The more commonly considered hazard of boiling or evaporation of inadvertently heated liquids, and consequent release of large volumes of vapor, might normally comprise the subject matter of a lecture in this general area. It is suggested that additional emphasis be given to flashing due to a particular component's incomplete equilibration with a gas.

CONCLUDING REMARKS

In addition to what has been outlined in the preceding sections, lecturers are encouraged to introduce additional material on the toxicity and other hazards of chemicals encountered in their curricula. For this purpose a variety of sources are available, among them the monograph references (8).

Chemical engineering faculty members are also encouraged to keep abreast of developments in the area of design of emergency relief systems, particularly those published as results of the AIChE's Design Institute for Emergency Relief Systems (9).

Moreover, the AIChE recently announced the establishment of a Center for Chemical Plant Safety (CCPS). The AIChE task force on Chemical Plant Safety has identified four issues for the center's initial attention:

a) hazard evaluation procedures

b) bulk storage and handling of toxic and/or reactive materials

c) good plant operating procedures

d) safety training

Educators are urged to be in touch with the CCPS, and to obtain copies of its recently issued guidelines on acceptable industrial practice regarding hazard evaluation procedures.

REFERENCES

1. "Union Carbide: New Accidents Revive Safety Issues," Chemical and Engineering News, 8/19/85, p. 4.

2. American Conference of Governmental Industrial Hygienists, "Threshold Limit Values and Biological Exposure Indices for 1985-86", 1985.

3. New York Times, 8/13/85, 8/14/85, 8/19/85, 8/24/85.

4. "Prevent LNG 'rollover'," E.M. Drake, J.M. Geist and K.A. Smith, Hydrocarbon Processing, 3/73, p. 87.

5. "LNG Rollover - Update," E.M. Drake, Hydrocarbon Processing, 1/76, p. 119.

6. Esso Engineering in-house report, 1972.

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8. Priority Toxic Pollutants. Health Impacts and Allowable Limits, M. Sittig, Ed., Noyes Data Corp., Park Ridge, NJ, 1980.

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11. "What every chemical engineer should know about environmental health hazards," P.F. Deisler, Jr., Regulatory Toxicology and Pharmacology, Vol. 4, 1984, p. 400.

12. Industrial Hygiene Aspects of Plant Operations, Vol. I, Process Flows, Vol. 2, Unit Operations and Product Fabrication, L.J. Cralley and L.V. Cralley, Eds., MacMillan, New York, 1984.

Health and Safety Course Material

in

Civil Engineering

by

Lewis Edgers, Ph.D.
Civil Engineering Department
Tufts University
Medford, MA 02155

UNIT OVERVIEW

METHODS: Lectures

PURPOSE: Integrate an appreciation of safety and the engineer's responsibility to the public with the development of basic geotechnical engineering principles.

OBJECTIVES: 1.   Emphasize the lessons related to public safety illustrated by detailed study of the catastropic failure of an engineered system.

                2.   Summarize legislation, methods, and results of safety evaluation of existing dams in the United States.

                3.   Illustrate the failure and loss prevention programs of the Association of Soil and Foundation Engineers (ASFE).

RATIONALE: Recent catastropic events have graphically demonstrated the need for the engineering profession to broaden its concerns and interpretation of occupational health and safety issues. This unit presents materials which illustrate a response to this need.

PRESENTATION: The two lectures on the failure and loss prevention programs of ASFE are designed to be presented in a Senior-level course. The lecture on catastropic failure of an engineered system and the lecture on legislation, methods, and results of safety evaluation of existing dams in the United States, are developed to be presented in advanced-level couses.

INSTRUCTOR
MATERIAL: Chalkboard
2 x 2 slides and overhead transparencies
Videotape

STUDENT
MATERIAL: Lecture outlines
Reference lists

INTRODUCTION

This lecture will summarize recent geotechnical analyses of the Vaiont Slide presented by Hendron and Patton (1985). The Vaiont Slide, located in the Italian Alps, occurred October 9, 1963, when 270 million cu. m. of rock slid into the newly completed Vaiont Reservoir. 2043 persons died directly as a result of the wave of water that was displaced from the reservoir. The lecture will emphasize the lessons related to public safety that this disaster illustrates. The lecture will be presented in an advanced Geotechnical engineering course described as follows:

CE-248 Earth Structures

   A study of slope stability, groundwater flow analyses, and other aspects of earth embankment engineering. Topics include earth pressure and stability analysis, seepage analysis, drainage design, foundation analysis and preparation, site evaluation and construction considerations. Spring 1986 and alternate years. Prerequisite: CE-42 or consent.

The material will be presented in lecture format using 2x2 slides and overhead transparencies.

MATERIALS DESCRIPTION (LECTURES)

I. LECTURE OUTLINE

  A. Introduction

    1. Importance of the Slide
    2. Earlier Analyses

  B. Description of the Slide

    1. Movement of Slide Masses
    2. The Wave and Resulting Losses
    3. Features of the Slide Area

  C. Geology

    1. Previous Geologic Studies
    2. General Geologic Setting
    3. General Stratigraphy
    4. Clay Interbeds and Layers
    5. Structural Geology
    6. Minor Structures
    7. Geomorphology
    8. Hydrogeology

  D. Physical Properties of the Clays

    1. Grain Size Analyses/Atterberg Limits
    2. Shear Strength Tests
    3. Clay Mineral Analyses

  E. Chronology of Significant Events

  F. Correlations Between Reservoir Level, Precipitation, and Rate of
     Movement.

    1. First Reservoir Filling
    2. Construction of the Bypass Tunnel
    3. Second Reservoir Filling
    4. Third Reservoir Filling
    5. Erroneous Assumptions Regarding the Effect of Reservoir Levels
    6. Combined Effects of Precipitation and Reservoir Level

G. Stability Analyses

    1. Purpose and Scope
    2. Assumptions
    3. Periods Examined for Stability
    4. Two-Dimensional Stability Analyses
    5. Three-Dimensional Stability Analyses

H. Conclusions

    1. General Geology
    2. Hydrogeology
    3. Shear Strength of Clays
    4. Stability Analyses
    5. Precipitation and Reservoir Levels
    6. General

II. REFERENCE

Hendron, A.J., Jr. and F.D. Patton. 1985. The Vaiont Slide, A geotechnical analysis based on new geologic observations of the failure surface, Vol. 1 and Vol. 2, Technical Report, U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. (In Press)

III. OTHER USEFUL SOURCE MATERIALS

1. Broili, L. 1967. "New knowledge on the Geomorphology of the Vaiont Slide Slip Surfaces." Rock Mechanics Engr. Geol., Jour. Int. Soc. Rock Mechanics. Vol. V, No. 1, pp. 38-88.

2. Chowdhury, R. 1978. "Analysis of the Vaiont Slide - new approach." Rock Mechanics, Jour. Int. Soc. Rock Mechanics, Vol 11, pp. 29-38.

3. Gruner, E.C., 1969. "Vigilance Over Reservoirs." Water and Water Engineering. Sept., pp. 369-373.

4. Jaeger, C. 1965a. "The Vaiont Rockslide, Part I." Water Power. March, pp. 110-111.

5. Jaeger, C. 1965b. "The Vaiont Rockslide, Part 2." Water Power. April, pp. 142-144.

6. Jaeger, C. 1968a. "The Dynamics of the Slide," discussion of paper by L. Muller on new considerations on the Vaiont Slide. Rock Mechanics and Engr. Geol., Jour. Int. Soc. Rock Mechanics. Vol. 6, No. 4, pp. 243-247.

7. Jaeger, C. 1979. "The Vaiont Slide," Ch. 14, pp. 402-423 in Rock Mechanics and Engineering. University Press, Cambridge.

8. Kenney, T.C. 1967a. "Stability of the Vaiont Valley Slope," discussion of paper by L. Muller (1964) on the rock slide on the Vaiont valley. Rock Mechanics and Engr. Geol. Jour. Int. Soc. Rock Mechanics. Vol. 5, No. 5, pp. 10-16.

9. Kiersch, G.A. 1964. "Vaiont Reservoir Disaster." Civil Engineering. Amer. Soc. Civil Engrs. March, pp. 32-39.

10. Kiersch, G.A. 1965a. "Vaiont Reservoir Disaster." Geotimes. Geol. Soc. Amer. May-June, 1965, pp. 9-12.

11. Kiersch, GA 1965b. "The Vaiont Reservoir Disaster." pp. 136-145. In Landslides and Subsidence. Geologic Hazards Conference, Los Angeles, CA, May 26-27, 1965. The Resources Agency, State of CA.

12. Lo, K.Y., C.F. Lee, and P. Gelinas. 1972. "Alternative Interpretation on the Vaiont Slide," pp. 595-623 in Stability of Rock Slopes. E.J. Cording, ed. Proc. 13th Symposium on Rock Mechanics, Univ. Illinois, Urbana, Aug 30-Sept 1, 1971. ASCE, New York.

13. Mencl, V. 1966. " Mechanics of Landslides with Non-circular Slip Surfaces with Special Reference to the Vaiont Slide." Geotechnique. Vol. 16, No. 4, pp. 329-337.

14. Muller, L. 1964a. The Rock Slide in the Vaiont Valley. Rock Mechanics and Engr. Geol., Jour. Int. Soc. Rock Mechanics. Vol. 2, pp. 148-212.

15. Muller, L. 1968. "New Considerations on the Vaiont Slide." Rock Mechanics and Engr. Geol., Jour. Int. Soc. Rock Mechanics. Vol. 6, No. 1, pp. 1-91.

16. Nonveiller, E. 1967a. Discussion of paper by V. Mencl on mechanics of landslides with noncircular surfaces with special reference to the Vaiont slide. Geotechnique. Vol. 17, No. 2, pp. 170-171.

17. Romero, S.U., and R. Molina. 1974. "Kinematic Aspects of the Vaiont Slide." Proc. 3rd Congress Int. Soc. Rock Mechanics, Denver, Colo. Sept. 1974, Vol. II, Part B, pp. 865-870.

18. Skempton, A.W. 1966. "Bedding-plane Slip, Residual Strength and the Vaiont Landslide." Letter to the editor. Geotechnique. Vol. 16, No. 1, pp. 82-84.

INTRODUCTION

The National Dam Safety Inspection Act of 1972 (P.L. 92-367) was enacted as a result of a number of catastrophic dam failures. Due to limited funding, the Act was not implemented until 1977, subsequent to the failure of the Teton Dam. Since that time, extensive programs of inventory and inspection of federal and non-federal dams have been developed. Efforts to repair deficiencies have been encumbered by financial and organizational difficulties. This lecture will summarize legislation, methods, and results of safety evaluation of existing dams in the United States. The lecture will be presented in an advanced geotechnical engineering course described as follows:

CE-248 Earth Structures.

>   A study of slope stability, groundwater flow analyses, and other aspects of earth embankment engineering. Topics include earth pressure and stability analysis, seepage analysis, drainage design, foundation analysis and preparation, site evaluation and construction considerations. Spring 1986 and alternate years. Prerequisite: CE-42 or consent.

The material will be presented in lecture format using 2x2 slides and overhead transparencies.

MATERIALS DESCRIPTION (LECTURES)

I. LECTURE OUTLINE

    A. Initiation of SEED Efforts

        Buffalo Creek Failure, 1972
        Teton Dam Failure, 1976
        National Dam Safety Inspection Act, 1972
        Presidential Directive, 1977

    B. Agencies Involved with Dam Safety Programs

        Federal Energy Regulatory Commission, FERC
        U.S. Army Corps of Engineers
        U.S. Bureau of Reclamation, USBR
        U.S. Committee on Large Dams, USCOLD
        States - National Association of State Dam Safety Officers,
                NASDSO
              - New England Association for Dam Safety, NEADS

    C. Performance of Dam Inspections

        Required Information
        Equipment
        Methods
        Sequence
        Design Standards and Guidelines
        Example Inspection Report - Windsor Reservoir Dam

    D. National Program of Inspection of Non-Federal Dams

        Program Development
        Inventory of Dams
            Procedures
            Problems
            Results
            Costs
        Inspection of Dams
            Procedures
            Problems
            Results
            Costs

Recommendations for Remedial Measures
Program Impact

E. State Non-Federal Dam Safety Programs

Review Summary of Non-Federal Programs - Tschantz
NASDSO Activities
NEADS Activities
Example State - Vermont

F. Problems

Organizational
Management
Funding
Cost of Repairs

II. REFERENCES

1. American Society of Civil Engineers (1973), "Inspection, Maintenance, and Rehabilitation of Old Dams," Engineering Foundation Conference, Pacific Grove, CA.

2. American Society of Civil Engineers (1974a), "Safety of Small Dams," Engineering Foundation Conference, Henniker, NH.

3. American Society of Civil Engineers (1974b), "Foundation for Dams," Engineering Foundation Conference, Pacific Grove, CA.

4. American Society of Civil Engineers (1976), "The Evaluation of Dam Safety," Proceedings of Engineering Foundation Conference, Pacific Grove, CA.

5. American Society of Civil Engineers (1977), "Teton Dam Failure," Civil Engineering Magazine, August, pp. 56-61.

6. Federal Coordinating Council for Science, Engineering and Technology (1979), "Federal Guidelines for Dam Safety," U.S. Superintendent of Documents, Washington, D.C.

7. National Research Council (1983), "Safety of Existing Dams, Evaluation and Improvement," Committee on the Safety of Existing Dams.

8. Tschantz, Bruce A. (1984), "Updated Review Summary of State Non-federal Dam Safety Programs," National Conference on Dam Safety Issues in the 80's--Responsibilities, Liabilities, and Alternatives, Denver, CO.

9. U.S. Army (1980), "Windsor Reservoir Dam, Phase I Inspection Report," Department of the Army, New England Division, Corps of Engineers.

10. U.S. Army (1982), "Report of the Chief of Engineers to the Secretary of the Army on the National Program of Inspection of Non-federal Dams," Department of the Army, Corps of Engineers.

11. U.S. Bureau of Reclamation (1984), "Guidelines to Decision Analysis," Chapter 14, in Design Standards on Embankment Dams, No. 13, Published by USBR.

12. U.S. Bureau of Reclamation (1985), "Information for SEED Analysis Reports and Management Summaries".

13. U.S. Committee on Large Dams (1975), "Lessons from Dam Incidents USA." by The Committee on Failures and Accidents to Large Dams of the USCOLD.

14. U.S. Department of the Interior (1972), "West Virginia's Buffalo Creek Flood, A Study of the Hydrology and Engineering Geology," Geological Survey Circular 667.

INTRODUCTION

These two lectures will present the failure and loss prevention programs of the Association of Soil and Foundation Engineers (ASFE). They will be presented in a senior level geotechnical engineering course described as follows:

CE-146 Foundation Engineering.

> The art of foundation engineering with emphasis on bearing capacity and settlement analyses for shallow (footings) and deep (pile) foundation problems. Design of footings, rafts, piles, and piers subjected to axial and lateral loads; building code requirements for design; and evaluation and selection of foundation types and alternatives. Case studies and field trips. Prerequisite: CE-42 or equivalent or consent.

The first lecture will consist of a videotape presentation of ASFE activities followed by discussion. The second lecture will consist of presentation, discussion, and analyses of case histories to demonstrate the application of failure and loss prevention programs.

MATERIALS DESCRIPTION (LECTURES)

I. A. LECTURE 1 OUTLINE - VIDEOTAPE/DISCUSSION ON FAILURE AND LOSS
        PREVENTION PROGRAMS OF ASFE.

    1. ASFE - History and Programs

        a. Why? - peer group contact, cohesiveness.
                    professional liability concerns (insurance)
                        loss prevention.

        b. Beginnings
                1940's - first soil and foundation engineering
                    consulting firms.
                1940's-1950's - few losses, claims.
                1960's increasingly unfavorable loss, liability insurance
                    situation.
                11 Dec 1968 - O'Hare Meeting - Principals of about 10
                    leading firms (Shannon, Gnaedinger, Haley, Schnabel,
                    Waller, etc.) agreed on need and schedule for
                    establishment of ASFE.
                May 1969 - ASFE Incorporated, liability insurance
                    offered.
                June 1969 - First loss prevention programs.

        c. Goals
                Improve quality of profession.
                Loss Prevention
                Improved Insurability

        d. Acitivities
                Seminars
                Newsletters
                Loss-prevention Manual
                Video and audio tapes, pamphlets
                Peer review
                Terra Insurance Co.

    2. Quick Fixes

        a. Select clients carefully
                Dishonest client
                Underfinanced client
                Unsophisticated client

2-12

      b. Don't compromise fees

      c. Communication
          Unreal expectations, promises
          Non-verbal communication failures (silence)
          Word meaning ("supervise")-500 wds, 14000 meanings
          Extreme words ("all", "safe", "to be")
          Confessions
          Documentation - record, models, photographs, memoranda

3. Long Range Programs for Professional Enhancement

      a. Report review by peer firms - begun 1973.

      b. Institute of Professional Practice
          12 week home study
          Entrance exam
          2 1/2 day seminar

      c. Council of Fellows - Preeminent senior members.

      d. Peer review visit of firms - Begun 1978.

      e. Standard clause - Limit of Liability

      f. Encourage mediation/arbitration of construction disputes.

B. LECTURE 2 OUTLINE - ASFE CASE HISTORIES

    Presentation, discussion, and analysis of case histories
selected from ASFE collection of case histories. Emphasis will be
on problems, outcome, and lessons learned relative to loss
prevention and liability. Non-technical factors, responsible for
70% of claims, will be stressed.

II. REFERENCES

1. "An Introduction of ASFE and Professional Liability Loss
   Prevention," Videotape.

2. Professional Liability Loss Prevention Manual.

3. Case History Series

   Published by the
         Association of Soil and Foundation Engineers
         8811 Colesville Road/Suite 22
         Silver Spring, Maryland 20910

III. OTHER USEFUL SOURCE MATERIAL

1. Bell, Glen, "Techniques for Investigating Structural Failures", presented at the Conference on Forensic Engineering, Mohawk-Hudson Section, ASCE, April 19, 1984.

2. Chesson, Eugene, "How Not To Do It!", Session 29B1. Proceedings, National Conference on Engineering Case Studies, March 28-30, 1979, pp. 117-121.

3. FitzSimons, Neal, "Types of Failures", Failure Workshop, ASCE, 1984.

4. FitzSimons, Neal, "Notes on the Statistics of Failures of Constructed Works" ASCE/NSF Workshop for Reducing Failures.

5. Haines, D.W., "Forensic Engineering: What Role for ASCE?," Civil Engineering, July 1983, pp. 53-55.

6. Janney, J.R., "Guide to Investigation of Structural Failures." ASCE, 1979.

7. Kornblut, Arthur, "Information Availability", Failure Workshop, ASCE, 1984.

8. Leonards, G.A., "Investigation of Failures." The Sixteenth Terzagni Lecture presented at the ASCE Annual Convention and Exposition, Hollywood Beach, Florida, Oct 30, 1980. Published in Journal ASCE, GT2, February 1982, pp. 185-243.

9. LePatner, B. and Johnson, S.M., "Structural and Foundation Failures: A Casebook for Architects, Engineers," McGraw-Hill Book Company.

10. Pritzker, P.E., "Investigative Techniques." Consulting Engineer, Vol. 62, No. 1, pp. 44-47, 1984.

11. Thornton, Charles, "Failure Statistics Categorized by Cause and Generic Class, Failure Workshop, ASCE, 1984.

INTRODUCTION

The Construction Industry Manufacturer's Association (CIMA) has produced a number of educational materials on the principles of operation, application, and safe operation and maintenance of heavy construction equipment. It is unlikely that engineering students will operate or maintain this equipment. However, engineers, as supervisors and observers of construction, should be familiar with the basic operating and safety principles of heavy construction equipment. These materials will be presented in CE-42, Introduction to Soil Mechanics, described as follows:

CE-42 Introduction to Soil Mechanics.

> The engineering properties of soils and their influence on the design and construction of buildings, tunnels, dams, etc. Occurrence, exploration, and sampling of natural soil deposits and the permeability, compressibility, and strength of soil masses subjected to superimposed loads. With laboratory. Prerequisite: Engineering Science 5 or consent.

The lecture will consist of a presentation of the slide program "Man the Builder," produced by CIMA. The students will also read Safety Manuals, also produced by CIMA.

MATERIALS DESCRIPTION (Lectures)

This program describes the functions and variations of cranes and excavators as well as equipment and attachments used on or with these machines. It shows not only how they operate and their applications, but how the machines serve people around the world. Safety manuals for operating and maintenance personnel:

Crawler Tractor/Loaders
Hydraulic Excavators
Motor Grader
Off-Highway Track
Roller Compactor
Scraper
Wheel Loader/Dozer

Health and Safety Course Material

in

Electrical Engineering

by

Arthur Ulhir, Ph.D.
Electrical Engineering Department
Tufts University
Medford, MA 02155

UNIT OVERVIEW

METHODS: Lectures, Laboratory Materials and Exam Questions

PURPOSE: Improve the safety conciousness of undergraduate electrical engineering students in ways that are likely to be effective in their subsequent work.

OBJECTIVES:

1. Emphasize the hazard of electric shock.

2. Point out the treacherous aspects of charged capacitors.

3. Provide antidote to widespread beliefs that may undermine first aid efforts in case of electric shock.

4. Give students of microwaves a balanced view of the uncertainties about biological effects of electro magnetic fields.

RATIONALE: Engineers are more likely to think of safety at the right time if the discussion is associated with other engineering subject matter that they will be called upon to apply.

PRESENTATION: The information on electric shock and lightning will be presented in two lectures in a required junior-level course. The material on microwave safety is presented in a senior-level course.

INSTRUCTOR MATERIAL: Chalk board.

STUDENT MATERIAL: Handout material (white paper).
Books on library reserve.
Selected material from papers.
Laboratory handout material.

INTRODUCTION

The main effort focused on the elective senior/graduate level course, EE117:

A. EE117   Introduction to Microwaves

Electrical characterization and circuit applications of microwave devices. Reflection, transmission and use of the Smith chart. Time-domain reflectometry. Matching techniques and filters. Two-port theory, scattering matrices, and use of flow graphs to analyze networks of microwave devices and transmission lines. Radar and communication system functions of semiconductor devices, ferrites, and electron tubes. Biological effects. Laboratory measurement of power, frequency, attenuation, Q-factor, reflection and matching. Prerequisite: Electrical Engineering 18 or 13 and consent.

The method of presentation consists of

1. A "white paper", attached, given to each student.

2. Books on library reserve, as mentioned in (1).

3. Selected copies of key pages in certain papers mentioned in (1).

4. Incorporation of safety precautions as the lead topic in the instructions for laboratory experiments (samples enclosed).

The information on electric shock and lightning, included in the white paper above, is too important and urgent to be limited to an elective course. Therefore, it was presented (repeated) in two separate lectures in the required junior course, EE13:

B. EE 13   Circuit Theory

System response to various excitations, impulse response, and natural frequencies: s-plane and pole-zero interpretations, state variable analysis by digital computer. Laplace transform analysis, network topology. Prerequisites: Engineering Science 3 and Mathematics 38.

The capturing of attention has been enforced by including questions about resuscitation in the first examination attached.

MATERIALS DESCRIPTION (WHITE PAPER)

MICROWAVE SAFETY

INTRODUCTION

The early intensive development of microwave technology was driven by the application to military radar in World War II. Military and civilian radar continued to be important after the war and other uses were sought in communications, cooking and industrial heating. Medical uses seem imminent.

Workplace hazards exist in the manufacturing, testing, and application of microwaves. Nearly all fatalities have been the result of electric shock from the high-voltage D-C power supplies required by microwave tubes, or even from the A-C power lines supplying the equipment. For this reason, the microwave practitioner should know some conjectures about electric shock that may not even be generally accepted medical facts.

Two recent deaths in the Boston-area microwave industry have resulted from inhalation of toxic gas. One has been stated to be suicide by deliberate inhalation of arsine gas, which is toxic even beyond what might be expected from its arsenic content. Its chemical analog, phosphine, is also quite toxic even though it contains only phosphorus and hydrogen. The other death occurred under circumstances of working alone at night. The same chemical hazards are present in the general semiconductor industry, but larger work groups are more likely to halt inappropriate behavior by individuals.

Exposure to sufficiently high levels of microwave power densities can produce dangerous heating of flesh. Much controversy has arisen over the possibility that far lower levels, having negligible heating effect, may nevertheless be harmful in some way to workers and to the general public.

One option that does not seem to be available is to do without microwaves, entirely. Cessation of television broadcasting would be politically difficult while evidence of hazard to the viewing public is essentially nonexistent. The use of radar in navigation of ships and airplanes probably should be considered an indispensable safety measure (although "radar-induced accident" has come into use to describe over-confident dependence on radar under circumstances of reduced visibility). Engineers must seek designs that are reasonable, with limited information because of very little evidence about long-term effects.

DESIGN, FABRICATION, TEST, INSTALLATION, USE, REPAIR, AND THE PUBLIC

Only a small fraction of workers within the producing industry--those
involved in testing--are likely to receive long-term exposure to microwaves,
at present, and then only if careless practices are tolerated. That was not
always true. For example, high-power microwave tubes were, in the past,
sometimes tested with "horn loads". That expression is a euphemism for the
nefarious practice of indiscriminately radiating the power through a horn
antenna to avoid the inconvenience and expense of providing a water-cooled
absorbing termination.

Marine and aviation workers, on the other hand, may have to be near high-
power microwave sources for long periods of time. Their levels of exposure
will be determined by equipment design and installation. For example,
personnel responsible for airport radar spend all of their working time in
buildings generally situated under towers upon which the radar antenna is
mounted. It is easy to design shielding so that the level inside is
unmeasurably small despite the highest power transmitters now in use.

The high-voltage hazard is broadly encountered in the microwave industry.
Care is needed in development, routine testing, and operation. Further, the
role of the repairman must be considered in design. It is the designer's
responsibility to include interlocks, reliable bleeders, and warning signs.

ELECTRIC SHOCK

The principal effect of high-voltage shock is to produce unconsciousness and
a cessation of breathing and heart action. The failure of the heart to pump
may be the result of disorganized contractions called fibrillations. The
first and most serious aspect of these failures is oxygen deprivation of the
brain. To emphasize the importance of prompt first aid, the fact has been
widely publicized that brain damage can occur in as little as five minutes
of oxygen deprivation.

That publicity has usefully underlined the urgent need for action in common
cases of heart attack and apparent drowning. Unfortunately, the thought can
be carried too far. Gradually, news accounts of resuscitation of victims
who have been immersed in cold water for periods up to 45 minutes have
spread the knowledge that resuscitation after such periods is not
necessarily futile or pragmatically undesirable. Apparently, there is the
possibility of a physiological state which reduces the brain's oxygen
demand--sometimes called "the diving reflex" and probably in part a function
of water temperature.

What is not nearly well-enough known is the anecdotal evidence that electric
shock, including lightning, may also induce a state in which the oxygen
demand is reduced. Recovery after times up to 45 minutes has been
reported. From a scientific point of view, it is hard to determine from the
observers or from the resuscitated victim if a slight undetected breathing
and heart action prevailed before cardio-pulmonary resuscitation was begun.
Whether the anecdotes are good science or not, it is obvious that current

policy should be to work much longer to revive electric shock victims than would be considered worthwhile in the case of an apparently unprovoked heart attack. The principle, "DO NOT WORK ALONE," has life-and-death significance when high-voltage is involved.

A peculiar hazard in high-voltage systems is that capacitors may not fully discharge the first time they are short-circuited. It takes a few seconds for the charge to redistribute and it is possible to receive a lethal shock if the capacitor is not discharged repeatedly or kept short-circuited.

Whenever possible, bleeder resistors should be provided that will discharge the capacitors in the second or two required for a repair person to expose any high-voltage conductor, after turning off the power. Interlocks should be provided that require the power to be off before doors are opened. Even with such interlocks and resistors, warning signs are worthwhile in case something goes wrong with the designed-in protection.

The bleeder resistor is an example of the challenges of designing for safety in situations that seem quite simple. The failure of a bleeder resistor could lead to a worse situation than not having one at all, in case a maintenance worker has come to depend upon its presence. To avoid failure, one might think to use a "high-quality" resistor, such as a wire-wound resistor instead of an inexpensive carbon resistor. Such a choice would be particularly unfortunate for equipment used in the tropics or any other damp climate. Wire-wound resistors are not impervious to moisture and they have a potential applied to them continuously in use. These conditions lead to electrolysis of the wire and eventual open-circuiting of the bleeder. Carbon resistors seem to be more reliable. Some engineers are concerned enough about bleeder design to use two carbon resistors in parallel (or two strings of resistors, if suitable values are not available).

High-voltage D-C power supplies for microwave tubes nearly always have ample current capability to electrocute. They also can provoke involuntary motions that can result in injury. However, some such supplies do not have the sustained power capability to cause extensive burns. But regular alternating current from power lines and, especially, high-voltage alternating current produced by transformers often have the power to burn and char flesh. Furthermore, alternating-current shocks have a tendency to cause the victim to clutch involuntarily the source of the current, prolonging exposure. Thus, concern about high voltage must include the circuits that precede the high-voltage rectifier.

The study of injury from low-frequency electricity has a certain parallel to the microwave situation. Despite the obvious burning action, the question has been raised of whether additional damage is produced by the flow of electric current, even when the temperature of the flesh is not raised to an extent that would produce damage in case of nonelectrical heating. The proposition that there is such a form of damage is called the "athermal hypothesis," both in low-frequency and microwave cases. Research on this hypothesis is in progress at M.I.T.. Dr. Chatham Cooke of the High-Voltage Laboratory there is of the opinion that the athermal hypothesis has been

adequately established and that the problem now is to understand the mechanism whereby cells that are not immediately killed nevertheless lose the ability to multiply.

AVOIDANCE OF ELECTRIC SHOCK IN THE MICROWAVE LABORATRORY

Unlike the world of modern digital electronics, microwave laboratories sometimes have rather old equipment. This circumstance is true in industry as well as in universities. The reasons for the obsolescence in industry include parsimony and the high cost of capital. But they also include the arcane nature of some microwave testing. There is a possibility that new equipment and correct procedures will not produce the answers to which the industry has become accustomed.

The problem with old equipment is that it harkens back to times when safety was not considered as important as it is today. Part of the problem has wartime origins, when it might be unseemly to be concerned about small but real hazards when so many are risking life in combat situations. High-voltage leads to tubes may have inadequately-shaped insulators on their caps, according to the logic that no one with any sense would get near them. Yet such tubes may be mounted directly on waveguide assemblies and only the conscience of the final circuit designer will provide the needed guards to prevent contact with the high voltage. Watching out for exposed high-voltage leads is a precaution that should not be necessary but sometimes must be remembered.

Another legacy of low concern about safety is occasional lack of grounded three-wire power cords. Some older microwave instruments were manufactured with metal cases directly connected to the intended microwave ground yet with two-wire ungrounded power cords. No one would do that now, of course, but tube-type microwave signal generators until quite recently gave much purer microwave oscillations than any solid-state oscillators. For this reason, one may still find quite old generators in use.

Thus, careful attention to grounding is a key to safety in microwave circuits. One should preferably connect several instruments, by grounded power cords to a single power strip and then only after establishing that the outlets have all been correctly wired. (A local electrical contractor once incorrectly rewired a large microwave laboratory. Fortunately, the director of the laboratory was astute enough to have unplugged all of the microwave instruments and tested the outlets before plugging them in. The contractor had to replace all of the fluorescent lights, however.)

BIOLOGICAL EFFECTS OF MICROWAVES

Two books have been placed on reserve for this course in Lufkin Library. One is an anthology of papers on "Biological Effects of Electromagnetic Radiation," edited by John M. Osepchuk and published by the IEEE Press. You should be advised that John Osepchuk is an employee of the Raytheon Corporation, which has a vital interest in the application of microwaves. The papers do not, however, gloss over the possibility of significant harm

from microwaves. At the same time, possible medical uses are also mentioned.

Your attention is called to several papers in this anthology. One is by a Tufts biology professor emeritus, Dr. Russell L. Carpenter, and his student Clair Van Ummersen. It is titled "The Action of Microwave Radiation on the Eye" and appeared in the Journal of Microwave Power, vol. 3, pp 3-19 (March 1968). Its importance goes beyond the matter of the eye, although that is important enough. It includes an experimentally-grounded affirmation of the "athermal hypothesis": that damage can be produced by microwaves at levels that do not significantly raise the temperature of the tissues.

Reprints of key parts of the article have been provided for you to comtemplate the implications. For one thing, this damage to the rabbit eye has the characteristic of appearing from one to eight days after the microwave irradiation. The relation between power density and exposure time to induce damage is an inverse one, as might be expected. But think how hard it is to extrapolate this data to longer exposure times. Is there a threshold of power below which no damage occurs, no matter how long the exposure? Within the lifetime of man instead of rabbits?

One feature of the microwave cataracts seems to be that limited doses can produce minor damage. Thus, a person might only vaguely suspect that vision had been somewhat impaired. Perhaps such damage has occurred to a greater extent than has been reported.

Dr. Carpenter and others had preliminary evidence of eye damage before the more quantitative evidence summarized in this paper was accumulated. And just in time! The Raytheon Company had gone so far as to design a microwave diathermy machine intended to treat sinus problems. The user was supposed to put the troubled nose into the microwave field. Dr. Carpenter suggested that such a machine had better not be marketed.

The effect of heat is unquestioned. It is not good for living things to be cooked. The issue is whether heating fully accounts for all the deleterious effects ("thermal hypothesis") or not ("athermal hypothesis").

The most notorious advocate of the thermal hypothesis has been Herman P. Schwan. It is hard not to seem like a villain while insisting upon the thermal hypothesis, for several reasons. One is that it is the least conservative viewpoint from a safety standpoint. Another is that it doesn't lead to good science. The electromagnetic energy is somehow converted to heat and, until we elucidate the mechanisms of this conversion, we cannot assume that the conversion process itself is biologically harmless. Then there is the matter of quite careful experiments that seem to support the athermal hypothesis--like those of Dr. Carpenter. Further, Dr. Schwan has been sponsored by military services that might be supposed to favor the thermal hypothesis for operational convenience. His curt behavior in public, as described by Steneck, has not promoted patient entertainment of his hypothesis that all important effects are thermal in nature.

The existence of "athermal" effects is not universally accepted, mainly

because of the recognized difficulty of determining temperature without affecting both the electromagnetic field and the temperature by the intrusion of a sensor. Do read the article "State of the Knowledge for Electromagnetic Absorbed Dose in Man and Animals," by Om P. Gandhi on page 91 of the anthology (reprinted from the Proceedings of the IEEE, pp 24-32, Jan 1980). The difficulties in predicting or even measuring absorption are acknowledged in this article, perhaps more so than in the earlier articles by Schwan and by Guy.

One death following possible exposure to high-power radar is mentioned by Steneck but has little relevance to the overall issue. Even if microwaves were responsible, the case is not informative, because there is inadequate knowledge of whether the exposure might have exceeded that needed for an immediate thermal injury.

Epidemiological data is not very definitive, either. For example, one study of persons who have worked with microwaves for a long time at Ft. Monmouth concluded that microwaves had no significant effect on eye damage (Appleton, et al, Archives of Ophthalmology, 93:257-258). This year, however, that data was reanalyzed to justify the opposite conclusions (Frey, J Microwave Power, 20:53-55). The early work was criticized for including in the control group persons with exposure to other environments capable of inducing cataracts, e.g., welding. However, this criticism has in turn been totally rejected (Wike and Martin ibid., pp 181-184) on the grounds that all differences can be accounted for by the different age distribution of the two groups, leaving no significant effect to be attributed to microwave exposure.

A translated Polish review titled "Biological Effects of Microwaves" (Baranski and Czerski, Dowden, Hutchinson & Ross, 1976) gives an extensive survey of papers up through 1971 without any mention of cancer statistics.

A recent epidemiological study of the Polish military has been reported in the press (e.g., Microwave News, 5:2, March, 1985) as indicating "a definite risk of neoplasms resulting from exposure to radio-frequency and/or microwave radiation". It is to be hoped that this research, attributed to Dr. Stanislaw Szmigielski, will be published with details about factors like age and smoking.

PUBLIC POLICY AND ENGINEERING DESIGN

The other book on reserve is "The Microwave Debate," by Nicholas H. Steneck (M.I.T. Press, 1984). This book seems fairly to present opposing sides in controversies over possible health effects of microwave radiation, particularly in the uncertain matter of long-term effects of low levels of exposure.

Although the book is a unique reference and you are urged to browse in it, it necessarily presents a great deal more argument than fact. I will presume to summarize it in the logical distinction between two questions:

"What microwave doses will NOT SURELY cause injury?"
"What microwave doses will SURELY NOT cause injury?"

The first question is one that was asked to win a war. It was answered (after the war--see Mumford article in the anthology) by noting that about 100 milliwatts per square centimeter rather surely produced cataracts in a technician's eyes (both eyes at the same time is strong evidence and particularly unfortunate). Also, this power level is about where the heating effects become perceptible and where estimates would suggest that the body's cooling system would not be easily able to limit heating. Most of the work then and now has been carried out with 10 to 20 centimeter wavelengths under the supposition (not yet contradicted) that effects are most serious in this range and that standards developed thereby will be conservative when applied to higher and lower frequencies.

But then a factor of safety of ten was applied to get the early standard of 10 milliwatts per square centimeter. This factor of safety seems inadequate now, not so much from proof of long-term injury as from the difficulty of estimating power densities of coherent waves when perturbed by subjects of complex shape and properties. Further, the technician's exposure, though habitual, was probably not continuous.

Bell Laboratories adopted an early standard of 0.1 milliwatts per square centimeter, apparently on the thought that a factor of safety of 1000 was more prudent than a factor of 10 and yet would allow all necessary work to be conducted with the exercise of reasonable precautions.

The second question is one that can hardly ever be answered to the satisfaction of everyone, when long-term effects are included.

According to Steneck, the Russians asked a different question: "What microwave power level will not make workers uncomfortable?" The standard adopted in Russia was 0.01 milliwatts per square centimeter.

Thus, it seems that the old-fashioned notion of a "factor of safety" is still a basis for design, but it must be chosen with an adequate allowance for uncertainties in both biology and technology.

One of the problems is the determination of the power levels in complex geometries. Radar installations on ships are an example. If the radiation cannot be computed, it can be determined from model studies in advance or by actual measurements. Electromagnetics may be complicated in many respects, but it is highly linear and very scalable. Availability of millimeter-wave components makes it possible to construct small-scale models of microwave installations. Linearity makes it possible to take measurements at power densities well below a microwatt per square centimeter, so that the danger to anyone taking the measurements is minimal. When conducting the lengthy measurements needed to evaluate a radar system over the full range of its antenna motions, one may be well advised to take advantage of this additional safety factor.

It is difficult to say if large ships with higher power radars present a greater or lesser hazard to the seaman on deck than do smaller ships with lower power radar. The installations are more varied on the smaller ships. Small boat safety manuals simply say to mount the radio and radar antennas "above eye level", a suggestion which is clearly not good enough.

One reason for the last opinion is that shipboard radar antennas are designed for accuracy in azimuth, with little resolution in elevation. Thus, a broad beam results in the vertical direction and it is not at all sure that the seaman below the level of the antenna receives a much reduced microwave intensity. Design of the antenna for better vertical resolution might improve the safety, uncertain though its present level may be, and would tend to improve the range of the radar at the same time. However, it could make the radar more sensitive to misalignment and increase therefore the chance of missing some targets--which would not be a contribution to overall safety.

Radar installations in large aircraft up until now have had the benefit of the fact that such aircraft have metal skins which are excellent shields against microwaves. The crew and passengers are thus well protected from microwaves which, apart from possible microwave ovens, are intended for use outside of the aircraft. Conceivably, microwaves could enter through windshields and cabin windows, although such an eventuality is unlikely and could easily be detected and corrected. Metal screens for windows would rarely be found necessary, although they might be considered for "radar picket planes" which carry extraordinarily powerful radars. The problem of shielding in aircraft may become more serious when aircraft are constructed of nonmetallic composite materials.

SURVEYING THE HAZARD

To make an effective evaluation of the safety of a pre-existing situation or of a prototype about to be turned on, with respect to microwave radiation, one needs instrumentation, of course. It is also helpful to understand something of the designer's problems and the weak points that have been learned from experience.

Microwaves may be defined as frequencies from 300 MHz to 30 GHz (30000 MHz). One can readily extend one's survey down to 100 MHz or lower because instrumentation is inexpensive and readily available. On the other hand, the region above 12 GHz requires instrumentation that is costly and not as well-developed for survey purposes as that available for the lower microwave frequencies.

Microwave survey meters have been developed mainly for the region up to 12 GHz. The design of these instruments is not trivial but isn't very profound, either, after one accepts the fact that no one antenna will respond equally well in all directions. Three or more antennas are used and the detected powers of all of the antennas are added. Diode detectors are commonly used because high accuracy is not required.

It goes without saying that instruments should be calibrated before use. In this application, however, it is especially important to make sure that the instruments have the expected response characteristics after use. A situation should not be approved just because it burned out the detector!

At present, the need for instrumentation at frequencies above 12 GHz is fairly unusual and unpleasant surprises are unlikely. In most situations within the United States, one has available knowledge of microwave transmitters that are capable of producing power levels that could be considered significant by any reasonable standard. One is usually trying to find out if the particular directional pattern of intentional radiating devices concentrates the power in a way to affect safety, or if the shielding is unintentionally defective.

Very few powerful transmitters are in service above 12 GHz. Exceptions are some military aircraft and the up-links of satellite communications systems. Both make their presence rather obvious. Television mobile units are likely to be found in increasing numbers at frequencies above 12 GHz but are of modest power and temporary use. All of the commercial transmitters are supposed to be registered with the FCC and some companies have put this data on computers and can supply information on a locality with considerable ease, as a service for hire.

Devices such as "free-electron lasers" have been proposed that should be able to generate enormous powers at frequencies above 12 GHz. If these devices are placed in systems, the frequency range of safety instrumentation will have to be extended.

Microwave heating installations are not cataloged, because they are supposed to have designs and interlocks that prevent significant radiation. All the more reason that a microwave survey should pay special attention to the possibility of malfunctioning heating devices--especially the ubiquitous home ovens at a frequency of 2450 MHz (more or less, depending upon how well they are functioning).

As shown by the skin-effect calculations done in this course, the field decreases by 1/e every skin depth. Skin depths are in the range of 1 to 10 micrometers in the microwave region. Furthermore, power is proportional to the square of the field. Thus, a millimeter of solid metal is a very effective shield.

Problems arise in shielding because a solid metal envelope is not practical. One has, at very least, to provide some kind of door or lid to introduce the material to be heated. Early home microwave ovens of certain designs exhibited high leakage in an alarming number of cases because of unsatisfactory door seals. Obviously, repeated openings and closings are a necessary part of checking for erratic behavior or effects of wear. The Federal government now tests and qualifies microwave oven designs.

Industrial microwave ovens include designs with doors. Walk-in sizes are not uncommon. But many industrial applications benefit from continuous

feeding. In these cases, the "waveguide-beyond-cutoff" principle is often exploited. A small-enough hollow conducting tube will not permit radiation of a long wavelength to emerge.

A conveyor-belt of nonconductive material such as polypropylene can be passed through such a waveguide-beyond-cutoff with only a small change in cutoff frequency. But a test of the empty oven would not prove that the entrance and exit ports are satisfactory when the belt is loaded with work.

Metal screens are often used in place of solid shielding. The screens work quite well if the holes are small enough. Besides saving metal and weight, screens can permit safe observation of work being treated in a microwave oven. Those used in the windows of home ovens have openings about one per cent of a wavelength.

Conductors that pass through a hole in a screen, or through a waveguide-beyond-cutoff section, can defeat the shielding effect to a remarkable extent. Low-level testing of shielding is a useful preliminary precaution, because most of the effects of concern are substantially linear. An exception is when the shielding material itself can be destroyed by the high power. An example would be the use of a too-thin screen that could not conduct away the heat dissipated in it at full power.

A received power of 0.1 microwatts is enough to produce a color television picture of excellent quality. In our microwave relay system, an antenna of one square meter acquires this power, so that the power density is about 0.00000001 milliwatts per square centimeter. The power density from satellites can be somewhat lower because larger receiving antennas are used. Low-noise receivers are used, of course.

The power levels that suffice for reception thus should be tolerable to almost anyone who would accept a "factor-of-safety" approach to microwave exposure. Most deserving of attention are the surrounds of transmitters, microwave ovens or other high-power sources (such as the microwaves used in some of the particle accelerators of physics research).

If one nevertheless wishes to survey the faint coherent signals that may be present, one uses a spectrum analyzer with antennas designed for broadband coverage. Usually, several antennas are used to cover the microwave frequency range and the antenna is pointed in various directions. Spectrum analyzers are not as sensitive as low-noise receivers (because they look at each frequency only a small fraction of the time) but are more than sensitive enough to detect any level of power likely to have biological significance. They are routinely sensitive to nanowatts.

The evidence of athermal damage is very scant for frequencies below the microwave region (in contrast to the careful microwave experiments on the induction of cataracts in rabbit eyes, mentioned previously). One has, of course, at all frequencies a responsibility to guard against excessive thermal effects. Industrial heating makes extensive use of radio frequencies. A notable example is the use of 27 MHz for sealing vinyl

plastics (as in making raincoats). Apparatus reminiscent of sewing machines has been constructed for this purpose and the shielding is not as thorough as would now be insisted upon for microwave heating. For better or worse, frequencies in this range have been used for half a century in medical diathermy, where the dominant concern is the obvious hazard of overheating.

The possibility of athermal effects at frequencies of 60 Hz or even lower is a matter of concern to those living or working near high high-power installations. But that is another controversy.

CONCLUSION

Exposure of personnel to microwave radiation can usually be kept below known damage thresholds by large factors of safety without excessively burdening the functioning of devices or greatly increasing cost. Large factors of safety are appropriate because the effects of long-term low-level exposure are difficult to assess.

MATERIALS DESCRIPTION (LABORATORY)

COAXIAL SLOTTED LINE

PURPOSE

The plotting of experimentally-determined reflection coefficients is introduced. The effect of generator impedance on standing-wave patterns is illustrated.

Single-stub matching is accomplished.

Thermistor and thermoelectric power meters are used to illustrate decibel notation for power.

PRECAUTIONS

The microwave signal generator used in this experiment will deliver no more than 20 milliwatts of microwave power. The shock hazard from the generator and other instruments will be negligible if all of the instruments are equipped with three-prong plugs and the slotted line itself is grounded. (Earlier models of the tube-type generator that may be used came with two-prong plugs; we don't have any but watch out for them elsewhere.)

Although the slotted line is not completely surrounded by metal, we can show theoretically that microwaves of frequencies below 3000 MHz will not emerge significantly unless a perturbing object is inserted to guide them out. The probe carriage provides shielding in and beyond the region where the measuring probe could have such an effect. Turn off the microwave power to the slotted line when looking under the carriage to see the probe. A button on the solid-state generator toggles the "RF" (microwave) power on and off. Alternatively, the 130 dB attenuator on the tube-type generator is more than adequate.

The probe is adjustable and should be withdrawn enough so that the results do not depend upon its position, but not so far that you don't have enough signal. But you don't have to look at the probe to do this. Ordinarily, a wide range of probe settings produce acceptable results.

The thermistor can stand much more microwave power than available in this experiment, but can be burned out by its own read-out device ("power meter"). Do NOT connect or disconnect the thermistor head from the power

meter (which is a self-balancing bridge) while the power meter is turned on. (This precaution refers to the 60 Hz a-c supply, not to the microwave power.)

The thermoelectric power meters have a very low factor of safety (sometimes less than two!) with respect to microwave power, compared to their rating (see rating on power head). Don't use them until very sure of the maximum power (by thermistor measurement, for example). The read-out device for these power heads is just a microvoltmeter and can't hurt the element if grounds are correct.

PROCEDURE

Warm up the standing-wave indicator (VSWR meter). Turn on the microwave generator. The initial setting is not likely to damage anything or anyone. Set the frequency at 1499 MHz or other frequency you are instructed to use. Connect the thermistor head to the DUT (device under test) end of the line, which is the end opposite the one to which the generator is connected. Zero the power meter, if necessary, by momentarily turning off the microwave power with the appropriate button (NOT the on-off switch) or by attenuating the power until it is negligible. Then establish a correspondence between the generator output reading and the power-meter reading in the 0.1 to 10 milliwatt range. But use dbm notation! Only after the thermistor power meter confirms that the power is within the range of the thermoelectric meter should you connect the latter. Take a reading at a level such that comparison of the two meters is possible. Then see how small a power you can read reliably (within 0.5 dB) with the thermoelectric meter.

Now turn on the 1000 Hz modulation. Note the effect on the power reading (at any one generator setting). Forgetting to turn on the modulation when it is needed is the second commonest way to get stuck while trying to do this experiment.

Now for the first most common sticking point. You might at this time see an indication on the VSWR meter, but it is unlikely unless someone has blessed you with just the right setting of the tuner on the carriage. Tune for a maximum signal.

Use the VSWR meter to measure the impedance of the thermistor mount and subsequent objects in the following manner. Move the probe until the VSWR meter indicates a maximum signal (to the right, like any other meter). Change scales if necessary. Now adjust the gain control until the needle is on 1.0, without moving the probe carriage. Then, without changing the gain adjustment, move the probe until the needle indicates a signal minimum. The reading gives the standing-wave-ratio. If you have to change ranges to read both maximum and minimum, you will find it much more agreeable to take the readings from the decibel scales than from the ratio scales. The procedure is the same whether the expanded scale setting or the normal setting is used, but you must be sure to use the scale corresponding to the operating mode you have selected.

Read the position of the probe carriage for the minimum and record this position and the VSWR. Repeat after turning off the a-c power to the power meter. You have now measured the reflection coefficient of the thermistor in the on and in the off condition, except that an experimental determination of the wavelength in the slotted line is much to be preferred over a presumptive calculation from the frequency. The wavelength is best measured when the DUT has a very high VSWR, as with the open circuit, below. Next measure the reflection coefficient of the thermoelectric power meter with the a-c power on and off. Summarize the difference in behavior.

Replace the power head with the Type-874 3-cm open circuit, which will have a high VSWR (perhaps too high to measure if the configuration does not permit much radiation). Repeat as before except record the position of all of the minima that you can find. Also, do not worry if the minimum is so low that you cannot get an accurate VSWR; then just record a lower limit for VSWR. The distance between minima is a half-wavelength and you should calculate all of the distances to check consistency of measurements.

When the minimum is lost in noise, you can estimate both the minimum position and the VSWR from the shape of the standing wave near the minimum. Take data now to do this (just once in this experiment). The minimum nearest the load is preferred.

Use the 3-cm short-circuit as DUT and repeat as for the open circuit. Next measure the VSWR and position of minimum (one position sufficient) for a 100-ohm mismatch and then for a 25-ohm mismatch made from a tee and two 50-ohm terminations.

For the report you will plot the short, open, and two mismatches on a Smith chart in impedance coordinates, using the short as the phase reference standard (-180 degrees on impedance reflection chart!). You will be asked a silly but answerable question: "Is the open circuit capacitive or inductive?" You also should derive and apply the curve-fitting technique for the high VSWR measurement.

Now tune the 25-ohm mismatch with an adjustable line and a single adjustable shunt shorted stub. How low a VSWR can you achieve?

As a final piece of mischief, place the shunt stub at the generator end of the slotted line and measure the VSWR and position of minimum for the 25-ohm mismatch, for two or three different (random) settings of the stub. Plot these readings on the same Smith chart.

POWER TRANSFER AND THE X-BAND SLOTTED LINE

PURPOSE

The skills objectives are the manipulations necessary to measure complex reflection coefficient with a slotted line and associated equipment. Some experience with power and frequency measurements and ferrite isolators is included.

Concepts include phase velocities greater than the velocity of light and the principle of conjugate matching.

HAZARDS TO HEALTH

There is no evidence that microwave radiation from equipment of this kind has ever injured anyone, even slightly. But computations indicate that moderate caution should be exercised. About 100 milliwatts of power will be available from the solid-state source intended to be used for this experiment. (As you have found out, we sometimes have to substitute tube sources when the solid-state sources burn out. In such an event, be twice as careful because some X-13 tubes can put out 200 milliwatts. Above all, review the cautions that have been passed out concerning high voltage. The X-13 requires 400 volts.) At the open end of WR90 guide, 100 milliwatts would give an average power density of 50 milliwatts/cm^2. This amount is 5 times higher than the level that would surely cause concern for long-term exposure, even under the least conservative (early American) standard. It is 500 times the Russian standard for worker comfort. You have a shorting switch in the system; use it when connecting objects to the end of the waveguide. The isolator protects the source from reflections from the short.

The power density falls off rapidly with distance from a low-directivity antenna such as the open end of a waveguide. Just the same, you can use less than one milliwatt when measuring the reflection coefficient of antennas. And close the shorting switch if some person walking through the laboratory seems likely to walk through the boresight of the antenna.

HAZARDS TO EQUIPMENT

If the power measuring head contains a thermistor (negative temperature coefficient of resistance) or a bolometer (positive T.C.), it should not be connected or disconnected from the power meter while the power meter is on. (A thermistor may survive such a mistake—a bolometer would not.) A thermoelectric power measuring head is susceptible to burnout from only moderate overloads above the rated maximum power (which is therefore usually stated on the label of the head); however, it is in little danger from its own indicator, which is essentially a microvoltmeter.

Ground yourself before inserting a microwave detector of mixer diode into a socket and make ground-to-ground contact first in connecting cables that are attached to such diodes. The idea is to avoid discharging your body's static electric charge through the diode. Most connectors are arranged so that the

ground makes first contact but there is no harm in being extra careful.

PROCEDURE

Make sure that the power-measuring head is connected to the power meter. Then turn on the line switches of the oscilloscope, the standing-wave indicator and the power meter.

Before turning on the generator, make sure that at least 10 dB of attenuation is present in the main line. Do not use the main power switch of the generator to turn off the microwave power during the experiment. There will usually be an "RF" on-off switch on the generator. Alternatively, one may use the shorting switch in the waveguide line to block the power for zeroing of a power meter (the isolator protects the generator from the reflection from a short circuit). After the initial turn-on you will be able to control the power at the generator and no particular amount of attenuation is required in the line as long as instruments do not indicate that they are overloaded.

Set the power meter to the 10 mw scale and zero it when no microwave power is incident. If the generator is set for modulation, turn off the modulation for the first part of the experiment.

A wavemeter is an absorption cavity which one sets for a dip; that is, a "peak of absorption" indicates the frequency. With a direct-reading wavemeter, one may have to be very careful to identify the proper scale among many. Set the generator at a frequency between 9 and 10 GHz. Record this frequency and also confirm it by using the cavity wavemeter(s) to get a dip on the power meter. You may wish to try any other frequency-measuring devices that are available.

Now measure the insertion loss of the isolator, using the power meter and attenuator. The isolator is a device which will pass a considerable fraction of the power in one direction and very little in the other.

Measure the insertion loss in the forward direction; then reverse the isolator and measure the isolation if you can. If the isolation is very high, go to a lower scale of the power meter, re-zero (use shorting switch), and see if you can now measure the isolation.

If the isolation still can't be measured, estimate the value it must exceed. Even though the power meter has good absolute accuracy, the rotary vane attenuator can be expected to have better relative accuracy for most of the power ratios that you will be called upon to measure (you can judge this matter reasonably well for yourself by studying the gradations on the scale of the attenuator).

On the lowest usable range of the power meter, observe the effect of warming the power sensor with your hand (depends on type of power meter; some have temperature compensation).

DETECTION OF MODULATED SIGNALS   .

The crystal detector provides more sensitivity than the ordinary thermistor barretter. This sensitivity may be exploited to measure the high isolation of the isolator with ease. The detector can give particularly dependable high sensitivity when its output is connected to a high-gain A-C amplifier. For this reason, the input microwave signal is modulated. Most instruments use 1000 Hz square-wave modulation so that the power alternates between full on and completely off.

Observe the detected envelope on an oscilloscope. Confirm the suitability of the modulation by running the frequency meter through the frequency. Desirably, the "on" portion of the square wave should dip as a whole (flat). The supposed zero-power portion should not be affected by the frequency meter. And zero should be identifiable on the oscilloscope (use D-C input setting).

After the modulation is established properly, read and record the microwave frequency. Connect the waveguide crystal detector by means of BNC cable to the "standing-wave indicator". Put the detector on the output side of the reversed isolator. Establish that signal is coming through: observe it on a standing-wave indicator connected to the crystal detector and confirm that the signal is above the noise level indicated when the shorting switch is inserted.

Set the waveguide attenuator to zero dB and adjust the gain on the standing wave indicator so that the needle points to some value that you can remember. (A "standing-wave indicator" contains a high-gain tuned amplifier: later, you will use it to measure standing waves.) Now, turn the attenuator to its maximum attenuation to protect the meter and remove the reversed isolator: apply the power directly to the crystal detector. Next, restore the power gradually by changing the attenuator until the standing-wave indicator level is back to the previous remembered position. The isolation of the isolator is given by the attenuator (as corrected, if a calibration chart is provided).

Before precision microwave attenuators were available, attenuation measurements were sometimes based on the fact that a crystal detector is a "square-law device" for sufficiently low values of incident power. Record the readings of the precision attenuator and the standing-wave indicator (range switch decibels plus dial decibels) over a wide range of attenuator settings. You should find that the decibel readings track well when low power is incident upon the detector, but they will deviate at higher powers. Sometimes an intermediate pseudo-square-law region is observed.

Optionally, you may wish to establish an absolute power reference with the power meter and/or an output voltage reference with a voltmeter, with due consideration of the fact that the source is modulated.

Materials Description (Laboratory)

SLOTTED LINE

Now connect a VSWR meter to the probe of the slotted line. Tune the probe
to maximize the indication (have a matched load on the slotted line for this
tuning).

Clamp a flat metal plate across the waveguide flange and measure the
position of minimum to have a reference for plotting reflection
coefficients. Conventionally, this minimum position will correspond to
= -1. This reference position will be important in checking the complex
conjugate matching principle.

The short also provides an excellent condition for measuring guide
wavelength by noting the position of successive minima. Read as many
minimum positions as you can find, to the best possible accuracy. Note that
scale may read from right to left, a feature that also affects the reading
of the vernier.

CONJUGATE MATCHING

The standing-wave ratio (VSWR) is determined by comparing the VSWR meter
reading at maximum to the VSWR meter reading at minimum OR by noting the
change in attenuator setting required to get the same VSWR reading at
maximum as at minimum. The attenuator method is more accurate (except
possibly for VSWR values very near unity) and does not depend upon the law
of the detector.

The conjugate matching demonstration consists of measuring the complex
reflection coefficient of a designated "test object," matching each object,
if possible, with a tuner, and measuring the tuner. An E-H tuner and a
slide-screw tuner are provided (use separately, not in combination). Follow
these steps:

1. Note VSWR and position of minimum with object connected to
    slotted line.

2. Insert tuner and tune for minimum VSWR. A directional
    coupler with yet another detector and standing-wave indicator
    is helpful, though it is good to be able to tune with only
    the slotted line.

3. If tuning is successful (VSWR < 1.03), remove object, reverse
    tuner, terminate, and measure VSWR and minimum position for
    reversed tuner.

Also measure the VSWR of the crystal detector, the power-measuring head
(with power meter on and power meter off), and a horn antenna.

PHASE VELOCITY AND WAVELENGTH

With the shorting plate in place, note the position of several minima for a

3-21

relatively low and a relatively high frequency within the usable band of the waveguide. Note that it will usually be necessary or desirable to retune the probe when the frequency is changed.

CALCULATIONS

Compare guide wavelengths with guide wavelengths calculated from measured frequencies. Use nominal waveguide width of 0.90 inches (WR90 guide).

Plot slotted-line data on Smith charts to illustrate conjugate matching principle.

Calculate the reflection loss in decibels and also the "efficiency" of the power meter and the waveguide crystal detector.

Plot the test of square-law response.

Report also the measurements obtained with little or no calculation: insertion loss and isolation and the several VSWR's.

MATERIALS DESCRIPTION (EXAMINATION)

Some of the multiple-choice questions may have more than one right answer. In those cases, the scoring will be proportional to two for the first right answer plus one for each additional right answer minus one for each wrong answer, but not less than zero for any question.

On the other hand, some questions call for only one answer. Circling more than one answer letter will result in zero credit for that question.

The scores on individual questions will be weighted in the total score on the basis of importance, timing in the course, and firmness of the answers.

1. Given the polynomial equation:

$$s^5 + 3s^4 + 7s^3 + 2s^2 + s + 3 = 0$$

Which of the following quantities are NOT roots of the equation within the indicated precision? (Hint: persons with root-finding calculators have no significant advantage in answering this question.)

      (a) 0.13287   (b) -0.8994

      (c) 0.8653   (d) $0.319 + j0.652$

      (e) -1.000   (f) $-1.369 + j2.111$

2,3,4,5 in each of the following cases you are to assume that it is known with reasonable certainty when the period of immersion or cessation of breathing began. Also, CPR (cardio-pulmonary resuscitation) has not been applied during any of the intervals in question. You are asked to give an opinion of when it is reasonable to conclude that massive irreversible brain damage has occurred.

What is to be done with this opinion is not the question; circumstances and judgment could determine action to be based on this opinion. (For example, recovery from a boat in storm seas; landing an aircraft at an emergency field under questionable conditions; tunneling in earthquake-damaged buildings; cases where serious hazards to others may be involved.) One answer only for each question:

2. Immersion (without breathing apparatus) in 77F (25C) water:
    (a) 5 min   (b) 15 min   (c) 60 min   (d) 120 min

3. Immersion (without breathing apparatus) in 41F (5C) water:
    (a) 5 min   (b) 15 min   (c) 60 min   (d) 120 min

4. Electrocution by high-voltage direct current:
    (a) 5 min   (b) 15 min   (c) 60 min   (d) 120 min

5. Struck by lightning:
    (a) 5 min   (b) 10 min   (c) 20 min   (d) 60 min

6,7
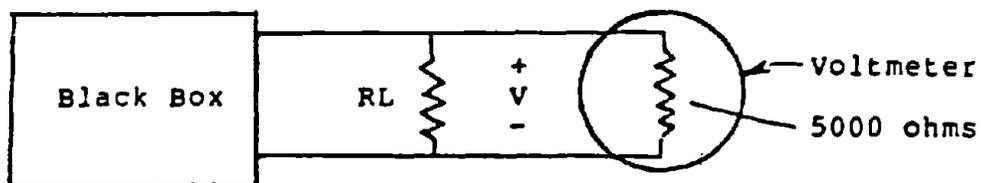
The voltmeter has a resistance of 5000 ohms (regardless of its reading) and gives a true value of the voltage across its terminals. When the resistor RL has the value 4000 ohms, the voltmeter reads 0.9 volts. When the resistor RL has the value 2000 ohms, the voltmeter reads 0.60 volts.

6. The Thevenin-equivalent resistance of the Black Box is, most nearly (circle only one):

    (a) 600   (b) 1250   (c) 2222   (d) 7500   (e) 20000   ohms

7. The Thevenin-equivalent voltage of the Black Box is, most nearly (circle only one):

    (a) 0.964   (b) 1.000   (c) 1.16   (d) 1.41   (e) 9

8. A completely-connected planar circuit has 21 meshes and 14 nodes. How many branches does it have ? ....

9. The time constant of the circuit below is:

    (a) $(L1 + L2 + M)/R$

    (b) $(L1 + L2 - M)/R$

    (c) $(L1 + L2 + 2M)/R$

    (d) $(L1 + L2 - 2M)/R$

    (e) none of the above
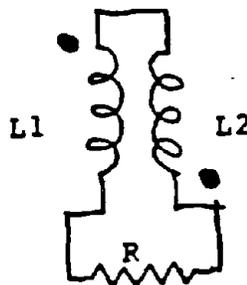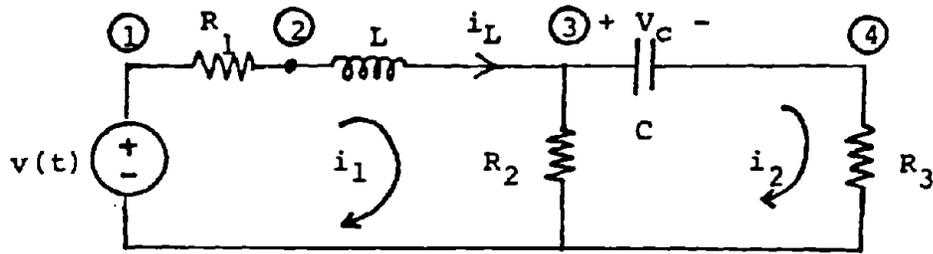
The state equations for the above circuits are included below. Try to pick them out by inspection and by eliminating obviously incorrect or irrelevant answers.

(a) $\quad \dfrac{di_L}{dt} = \dfrac{(R_1 + R_2)i_1}{L} + \dfrac{v(t)}{L}$

(b) $\quad \dfrac{di_L}{dt} = -\dfrac{R_1 i_1}{L} \quad \dfrac{R_2(i_1 - i_2)}{L} + v(t)$

(c) $\quad \dfrac{dV_C}{dt} = \dfrac{i_2}{C}$

(d) $\quad \dfrac{dV_C}{dt} = -\dfrac{1}{C(R_2 + R_3)} V_C + \dfrac{R_2}{C(R_2 + R_3)} i_L$

(e) $\quad \dfrac{dV_C}{dt} = \dfrac{i_L}{C} - \dfrac{V_3}{RC}$

(f) $\quad \dfrac{di_L}{dt} = -\dfrac{R_2}{L(R_2 + R_3)} V_C - \dfrac{R_1 R_2 + R_1 R_3 + R_3 R_2}{L(R_2 + R_3)} i_L + \dfrac{v(t)}{L}$

(g) $\quad \dfrac{di_L}{dt} = -\dfrac{V_C}{R_2 + R_3} - \dfrac{R_2}{L(R_1 + R_3)} i_L$

11. The circuit shown in problem 10 has _____ nodes.

12. A nonlinear capacitor has the characteristic $Q = KV^3$. The work required to change it from zero to v is

   (a) $\frac{3}{4} KV^4$ (b) $\frac{2}{3} KV^4$ (c) $\frac{1}{2} KV^4$

   (d) $\frac{1}{2} KV^2$ (e) $\frac{4}{3} KV^3$ (f) none of the above.

13.
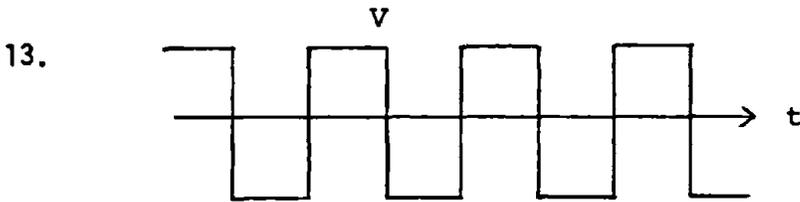
A square wave is shown above. The derivative of the square wave is (one only):

(a)

(b)

(c)

(d)

(e)

14.

+C

i_3

R   R_1   R_2

v(t)   (+/-)   i_1   R_3   i_2   R_9
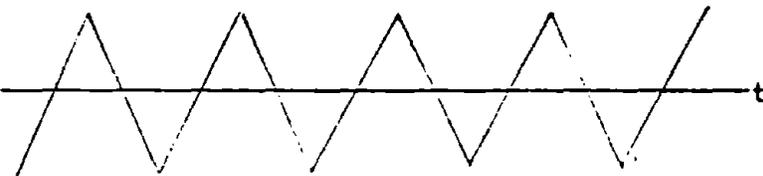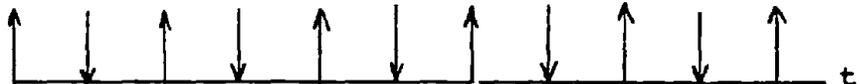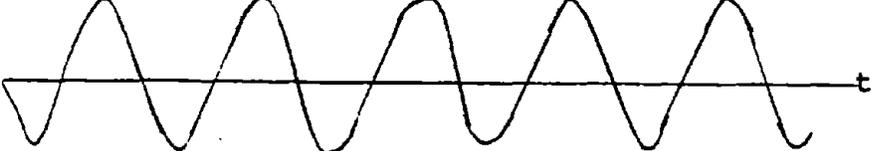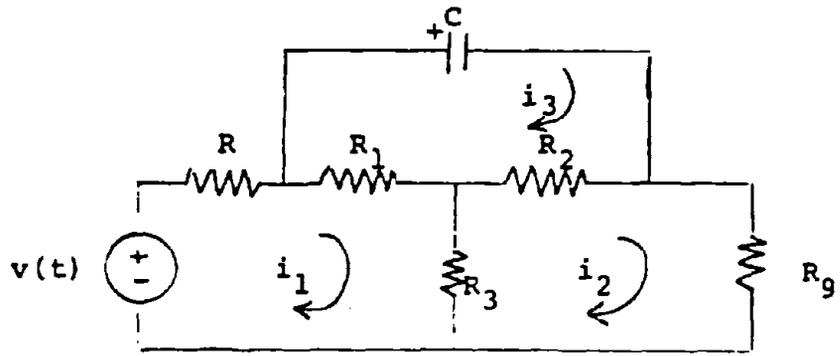
Write the loop equations for the above circuit.

Health and Safety Course Material

in

Engineering Design

by

John G. Kreifeldt, Ph.D.
Engineering Design Department
Tufts University
Medford, MA 02155

4-1

UNIT OVERVIEW

METHOD: Lectures, Homeworks, Individual and Group Projects

PURPOSE: To introduce biomechanical analysis pertaining to back injuries within the context of engineering analysis in design.

OBJECTIVES: Acquaint student engineers with:

1. Need to consider the human as part of the total design.
2. The prevalence of back injuries in the populations.
3. Biomechanical analysis techniques as related to back stress and strain.
4. Government agency design standards and recommendations related to reducing back injuries.
5. Research literature and methods treating back injuries.

RATIONALE: "Back injuries" are treated in the context of consumer products rather than industrial settings (e.g. manual materials handling) because:

1. This area is largely neglected.
2. Students have ready and "hands on" access to the product (playpen in this case) and can thus verify their designs.
3. Discussion of application of the techniques etc. to industrial manual materials handling is given in class lectures and readings.

PRESENTATION: The material is designed to be introduced as part of an introductory course for engineers treating various aspects of Human Factors in Design in an engineering context. Occupational Safety and Health issues are discussed and for the project, the "occupation: of parent, day-care personnel, etc." is used.

INSTRUCTOR
MATERIALS: Chalkboard
.Projection foils
Overhead transparency projector and screen
Anthropometric Mannikins
Anthropometric Data

STUDENT
MATERIALS: Mannikin Tracings
                    Mockup materials (Fomecor, etc)
                    Lesson supplements
                    Project/homework descriptions

INTRODUCTION

The material on back injuries from manual materials handling will be presented in the course: Engineering Design (END) 61 - <u>BIOTECHNOLOGY IN HUMAN SYSTEMS DESIGN,</u> a spring semester course.

A. END 61   Biotechnology in Human Systems Design

An introduction to human performance and to designing for human use. Study of human factors, ergonomics, environmental and legal concerns which impact on design for human use and on human performance and environments. Examples of good and bad designs drawn from various areas. Students will have the opportunity to practice the course material in an assigned project. A practical course that will provide more humane design. Prerequisite: Engineering Science 1 or consent of instructor.

B. Format of Course Material

The format will consist of (1) several lectures, (2) assigned readings and (3) a project to design/evaluate some product or work situation in which back injuries are or should be an important consideration. The project will consist of individual and group assignments assuring that each class member practices the material as well as participates in a group effort to produce the final design. The final effort or design will be critiqued during student presentation by a panel of experts and the individual and group assignments will be evaluated by the instructor. Each group will submit a complete report detailing the entire project.

C. Material Integration

END 61 (Biotechnology in Human Systems Design) is a sophomore-level course required of all students in the Engineering-Psychology program and taken by other students as well. Students are considered as having basic introductory engineering skills appropriate to the sophomore level. The material on manual materials handling will follow the

usual lecture - readings - assignments format except for the heavy use of this material as part of a class project as outlined in section B above. It is my experience that students benefit from the attempt to apply the class material in a realistic problem - hence the project emphasis. Our approach to project assignments is described in references 7.

D. Occupational Safety and Health Application

The material is applied in "consumer product" setting although such a product (e.g. playpen) may be used in a occupational setting (e.g.daycare centers etc.). In any case, the approach is the same and discussion of its application to "manual materials handling" in industry is presented in the lectures.

MATERIALS DESCRIPTION

Attached to this section are sample assignments (both group and individual) for student practice and application of the material in a product design problem taken from actual practice.

The attached project description, individual and group assignments are referenced to specific lecture material/readings which an individual instructor may abstract for his/her own uses. Generally, there is emphasis on engineering analysis/synthesis as opposed to just memorization of pertinent facts.

A description and rationale of the project/case study follows.

> Homework Problem - Compressive Stress on L_5/S_1
>
> As a first example, students are required to compute the center of gravity (CG) and the torque at the L_5/S_1 vertebrae using the drawing attached. The height and weight of the worker is given. The following materials will also be given:
>
> Template for Determining Total Body Center of Mass from:
> J. S. Warton - "A Template for Locating Segmental centers of Gravity." Research Quarterly of the American Association of Health, Physical Education and Research 41:615 -618, 1970.
>
> Weights of Body Segments - Table 6-7 from:
> J. A. Roebuck, Jr., K.H.E. Kroemer, W. G. Thomson, Engineering Anthropometry Methods, John Wiley & Sons, N. Y. 1975.

Lecture material will work a sample problem using the two materials referenced above. (They are not reproduced here for copyright purposes). The center of gravity and torque computation are very elementary computations for a rigid body and this exercise serves to demonstrate familiar computations in a common biomechanical setting.

The first lecture will be a discussion of the implication of the torque values at the L_5/S_1 joint based on the following readings.

E. R. Tichauer, The Biomechanical Basis of Ergonomics, John Wiley & Sons, N. Y. 1978.

5.1: Elemental Analysis of Lifting Tasks

D. Chaffin, G. Andersson, Occupational Biomechanics, John Wiley & Sons, N. Y. 1984.

Chapter 6: Occupational Biomechanical Models (for more advanced computation of biomechanical lifting stress and strain).

U. S. Department of Health and Human Services, Work Practices Guide for Manual Lifting, DHHS (NIOSH) Publication No. 81-122, March, 1981.

Chapter 3, Basis for Guide: Biomechanical Approach.

Students in the course will have had elementary engineering physics covering Newtonian mechanics as well as an elementary course in statics.

The second lecture will discuss the background to the problems of manual materials handling as well as guidelines for lifting. The lecture and readings will be based on:

Chaffin and Andersson, Chapter 8, Manual Materials Handling Limits.

NIOSH Publication No. 81-122.
Chapter 8: Recommendation

S. Snook, "The Design of Manual Handling Tasks." Ergonomics, 21 (12) 963-986 (1978).

Snook's data and the NIOSH limits for lifting will be illustrated with a sample in-class problem (attached).

The semester-long group project is described below.

A. Project Description - A Safer Playpen

The project description is actually for the design of a safer playpen. However, part of the designer's moral and legal responsibilities are to ensure that the design does not injure the user who uses it in a "reasonably forseeable" manner. In this case, back stress and strain in lifting infants in and out of a playpen is definitely a foreseeable possibility and therefore appropriate analysis must be made as part of the design process. Thus this biomechanical analysis becomes a part of the mechanical analysis

and design also being made and the problem is set out in such a way that the possibility of back injury to a user is stressed while the means to analyze and prevent it are presented in lectures, readings and homework. Only static (not dynamic) lifting stresses are considered for simplicity at this level.

The problem statement is based on an actual case from the Consumer Product Safety Commission and some motivation will be supplied by a discussion of the problem in terms of the infant mesh entrapment deaths that have occurred in the present design of the folding - mesh sided playpen.

The requirements section of the project statement will be amplified in the later assignments (attached).

B. Individual Assignments

   1. Individual Assignnment 1 - Product Dimensioning

       This assignment requires basic engineering measurement, drafting and dimensioning of a playpen of choice. Engineering judgments must be made as to the level of drafting detail and accuracy required in order to produce an articulating 2-D (profile) model later based on these drawings.

       Basic drafting has been covered in previous "intro to engineering" courses ES001/002 which are prerequisites for the present course. A computer-aided design (CAD) system is also available for student optional use. Basic instructions on this has been given in ES001/002 and may be used if desired for this project.

       The assignment will be due two weeks after it has been assigned which is concurrent with the project statement which will be handed out the first week of classes.

       Assignment 1 can be begun immediately without benefit of class lectures. Each student will complete this (and all other individual) assignments.

   2. Individual Assignment 2 - Scale Models and Mannikins

       This assignment requires the student to fabricate a 2-D profile model of the playpen to 1/4 scale and to illustrate its articulating feature of the folding side in suitable fashion for later analysis and use with 1/4 scale mannikins of the 5th and 95th percentile user of the playpen.

       Earlier lectures will have discussed mannikins and their use in design with enough information provided to allow each student

to construct suitable mannikins for individual use. (The mannikins may be obtained from reference 8 or 9).

Each student will receive further basic engineering practice in the use of simple readily-formed materials to produce working "models" of both user and product sufficiently accurate for later analysis and insights into product use.

Only a 2-D "sideview" model of the playpen is required. A three dimensional model is not required (or necessary) at this point.

Three weeks will be allowed for completion of this assignment. A lecture demonstration on "mock-ups" will have preceded this assignment.

3. Individual Assignment 3 - Biomechanical Analyses

This assignment concentrates on application of the lectures and readings in biomechanical analyses of lower back stress and strain, lifting limits, etc.. Previous lectures on anthropometry will have provided the background necessary for body sizes and weights, etc..

Three weeks are allocated to this assignment and each student will complete the assignment. The "answers" will differ depending on the positions assumed by the mannikins. Grading will be based on the appropriateness of the analyses.

These analyses on an existing playpen design will provide the practice and insight needed to make the similar appropriate analyses on the "safer" design.

4. Individual Assignment 4 - Warnings/Instructions

"Failure to warn" is a potent legal position that can be taken against a defendant designer whose product harms a user. (Handout Ref. 10 enclosed).

Following the design/analysis of the "safer" playpen design by a group effort, each student will produce a set of instructions for the safe use of the playpen as well as a set of warnings about the hazards of use. Lectures on instructions and warnings and the designer's legal responsibilities will have preceded this assignment.

Two weeks will be allowed for this assignment. This assignment will provide a model for the group effort as will be the case for the previous 3 individual assignments.

C. Group Assignment 1 - Design of the Safer Playpen

At this time, only one group assignment is anticipated. This assignment will be accomplished as a group effort with the assurance that through the individual assignments each student will have practiced the skills required to design and analyze the new safer playpen.

Groups will consist of 4-5 students per group and each group will be formed at the beginning of the course.

The final report will be a complete detailing of the new design including mockups, drawings, analyses, etc.. The biomechanical analyses pertaining to back injuries possible in "manual materials handling" in a home product context is especially emphasized although the point of its introduction is to familiarize engineers with such analyses and treat it as an essential part of the engineering analysis/design process.

RECOMMENDATIONS

The introduction of manual materials handling is primarily in an engineering design/analysis context and treated as a natural and required part of the engineering design process. The material presentation and practice draws on existing engineering skills so that its introduction is simplified and natural in that no "one time" specialized skills are required.

My experience is that students learn the application and perspective of such materials best in a realistic design context. The particular design problem detailed could be replaced with any of a number of similar product or workplace design problems as long as skills in analysis/design are emphasized and practiced.

Several suggestions for other design projects are listed below:

. Conveyor System Design

Many package handling businesses have workers resorting packages manually from a conveyor belt. These are high volume (high rate) jobs in which the worker must often reach across the belt and lift parcels from it to redirect the parcel onto a belt for another destination.

. Beer or "Soft Drink" Case Handling from Delivery Trucks to Stores

Although the in-plant handling of drink containers may be automated, palletized, etc., they are manually handled at the sales destinations by the delivery drivers. Often the task is such that it is potentially detrimental to the worker or such as to preclude females from this job because of the potential back injury problem. A design project can be directed toward analysis of an existing

delivery system of cases and truck, etc. and redesign of the delivery system.

Students may obtain data from existing delivery trucks visiting distribution stores in their neighborhood.

. Patient Handling Device for Hospitals

Hospital workers have a high incidence of back injuries from lifting patients. Existing devices for this purpose can be analyzed together with the task in terms of back injuries, cost, etc.. A better (i.e. safer and more economical device) is to be designed, analyzed and mocked-up.

The project requires "construction" of at least a simple 2-D profile articulating model of the "safer" playpen design in order for the student to learn how to translate analytical work into reality. The assignments and projects are designed so as to keep the student in close contact with engineering practice in terms of analysis/synthesis and to develop elementary skills at mockup, visual communication etc..

A discussion of project grading criteria, etc. is given in Kreifeldt (ref 7).

REFERENCES

1. J. S. Walton, "A Template for Locating Segmental Centers of Gravity", Research Quarterly of the American Association of Health, Physical Education and Research 41: 615-618, 1970.

2. J. A. Roebuck, Jr., K.H.E., Kroemer, W. G. Thomson, Engineering Anthropmetry Methods, John Wiley & Sons, 1975 (Table 6-7).

3. E. R. Tichauer, The Biomechanical Basis of Ergonomics, John Wiley & Sons, 1978, Section 5.1: Elemental Analyses of Lifting Tasks, 48).

4. D. Chaffin, G. Andersson, Occupational Biomechanics, John Wiley & Sons, 1984, (Chapter 6: Occupational Biomechanical Models) (Chapter 8: Manual Materials Handling Limits).

5. U. S. Department of Health and Human Services, Work Practices Guide for Manual Lifting PHHS (NLOSH) Publication No. 81-122, March, 1981 (Chapter 3, Basis for Guide: Biomechanical Approach) (Chapter 8, Recommendations).

6. S. Snook, "The Design of Manual Handling Tasks", Ergonomics, 2 (12) 963-986 (1978).

7. J. Kreifeldt, "Consumer Product Design Projects For Human Factors Classes", Proc. Human Factors Society, 26th Annual Meeting, 735-739, 1982.

8. Anthropometric Data Application Mannikin, P. O. Box 2653, Santa Barbara, CA 93120, (cut out articulating mannikins - 5th & 95th male approximately $30 per set).

9. Human Factors Engineering Design for Army Material MIL-HDBK-759A, 30 June 1981. Obtained from NAV. Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120 (This is a "fee" (nominal charge) handbook containing 1/4 scale mannikin templates for 5th & 95th male and female. Templates may be traced onto celluloid materials to make a set of articulating profile mannikins.

10. F. Fowler, "Failure to Warn", Proc. Human Factors and Industrial Design in Consumer Products, Tufts University, Medford, MA, May 28-30, 1980.

11. Eastman Kodak Co., Ergonomic Design for People At Work, Vol. 1, Wadsworth, Inc., London, 1983.

12. E. Grandjean, Fitting The Task to the Man: An Ergonomic Approach, Taylor & Francis, LTD. London, 1980.

13. E. Grandjean, Ergonomics of the Home, Taylor & Francis, LTD, London, 1973.

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END 61 BIOTECHNOLOGY IN HUMAN SYSTEMS DESIGN

Homework

For the attached figure compute the following:

1. The Center of Gravity (CG) of the figure. Mark its location on the drawing.

2. Is the figure stable in this configuration?

3. Assume the worker is holding a 30 pound weight in his hands. Is the worker stable now? (Locate the new CG).

4. Compute the strain in inch-lbs about the spot marked L_5-S_1 with the 30 lb load.

    Is the above strain found acceptable?

NOTE: Assume the worker weighs 170 lbs. and is 6' tall.

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DEPARTMENT OF ENGINEERING DESIGN

END 61 BIOTECHNOLOGY IN HUMAN SYSTEMS DESIGN   SPRING 1986

A Safer Playpen

Individual Assignment 1 - Product Dimensioning

Obtain dimensions for a folding, mesh side playpen of your choice such that
you can produce an accurately scaled profile drawing of the playpen. Your
drawing and dimensions will be essential for later work so they must be
carefully done. You may draw to any standard size drawing format.
"Nonessential" features need not be detailed. You will need to decide what
constitutes essential - nonessential details.

You will need to produce a profile mockup of the playpen from your
drawings/dimensions in the next assignment based on your drawings in this
assignment.

For dimensioning, review ES001/002 materials and standard texts such as:

          J. Earle - Engineering Design Graphics

          W. Luzadder - Fundamentals of Engineering Drawing

If you are proficient on the CAD system you may use that.

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DEPARTMENT OF ENGINEERING DESIGN

END 61   BIOTECHNOLOGY IN HUMAN SYSTEM DESIGN   Spring 1986

A Safer Playpen

Individual Assignment 2 - Scale Models and Mannikins

  (1) Based on your drawings and dimensions, make an accurate,
    quarter-scale articulating profile model of your "target"
    playpen.

  (2) Make articulating, accurate quarter-scale models of the 5th
    and 95th percentile female user of the playpen.

The playpen model can be made of any suitable materials appropriately
fashioned such as tongue depressors, balsa sheet material, "fome cor" etc..
The mannikins are best made of transparent, plastic material, thin enough to
cut out with a knife or scissors but not so thin as to "flop" or curl.
Charrettes is a likely source for construction materials.

Mount the mannikin(s) and model in a functional arrangement which permits
manipulation showing the interaction of user and playpen with its folding
side. Establish reference positions for positioning mannikins relative to
playpen.

  (3) Submit a report detailing your observation and anthropometric
    analyses of the 5th and 95th percentile users interacting
    with the playpen.

  (4) Submit your models in Anderson 109 for evaluation.

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END 61   BIOTECHNOLOGY IN HUMAN SYSTEM DESIGN   SPRING 1986

A Safer Playpen

Individual Assignment 3 - Biomechanical Analyses

In this assignment you are to make a biomechanical analyses of the body
stresses of the user interacting with the playpen/occupant in different
modes as outlined below:

1.   Lifting/Lowering infant for the conditions:

      Sides: (a) up   Infant: (a) 2 mo.
             (b) down   (b) 12 mo

      User: (a) 5th percentile female
             (b) 95th percentile male

      (i.e. 2x2x2 = 8 different combinations)

2.   For each combination find the relative positions of
      user/infant interacting with the playpen which
      produces maximum stress and give:

      1. maximum stress
      2. configuration of playpen/infant/user
      3. submit results in a brief report with
         discussion

NOTE: You will need to find appropriate weights for these two
       ages.

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END 61   BIOTECHNOLOGY IN HUMAN SYSTEM DESIGN   SPRING 1986

A Safer Playpen

Individual Assignment 4 - Warnings/Instructions

Based on your group's design of the "safer playpen";
anthropometric/biomechanical/hazard analyses; etc., you are to produce an
adequate set of:

1. Instructions For Use

2. Warnings

Pay particular attention to "presentation" as well as content of both
Instructions and Warnings. In addition to this "text" material your group
should "design in" the appropriate safety features.

It is expected that you will produce the instructions and warnings as they
would appear in the final product, that is, to appropriate sizes, locations,
formats, etc..

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END 61   BIOTECHNOLOGY IN HUMAN SYSTEM DESIGN   SPRING 1986

A Safer Playpen

Group Assignment 1 - Design of the Safer Playpen

Based on the knowledge gained in the previous individual assignments, your group is now to produce the safer design complete with analyses of its safety, lifting stresses, anthropometric analyses, etc., as outlined in the original document. You should all work together in the "ideation" stage but may partition responsibilities for "routine" other work.

This assignment will culminate in the original problem statement requirements of report, model, analyses, etc.. Each group will make its project presentation and submit the final report as well.

DEPARTMENT OF ENGINEERING DESIGN

END 61   BIOTECHNOLOGY IN HUMAN SYSTEM DESIGN

Spring, 1985
Prof. Kreifeldt

All play yards
fully padded

GROUP DESIGN PROJECT

A SAFER PLAYPEN

INTRODUCTION

The folding side playpens presently on the market have been involved in the deaths of several dozen infants up to the age of 12 months. The problem is that if the mesh side is either down or up but not locked, an infant may get itself over the edge of the playpen floor and become trapped in the slack mesh with resulting suffocation. The suffocation appears to happen because the infant's face with its soft nasal structure is pressed tightly against the "draft shield", or because the entanglement so constricts the soft and weak chest/thorax that it can't be expanded to breath. Such conjectures are based on the positions in which the tiny bodies are found.

The problem could be eliminated of course if the sides did not come down at all but it is clear that this is the most attractive feature for parents who must transport or store the playpen and must also lift the infant in/out of it or otherwise have ready and easy access to the infant. It is clear that if the playpen did not have these features it would not be purchased. Society - courts and government agencies such as the CPSC (Consumer Product Safety Commission) - have ruled that the benefits outweigh the risks and have mandated <u>warnings</u> on the playpen rather than product removal.

However, the CPSC is searching for a safer design for a "folding playpen" which does not need to depend solely on printed warnings.

It is your group project to design this safer playpen. Your work will progress by several individual and group assignments.

PROBLEM STATEMENT

A. <u>Playpen</u> - You will need accurate and appropriate dimensions of a "folding playpen" for your final design which will also be presented in an articulating profile mockup. For purposes of this project, you may take as a "target" playpen any of your choice on the market. A very common playpen is the "40 x 40" inch referring to the side dimensions. Certain dimensions are already mandated by Federal standards, as explained later.

B. <u>Occupant</u> - Infants older than 9-12 months, apparently are able to extricate themselves from the mesh sides if they do get entangled so you may assume your are to protect infants up to the 12 month age from this hazard.

C. <u>User</u> - The primary users of the playpen are females (mothers, babysitters). In the analyses to be made you may focus solely on female users.

D. <u>Environment</u> - The environment of use is normally a room where the user can "keep an eye" on the infant in the playpen or in a quiet room where the infant may sleep. The playpen must be easily transportable from room to room, stored, or even put in a car for moving to temporary locations (babysitter's house).

E. Task - The User's tasks involve lifting the infant in/out of the playpen, changing its "nappies", retrieving objects for it, etc.. Thus the user should have ready access to the infant in the playpen and to the playpen interior itself.

REQUIREMENTS

Your group will supply a complete report which will include at least:

1. The "safer design" demonstrated by:

    a. Complete dimensioned drawings of the playpen profile and linkages (if any) etc., sufficient to build a mockup from the drawings.

    b. A working scaled profile model demonstrating necessary features and action.

2. Anthropometric and biomechanical analyses pertaining to the user lifting infants in/out of the playpen, accessing the interior, etc.

3. Anthropometric analyses of the occupant in the playpen pertaining to the occupant's safety in the playpen.

4. Hazard analyses of the product.

5. Adequate instructions and warnings design.

6. Others as judged necessary.

NOTE: It is expected that your design will at least conform to existing industry and Federal standards for playpens. It is perfectly appropriate to exceed standards if you demonstrate adequately that doing so produces a safer design. Standards are minimums not maximums.

The work will be scheduled in a series of individual and group assignments.
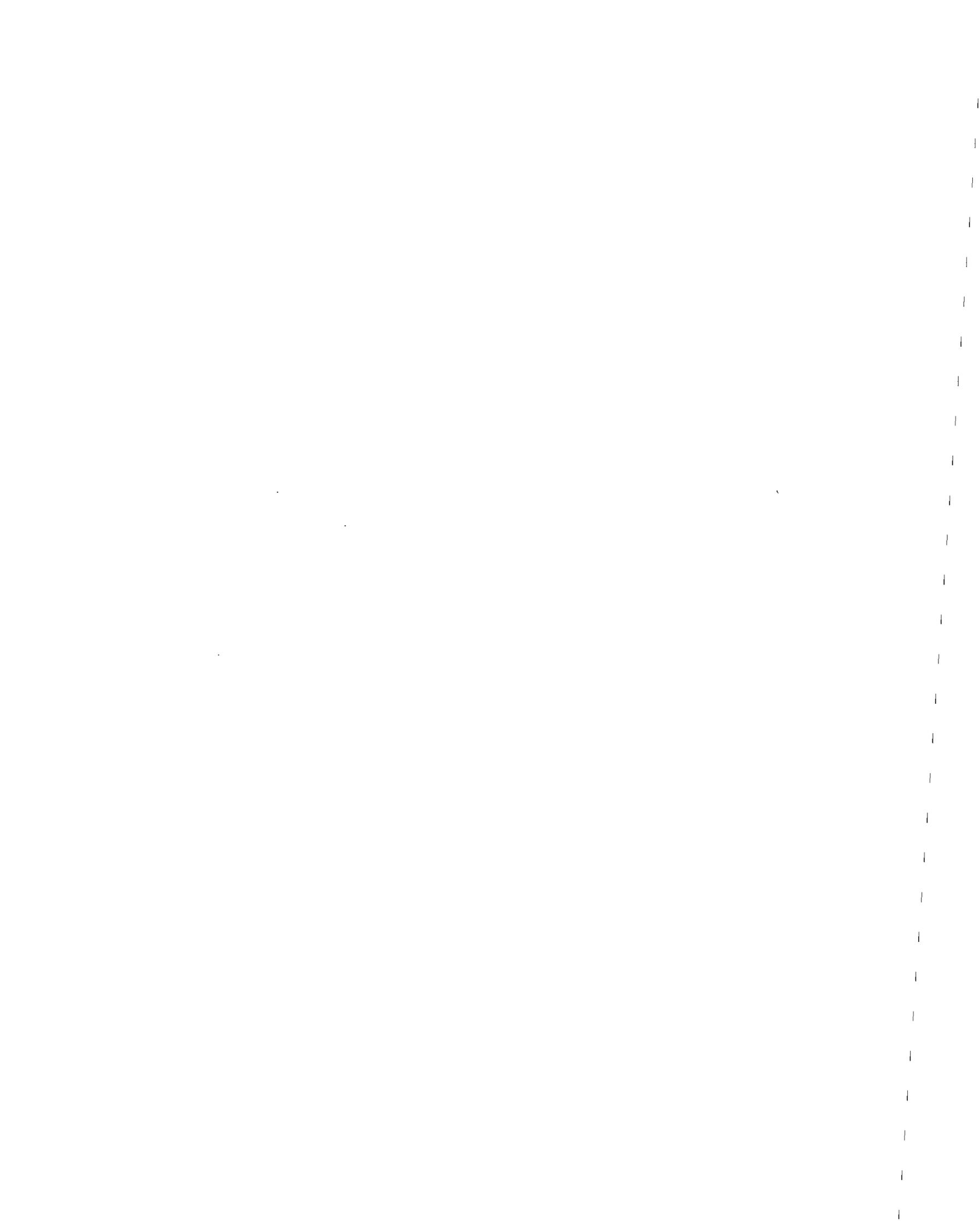
Health and Safety Course Material

in

Mechanical Engineering

by

Anil Saigal, Ph.D.
Mechanical Engineering Department
Tufts University
Medford, MA 02155

UNIT OVERVIEW

METHODS: Lectures, Case Study, Laboratory

PURPOSE: Integrate more effectively into existing mechanical
                engineering course work the concept of safety and health
                considerations in the design process.

OBJECTIVES: 1. Emphasize the importance of safety and health
                   considerations in the design process.

                2. Provide basic guidelines for maximizing the safety level
                   of a design.

                3. Provide student exposure to health and safety hazards
                   associated with the foundry industry, product design and
                   noise.

RATIONALE: The consideration of safety and health hazards, as part of
                the natural development of the design process, will stimulate
                a sensitivity to these problems in the undergraduate
                engineering student body.

PRESENTATION: The lecture material on the introduction of safety and health
                considerations in the design process and the laboratory on
                noise will be presented in required undergraduate courses.
                The case study on product design was developed for an
                advanced-level undergraduate course.

INSTRUCTOR
MATERIAL: Chalkboard
                Visit to local foundry

STUDENT
MATERIAL: Lesson supplements
                Sound level meter
                Probability graph paper
                Reference books

INTRODUCTION

The students in the Department of Mechanical Engineering will be introduced to the subject of health and safety engineering through three courses.

A. ME - 25 Engineering Materials

> A study of the structure-property relationships of engineering materials. It covers the internal structure of both perfect and imperfect materials and the principles and techniques by which the structure can be controlled. The relationship of mechanical properties to structure is studied and the influence of these properties on actual production process is covered.
>
> This is a required course for all undergraduate students in the department of mechanical engineering.

B. ME - 125 Materials Technology and Manufacturing Processes

> A study of manufacturing processes including casting, metal machining and computer-aided manufacturing. Topics include properties and behavior of materials, selection of materials for elastic and plastic deformation, brittle fracture, creep, corrosion, high temperature design applications, and economic constraints.
>
> This is an elective course for seniors and graduate students in the department of mechanical engineering.

C. ME - 18 Mechanical Engineering Laboratory

> Students devote two afternoons each week to experimental work in mechanical engineering. During the first half of the course, experiments will be done in fluid flow, vibrations, acoustics and thermal behavior. The last half of the course is devoted to experimental projects with various members of the department.
>
> This is a required course for all undergraduate students in the department of mechanical engineering.

The various aspects of the subject will be presented in the form of:

1. Laboratory
2. Lecture
3. Case Study

The lecture and the case study will be presented in ME-25 and ME-125. It is expected that 1 lecture in ME-25 and at least 2 lectures in ME-125 will be spent on this subject towards the second half of the respective courses.

The laboratory will deal with noise measurement, recommendations for permissible exposure to industrial noise levels and design methods to reduce noise levels. Two afternoons in ME-18 will be devoted to this topic.

MATERIALS DESCRIPTION (LECTURE)

INTRODUCTION

In an effort to protect society from the problems of acid rain, air and water pollution, occupational cancer, and hazardous wastes, that have been associated with rapid technological gains, dozens of regulation have been passed over the past 15 years. Many of these deal with the safe manufacture, use, transportation and disposal of hazardous materials.

The role of the engineering community is to direct the power in nature for the use and convenience of man. Experience has shown that even though most engineering contributions are well-meaning and well-designed, they often introduce other problems. Automobile exhausts, asbestos insulation, acid rain, degradation of ozone layer and pollution of ground water are but a few of the man-made hazards that have accompanied our engineering accomplishments. Today the engineer must also have a sound understanding of the sociological implications of his efforts in addition to sound science and sound economics. This understanding is necessary since the history of human relationships to the environment has, more often than not, been characterized by failures. One outcome is that engineers are expected to investigate the health risks and the benefits of an innovation of new manufacturing process before it ever leaves the drawing board.

Hazard control technology is the special province of industrial hygiene and safety engineers. However, today most of the industrial hygienists are not engineers, and the percentage of engineers in this field has been decreasing steadily even though a majority of the health and safety hazards are engineering-related.

The need to have a good understanding of safety or industrial hygiene engineering has never been greater. In recent years, industries have spent billions of dollars on engineering controls whose goal is to prevent occupational hazards. For the most part, these expenditures represent retrofitting. In many cases, had the engineer been knowledgeable of the potential hazard, a proper initial design would have been achieved, and much of this cost and related morbidity/mortality could have been avoided. For example, the annual cost to industry for protecting worker safety and health in the United States in 1981 was estimated at 2 billion dollars. In other words, about 2 percent of the total overall capital spending is devoted to protecting employee safety and health. In addition, a great deal of money is spent on local exhaust ventilation, noise controls and protective shields

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installed after start-up. In the past, most negligence cases in product liability suits were predicated based on production defects. In recent years, however, design effects have been shown to be more significant source of accidents.

SAFETY AND HEALTH CONSIDERATIONS IN DESIGN

Any design which includes safety and health considerations will bring improvements of direct importance to the manufacturer. These include:

1. Reduced risk of injury or health impairment.

2. Fewer product recall and an enhanced reputation for both quality and efficient operation.

3. Reduction in occupational injuries and illness can decrease the premium paid for worker's compensation.

4. Group health insurance rates can be reduced as amounts paid out decrease.

5. Excess labor costs incurred by workers absent because of illness or injury can be reduced.

6. Savings can be realized in personnel replacement and training costs.

7. Goodwill can be secured from employees, stockholders and the public.

8. Reduced chances of being sued by someone injured while using a product.

The six basic guidelines a designer can apply in order to maximize the safety level of his products or manufacturing processes are:

1. Eliminate the hazard from the product or process by altering its design, material, usage or maintenance method.

2. Control the hazard by capturing, enclosing or guarding it at its source.

3. Train personnel to be aware of the hazard and to follow safe procedures for avoidance.

4. Provide adequate warnings and instructions in appropriate forms and locations.

5 Anticipate common areas and methods of abuse, and take steps to eliminate or minimize the consequences associated with such actions.

6. Provide personal protective equipment to shield personnel against the hazard.

Both products and manufacturing processes have some unavoidable degree of hazard associated with them. One of the first and important steps for the safety conscious designer to take is to identify all the major hazards which may apply in case of the product failure. This constitutes the initial line of defense in their control and minimization.

A systematic approach to hazard analysis is:

1. Specifying the basic elements of the design.

2. Searching for hazards associated with each element.

3. Specifying the hazard potential for causing injuries or illness.

After the first design cycle is complete, the design should be once again evaluated for safety and health. The evaluation process should encompass the following seven step approach to ensure that a reasonably safe design will eventually emerge:

1. Describe how the product will be used.

2. Identify the environments where it could be used.

3. Describe the user population.

4. List all of the hazards associated with the product along with their respective probabilities of occurrence and harm that can result including illness, injuries and damages. Use this data to develop interrelationships or combinations of events that can result in injuries or illness.

5. List alternative design features or production techniques that can help reduce or eliminate these hazards.

6. Evaluate each alternative technique with respect to how it will affect performance, usefulness, and cost, and if it will introduce other hazards.

7. Include which is the safest combination of features to include in the final design.

Procedural safeguards such as instructions and warnings once the design is complete, are often inadequate for a variety of reasons:

1. People do not always follow the instructions.

2. Any job that can be done wrong eventually may be done wrong.

3. People may imagine themselves personally immune to accidents and thus do not pay attention to procedural safeguards until it is too late.

4. Designers presume that people will use common sense with their products. This can be a misleading assumption because it sometimes requires a good deal of specific knowledge about the product which the user just may not have.

Any machine guard or similar protective devices can always be circumvented by a worker thus making it useless. It is therefore much better to depend on integral or built-in systems which prevent unintended actuation of the operating mechanism.

In most jurisdictions, the only recourse an injured worker has against his employer is workmen's compensation. In order to obtain larger sums, a worker may sue the manufacturer of the product which caused the injury. The designer must keep in mind what may be done to the product and how it may be used during its life.

It is thus best to upgrade an original design than to improvise retrofits after a pattern of incidents has occurred or someone has been injured or killed. It is the threat of product liability law suits that has been instrumental in improving the design of products and systems by upgrading their built-in safety level.

OCCUPATIONAL SAFETY AND HEALTH HAZARDS

Air and water pollution are two important problems that are to some extent directly related to processing and manufacturing.

AIR POLLUTION (INDOOR)

Air pollution is the result of exhausts from industry, transportation, power plants, heating and refuse disposal. The foundry and manufacturing industry contributes to air pollution through metal cutting, machining and casting processes. In metal cutting, air contaminants are generated when straight oils are used as coolants, and metal is removed at relatively high volume rates. The exhaust of the air contaminants to the atmosphere is not permitted. Even though there is a ventilation system to reduce the concentrations to avoid discomfort, it is passed through electrostatic precipitators, scrubbers, gravity type settling chambers or cyclone separators. Paint finishing and welding fumes also cause considerable amount of air pollution.

Workers in the foundry industry are subjected to a number of health hazards of which air contamination is one. The following are some of the sources of air contamination in a foundry:

a. Crystalline silica - Silica sand is the primary foundry mold constituent. It is slowly broken down into dust particles during the shake-out of castings, recycling of sand and cleaning of castings using the grinding process. This can be controlled to a certain extent by use of relatively expensive non-silica sands for molding.

b. Metal fumes - Metal fumes are primarily generated during melting and casting operations, during the cutoff of appendages using torches and during welding. Foundry alloys usually consist of a number of individual metals, all with different melting and boiling points. Fumes begin to be emitted as soon as the metal is melted, but the rate is low until the metal is further heated. When the temperature reaches the boiling point, all of the metal can freely boil off. The following observations on fume generation are important:

1. Although the amount of metal which is molten at any time during welding and torch cutting is only a tiny fraction of the metal involved in the casting process, the temperature of the metal during welding and torch cutting is above the boiling points of all metals involved, and fume generation is significant.

2. Zinc, a common metal in Copper base alloys, boils at a low temperature and Zinc loss during casting is thus significant.

3. Lead, which may be found in significant percent in some Copper base alloys, is also present as a tramp metal (an impurity in the scrap) during most ferrous casting. Although its percentage in ferrous castings may be low, the metal boils at typical ferrous melting and pouring temperatures.

c. Carbon Monoxide - Carbon monoxide is an acute gaseous hazard generated in significant quantities. It is generated by combustion of coke in cupola furnaces and during decarburization to produce steel in arc furnaces. It is also generated from combustion of organic materials which are added to green sand molds. The chemical binders used in molds and cores produce carbon monoxide during thermal decomposition.

d. Gases Evolved During Coremaking

1. Acrolein - formed by the thermal decomposition of glycerine which is present in many core oils. Oil sand cores are baked in an oven before use in the mold.

2. Methylene bisphenyl isocyanate - formed during the thermal breakdown of urethane binders during casting.

3. Ammonia - formed during the thermal breakdown of nitrogeneous materials during hot core making and casting.

4. Formaldehyde - used as a binder in sand molds.

e. Other Gaseous Contaminants

1. Triethylamine (TEA) and dimethylethlamine (DMEA) are used as catalysts in the core making process.

2. Sulphur dioxide emissions during melting in a cupola.

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3. Hydrogen sulphide emissions during slag quenching.

4. Chromium, nickel, cadmium, zinc, tin, etc. exposures during the plating operation.

5. Hydrochloric acid, hydrogen fluoride, nitric acid, sulfuric acid, sodium hydroxide, etc. exposures during pickling, acid dipping and metal cleaning operations.

Exposures to the above-mentioned metal fumes and air contaminants (even for small time periods) have been found to result in perforated septa, ulcers, nasal mucosa, dermatitis, hepatitis, jaundice, tonsillitis, skin rashes, lung and pleural cancer, coughing, bronchitis, nose bleeds, abdominal pain, dizziness, pain in the muscles and joints and various other health hazards. In certain cases, exposure has even resulted in death. Efficient exhaust ventilation is a must to reduce the risks and health hazards in the foundry and plating environments.

WATER POLLUTION

Industrial water pollution is due largely to chemical wastes discharged into sewers. Of major concern in the industrial sector have been plating, pickling and coolant wastes. Operations such as plating, chemical cleaning, chemical etching, chemical stripping, etc. pose waste disposal problems. These operations typically use salt solutions of Cadmium, Nickel, Copper, Tin, Indium and Chromium. To reduce the hazardous effect of the effluents, they are chemically treated before disposal (Fig. 1). The resulting sludge is then used as landfill.

The Kodak plant at Rochester, New York processes about 28 million gallons of waste water per day and more than 1500 tons of solid waste per week. Ford Motor Company at Lorraine, Ohio processes about 55,000 gallons of slurry per day. This should provide some insight about the magnitude of the waste disposal problem.

The foundry wastewater regulations were put into effect in 1973 by the EPA. The foundry discharge usually contains metallic particles and organics. The metallic particles are either filtered or are settled through lime solution. The organic compounds are chemically oxidized. According to estimates, the capital cost associated with these are of the order of 100 M dollars with an additional 50 M dollars per year of operational costs.

VIBRATION

Vibration is another important health hazard. Workers are often subjected to large amounts of vibrations in cleaning of castings and construction and renovation works. This leads to whitefingering (a problem related to blood circulation) and trigger finger (loss of flexion control of a finger caused by the growth of a nodule on one of its tendons).

The extent of vibration impact is measured using accelerometers attached to
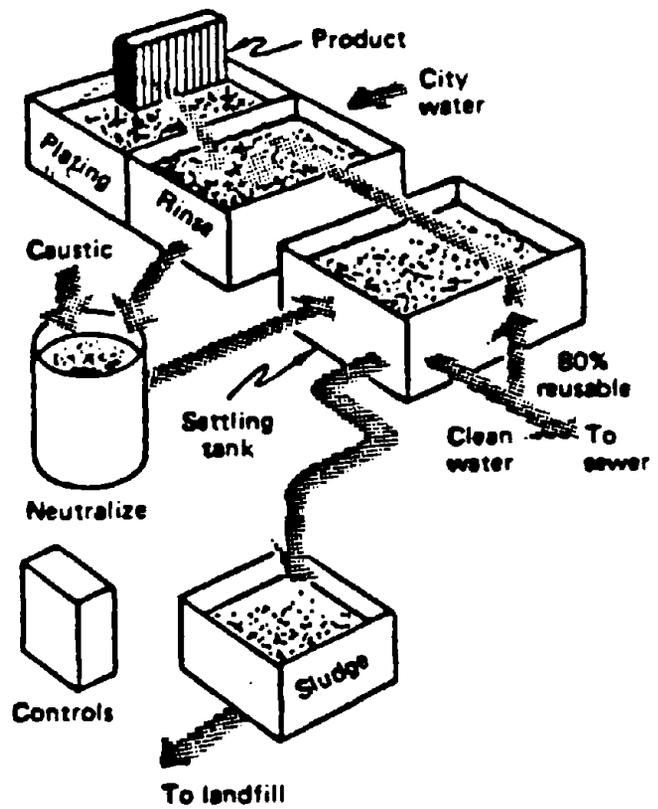
Figure 1   Liquid wastes from plating operations are treated as shown
            in the diagram before discharging into the sewer system.

the worker's hand. In a recent test by a special glove manufacture using chipping hammers, it was shown that compared to the use of bare hands, the following vibration levels were recorded:

	Reduction
ordinary leather gloves	12%
energy absorbing gloves	38%
plastic sleeve	59%
plastic sleeve + sorbothane	75%
plastic sleeve + sorbothane + gloves	76%

These kinds of developments should significantly reduce the health hazards associated with vibrations. However, basic tool design improvements to prevent the vibration impact on the worker is the preferred approach.

Other important physical hazards are radiation, equipment operations which could cause amputation, eye loss, or other traumatic injury, and jobs which can result in back strain, carpal tunnel syndrome and other musculoskeletal injury. The whole area of man-machine interactions (ergonomics) should receive more emphasis at the start of the design process to reduce the possibility of a health hazard as a result of the job.

MATERIALS DESCRIPTION (CASE STUDY)

INTRODUCTION

It has been said that "Engineers can be hazardous to your health".[1]
Engineering and engineers are responsible for improving the quality of life
and the well-being of the society. However, disregard and lack of knowledge
with regard to health hazards and safety has posed a threat to the
well-being of society and life in general. More often than not, safety and
health hazards have been considered in engineering designs as a result of
injury, loss of life or financial losses from a law suit.

This case study is in the areas of material selection, manufacturing
processes and design. These areas cover a significant portion of the
undergraduate mechanical engineering education. Occupational safety and
health engineering have received considerable attention over the past few
years and hence it is only appropriate that we incorporate this very
important subject into our mechanical engineering curriculum.

This case study outlines a 4-prong spider casting used as a seat base. It
describes the material used, manufacturing process used and design
features. This product failed in service, resulting in a law suit, and
finally a change in design and material used.

BACKGROUND

The 4-pronged spider attaches to the seat bottom ie. it is used as a seat
base. It swivels easily on precision stanchion tubing which is attached
securely to a flat base. The swivel of the seat/spider can be locked with a
simple lock handle provided. Holes are drilled towards the end of the
prongs. Bolts are passed through the holes and are used to attach the seat
to the spider. The prongs are gusseted to a location near the hole. The
spiders are recommended to be used as a base seat under normal circumstances
and for certain seat size. Most of the conditions are quite common, and
this kind of spider design is often used. The gussets are used to
strengthen and stiffen the spider by increasing the inertia of the section
under the prongs. A typical spider is shown in Figure 1.

A product of this complexity can be produced by a number of different
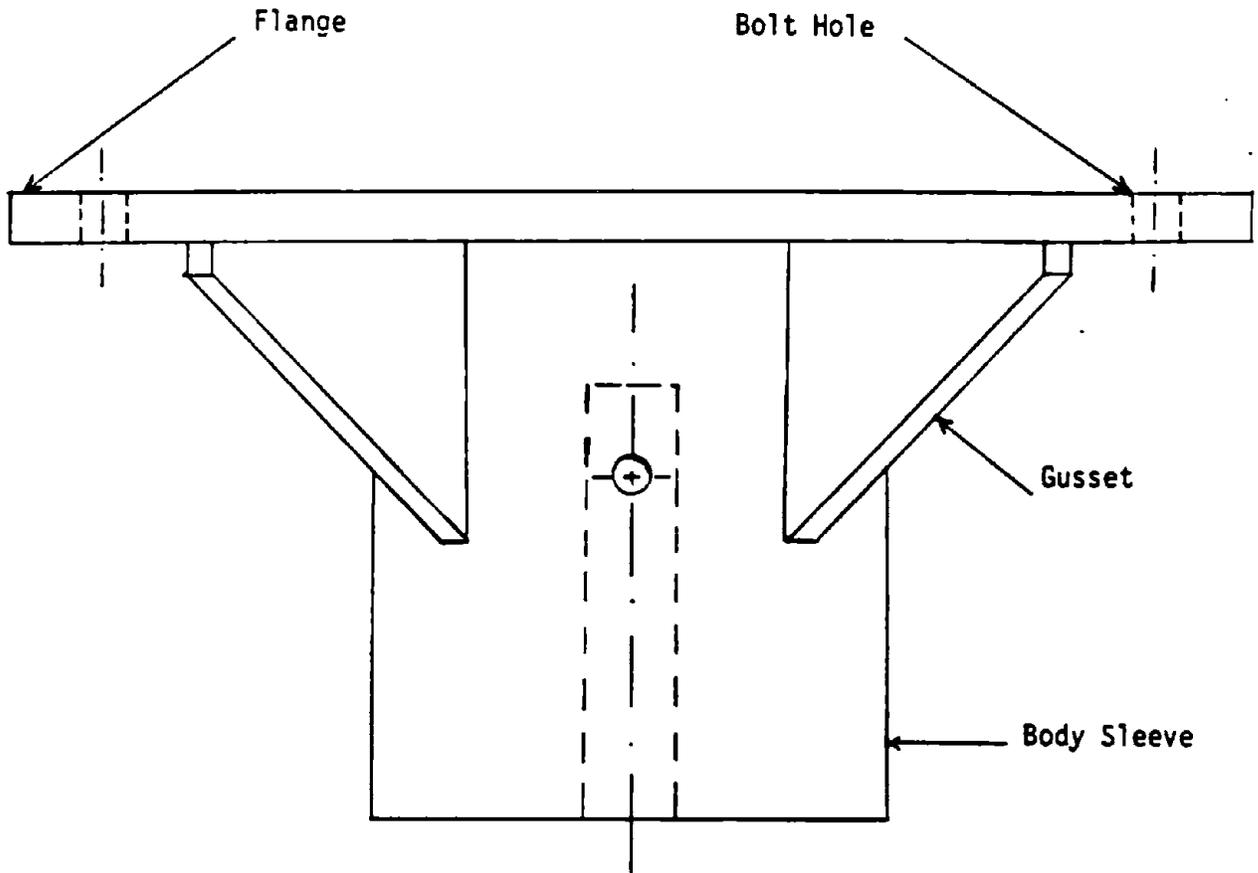manufacturing processes. The product does not require:

    a. Close tolerances

Figure 1   A Typical Spider

b. Fine finish

c. Nice external appearance

d. Critical control of properties

Under the above conditions and keeping in mind the cost consideration, casting is probably the most economical manufacturing process. The spider is required to support a load of 300 lbs. or about 75 lbs. per prong.

For the given prong dimensions and using the case of a simply supported cantilever beam analysis:

width, w = 1"   thickness, h = 0.25"

length, L = 0.75"   load,   P = 75 lbs.

and the bending stress (s) at the gusset end is given by

$$s = 6 P L / w h 2 = 5400 \text{ psi}$$

Among the commercially cast metals, aluminum is widely used. Aluminum silicon alloys exhibit good casting characteristics and are used where pressure tightness and moderate strengths are required. Among the cast aluminum alloys, alloy 319.0 is widely used for similar applications requiring moderate strengths and non-stringent control of dimensions, finishes and properties. Alloy 319.0 can be cast as:

1. Sand Cast

2. Permanent Mold Cast

Depending on the volume of the castings to be produced, one usually decides the particular casting method based on least cost. Sand casting was used in this case.

Average properties of Al 319.0 sand cast alloy are:

UTS 27 ksi   YS 18 ksi   Elongation 2%

Fatigue Strength 10 ksi

Composition 6% Si   3.5% Cu   Fe,Zn <1%   Mg < 0.1%

EVALUATION AND ANALYSIS

The product in this case is a simple 4-pronged single gusseted spider to be used as a seat base. As discussed earlier, evaluating a design for safety and health involves seven steps.

1. Description of how the product will be used.

The product is to be used as a seat base. It is to be bolted to the seat with the help of 4 bolts. The weight is expected to be distributed evenly on the bolts and the spider and be vertical. The spider swivels on stanchion tubing. Under the expected conditions of operation, the product should be satisfactory.

2. Identification of the environments where it could be used.

The spider is to be used as a seat base and is to be subjected to more or less vertical loads. However, many people have a tendency to push back on the seats and press their feet against a wall or support for ease. The horizontal force that can be exerted on the seat is of the order of the weight of the person. This can lead to large moments and stresses on the spider.

3. Describing the user population.

The seat can accommodate any average human being weighing 100 to 300 lbs.

4. Listing the hazards associated with the product, its probabilities and the resulting damages.

As many products usually do, this product failed in service. A person was sitting in the "easy" position, pressing his feet against the front support. The owner of the spider had machined the holes to increase its size to fit the larger seat. Also with time, play had developed between the spider and the seat pillar.

For the Al 319.0 sand cast alloy, Yield Strength = 18,000 psi which gives a $P_{critical}$ = 250 lbs.

When the seat is pressed back and tilted, the load is not applied through the center. Using the set up as
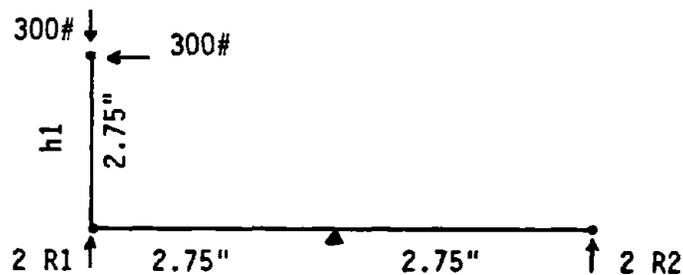
R1 = 225 lbs. = 90% of critical load

safety factor = 250 / 225 = 1.1

If h1 > 2.75" , then R1 will be still greater.

To account for the rocking action because of loose bearing surface between the seat pillar and spider over time, a "dynamic factor" of 2 is used. This gives

$$R1 = 450 \text{ lbs.} = 180\% \text{ of critical load}$$
ie. a stress of 180% of Yield Strength.

The high stress state in addition to poor ductility of the alloy (2%) resulted in the fracture of the product without warning. As a result, the person fell straight back and fractured his elbow. The person later had to retire from his job as his other activities involved lifting relatively heavy components. The person then sued the spider manufacturer for compensation.

5. Listing alternative design features or production techniques that can help reduce or eliminate these hazards.

A number of alternatives were and are available to reduce the possibility of the failure of the product. It is possible to modify the final product by changing any one of the following three parameters:

a. Manufacturing process

b. Material

c. Design

6. Evaluating each alternative technique with respect to how it will affect performance, usefulness and cost, and if it will introduce other hazards.

For economic reasons, casting is the best process. However, there are two alternatives for processing:

a. Use permanent mold casting instead of sand casting

b. Heat treat the final product

Average modified properties for 319.0 alloy are:

	Ultimate Strength (ksi)	Yield Strength (ksi)	Elongation (%)
Sand Cast, T6 treatment	36	24	2
Permanent Mold, as cast	34	19	2.5
Permanent Mold, T6 treatment	40	27	3.0

It can be seen that using permanent mold casting with T6 treatment will increase the strength and ductility by 50 percent. In fact on further inquiry, it was found that the company had changed over to the permanent mold casting process later.

With regard to the material, once again cost plays an important part in the selection process. An alternative material to aluminum for similar applications is steel. Steel has higher strength and is much better in terms of ductility. A search through the literature revealed other manufacturers using steel instead of aluminum for spiders. However, steel is not an easy material to cast.

The design of the spider plays the most important role in controlling the stresses. By increasing the thickness by a factor of 2, the stresses can be reduced by a factor of 4, but it is not economical to increase the overall thickness of the spider prongs. However, for similar design configurations, two alternatives are recommended:

    a. Use of double gussets

    b. Use of double gussets past the holes to the tips and not to reduce the final gusset thickness at the tips to zero

The second of the above two alternatives is often used and is most effective of all alternatives in reducing the stresses. No new hazards are introduced by any of the above mentioned modifications.

    7.   Including the safest combination of features in the final design.

The best combination of material, manufacturing process and design appears to be:

    a. Aluminum 319.0 cast alloy

    b. Permanent mold casting process

    c. Use of double gussets past the holes to the tips and not to reduce the final gusset thickness to zero at the tips

It was found that the cost difference in implementing the modifications after tooling is only a dollar or two per spider. These spiders typically cost around $50 per piece. Also, it is interesting to mention that on inquiry after the incident, it was found that the company had already implemented some of these modifications into the product.

CONCLUSIONS

Most of the manufacturers of engineering products take safety and health hazards in consideration only after an accident results in injury, loss of life or a law suit. It is important for engineers of today to consider safety and health hazards during the design process rather than at the end of the design cycle.

MATERIALS DESCRIPTION (LABORATORY)

INTRODUCTION

This experiment has three main purposes: to expose you to noise as a health and safety hazard; to familiarize you with the operation of a sound level meter and its use in environmental noise measurement; and to acquaint you with the ways of analyzing statistical data.

BACKGROUND

"Noise" has been defined as unwanted excessive sound. Environmental noise is a mixture of noise due to transportation, industrial facilities and homes. Noise is one of the most widely and most frequently experienced problems of the industrial working environment.

(1) Researchers have shown that the average ambient noise level is increasing by 0.3 to 0.7 dB per year. In some high noise areas the increase has been found to be as high as 1 dB per year. Traffic noise is a dominant contributor to the ambient noise level and, as such, it is a major target in any environmental noise abatement program. Noise affects man physically, psychologically and socially. Noise can damage hearing, be annoying and has been found to result in increased heart rate, high blood pressure and fatigue, and reduced efficiency.

(2) Due to the variable nature of the level of traffic noise, interest has focused on obtaining the statistical variation of traffic noise level with time. In community noise abatement and municipal planning criteria data developed from statistical standards are used. Values such as L_{10}, L_{50} and L_{90} (the sound levels exceeded 10%, 50% and 90% of the time) are required for these criteria.

One of the purposes of this experiment is to obtain the statistical variation in traffic noise at some location on the campus and then to evaluate it in terms of the Noise Pollution Level (NPL).

EQUIPMENT

1. General Radio Type 1565-B Sound Level Meter

2. General Radio Type 1562 Sound Level Meter Calibrator

3. Stop watch, or watch with sweep second hand

4. Probability graph paper

PROCEDURE

First, calibrate the sound level meter according to the instruction manual.

Select the measurement location. A busy street corner with traffic lights is an interesting observation point. Note distance to curb, location and time of measurement. Check for wind effects, and, if any are found, either delay measurements or install a windscreen over the microphone.

Set the meter reading on "slow" and use the A scale for measurement. Over a one-hour period, sample the sound field every 30 seconds. This is best done with three people, one to read the meter, one to keep time and one to record data.

REPORT

Fit your data to a Gaussian probability distribution with the aid of the probability paper and determine L_{10}, L_{50} and L_{90} from the smoothed data.

Compute the Noise Pollution Level

where

$$NPL = L_{50} + d + \frac{d^2}{60}$$

$$d = (L_{10} - L_{90})$$

The NPL is used by the U.S. Department of Housing and Urban Development (HUD) to set external noise exposure standards for zoning and new residential constructions as follows:

	Approx. NPL
Clearly unacceptable	
Exceeds 80 dB for 60 min/24 hr	88
Exceeds 75 dB for 8 hr hr/24 hr	
Normally unacceptable	
Exceeds 65 dB for 8 hr/24 hr	74-88

Normally acceptable

    Does not exceed 65 dB for more than   62-74
    8 hr/24 hr

Clearly acceptable

    Does not exceed 45 dB for more than   62
    30 min/24 hr

The report should investigate the following questions:

    a.   What is the subjective rating of your noise sample.

    b.   How does the permissible industrial noise exposure level vary with the duration hours per day.

    c.   What are the noise levels of typical home appliances, building equipments and construction equipments (two each).

    d.   Given the principle, how do you reduce or control the noise in the given example.

REFERENCES:

1.   Instruction manuals for the sound level meter.

2.   J.P. Holman, Experimental Methods for Engineers, McGraw-Hill.

3.   P.N. Cheremisinoff and F. Ellerbusch, Guide for Industrial Noise Control, Ann Arbor Science.

4.   E.B. Magrab, Environmental Noise Control, John Wiley and Sons.

5.   A.P.G. Peterson and E. Gross, Jr., Handbook of Noise Measurement, General Radio Co.

TABLE 1   PERMISSIBLE NOISE EXPOSURE

(after Mageab)

Duration Per Day (Hours)	Sound Level, db, Slow Exposure
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

TABLE 2   SOUND LEVELS AT 0.9m FOR VARIOUS HOME APPLIANCES

(after Mageab)

Appliance	Range (dB)	Mean (dB)
Refrigerator	35-52	42
Fan	38-69	57
Clothes dryer	51-66	58
Air conditioner	50-67	58
Electric shaver	47-69	60
Hair dryer	59-65	61
Clothes washer	47-72	62
Water closet	50-72	63
Dishwasher	54-72	65
Electric can opener	54-76	66
Food mixer	49-79	68
Vacuum cleaner	62-85	72
Food blender	62-88	75
Food waste disposer	67-93	78
Home shop tools	72-97	83

TABLE 3   SOUND LEVELS AT 0.9m FOR TYPICAL BUILDING EQUIPMENT

(after Mageab)

Equipment	Range(dB)
Fluorescent lamp ballast	20-50
Fan coil units	25-55
Diffusers, grilles and registers	20-60
Induction units	25-60
Dehumidifiers	40-70
Humidifiers	20-70
Mixing Boxes	25-80
Unit heaters	45-80
Transformers	70-80
Boilers	55-90
Rooftop a/c units	70-90
Pumps	45-92
Steam valves	60-92
Air compressors	75-105
Cooling towers	85-110

TABLE 4   SOUND LEVELS AT 15m FROM TYPICAL CONSTRUCTION EQUIPMENT

(after Mageab)

Equipment	Range(dB)
Earth movers	
Front loaders	72-84
Backhoes	72-93
Tractors	76-96
Scrapers	80-93
Pavers	86-88
Trucks	82-94
Material handlers	
Concrete mixers	75-88
Concrete pumps	81-83
Cranes(movable)	75-86
Cranes(derrick)	86-88
Stationary	
Pumps	69-71
Generators	71-82
Compressors	74-86
Impact	
Pneumatic wrenches	83-88
Jack hammers and rock drills	81-98
Pile drivers(peaks)	95-105

TABLE 5   SOUND LEVELS AND HUMAN RESPONSE

|	Noise Level (dB)	Response	Hearing Effects	Conversational Relationships
Carrrier Deck Jet Operation	140			
		Painfully Loud		
	130	Limit Amplified Speech		
Jet Takeoff at 60 meters (200 ft)	120			
Discotheque Auto Horn at		Maximum Vocal Effort		
1 meter (3 ft)	110			
Riveting Machine Jet Takeoff at				Shouting in Ear
600 meters (2000 ft)	100			
Garbage Truck NY Subway Station Heavy Truck at		Very annoying		Shouting at 0.6 meter (2 ft)
15 meters (50 ft)	90	Hearing Damage (8 hours)		
Pneumatic Drill at 15 meters (50 ft)		Annoying		Very Loud Conversation at 0.6 meter
Alarm Clock	80			
Freight Train at 15 meters (50 ft)		Telephone Use		Loud Conversation at 0.6 meter
Freeway Traffic	70			
at 15 meters (50 ft)		Difficult		Loud Conversation at 1.2 meter (4 ft)
		Intrusive		
Air Conditioning Unit at 6 meters (20 ft)	60			Normal Conversation 3.2 meters (12 ft)

Contribution to Hearing Impairment Begins

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TABLE 5   SOUND LEVELS AND HUMAN RESPONSE(continued)

	Noise Level (dB)	Response	Hearing Effects	Conversational Relationships
Light Auto Traffic at 30 meters (100 ft)	50	Quiet		
Living Room				
Bedroom	40			
Library		Very Quiet		
Soft Whisper at 5m (15 ft)	30			
Broadcasting Studio	20			
		Just Audible		
	10			
	0	Threshold of Hearing		

LOW MASS AND LOW FALL HEIGHTS GIVE LEAST SOUND

Principle

The noise level generated when a panel is struck by a falling object depends primarily on the mass and velocity of the object. The greater the mass and fall height, the louder the noise, because greater energy is available for transfer into the panel via the impact. A reduction in height or in mass by a factor of ten reduces the noise generated by approximately 10 dB.
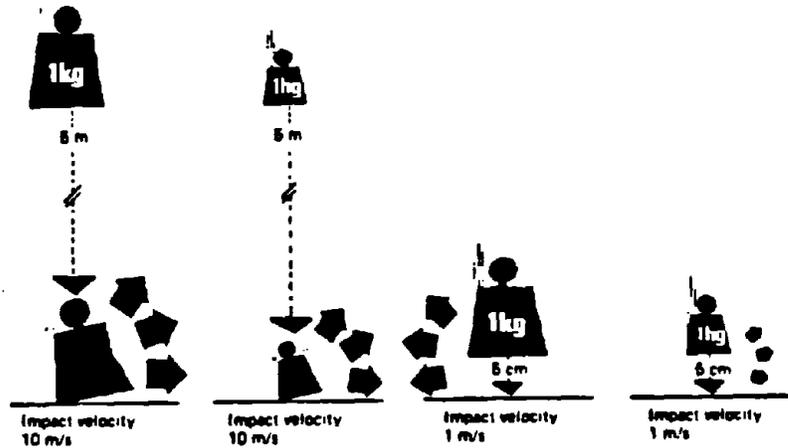
Problem

A material conveyer feeding a hopper deposits the material in the center of the hopper and the fall height is therefore large. The hopper itself is also a very resonant structure.
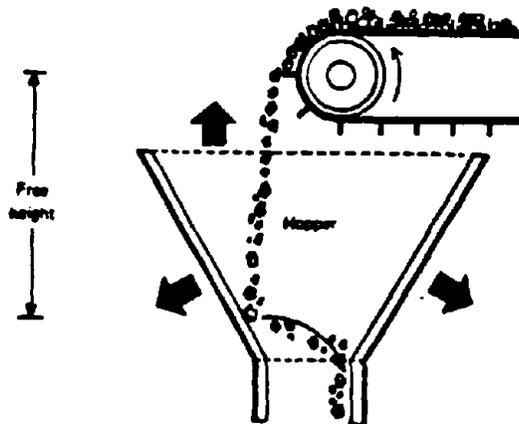
Solution

Mount the conveyer so that the material falls on the edge of the hopper so
that the free height is minimized. The interior of the hopper can be lined
with wear-resistant material to absorb the impact better, and the external
surfaces can be mounted with damping sheets to reduce resonances even further.
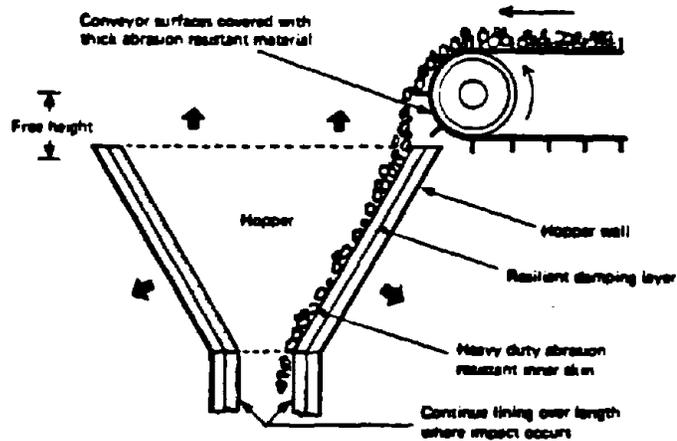
FREE EDGES ON PANELS ALLOW PRESSURE EQUALIZATION AROUND THEM AND REDUCE RADIATED NOISE LEVELS

Principle

It is not always possible to avoid the use of large vibrating panels which give rise to high noise levels. In many cases, these may be replaced by a perforated panel or another type with a broken surface. A plain panel radiates noise from all its area efficiently as there are only four sides along which the sound pressure can be partially cancelled out by the negative pressure from the other face. If the panel is perforated, not only is there less surface to radiate the sound, but there are far greater possibilities for this equalization to take place. Noise levels are therefore reduced substantially. Mesh, or expanded metal panels can also be used. For the same reason, a narrow panel radiates less noise than a square panel of the same area.
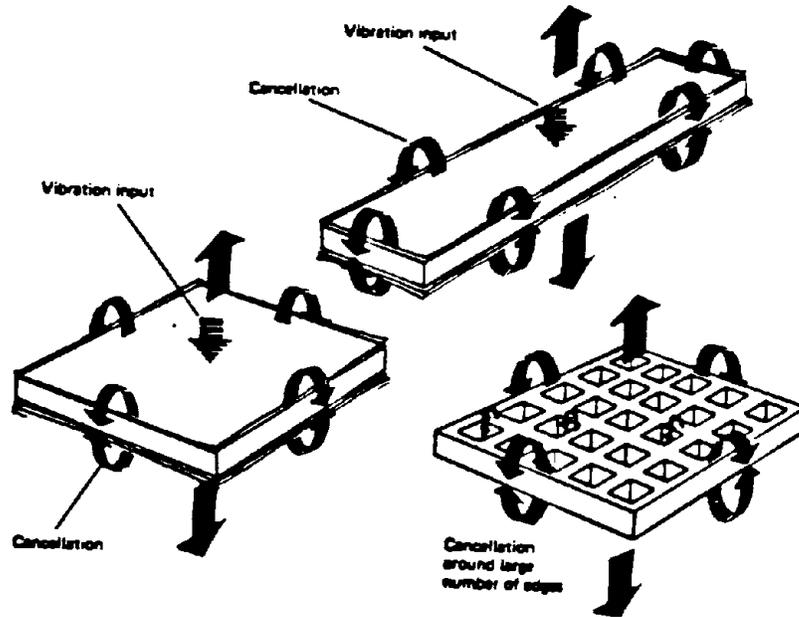
Problem

Vibration of wide drive belts on industrial drives can lead to high levels of low frequency noise.
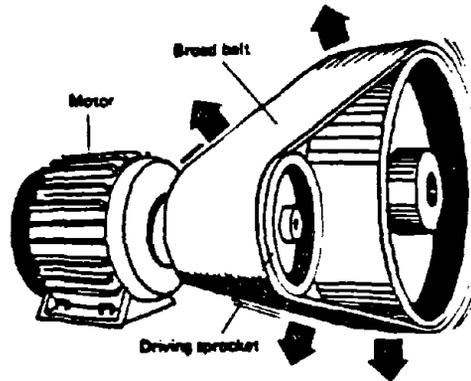
Solution

Replacing the single drive belt with a number of narrower drive belts with gaps between them increases the amount of cancellation which is possible between the top and bottom of each belt and between one belt and the next one. The noise level is therefore reduced.
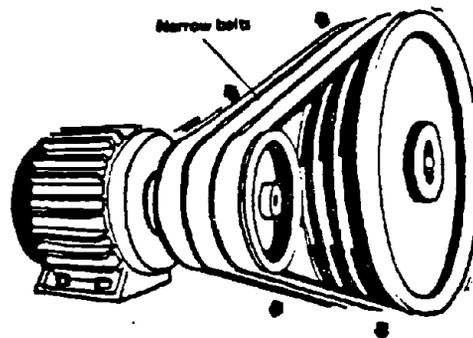
## JET NOISE CAN BE REDUCED BY AN EXTRA AIRSTREAM

Principle

At velocities above about 100m/s jet noise occurs. Because the formation of turbulence in the mixing region outside the exhaust is so violent, the condition of the airstream before the outlet is not important. Halving the outlet velocity reduces the noise level by approximately 20 dB under these conditions. The strength of the turbulence is determined by the relationship between the speed of the jet and the speed of the ambient air. The noise level therefore often can be significantly reduced by introducing an extra air stream with a lower speed alongside the jet, so that the velocity profile across the jet is less steep.
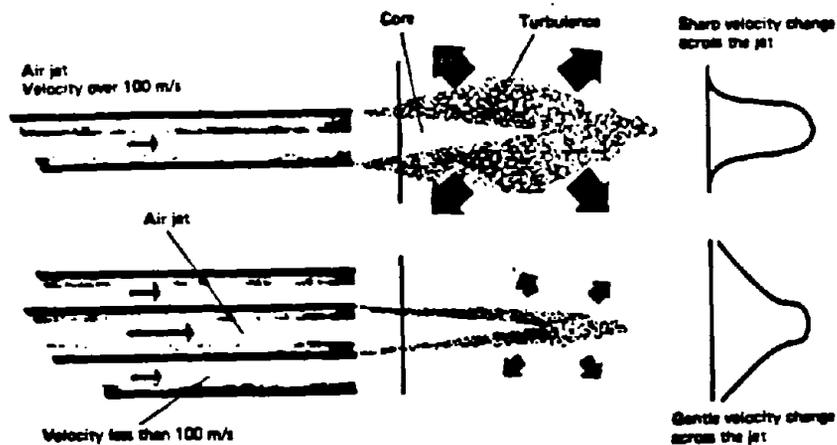

Problem

Cleaning machine components with compressed air to remove swarf and dirt is often done using a single jet from a simple nozzle. The high velocity airstream required for this purpose gives rise to unacceptable high frequency noise.
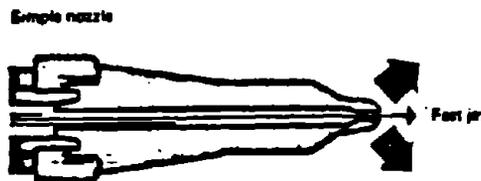
Solution

The simple nozzle can be replaced by a compound nozzle which feeds a lower
speed annular airstream around the main high speed airstream. The transition
from the high speed of the central airstream to the still air is much less
sudden and the noise level is reduced substantially.
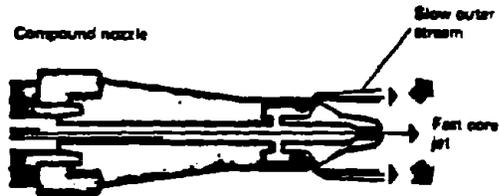
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7. Author(s)
N. Bruce Hanes and Annette M. Rossignol

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Department of Civil Engineering
Tufts University
Medford, MA 02155

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This course package contains educational materials related to occupational health and safety developed by faculty of the Tufts University College of Engineering for incorporatio into existing undergraduate courses for engineering students.

Five groups of educational materials were developed, each group by participating faculty members in the following departments:

Chemical Engineering
Civil Engineering
Electrical Engineering
Engineering Design
Mechanical Engineering

The strategy of exposing a majority of undergraduate engineering students to pertinent information about occupational health and safety within existing departmental courses will reach virtually all undergraduate engineering students. It is hypothesized that engineers are more likely to think of safety at the critical time if the educational exposure is associated with basic engineering subject matter that is used in later practice. It is als anticipated that an introduction to occupational health and safety concerns in this setting will stimulate further study. Such a strategy can be effective only if participating facul are willing to incorporate appropriate educational materials into required course work for undergraduate engineering students.

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