ENGINEER’S RESPONSIBILITY FOR SAFETY

Unit-III

SAFETY AND RISK

Imagine you are a fresh graduate.

You get a job as an engineer in a large atomic power plant.

- Would you take it or not?
- Under what conditions would you take it?
- Under what conditions would you not?
- Why?

People as Consumers

- *Active Consumers*: directly involve themselves e.g., mowing the lawn, washing clothes or toasting bread.
- *Passive Consumers*: have less choice and less control e.g., Water, Electricity, Petrol etc..
- *Bystanders*: e.g., exposed to Pollution from unknown sources

Safety- An Elusive Term

- What is safe to Entrepreneurs, may not be so to Engineers. e.g., Pilots: "Indian Airports are not safe; Low Vision in Fog“

- What is safe to Engineers, may not be so to Public. e.g., Top loading Washing Machine

- Typically several groups of people are involved in safety matters but have their own interests at stake. Each group may differ in what is safe and what is not.

Concept of Safety

1. "A ship in harbor is safe, but that is not what ships are built for" – John A. Shedd
2. 'A thing is safe if its risks are judged to be acceptable' - William W. Lawrence

- We buy an ill-designed Iron box in a sale-> Underestimating risk
- We judge fluoride in water can kill lots of people -> Overestimating risk
- We hire a taxi, without thinking about its safety -> Not estimating risk

How does a judge pass a judgment on safety in these 3 cases?

….So, this definition won't do in real life.

Definition of Safety

What is acceptable risk also depends upon the individual or group's value judgment. Hence a better, *working definition* of *concept of safety* could be,

"A thing is safe (to a certain degree) with respect to a given person or group at a given time if, were they fully aware of its risks and expressing their most settled values, they would judge those risks to be acceptable (to that certain degree)." - Mike Martin and Roland Schinzinger

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Risks

A thing is NOT SAFE if it exposes us to unacceptable danger or hazard

- RISK is the potential that something unwanted and harmful may occur.
  - We take a risk when we undertake something or use a product that is not safe.
- Risk in technology could include dangers of
  - bodily harm,
  - economic loss, or
  - environmental degradation.

Risks (Continued)

- Some may assume that “safety” is a concrete concept, while “risk” is a vague, hypothetical concept .In fact, its the other way around.
- Risks always exist. But true safety never exists, except in hypothetical situations.
- So, risk is *reality*, safety is *fantasy.*

What degree of risk is acceptable?

- Safety is a matter of how people would find risks acceptable or unacceptable, if they knew the risks, and are basing their judgments on their *most settled value* perspective.

  So, to this extent, it is *objective*.

  Perspectives differ. To this extent, it is *subjective*.

  So, Safety is '*acceptable risk*'.

Acceptable Risk

- ‘A risk is acceptable when those affected are generally *no longer (or not) apprehensive* about it.’

- Apprehension (i.e. anxiety) depends largely on factors such as
  - whether the risk is assumed voluntarily.
  - how the probabilities of harm (or benefit) is perceived.
  - job-related or other pressures that causes people to be aware of or to overlook risks.
  - whether the defects of a risky activity or situation are immediately noticeable or close at hand .
  - whether the potential victims are identifiable beforehand.

Voluntary risk and Control

- A person is said to take *'VOLUNTARY RISK'*
  - when he is subjected to risk by either his own actions or action taken by others and
  -*volunteers* to take that risk without any apprehension.

For example, John and Ann Smith enjoy riding motorcycles over rough ground for amusement. They take voluntary risk, part of being engaged in such a potentially dangerous sport.

Voluntary risk and Control (Continued)

- Connected to this notion of voluntarism is the matter of *Control*. In the example cited, the Smiths are aware of the high probability of accident figures in such a sport, but they display characteristically *unrealistic confidence* of most people when they believe the dangers to be *under their control.*
- Chauncey Starr informs us that individuals are more ready to assume voluntary risks than involuntary risks, even when voluntary risks are 1000 times more likely to produce a fatality than the involuntary ones.

Effect of information on Risk Assessments

- The manner in which information necessary for decision making is presented can greatly influence how risks are perceived.
- Consider this example:

  In a particular case of disaster management, the only options available are provided in 2 different ways to the public for one to be chosen (where lives of 600 people are at stake).

Effect of information on Risk Assessments(Continued)

- **Alternate 1**

  If program A is followed, 200 people will be saved. If Program B is followed, 1/3 probability that 600 people will be saved, and 2/3 probability that nobody will be saved.

- **Response**

  72% of the target group chose option A and 28% option B

Effect of information on Risk Assessments(Continued)

- **Alternate 2**

  If program A is followed, 400 people will die. If Program B is followed, 1/3 probability is that nobody will die and 2/3 probability that 600 people will die.

- **Response**

  This time only 22% of the target group chose option A and 78% option B

Effect of information on Risk Assessments(Continued)

Conclusion:

- The option perceived as yielding firm gain will tend to be preferred over those from which gains are perceived as risky or only probable.
- Option emphasizing firm losses will tend to be avoided in favor of those whose chances of success are perceived as probable.

JOB RELATED RISKS

- Many workers *are taking risks in their jobs* in their stride like being exposed to asbestos.
- *Exposure to risks* on a job is in one sense of *voluntary nature* since one can always refuse to submit to the work or may have control over how the job is done.
- But generally workers have *no choice* other than what they are told to do since they *want to stick to the only job* available to them.

JOB RELATED RISKS (Continued)

- But they are *not* generally *informed* about the exposure to toxic substances and other dangers which are *not readily* seen, smelt, heard or otherwise sensed.

- Occupational health and safety regulations and unions can have a better say in correcting these situations but still things are far below expected safety standards.

- Engineers while designing work stations must take into account the casual attitude of workers on safety (esp. when they are paid on piece rate).

Magnitude and Proximity

- Our reaction to risk is affected by the dread of a possible mishap, both in terms of magnitude and of the personal identification or relationship we may have with the potential victims.

  Eg. A single major airplane crash, the specter of a child we know or observe on the television screen trapped in a cave-in.

  These affect us more acutely than the ongoing but anonymous carnage on the highways, at least until someone close to us is injured in a car accident.

Problems faced by engineers about *public concept of safety*

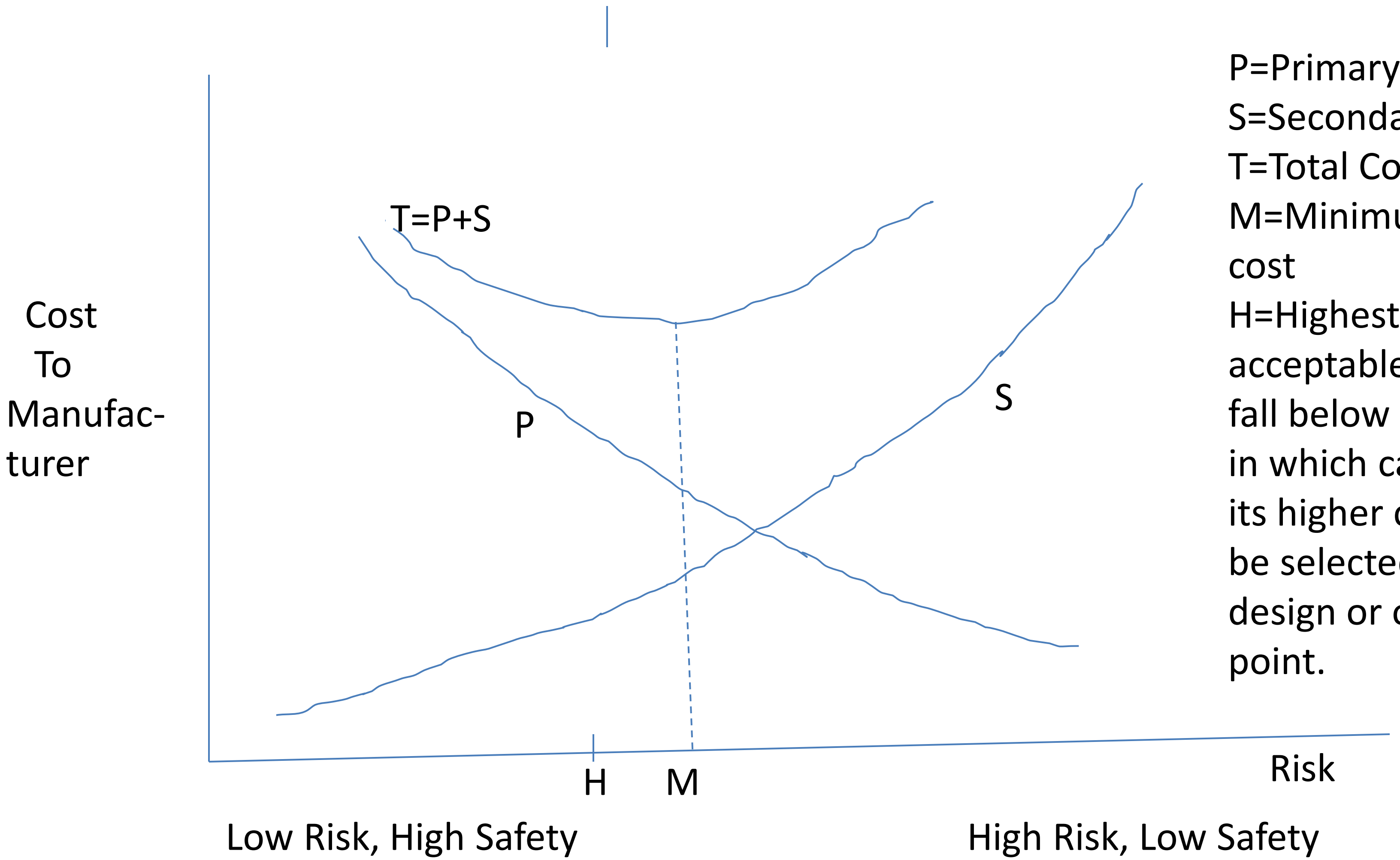
- The optimistic attitude that things that are familiar, that have not caused harm before and over which we have some control, *present no real risks*.

- The serious shock people feel when an accident kills or maims people *in large numbers* or *harms those we know*, even though statistically speaking such accidents might occur infrequently.

Assessment of Safety and Risk

- *Absolute safety is never possible* to attain and safety can be improved in an engineering product only with an increase in cost.
- *Unsafe* products *incur secondary costs* to the producer beyond the primary (production) costs, like warranty costs loss of goodwill, loss of customers, litigation costs, downtime costs in manufacturing, etc.
- *Primary costs are high for a highly safe* (low risk) product and S- *Secondary costs are high for a highly risky* (low safe) product.

Assessment of Safety and Risk



P=Primary Cost
S=Secondary Cost
T=Total Cost
M=Minimum total cost
H=Highest acceptable Risk may fall below risk at M, in which case H and its higher cost must be selected as design or operating point.

Knowledge of risk for better safety

- Robert Stephenson writes that all the accidents, the harms caused and the means used to repair the damage *should be recorded* for the benefit of the younger Members of Profession.
- A faithful account of those accidents and the damage containment was really *more valuable* than the description of successful work.
- Hence it is imperative that knowledge of risks will definitely help to attain better safety.
- But it should be borne in mind, that still gaps remain, because

i)there are some industries where information is *not freely shared*

and

ii)there are always *new applications of old technology* that render the available information *less useful.*

Uncertainties in design process

- A decision on maximizing profit or maximizing the return on investment.
- Uncertainties about applications like dynamic loading instead of static loading, vibrations, wind speeds.
- Uncertainties regarding materials and skills required in the manufacturing.
- Changing economic realities.
- Unfamiliar environmental conditions like very low temperature.
- The available standard data on items like steel, resistors, insulators, optical glass, etc are based on statistical averages only.
- Due to the inherent nature of processes, all computations have a tolerance in design leading to the probability statistics by which assemblies' capability is assessed.

Testing strategies for safety

Some commonly used testing methods:

- Using the past experience in checking the design and performance.
- Prototype testing. Here the one product tested may not be representative of the population of products.
- Tests simulated under approximately actual conditions to know the performance flaws on safety.
- Routine quality assurance tests on production runs.

The above testing procedures are not always carried out properly. Hence we cannot trust the testing procedures uncritically.

Testing strategies for safety (Continued)

Some tests are also destructive and obviously it is impossible to do destructive testing and improve safety. In such cases, a simulation that traces hypothetical risky outcomes could be applied.

- Scenario Analysis (Event -> Consequences)
- Failure Modes & Effects Analysis (Failure modes of each component)
- Fault Tree Analysis (System Failure -> Possible Causes at component level)
- What if there is a combination of factors?
  – All Analysis pre-suppose a thorough understanding of the physical system

Failure modes and effect analysis (FMEA)

This approach systematically examines the failure modes of each component, without however, focusing on relationships among the elements of a complex system.

Fault Tree Analysis (FTA) :

- A system failure is proposed and then events are traced back to possible causes at the component level.
- The reverse of the fault-tree analysis is ‘event – tree analysis’.
- This method most effectively illustrates the disciplined approach required to capture as much as possible of everything that affects proper functioning and safety of a complex system.

Example: A Simple Water System

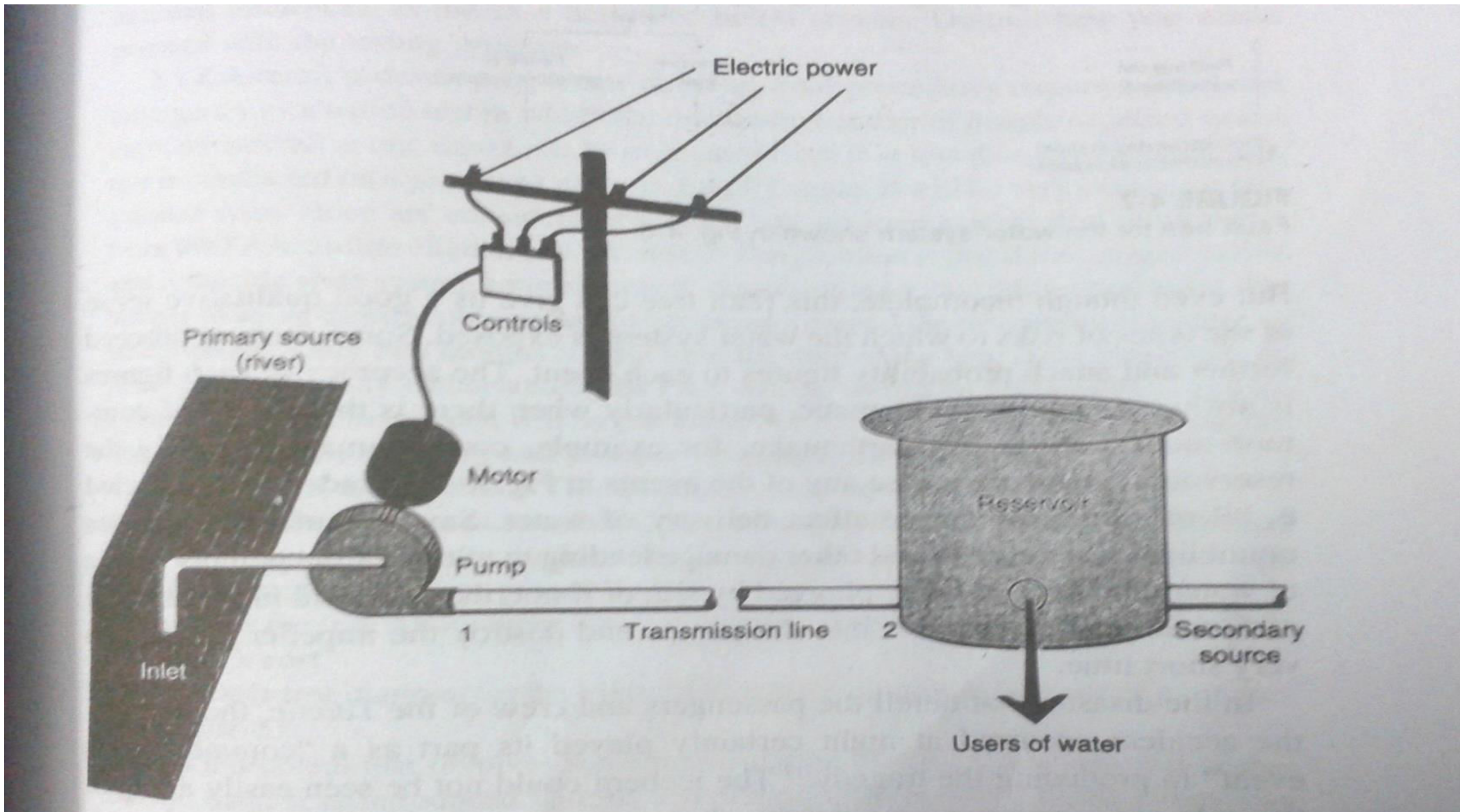


FIGURE 4-6
A simple water system.

Example: Fault Tree

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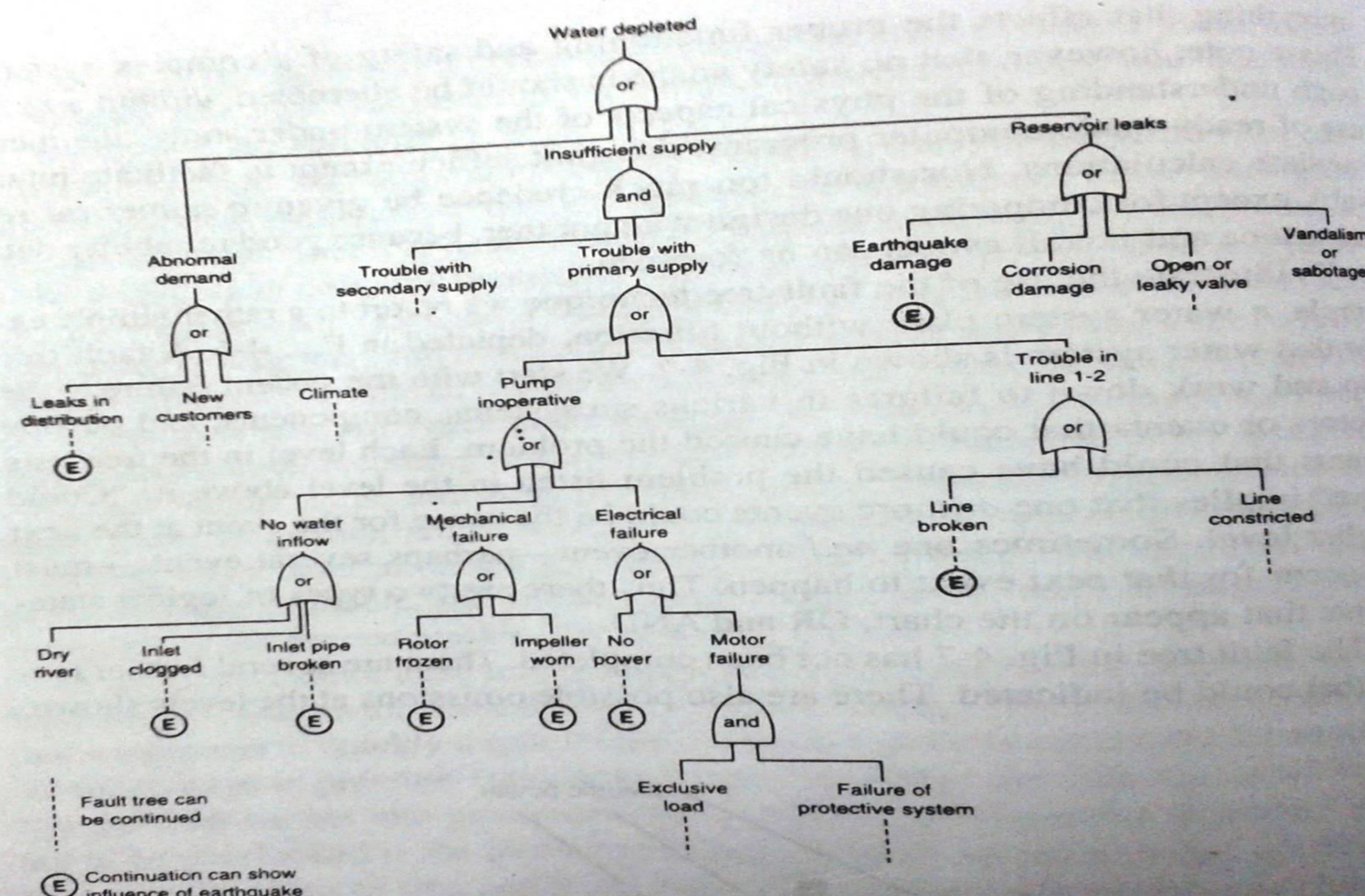


FIGURE 4-7
Fault tree for the water system shown in Fig. 4-6.

Risk Benefit Analysis

Many large projects, especially public works are undertaken based on risk benefit analysis.

The following are the questions to be answered:

1. Is the product worth the risks connected with its use?
2. What are the benefits?
3. Do they outweigh the risks?
4. Who are the ones to be benefited? and who are the ones subjected to risk? Are they the same set of people or different?

The issue here is *not*, say, *cost-effective* design but it is only *cost of risk taking Vs benefit* analysis.

Conceptual Difficulties in Risk-Benefit Analysis

Both risks and benefits lie *in future*

- Heavy discounting of future because the very low present values of cost/benefits do not give a true picture of future sufferings.
- Both have related uncertainties but difficult to arrive at expected values
- What if *benefits* accrue to *one party* and *risks to another*?
- Can we *express* risks & benefits in a *common set of units*?
  - e.g. Risks can be expressed in one set of units (*deaths* on the highway) and benefits in another *(speed of travel)*?

Many projects, which are highly beneficial to the public, have to be *safe also*.

Difficulties in Assessing Personal Risks

- Individuals are ready to *assume voluntary* risks than *involuntary* risks.
- It is difficult in assessing personal risks which are involuntary.
- The problem of quantification of risk raises innumerable problems.
  - For example, how to assign a rupee *value to one's life*. There is no over the counter trade in lives.
- Even when compensations are made to people exposed to involuntary risk, the basis on which it is made or even the intensity of risk could be *different for different people*.

Public Risk and Public Acceptance

- Risks and benefits to public are more easily determined than to individuals
- National Highway Traffic Safety Administration (NHTSA)- proposed a value for life based on:
  - loss of future income
  - other costs associated with the accident
  - estimate of quantifiable losses in social welfare resulting from a fatality
  - NOT a proper basis for determining the optimal expenditure allocated to saving lives

Accounting Publicly for Benefits and Risks

Engineers should account publicly for benefits and risks in the following manner:

- Engineers must remain as *objective* as humanly possible in their investigations and conclusions.
- They must also *state* openly any *personal biases* that they may have about the project being investigated.
- Engineers, even if they are acknowledged experts, may *not have complete knowledge* of the issues at hand.
- They should, if necessary, *admit* their *lack of knowledge*, in any particular area publicly.

Accounting Publicly for Benefits and Risks(Continued)

- A willingness to *admit uncertainty* and also to *reveal methodology* and sources particularly when numerical data is presented.
- The way statistical information is presented can create misconceptions in the public mind. Hence it should be *presented in a way to improve realistic interpretations*.
- They must *consider the views of the parties affected* by the project under study *before* coming to conclusions.
- The type of action taken should be morally evaluated regardless of its consequences. If it is wrong to violate certain rights, then figuring out the benefit of the consequences of doing so is irrelevant.

Difficulties in Establishing Safeguards

- Incomplete knowledge of the engineering subject
- Refusal to face hard questions caused by lack of knowledge
  - False sense of security
  - e.g. Nuclear waste disposal problem
- Caution in stating probabilities of rare events
  - Varying understanding of risk based on presentation of facts
- Risk assessments based on incorrect/unacceptable assumptions/data
  - Only a few persons/groups participate in the exercise

Some Misconceptions about Risk and Safety

- **Assumption:** Operator error and negligence are the principle causes of all accidents.

- **Reality:** Accidents are caused by dangerous conditions that can be corrected by design. E.g. automatic couplers for rail cars greatly reduced accidents.

Some Misconceptions about Risk and Safety(Continued)

- **Assumption:** Making a product safe invariably increases costs.

- **Reality:** Initial costs need not be higher if safety is built into a product from the beginning; life cycle costs are lower. Design corrections later are very costly.

Some Misconceptions about Risk and Safety(Continued)

- **Assumption**: We learn about safety after a product has been completed and tested.

- **Reality**: If safety is not built into the original design, people can be hurt during the testing stage.

Some Misconceptions about Risk and Safety(Continued)

- **Assumptions:** Warnings about hazards are adequate; insurance coverage is cheaper than planning for safety

- **Reality:** Depending on how well the warnings are displayed, this could cost big bucks in litigation. Warnings indicate that a hazard may exist. They do not provide protection!!

Examples of Improved Safety

- Magnetic door catch introduced on refrigerators
  - Prevent death by asphyxiation of children accidentally trapped inside
  - The catch now permits the door to opened from inside easily
  - Cheaper than older types of latches
- Dead-man Handle for Drivers in trains
- Semaphore signaling
- Volkswagen's car safety belt
  - Attachment on the door so that belt automatically goes in place on entry

Liability

- You are liable for everything you do and design; simple fact!
- You cannot rely on “codes and standards” alone. This is called minimal compliance and does not guarantee a safe product nor does it provide a valid excuse if a product fails or someone is hurt.
- Engineers are often compromised by timelines of their employer and do not spend the time necessary to look at safety in depth.
- You are not protected from liability just because you are part of a large company!!!

SAFE EXIT

- It is almost impossible to build a completely safe product or one that will never fail. When there is a failure of the product *SAFE EXIT* should be provided.

- Safe exit is to assure that

  i) when a product fails, it will fail safely,
  ii) the product can be abandoned safely and
  iii) the user can safely escape the product.

SAFE EXIT (Continued)

Some examples of providing ‘SAFE EXIT’:

- Ships need lifeboats with sufficient spaces for all passengers and crew members.
- Buildings need usable fire escapes
- Operation of nuclear power plants calls for realistic means of evacuating nearby communities
- Provisions are needed for safe disposal of dangerous materials and products.

The Government Regulator's Approach to Risk

- The Regulators face dilemma regarding risk management. On the one hand, regulators could decide to regulate only when there is provable connection between a substance and some undesirable effect, such as cancer. On the other hand, regulators could eliminate any possible risk, insofar as this is technologically possible.

Example

Assume that a scientist wants to investigate a causal link between a Compound X and cancer by performing cohort studies.

From the standpoint of protecting the public from carcinogens, we are more interested in discovering a causal connection between Compound X and cancer if one exists than in avoiding making a claim about a causal connection that does not exist. Only by adopting this policy can the public be adequately protected from carcinogens.

Example(Continued)

Thus, whereas scientist have a bias against false positives (making a claim for a causal connection when there is not one), those whose highest priority is protecting the public have a bias against false negative (claiming there is not a causal connection when there is one).

Scientists place primary emphasis on eliminating false positives. Eliminating false negative requires a large sample than eliminating false positive, thus making the cohort studies more expensive.

The Government Regulator's Approach to Risk (Continued)

- An acceptable risk is one in which protecting the public from harm has been weighted more heavily than benefiting the public.

CHERNOBYL NUCLEAR DISASTER

ETHICAL ISSUES CONCERNING ITS RISKS

CHERNOBYL NUCLEAR POWER PLANT

- In 25th and 26th, 1986 the world's worst nuclear disaster occurred in Chernobyl. It is located 80 miles north of Kiev, capital of Ukraine (formerly in soviet union).
- It consisted of four nuclear reactors of which units 1 and 2 being constructed between 1970 and 1977, while units 3 and 4 of the same design were completed in 1983. Two more reactors were under construction at the site, at the time of the accident.
- The April 1986 disaster at the Chernobyl nuclear power plant was the product of a flawed Soviet reactor design coupled with serious mistakes made by the plant operators

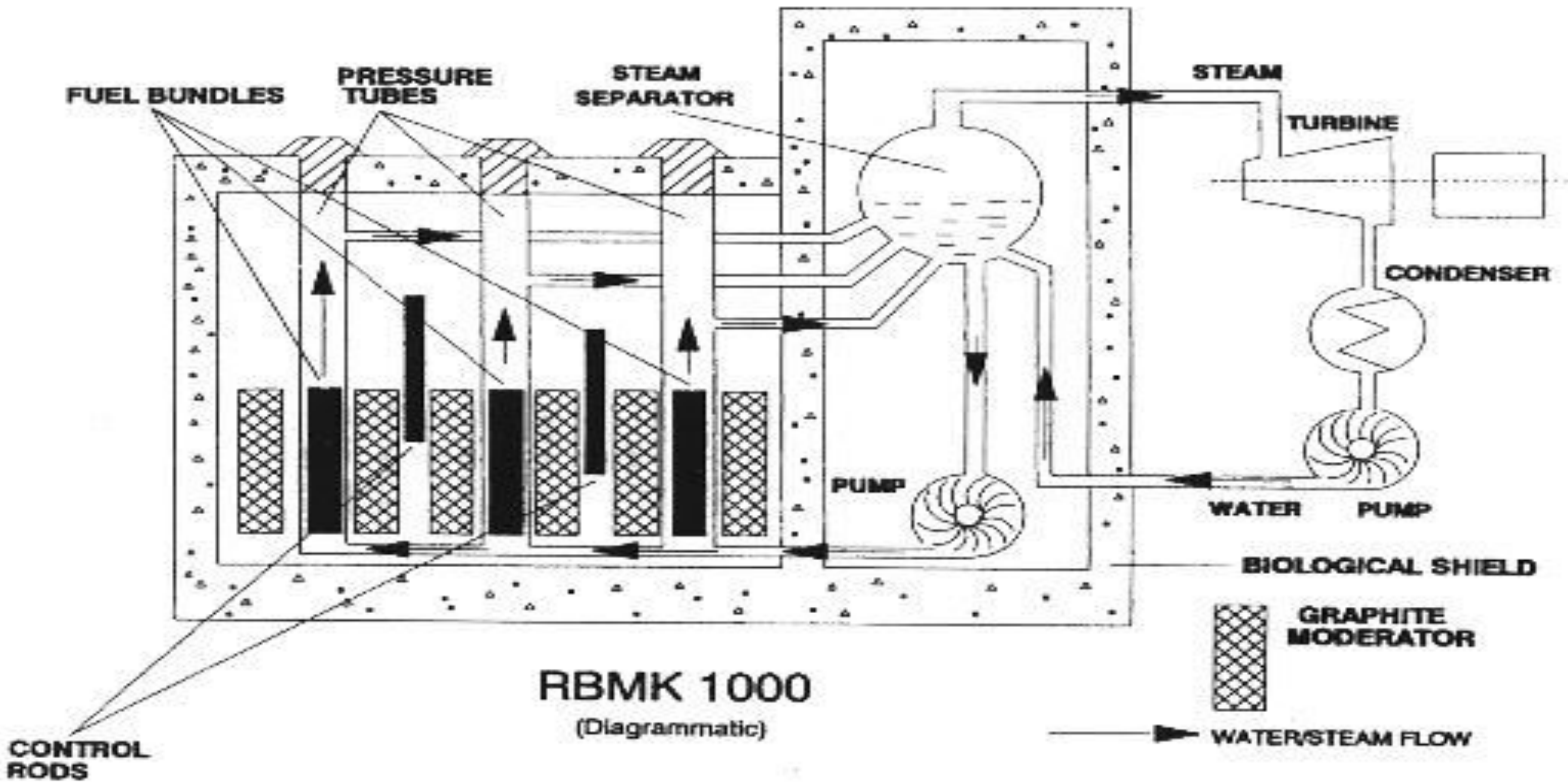
WHAT CAUSED THE ACCIDENT?

- It has four reactors and safety procedures were disregarded. At exactly 1:23 the chain reaction was unable to control creating explosion and fire blew the reactor’s heavy steel and concrete lid.
- There was lack of safety culture resulting in an inability to fix the weakness in design of the reactor despite being known before the accident

REASONS FOR CHERNOBYL ACCIDENT

- *Chernobyl construction weaknesses*
- *Default in the RBMK reactor*
- *Violation of procedures*
- *Communication breakdown*

SEQUENCE OF EVENTS THAT CAUSED THE ACCIDENT



SEQUENCE OF EVENTS THAT CAUSED THE ACCIDENT(Continued)

- The accident at Chernobyl was the product of a lack of safety culture.
- The reactor design was poor from the point of view of safety and unforgiving for the operators, both of which provoked a dangerous operating state.
- The operators were not informed of this and were not aware that the test performed could have brought the reactor into an explosive condition.
- In addition, they did not comply with operational procedures.
- The combination of these factors provoked a nuclear accident of maximum severity in which the reactor was totally destroyed within a few seconds.

SEQUENCE OF EVENTS THAT CAUSED THE ACCIDENT(Continued)

- The unit 4 reactor was to be shut down for routine maintenance on 25 April 1986. It was decided to take advantage of this shutdown to determine whether, in the event of a loss of station
- The aim of this test was to determine whether cooling of the core could continue to be ensured in the event of a loss of power.
- This type of test had been run the previous year, but the power delivered from the running down turbine fell off too rapidly, so it was decided to repeat the test
- Unfortunately, this test, which was considered essential was carried out without a proper exchange of information and coordination between the team in charge of the test and the personnel in charge of the safety of the nuclear reactor.
- Therefore, inadequate safety precautions were included in the test programme and the operating personnel were not alerted to the nuclear safety implications of the electrical test and its potential danger.

SEQUENCE OF EVENTS THAT CAUSED THE ACCIDENT(Continued)

ABOUT 1:00 AM

As part of a demonstration of the safety features (in retrospect, this may seem slightly ironic) of the reactor, the operators are beginning to reduce power from a nominal 3200 MW. There is nothing extraordinary about this test; it is a common test in western plants as well.

1:06 AM

One of the turbines is switched off as a part of the test.

3:47 AM

Thermal power reaches 1600 MW.

2:00 PM

The emergency core cooling system is disconnected as a part of the test. The test is now scheduled to continue with a further reduction of power. However, because of a power shortage on the grid, Unit 4 is ordered to keep operating until further notice. The test should be aborted by now. It is not.

11:10 PM

The test is resumed with the intention of reducing power to 700-1000 MW, but the power drops more rapidly than expected, and stops at 30 MW.

SEQUENCE OF EVENTS THAT CAUSED THE ACCIDENT(Continued)

1:00 AM

Power is raised to 200 MW. Running the core at low power has caused a buildup of xenon. This is compensated for by retracting the control rods more than regulations allow. An emergency shutdown will at this point take about 20 seconds. The test is still not aborted.

1:23:04 AM

The test is started by reducing the flow of steam to the turbine. As a result, water flow through the core is reduced and boiling is increasing. Reactor power is rising.

1:23:40 AM

An emergency shutdown is attempted, by inserting the control rods. It has the opposite effect.

1:23:43 AM

Unit 4 goes prompt critical.

1:24 AM APPROX.

A steam explosion followed by a chemical explosion destroys the reactor building and starts a fire.

ABOUT 5:00

External fires have been put out by firefighters. Although the chain reaction was stopped when the reactor was destroyed there are still considerable amounts of heat generated from radioactive decay and chemical fires.

ABOUT 6:00

Unit 3 (which resides in the adjacent building) is shut down.

Collective Collapse

- Design flaws
- Positive void coefficient
- Control rod insufficiency
- Lack of containment

- Operator errors

ETHICAL ISSUES

- **Duty**

  The duty of every engineer involved in experimenting with nuclear power reactor is to assure safe operation. Engineers in Chernobyl believed that they had enough experience and knowledge about the reactor so that they can perform their experiment in a safe way.

  They have lost control over reactor and caused a disaster. They have neglected their duty to place public safety as highest priority. Also the safety systems and routines of the reactor were deficient which means that the management of the site have neglected their duty to provide safety for public

- ***Rights***

  People had the rights to be properly informed about the hazards of nuclear power. People working that day at Chernobyl plant had rights to safe working environment where they are not supposed to be killed.

  The management had right to give proper technical knowledge to workers

ETHICAL ISSUES(Continued)

- ***Justice***

  Many people lost lives due to this disaster, which is not expected. The people living near affected area suffered from long-term diseases. A lot of people became homeless due to this disaster

- ***Utilitarianism***

  The experiment was designed to gain more knowledge about the behaviour of the reactor under extreme conditions. If performed successfully. It could have lead to the benefit for the society.

  However the fact that they failed in such a catastrophic way means that in spite of their possible good intention, from utilitarian point of view, taking unreasonable risks was not motivated.

REFERENCE

World Nuclear Organisation

http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Chernobyl-Accident/

http://www.stacken.kth.se/~foo/texts/chernobyl.html

http://group5-engineeringethicsblog.blogspot.in/2008/04/ethical-issues-concerning-chernobyl.html

Ethical Issues Concerning Risks in Science and Technology- Case Studies by

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BHOPAL GAS TRAGEDY

THE BHOPAL DISASTER

- Around 1 a.m. on Monday, the 3rd of December, 1984, In the city of Bhopal, Central India, a poisonous vapour burst from the tall stacks of the Union Carbide pesticide plant.
- This vapour was a highly toxic cloud of methyl isocyanate.
- 2,000 died immediately
- 300,000 were injured
- 7,000 animals were injured, of which about one thousand were killed.

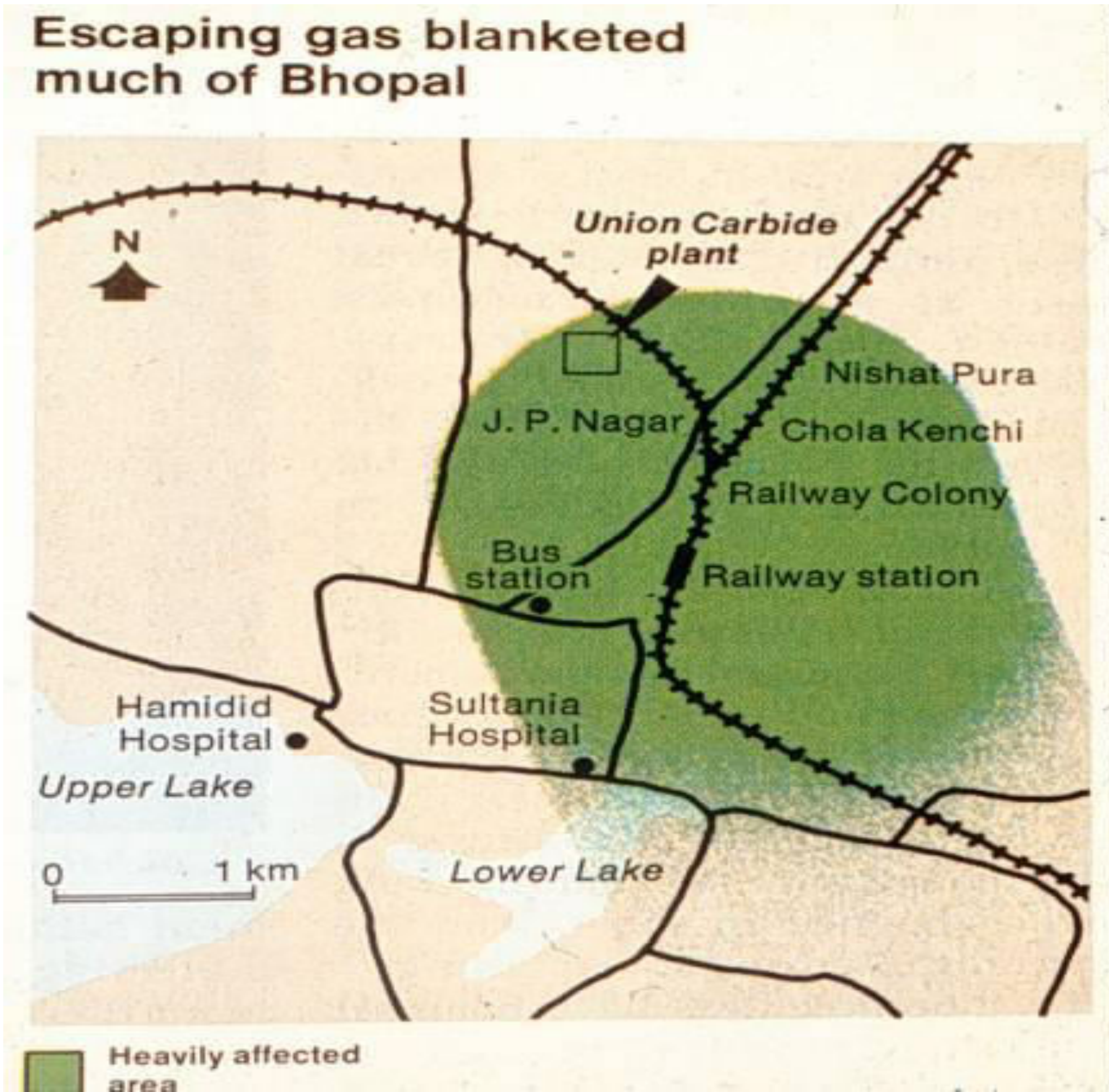
HUMAN SLAUGHTER

ANIMAL SLAUGHTER

BHOPAL SCENARIO

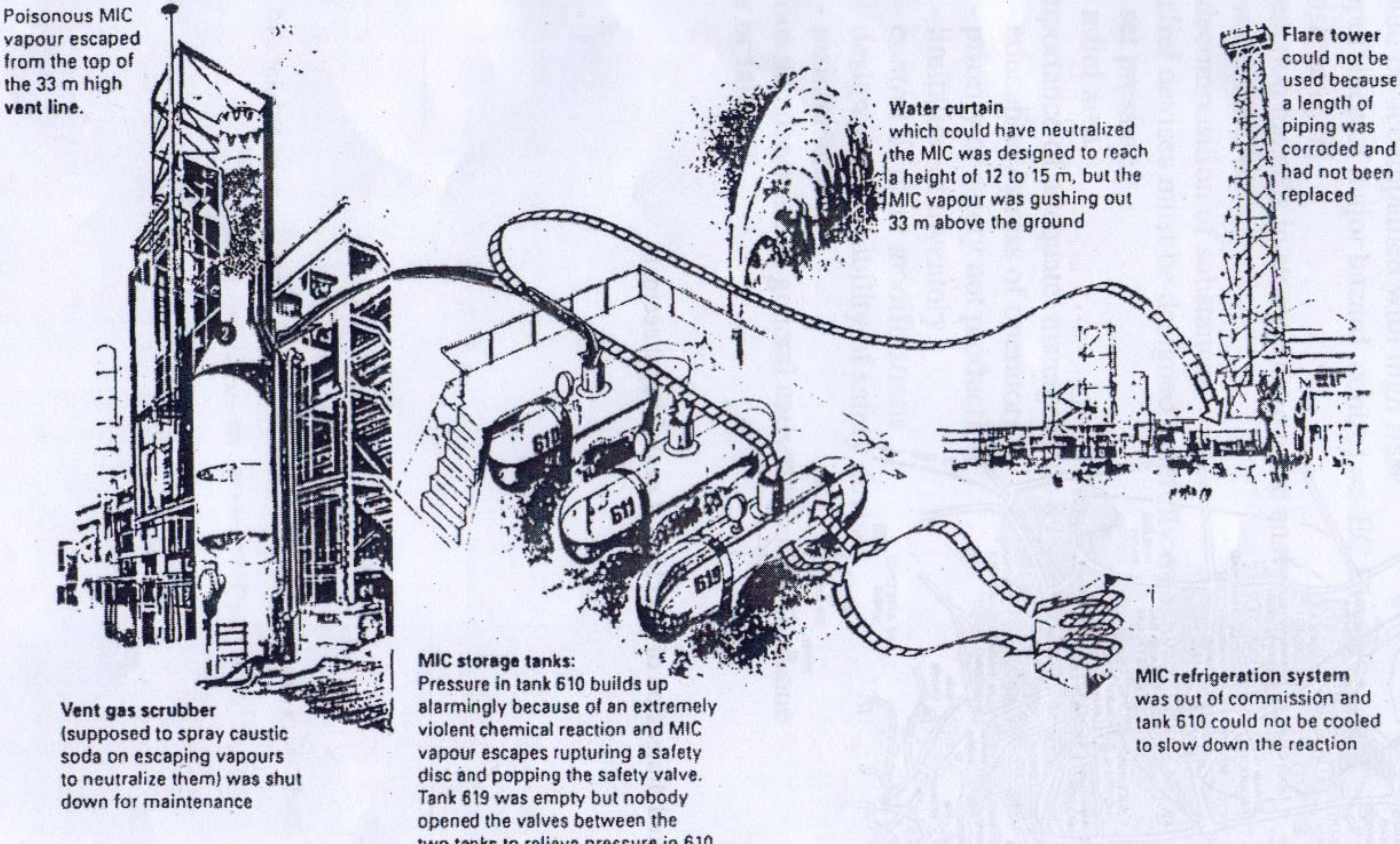
Union Carbide Corporation

THE AFFECTED AREA



THE POSSIBLE CAUSES

- A tank containing methyl isocyanate (MIC) leaked.
- MIC is an extremely reactive chemical and is used in production of the insecticide carbaryl.
- The scientific reason for the accident was that water entered the tank where about 40 cubic meters of MIC was stored.
- When water and MIC mixed, an exothermic chemical reaction started, producing a lot of heat.
- As a result, the safety valve of the tank burst because of the increase in pressure.
- It is presumed that between 20 and 30 tonnes of MIC were released during the hour that the leak took place.
- **The gas leaked from a 30 m high chimney and this height was not enough to reduce the effects of the discharge**.



State of safety features of MIC plant at Bhopal at time of disaster.

THE WEATHER EGGED ON THE PROCESS…

- The high moisture content (aerosol) in the discharge when evaporating, gave rise to a heavy gas which rapidly sank to the ground.
- A weak wind which frequently changed direction, which in turn helped the gas to cover more area in a shorter period of time (about one hour).
- The weak wind and the weak vertical turbulence caused a slow dilution of gas and thus allowed the poisonous gas to spread over considerable distances.

THE POSSIBLE REASONS…

- One of the main reasons for the tragedy was found to be a result of a combination of human factors and an incorrectly designed safety system.
- A portion of the safety equipment at the plant had been non-operational for four months and the rest failed.

<u>UNION CARBIDE'S VERSION..</u>

" A disgruntled plant employee, apparently bent on spoiling a batch of methyl isocyanate, added water to a storage tank".

--B. Browning Jackson (Vice President)

LAPSES ON THE PART OF THE GOVERNMENT

- The Madhya Pradesh State government had not mandated **any** safety standards.
- Union Carbide failed to implement its own safety rules.
- The Bhopal plant experienced six accidents between 1981 and 1984, at least three of which involved MIC or phosgene.

WHY DID THE PEOPLE STAY QUITE??

- The country needed pesticides to protect her agricultural production
- MIC is used to produce pesticides that control insects which would in turn, help increase production of food as a part of India's GREEN REVOLUTION.
- Initially, India imported the MIC from the United States.
- In an attempt to achieve industrial self-sufficiency, India invited Union Carbide to set up a plant in the state of Madhya Pradesh to produce methyl isocyanate.
- To the people of the city of Bhopal, Union Carbide was a highly respected , technically advanced Western company.
- This coupled with political power and scientific expertise worked together to changed the people's perception of what was dangerous and more importantly what was safe.

UNION CARBIDES AMERICAN PLANT

- Dr. Paul Shrivastava, an Associate Professor of Business in New York University conducted studies that revealed that Bhopal was neither an isolated incident nor the first of its kind in the corporation.
- There had been many accidents of similar nature in UCC's American plants prior to the Bhopal accident.
- He found that 28 major MIC leaks had occurred in UCC’s West Virginia plant during the five years preceding the Bhopal incident, the last one occurring only a month before.

PROCESS CHEMISTRY

- The reaction involved two reactants, methyl isocyanate (MIC) and alpha naphthol.
- The process begins with a mixture of carbon – monoxide and chlorine to form phosgene. Phosgene is then combined with monomethylamine to form MIC. MIC is further mixed with naphthol to produce the end product carbaryl.

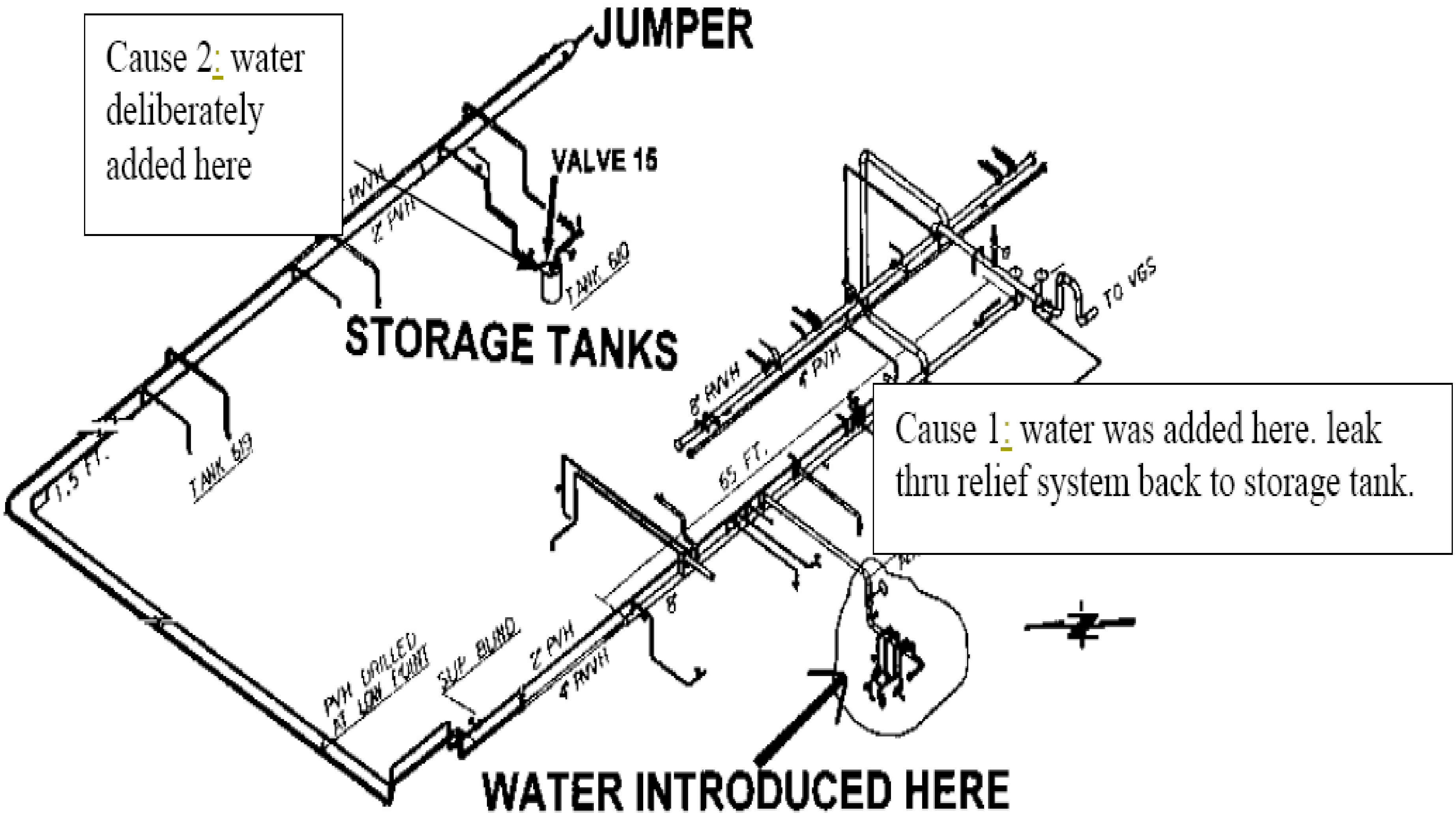
$CO + Cl_2$	$COCl_2$ (Phosgene)
$COCl_2 + CH_3NH_2$	$CH_3NHCOCl + HCl$
$CH_3NHCOCl$	$HCl + CH_3NCO$ (Methyl Isoacyanate)

THE WATER WASHING THEORY

- The media played a significant role in establishing the WATER WASHING THEORY as a plausible explanation.
- According to this story, an MIC operator was told to wash a section of a sub header of the relief valve vent header ("RVVH") in the MIC manufacturing unit.
- Because he failed to insert a slip-blind, as called for by plant standard operating procedures, the water supposedly backed up into the header and eventually found its way into the tank and flowed 400 feet to the tank which would require a massive pressure head and it would take some time to build up
- Conclusive reports indicated that 2000 lbs of water entered the tank and for this water to build up and have an instantaneous exothermic reaction would not be possible

THE DIRECT-ENTRY THEORY

- During the shift change -- that a disgruntled operator entered the storage area and hooked up one of the readily available rubber water hoses to Tank with the intention of contaminating and spoiling the tank's contents.
- He unscrewed the local pressure indicator, which can be easily accomplished by hand, and connected the hose to the tank. The entire operation could be completed within five minutes.
- Minor incidents of process sabotage by employees had occurred previously at the Bhopal plant.
- The water and MIC reaction initiated the formation of carbon dioxide which, together with MIC vapours, was carried through the header system and out of the stack of the vent gas scrubber by about 11:30 to 11:45 p.m



Cause 2: water deliberately added here
JUMPER
VALVE 15
STORAGE TANKS
TANK 610
TANK 619
1.5 FT.
2" PVH
8" PVH
4" PVH
65 FT.
TO VGS
PVH DRILLED AT LOW POINT
SLIP BLIND
Cause 1: water was added here. leak thru relief system back to storage tank.
WATER INTRODUCED HERE

LAPSES ON PART OF UNION CARBIDE

- Improper design of chimneys (without consideration of weather conditions in all seasons)
- Improper design and maintenance of safety equipment.
- Not following safety regulations as that followed by UCC plants in USA.
- Decision to neglect a flare system in need of repair.
- Inadequate emergency planning and community awareness.
- Lack of awareness of the potential impact of MIC on the community by the people operating the plant.
- Inadequate community planning, allowing a large population to live near a hazardous manufacturing plant.

<u>BASIC GREEN CHEMISTRY PRINCIPLES</u>

- These principles would have averted the disaster.
- Eliminate or reduce the production of Hazardous chemicals.
- Hazardous chemicals produced should not be stored and should be consumed in the course of the reaction.
- The inventory of Hazardous chemicals if inevitable should be of many small containers and not of one large container.

ALTERNATE CHEMISTRY (SUGGESTED SOLUTION)

- Alpha Napthol on carbonyl group addition followed by reaction with methyl amine would eventually gives carbaryl.
- This process does not generate or require handling the of Phosgene.
- This process does not require storage of MIC.
- Inherently safe process.

CONCLUSION

- The Bhopal gas tragedy could have been averted.
- There were lapses on part of the government and UCC.
- The actual reason for the tragedy is contrary to popular belief.
- An alternate way to produce carbaryl was suggested.
- Design of Inherently safer process was required.