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# RISK-BASED MANAGEMENT FOR EQUIPMENT RELIABILITY

## I. Introduction:

Risk-based management methods for systems and equipment have been evolving rapidly in the past five years. They are gaining acceptance in industry as an operational tool and by governments as a regulatory tool. The aerospace, nuclear and chemical processing industries in many countries, for example, have developed and currently are using systematic risk assessment/risk management tools for their regulatory and operational needs. These same methods and processes have been utilized by a number of Machinery Breakdown Insurance carriers as risk assessment and reliability improvement tools.

This presentation will describe some of these methods and processes. It will use examples to show how they are being used by the insurance industry to manage equipment breakdown risks and to improve the insured's equipment reliability.

## II. Risk Assessment/Risk Management Tools

Let's begin with the definition of risk. As we know, risk is the measure of the potential for harm or loss that reflects the likelihood (e.g. frequency) and severity of an adverse effect to safety, health, property or environment.

In mathematical terms: Risk = Probability x Consequence
or Risk = Frequency x Severity

How can we identify and minimize risk? Figure 1 shows the structure of a generalized risk management program. For the risk assessment portion of the program, tools such as Fault Trees, Event Trees, Failure Mode Effects and Criticality Analysis (FMECA). scenario analysis and consequence modeling are methods that can be employed to determine the frequencies and consequences of the risk equation.

These results can be compared to results achieved with previous more qualitative methods as a means to gauge their accuracy and effectiveness. This systematic and rigorous process helps us better understand the risks, so we can concentrate our loss prevention techniques where they will be most effective.

As shown in Figure 2, the probability of an adverse effect can be determined using "Logic Trees" (Fault Tree analysis) and branching decision networks (Event Tree analysis). This method, coupled with consequence modeling or scenario analysis, can determine the consequence portion of the risk equation.

The FMECA method depicted in Table 1 also can be used to determine risk. Adding certain decision analysis techniques to the process — for example, what type and when one performs certain inspections — provides the risk management tools to investigate specific risks.

## III Risk-Based Activity Examples

Intensified national and global competition and deregulation of major industries are all drivers for cost cutting. Loss of experienced personnel, reductions in maintenance, extending the usage of older facilities — all are outgrowths of these issues and result in increased risks. In order to help clients reduce costs without increasing risk, some Machinery Breakdown insurers are applying risk-based technologies to their needs.

The following are three examples of how risk management tools have assisted our clients in competing more effectively. The first example deals with the need of utilities to increase the time between major inspections and overhauls of steam turbines to reduce down time and maintenance costs. The second addresses the need to reduce maintenance costs and applies risk-based maintenance methods to electrical systems in a manufacturing facility. The third example applies these techniques to develop a risk-based approach to pressure systems in the chemical industry.

### A. TOOP Program

The Turbine Outage Optimization Program (TOOP) consists of a Microsoft Access database algorithm incorporating an extensive questionnaire for power generation steam turbines and generators based on engineering factors (design and history, operation, inspection and monitoring). Based on the questionnaire responses, turbine and generator risks are calculated from the failure modes, probabilities of failure, failure consequences and modifying factors included in the program.

The process to develop the reliability and risk factors follow The American Society of Mechanical Engineers (ASME) Risk-Based Inspection Guidelines. They were developed by Hartford Steam Boiler and leading members of the power generation industry, drawing upon the skills and experience of all members of the development team. These factors were calibrated during validation testing (beta testing) of approximately 30 different turbine generators and were checked against Hartford Steam Boiler and comparable U.S. National Electric Reliability Council failure data.

Cumulative risk ranking for a typical low pressure turbine per ASME risk-based processes is shown in Figure 3 for the top 25 sub-component/failure mode combinations (example, blade root/fatigue). Similar rankings are calculated in the program for high pressure and intermediate pressure turbines and the generator.

Output from the program is in terms of reports. These reports include component risk measured in terms of remaining equivalent operating hours for the steam turbine and generator. Estimated dates for the next outage are similarly provided. Risk/reliability drivers are provided for the major components, as well as recommendations to reduce risk and increase equivalent operating hours to the next outage.

"What if" analyses capabilities have been added to support cost benefit studies of potential improvements to reduce risk. Risk ranking or bench marking of steam turbine generator major components with other comparable industry major components in the database also is provided. Comparative risk ranking for a typical generator is shown in Figure 4.

**B. Risk Assessment for Power Plant Facilities**

An international manufacturer and Hartford Steam Boiler performed a joint risk assessment of a typical power house, evaluating the use of ASME Risk-Based Inspection methodology for electrical systems and equipment.

The risk was evaluated systematically by examining each equipment, its likelihood of failure and the severity of failure from postulated failure modes. Factors that would affect the probability and severity of failure modes were examined in detail.

The main parts of the ASME risk-based process were revised and expanded for the power house project:

(1) System Definition
(2) Qualitative Risk Assessment — Level 1
(3) Qualitative Risk Assessment — Level 2
(4) Effect of Decision Strategies on Risk
(5) Multiple Component Optimization

Inspection Program Development in the original ASME process was generalized to any type of decision such as repair, replacement, maintenance, system modification, etc. Two levels of risk assessment were incorporated and application of the methodology was investigated for electric power systems rather than the structural and mechanical systems.

The work plan was broken into two phases. Phase 1 contained a preliminary qualitative risk ranking of major components. Phase 2 is designed to contain a quantitative risk assessment, equipment condition assessment, life cycle predictions and risk-based decision analysis and multi-criteria optimization.

Phase 1 concluded that although the ASME process addresses primarily structural and mechanical equipment, it can be used successfully for electrical systems and equipment in electrical distribution facilities. For example, the qualitative risk assessment performed in Phase 1 showed about 90 percent of the total electric distribution facility risk can be attributed to 6 of 20 types of electrical equipment considered (see Figure 5).

In addition, only a few modes of failure were significant for each type of equipment — an observation with important implications as the manufacturer seeks to maximize risk management while reducing expenses. This can be accomplished by focusing key personnel and financial resources on certain key equipment and to prevent failures for a limited number of failure modes.

### C. Pressure Systems in the Chemical Industry

As all of us in the engineering insurance industry will appreciate, the chemical sector provides numerous examples of complex, high-risk installations. They invariably are subject to arduous service conditions, extremes of pressure, temperature and cyclic 'loading.' Mediums used can be toxic, explosion hazardous and often cause cracking or other forms of deterioration.

At Royal & SunAlliance Engineering in London, a tailored loss control service identifies a client's:

- **Obligations** (the maintenance of a safe operational regime)
- **Needs** (to maximize reliability, minimize downtime and protect the business assets)

Through the application of an integrated team of experts, it is possible to gain an in-depth knowledge and understanding of what is happening to the plant that leads to the optimization of the engineering inspection and control regime.

### Authoritative Review

The use of this approach requires an authoritative review of the integrity of the plant system. It typically involves the review of plant records, design, construction, maintenance and inspection. The establishment of possible failure modes applicable for the identified duty and condition of the plant. And validation of safe operating limits for the system.

It also includes the formulation of a cost effective inspection regime, the type of inspection that can be most effectively employed. Knowing the failure mode we are looking for, it is possible to select the most appropriate technique to detect defects. A great deal of work is currently being done in the use of state-of-the-art, non intrusive techniques.

Periods of inspection, or outages, can be optimized through the knowledge of failure modes and deterioration growth rates. Through criticality rating, the review identifies the most suspect items or even narrows it down to particular areas on items. This ensures that maintenance and inspection resource is prioritized and allocated to areas of most need.

**Ammonia Installation**

The application of this multi-disciplined approach to formulating a risk-based inspection regime include reduced downtime and enhanced profitability — and much better control of risks that are central to the assets of the business and obviously its insurer.

Take, for example, an ammonia installation. An authoritative review of a large ammonia storage system (Figure 6) is one of many applications of this philosophy by Royal & SunAlliance Engineering. It provided and continues to provide a cost effective solution to controlling integrity, reliability with a problematic item of plant.

We know from experience that stress corrosion cracking (SCC) is likely under certain conditions when ammonia comes into contact with carbon steel, the common construction material on such storage tanks. We also know it can occur at any weldment coming into contact with ammonia.

Having assured ourselves that the vessels have been designed and constructed to sustain main service parameters, we would take the following steps to ascertain levels of deterioration and its criticality level.

- At outage, a detailed inspection of all internal weldments to establish size and extent of defects, stress corrosion present.
- Metallurgical investigation, to categorize defect's nature and type. A typical SCC is shown in Figure 7.
- Establish critical defect sizes through fracture mechanics, for the various locations in the tank. This critical size is the point at which the defect will render the vessel unstable. On no account should defects ever be allowed to grow to this size, factors of safety are always prescribed when assessing acceptable defect sizes.
- Using this information, together with a history of service experience, postulated crack growth rates and failure mode analysis, cracks are invariably ground out in key areas providing adequate material in the vessel remains. If significant defects are present, Figure 7, then a more comprehensive major repair will be necessary.

## IV. Future Trends To Support Industry

### A. Technology

In the future, small business will continue to become more customized, streamlined and cost-effective as possible. However, mega risks and complex risks in the middle market will require providers of insurance and engineering services to focus more than ever on the needs of the client.

They must gain a greater understanding of the client's business and, above all, their needs and the delivery of a program to satisfy those needs. Successful "engineering insurers" in the upper echelon of the niche market of engineering are moving more toward providing solutions that embrace all the elemental forms of risk management.

An understanding and application is necessary for the use of leading-edge technologies in the multi-discipline fields of:

- Risk identification and evaluation
- Design and analysis
- Maintenance and operational management
- Failure mode determination
- Loss control
- Reliability/availability methodologies
- Root cause analysis
- Human factors analysis

These will be key competencies of those who will survive and succeed in the field of insurance and engineering services.

### B. Outside Influences

Risk-based legislation designed to ensure safety related aspects of critical plant operations to meet best practice requirements has become the norm in Europe and is gaining acceptance in the United States. Changes to statutory or jurisdictional inspection requirements from prescriptive to goal-setting regimes have permitted flexibility in setting the type and frequency of examination. As a result, many users of complex, high-risk plant look to their insurers for advise on risk-based programs to optimize maintenance and inspection.

Insurers need to be aware if the new regime has been formulated by other organizations which provide the service without the back-up of data and experience on which to base judgments. There also is a very real danger in software programs that guide the user through the risk-based process. When used by inexperienced staff, conclusions defining inspection/maintenance requirements may be reached through questionable input, without regard to the sensitivity to variations in data entry.

### C. Know-How

Leading engineering insurers are driven by "know-how" — a knowledge and understanding of engineering risks and the ability to establish solutions to identified customer needs. This is an increasingly more sophisticated trend. We also see more of a partnership, with the insurer and insured working together in harmony. The insurer's authoritative view of the risk elevates his presence with the client. But the market's view of the insurance industry needs to continue to change. Engineering insurers should be perceived as truly adding value.

### D. Loss Control Techniques

Developments in technology are continuing to improve the facilities and techniques available to carry out meaningful inspections and condition monitoring with minimum disruption. Vibration and other monitoring controls now are widespread in continuous process industries. Applied in the right manner, they obviously are a significant contributor to risk control on appropriate systems.

Extensive research is being carried out into the viability and dependability of non-invasive inspection techniques. Further work also is continuing to determine the reliability of conventional non-destructive inspection techniques and the factors that influence the ability to detect defects. The non-intrusive nature of many new techniques ensures minimum interruption, making it more likely that conditions will be checked on a more regular basis.

### E. Critical Items — Know-How and Statistical Information

In engineering insurance, a knowledge of design, construction and operation of key equipment is paramount. Traditionally, this knowledge is gained through experience and operational history. Plant reliability estimates for underwriters have been established through this method, perhaps crudely in some cases.

In order to obtain meaningful data to input the model, extensive investigation work is carried out on Fault Tree analysis, FMECA, development testing of components, metallurgical research and development, and full-load factory tests (see section II. Risk Assessment/Risk Management Tools). Each change from a proven design should be examined critically to make sure engineering parameter changes are fully considered and their implications accounted for.

As an industry, until relatively recently, insurers were poor at harnessing their biggest asset — data and knowledge about equipment and processes. Claims and general failure data are well recorded. When applying risk-based philosophies, there is a need for failure rates or probability data. This requires not only incident quantification, but also the population of categorized items.

## V. Conclusions

The successful engineering insurer of the future will make full use of risk-based methods and all the data and knowledge at its disposal to help the insured gain maximum benefit from the insured's equipment and processes.

As Johnson and Higgins noted in its 1997 Insurance Market Review & Forecast: "Increasingly, ... insurers will compete not on price or on how much data they possess, but on their skill in analyzing data. Each competitor will try to demonstrate that it possesses the best skills for performing client-specific analyses and developing client-specific solutions. This capability will help prove ... that an 'outsider' competing for their company's business really understands the business and merits their trust."

The successful insurer, therefore, will be a significant consultant to the insured with expertise in risk-management processes. And they will have the demonstrated ability to interpret extensive data and knowledge to apply those processes successfully and provide solutions for that client.

8/8/97

**Table I**
**Failure Modes Effects Analysis**

| | | | | | | |
|---|---|---|---|---|---|---|
| DATE: | | | | PAGE: | | |
| PLANT: | XYZ Plant | | | REFERENCE: | | |
| SYSTEM: | Reaction System | | | ANALYST(S): | | |
| Item | Identification | Description | Failure Modes | Effects | Safeguards | Actions |
| 4.2 | Valve B on the phosphoric acid solution line | Motor-operated, normally open, phosphoric acid service | Fails closed | No flow of phosphoric acid to the reactor<br><br>Ammonia carry-over to the DAP storage tank and release to the enclosed work area | Flow indicator in the phosphoric acid line<br><br>Ammonia detector and alarm | Consider alarm/shutdown of the system for low phosphoric acid flow<br><br>Consider using a closed tank for DAP storage and/or ensure adequate ventilation of the enclosed work area |
| 4.3 | Valve B on the phosphoric acid solution line | Motor-operated, normally open, phosphoric acid service | Leak (external) | Small release of phosphoric acid to the enclosed work area | Periodic maintenance<br><br>Valve designed for acid service | Verify periodic maintenance and inspection is adequate for this valve |
| 4.4 | Valve B on the phosphoric acid solution line | Motor-operated, normally open, phosphoric acid service | Rupture | Large release of phosphoric acid to the enclosed work area | Periodic maintenance<br><br>Valve designed for acid service | Verify periodic maintenance and inspection is adequate for this valve |

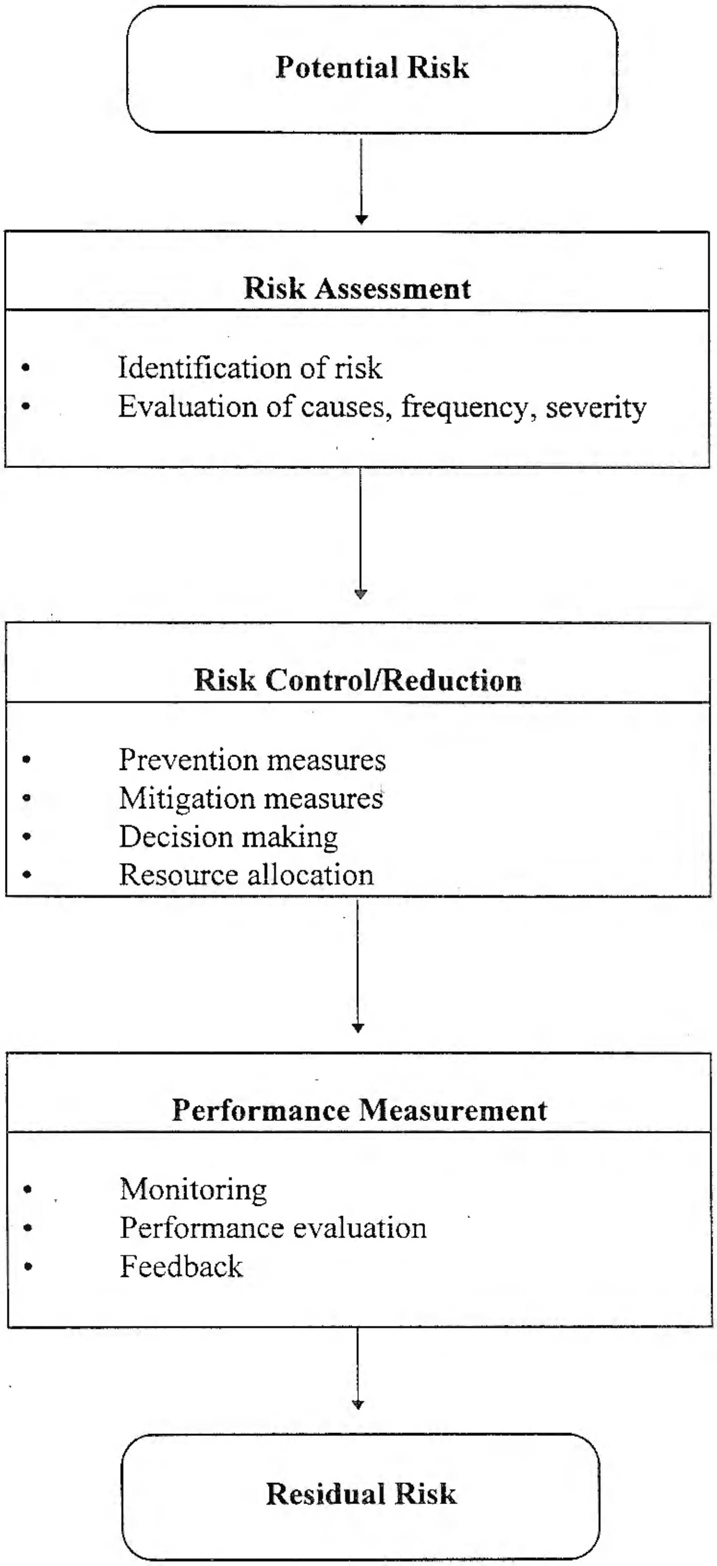



**Figure 1. A Simplified Overall Structure of Risk Management**

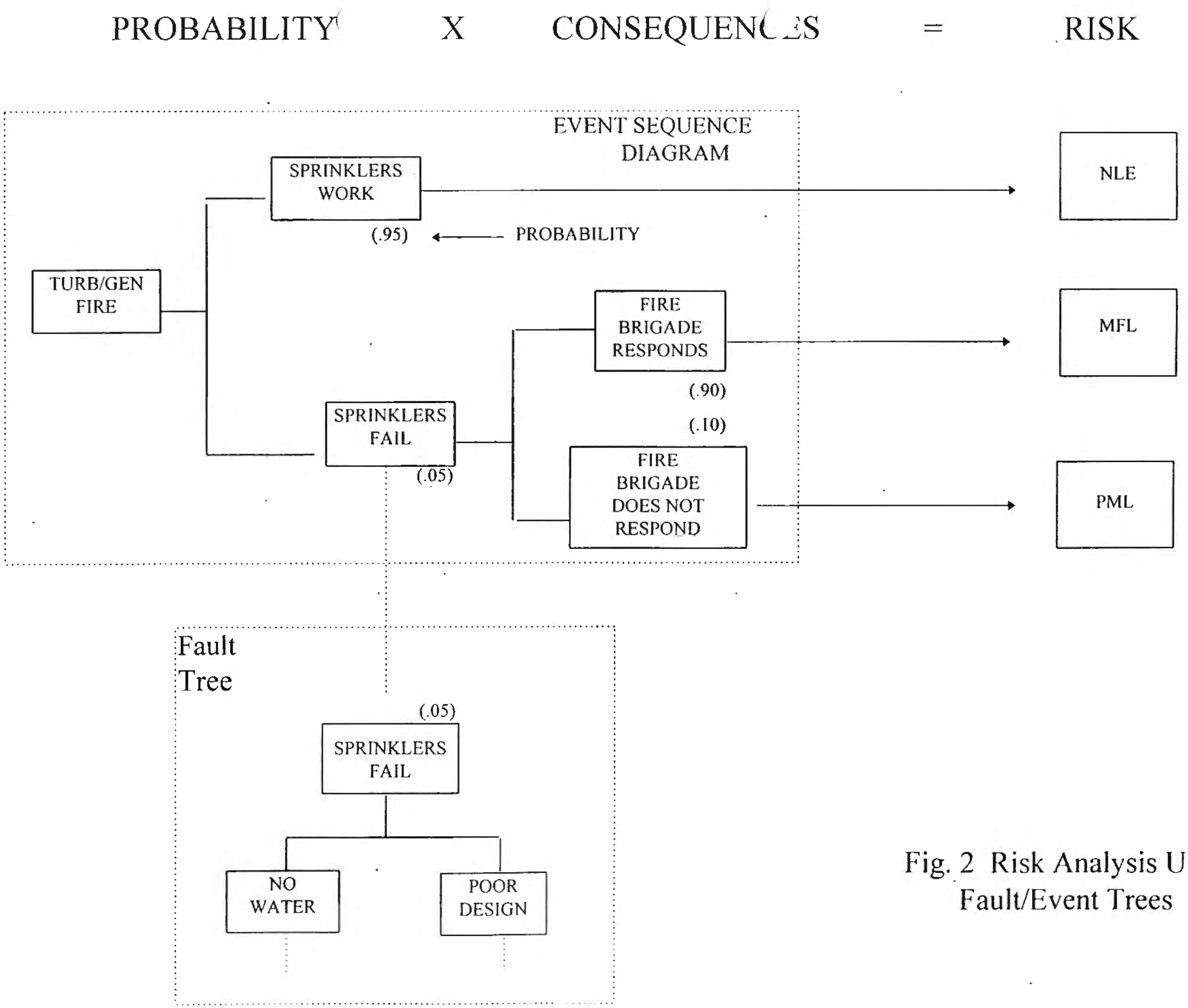



Fig. 2 Risk Analysis Using Fault/Event Trees

Figure 3 - Cumulative Risk Ranking for a Typical LP Turbine

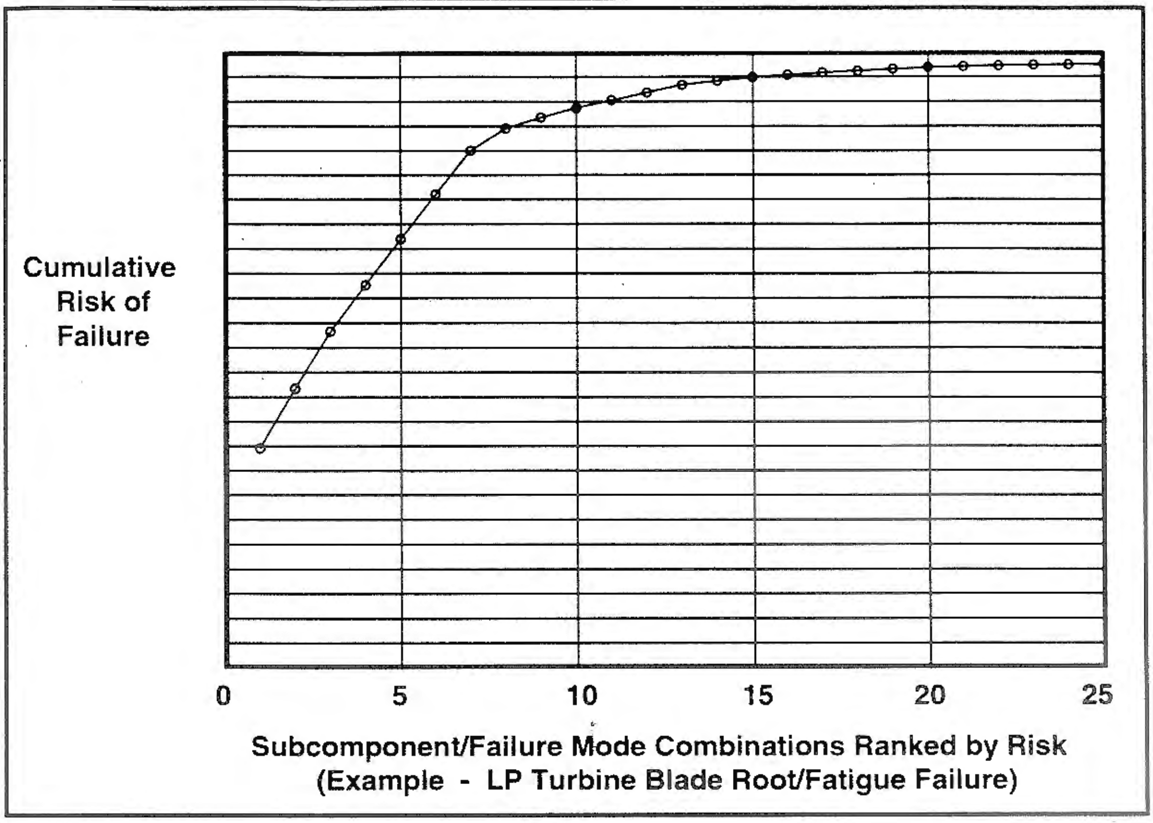



Figure 4 - Comparative Risk Ranking for a Typical Generator

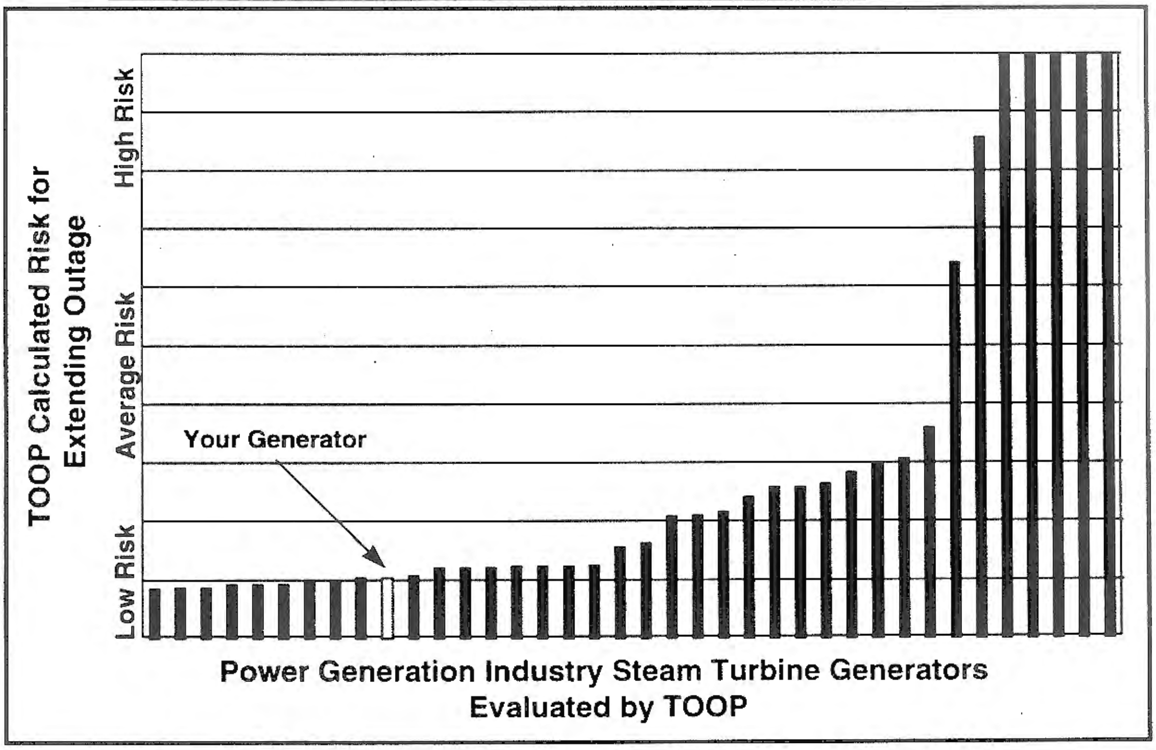
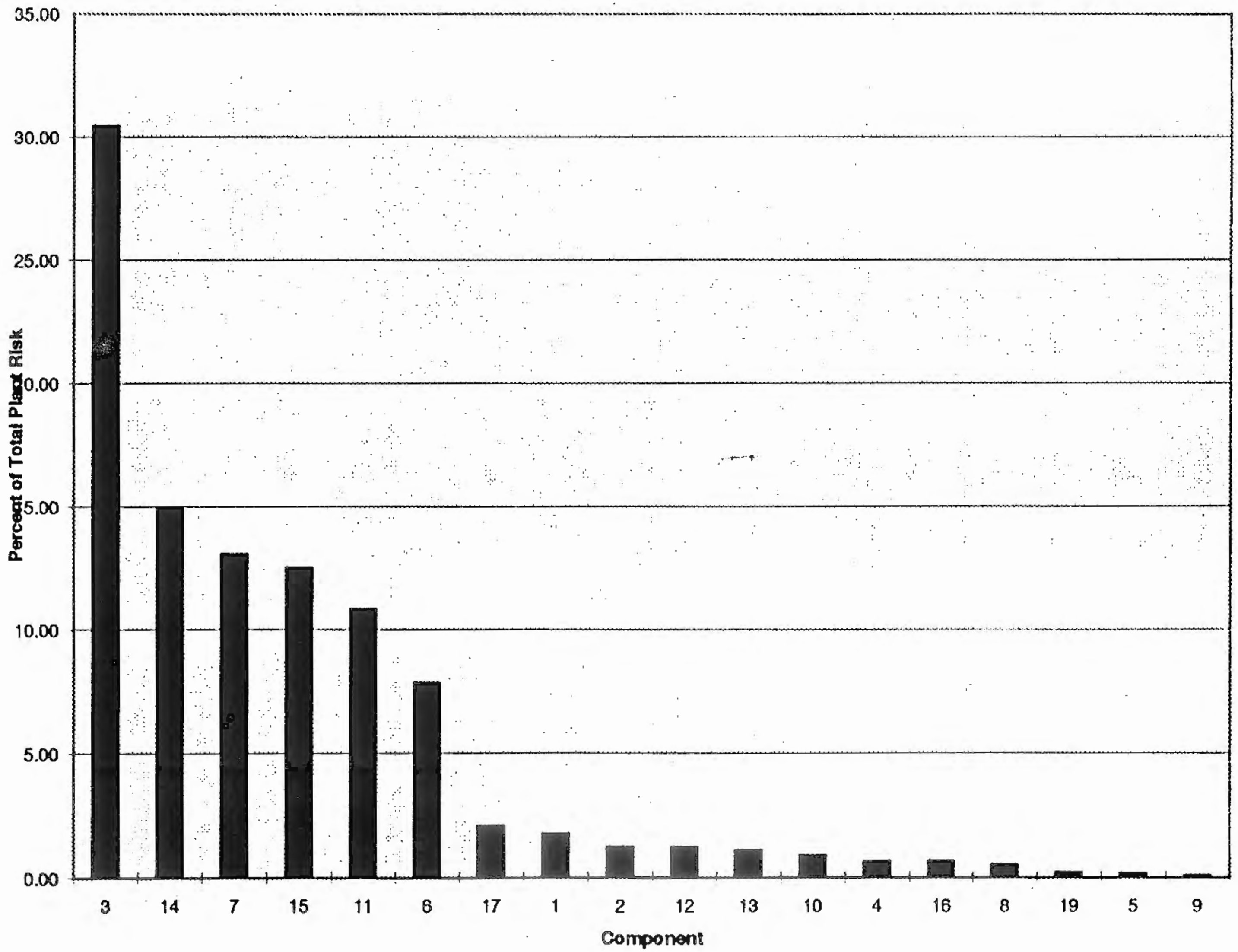


FIGURE 5. RISK OF COMPONENTS ON A TOTAL PLANT BASIS.



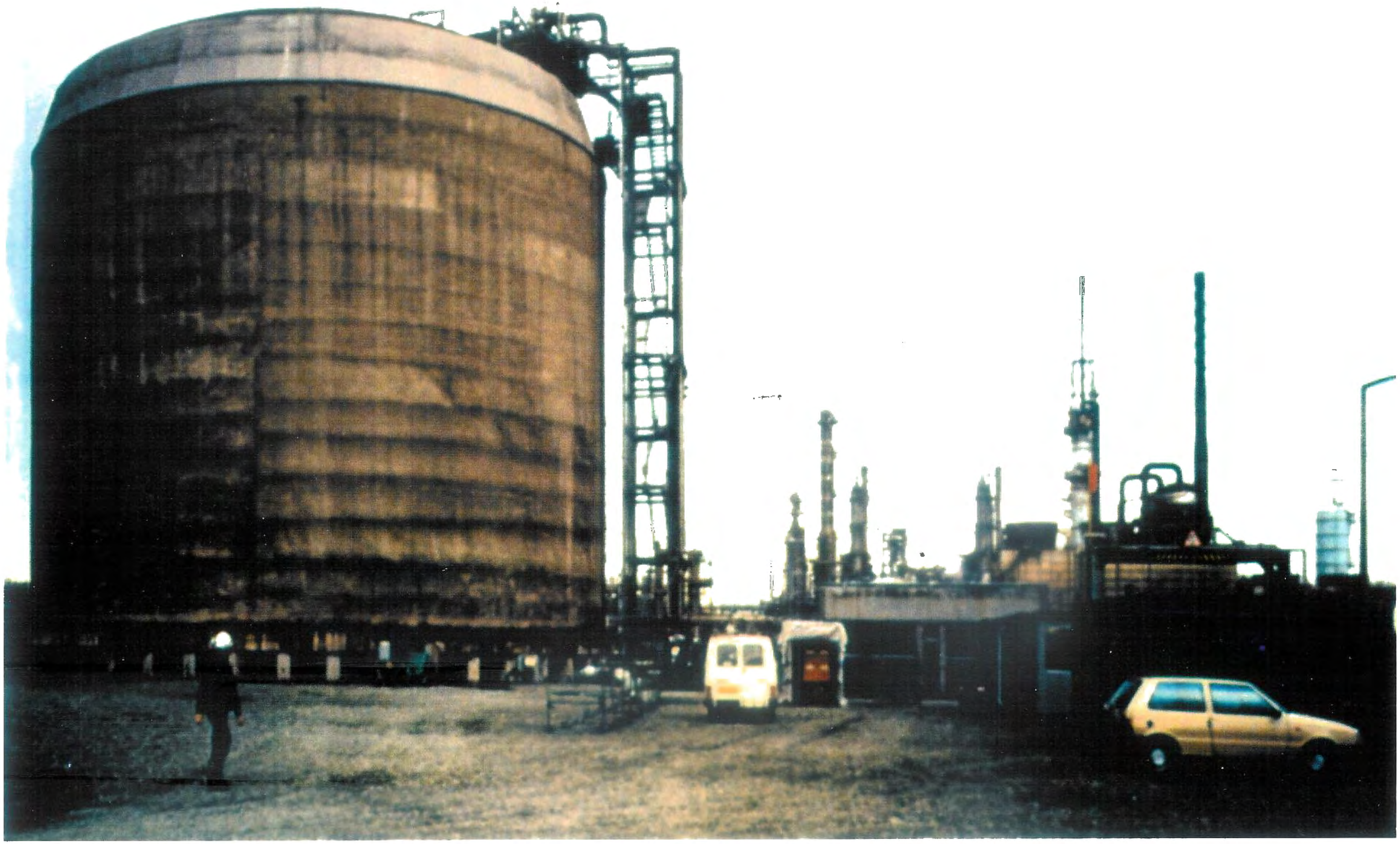


FIGURE 6. LARGE AMMONIA STORAGE SYSTEM.

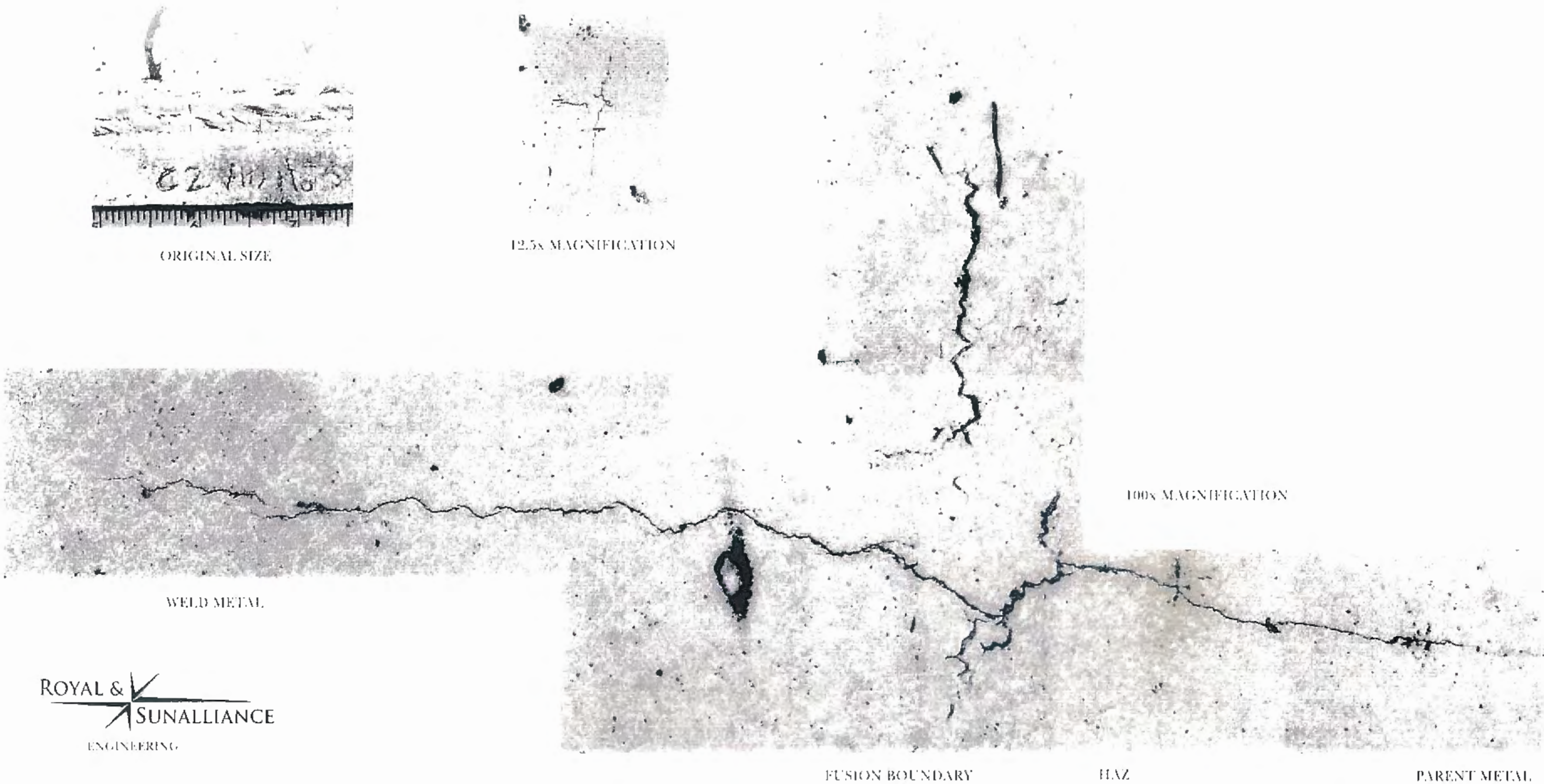



FIGURE 7. TYPICAL STRESS CORROSION CRACKING IN CARBON STEEL.