Experiences of safety analyses in the pulp and paper industry

Veikko Rouhiainen

ABSTRACT: Safety analyses have been used successfully in the pulp and paper industry to eliminate production disturbances. A new method has been developed to minimize accidental releases in pulp plants.

KEYWORDS: Accidents, analysis, evaluation, hazards, methods, paper industry, problem solving, pulp industry, safety, upgrading.

Safety analysis is the systematic examination of the structure and functions of a system. Its aim is to identify all factors having the potential to contribute to accidents, to evaluate the risk induced by them, and to find ways to minimize these risks. The objective is to eliminate accident hazards before any accidents have occurred.

This article describes experiences obtained from safety analyses carried out in the Finnish pulp and paper industry and presents a new method developed for minimizing accidental releases in pulp plants.

The application of safety analysis is based mainly on the motivation of and benefits perceived by the industrial enterprises themselves. Some experiences of the benefits obtained in process industries have been reported. When designing new process systems, for example, use of safety analysis has decreased the fatal accident rate by about 75% *(1)* and reduced the costs of changes and disturbances in a plant startup by 10% *(2)*.

In operating plants, safety analysis has been used to support safety programs. In an iron factory, a 50% reduction in human injuries was attained after a safety analysis had been conducted *(3)*. As a secondary benefit, a considerable increase in safety awareness was achieved. Quantification of hazards supports decision-making and shows the effect of design changes. For example, remedies developed during safety analysis have reduced the risk by a factor of from 3 to 10 *(4)* and increased plant reliability by a factor of 2.7 *(5)*.

In a paper plant, the improvements developed after individual machines had been studied reduced the number of days absent from work by 67%, in some cases by as much as 90%. In addition, 63% of the improvements made the performance of tasks easier and 21% decreased production stoppages.

Safety analysis of a black liquor recovery boiler plant

In North America, 113 recovery boiler explosions, including 80 smelt–water explosions, have been recorded between 1958 and 1979. Grace and Taylor *(6)* have verified that the first year of operation is the most critical where smelt–water explosions are concerned. According to the statistics, during the first year of operation such accidents are three times as common as on the average. This seems to indicate that operational experience decreases hazards.

Gases formed as a by-product of the process also pose a significant risk. An accident of this kind happened in a plant in Finland. During a maintenance shutdown, the explosive gas–air mixture leaked into an electro-filter and exploded. No injuries occurred, but the accident caused serious material damage and disturbances in production, as well as harm to the environment that lasted for several months.

Aim of the analysis project and methods used

A recovery boiler plant was subjected to a safety analysis carried out in cooperation between a Finnish paper company and the Safety Engineering Laboratory of VTT (Technical Research Centre of Finland). The aim of the safety analysis was to identify and evaluate the hazards associated with the plant, and the factors contributing to those hazards, to enhance the safety and reliability of plant operations.

The first phase of the study, risk mapping, sought to obtain a general view of the risks and to identify the most important accident potentials. It was performed by using a method called potential problem analysis (PPA) *(7)*.

In the second phase, the study shifted from the general approach to a detailed analysis of the most critical

Rouhiainen is senior research scientist at VTT, Technical Research Centre of Finland, Safety Engineering Laboratory, Box 656, FIN-33101 Tampere, Finland.

process systems. This was done by applying the HAZOP (hazard and operability study) method *(8)*. The accident hazards affecting the workers operating the equipment were then studied by means of work safety analysis (WSA) *(9)*. The most important maintenance tasks were studied using action error analysis (AEA). The aim was to identify potential human errors and to analyze their effects. Finally, problems relating to the organization of maintenance were analyzed with the MORT method (management oversight and risk tree) *(10)*.

All five methods were employed by work teams consisting of representatives from the recovery boiler plant and VTT. The teams were formed to include as much knowledge and experience as possible. The aim was to improve the personnel's overall safety awareness. The size and composition of each team varied, according to the method employed (**Table I**).

I. Participants in the safety analysis of the black liquor recovery boiler plant

Participant	*PPA*	*HAZOP*	*WSA*	*AEA*	*MORT*
Production manager	*				
Production engineer	*	*	*	*	*
Maintenance engineer					
Machine					*
Electrical					*
Senior foreman		*	*	*	
Foreman					
Production	*	*	*	*	
Maintenance					*
Mechanic					*
Electrician					*
Operators (three)			*		
Safety technician	*	*		*	*
Safety representative	*	*	*	*	*
Researcher					
Engineer	*	*	*	*	
Psychologist				*	*

Identifying the hazards and their contributors

In risk mapping, a total of 152 ideas for hazardous situations were identified at two meetings. In all, 13 hazards were then analyzed in more detail. This resulted in the identification of 78 contributors and 25 remedial measures. The major hazards which previously had not been perceived clearly enough and which had the potential to cause a smelt–water explosion were:

- Water entering the boiler (e.g., leakage or overfilling of the feedwater tanks above the boiler, or a failure of the inlet heat exchanger)
- Diluted liquor entering the boiler due to a failure in the density gauge.

With respect to the process system, 41 hazards having over 200 contributors were identified by HAZOP. The majority (51%) of the contributors pertained to process disturbances or equipment failures. Human errors or deficiencies in procedures also played an important role (40%). Over 60 factors contributing to the inadvertent dilution of the liquor were identified. However, most of the hazards identified by HAZOP had only minor potential consequences (**Fig. 1**).

With respect to the operating tasks carried out by the boiler operator, the stoker, and the evaporation plant operator, a total of 79 hazards with over 100 contributors were identified. The most significant problems pertained to the maintenance tasks, which involved lifting and removing machine parts and the isolation of different work objects to eliminate the risk of inadvertent starts (i.e., handling the correct valves, blinding the correct pipelines, disconnecting the correct hoses and pipes and reconnecting them correctly after the work).

Examples of the identified maintenance problems include:

- Improper storing of flammable materials, particularly during maintenance shutdowns
- Inadequate preventive maintenance of auxiliary devices
- Inadequate training of personnel concerning the maintenance of new equipment
- Deficiencies in task boundaries and responsibilities
- Improper use of safety switches.

Suggested improvements

Over 260 improvements were proposed at different phases of the safety analysis (**Figs. 2 and 3**). One third of them came up during the HAZOP study, another third during the maintenance survey, and the rest during risk mapping and work safety analysis. More than half of the proposed improvements were technical in nature.

The majority of the improvements affecting the pipelines and valves concerned the evaporation plant and the black liquor feeding system. A number of unnecessary pipe connections and valves were found; these could be removed or blinded. Changes of these kinds are typical of a plant where several modifications have been made over the years.

Effects of the proposed changes

Half of the proposed measures improved the reliability of the plant operation by eliminating the identified disturbance potentials or by reducing their probability. Thirteen of the liquor dilution disturbance potentials could be eliminated completely, and the probability of disturbance could be reduced in 26 cases. The probability of serious operational disturbances, in particular, could be reduced in nearly every identified case.

The plant personnel estimated that more than 80% of the changes could be made immediately. The rest could be realized in the near future in connection with other maintenance tasks or later on when major changes would be made. It also was estimated that over 70% of the measures could be realized at only marginal costs.

As to the human tasks, the accident risk could be reduced to 25% of the original estimation. In addition to the improved safety level, about 60% of the changes also facilitated the execution of the work tasks.

Evaluation of the execution and results of safety analysis

HAZOP is the most important and valid method of analysis for improving the operational safety of process systems. However, the study showed the importance of supplementing a plantwide analysis based on HAZOP by using other methods which focus on specific process parts and human activities (e.g., maintenance). For example, Suokas *(11)* shows that HAZOP can detect only about 35% of all hazard contributors in a process system.

The analysis uncovered new, formerly unidentified hazards, the elimination of which would lead to safer and more disturbance-free operation of the plant. Workers also received valuable information about the operations carried out in the plant. This will lead to better informed and more safety-conscious workers. This was surprising because the company had a long experience with recovery boiler plants, and this plant is one of the safest in Finland; in fact, its safety records are better than average.

A method for improving the management of accidental releases in pulp plants

The environmental impacts caused by a plant can be divided into continuous process emissions and accidental releases. Continuous process emissions normally occur when the plant is operating. Accidental releases are usually sudden, unforeseen releases of harmful substances. Since they are unexpected, they can cause very serious consequences.

Although production of the Finnish forest industry has increased in volume by about 60% in the last 20 years, the amount of emissions has decreased over 80%. Even so, the problem caused by potential accidental releases still remains. The publicity arising from accidental releases could have very negative impacts on the plant and perhaps on the attitudes of the public towards the whole industrial branch. The role of the accidental releases is emphasized by the fact that one major release could have an adverse effect on the microorganisms of the biological wastewater treatment system. This, in turn, could interrupt the operation of the whole pulp plant for a couple of weeks.

Procedure for managing accidental releases

A new procedure for eliminating and managing accidental releases of pulp plants has been developed at VTT. The procedure begins by defining and restricting the object and by collecting the factual information needed (**Fig. 4**). Identification and analysis of potential releases is carried out by applying the release risk analysis method (RRA) *(12)*. The method has been developed on the basis of PPA *(7)*. RRA obtains a general view of the release hazards and their contributors related to the plant and its operations.

When analyzing release potentials, their causes and consequences are evaluated in detail. This begins by rejecting release hazards which are less significant and do not need further consideration. The analysis includes ranking of the risks according to their relative magnitude by estimating the probability (P) and consequences (C) of each release potential (**Table II**). In addition, the amount of released chemical should be estimated (in tons, cubic meters, etc.).

Assessment of the effects of potential releases to the environment and to the wastewater treatment plant is made based on chemical data and experiences from releases that have occurred. The management of release potentials can be planned. This stage includes the development and implementation of remedies for eliminating or managing the release potentials. The management of releases should be a continuing process that includes the investigation of releases that have occurred.

Case studies

The procedure has been applied in two pulp plants. In the first case study, the plant was divided into four parts and a work team was formed for each part. Each team consisted of an operator, a production foreman, a maintenance worker or foreman, a production engineer, and the team leader. Each team used three 3–4-hour meetings for hazard identification and two 3–5-hour meetings to analyze the identified release potentials.

In the second case study, three work teams were formed to carry out the RRA. Each team used two 4-hour meetings for hazard identification. One meeting was replaced by personal work. Each team analyzed the most significant risks in one 4-hour meeting, during which the team was reinforced by an expert from the wastewater treatment plant. The less significant risks were left to be analyzed later by the personnel of the department in question.

Release potentials identified and improvements suggested

Both case studies identified a remarkable number of release potentials—about 350 in each study. A considerable number of these release potentials had not been recognized previously. The most significant release potentials arose from the storing of chemicals, fuels, and flammable products such as turpentine and tall oil. Loading and unloading of chemicals are generally known to be risky activities; overloading can cause a release, or chemicals can be loaded into the wrong vessel, thereby causing unexpected chemical reactions to occur.

Management of accidental releases is based on knowledge of the release potentials. This means that their causes and the place of release must be identified. When evaluating the amount of chemical released, one must check how the release can be detected. Once this is known, measures can be planned to eliminate each release potential, to decrease its probability, or to diminish its effects. The improvements that were developed included various technical improvements and changes in the operating procedures.

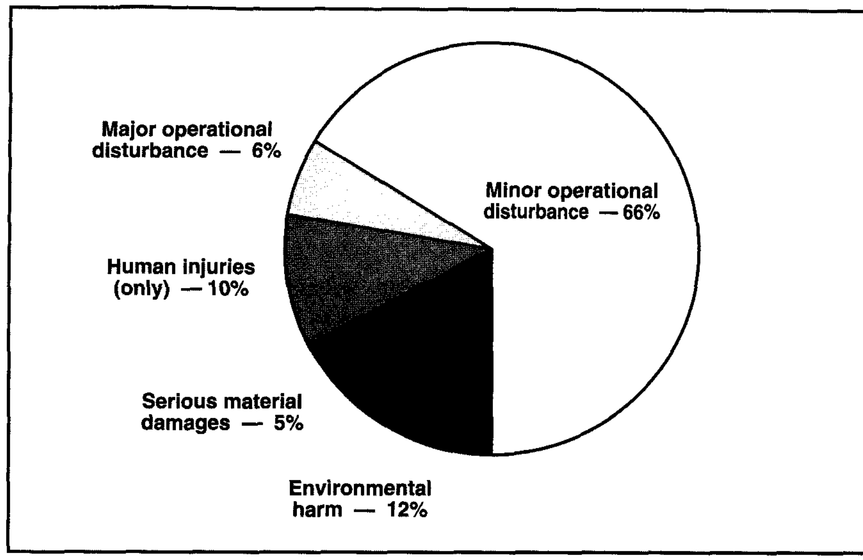
Management of accidental releases is closely linked with the management and control of the production process, equipment, and activities; the more stable the production process, the better it can be controlled and the lower the number of releases. Several improvements of the automation, instrumentation, and maintenance of the production system also were made.

Good control of the wastewater treatment system forms the foundation for treatment of most of the releases. Alarm systems and procedures play an important role. Continuously-operating devices were proposed for controlling the most critical points of the sewage and rainwater system. Such devices should detect releases as early as possible and should give appropriate information to the persons responsible for operating the wastewater treatment system and the whole process. However, the wastewater treatment plant should get that information even earlier, as soon as the disturbance in the production process has occurred.

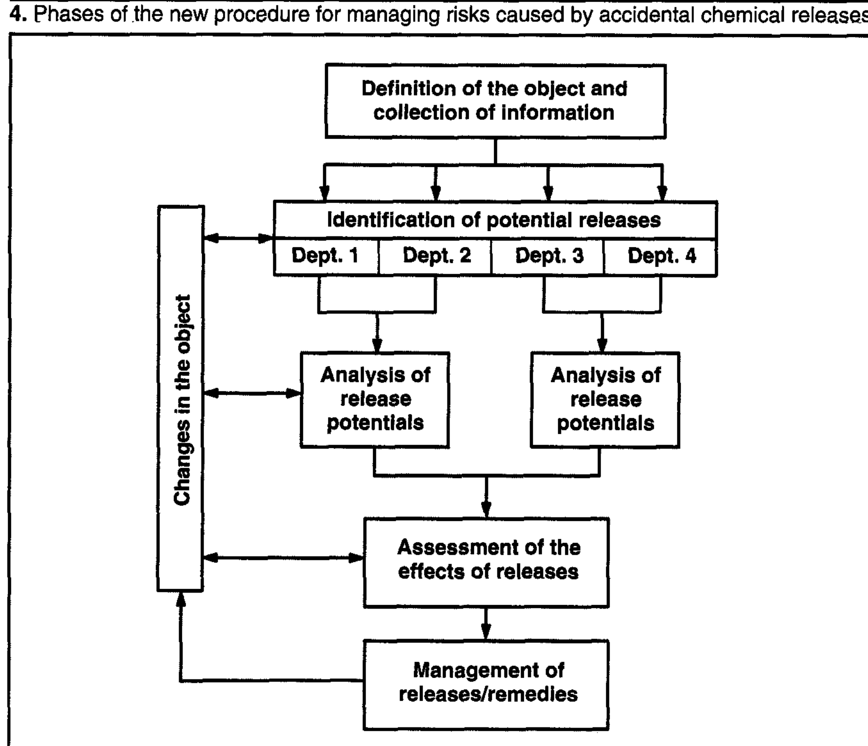
Evaluation of the execution and results of RRA

In both case studies, RRA detected a remarkable number of release potentials. However, there were problems in estimating the effects of release potentials and in assessing the most significant risks. The main reason for these problems was lack of information about the properties of the chemicals and on their effects on the wastewater treatment plant and on the environment. Therefore, the assessment often had to be based on the plant's own experiences (i.e., incident data from releases that have occurred previously) and on expert opinions.

1. The distribution of the probable consequences (N = 241) of the deviations identified by and evaluated in HAZOP



4. Phases of the new procedure for managing risks caused by accidental chemical releases

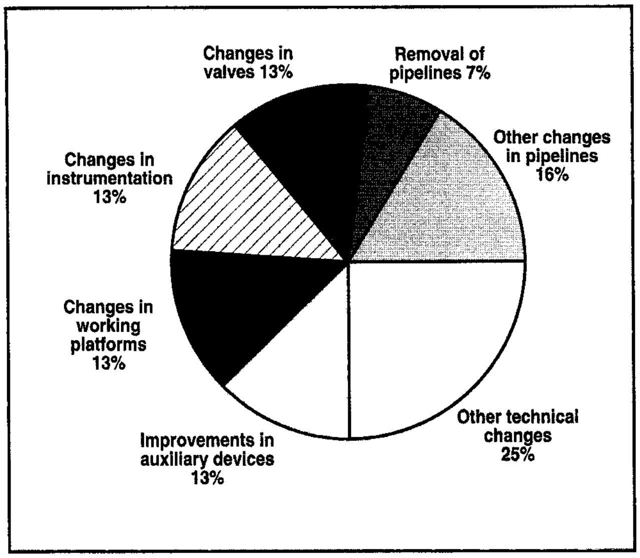


The approach used in RRA applies a much wider perspective to problem identification than the identification methods commonly used in safety and risk analysis. In practice, the wide perspective applied to problem identification also restricts the depth of the results. Hence, the analysis can be seen as the beginning of a systematic effort to manage the accidental releases more precisely.

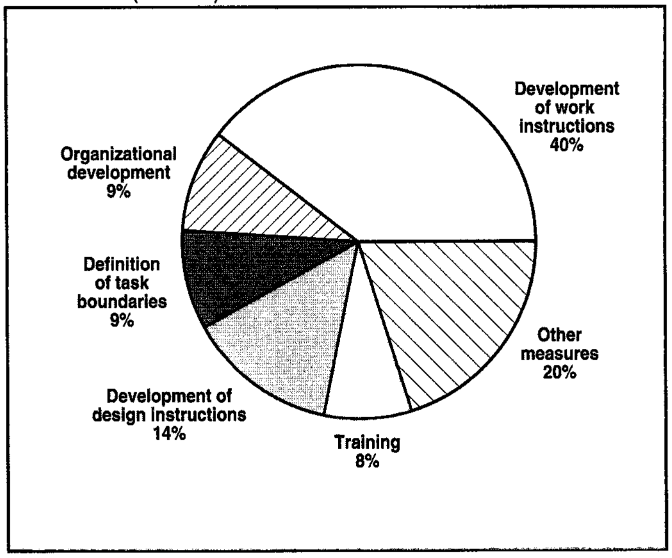
Summary

Operational experience has been used to improve the safety and reliability of process systems. The information available, however, has many restrictions. Many restrictions of incident investigations can be eliminated by using a detailed safety analysis; the use of safety analysis and the collection of in-

2. The distribution of technical improvement proposals (N = 158)



3. The distribution of improvement proposals other than those technical in nature (N = 108)



II. The scales used when estimating the probability and consequence of each release potential

Probability of the release (P)	*Consequence (magnitude) of the release (C)*
Very improbable Less frequently than once in 10 years	Insignificant release Harm only at the point of existence
Improbable Less frequently than once a year	Minor release Harm in the plant area or an increase in the load of the wastewater treatment plant
Possible Yearly	Moderate release Minor harm to the environment or problems in the wastewater treatment plant
Probably Monthly	Significant release, Harm to the environment
Very probably Weekly	Serious release Serious harm to the environment or interruption of the wastewater treatment plant

cident information thus supplement each other. However, the operational experience of the plant personnel provides the necessary background information when carrying out safety analysis.

This paper describes safety analyses as carried out in operating pulp plants. The analysis revealed a large number of defects, the elimination of which would increase the safety and reliability of these plants. Use of safety analyses can thus be considered very important when designing new plants.

One of the main ideas of the consultants involved in these studies has been to carry out the analysis and plan the improvements together with the personnel of the plant. This was motivated by the fact that the personnel have the best and most experience with the processes, their deficiencies, and equipment failures. Moreover, participation improves the personnel's awareness of the hazards and helps workers to realize that something can and must be done to improve the situation. ◼

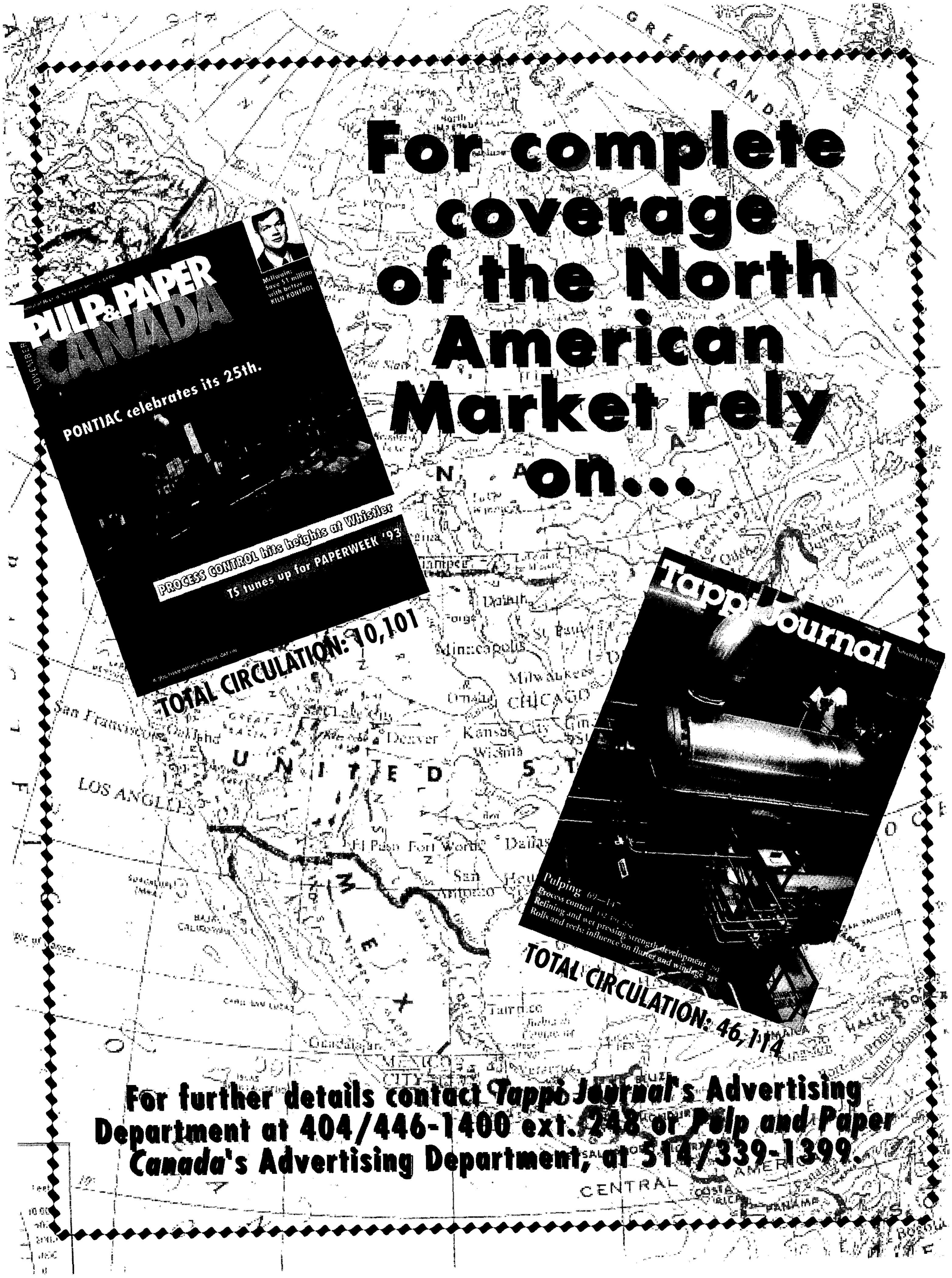
Literature cited

1. Illidge, J. T., Loss Prevention Bulletin: 053(1983).
2. Ridfleisch, H. N., Untersuchung zur Methodik von Sicherheitsanalysen, Dortmund, Universität Dortmund, Abt. Chemietechnik, Report No. INIS-MF-9784, 1984 (in German).
3. Suokas, J., Accident Analysis & Prevention 20(1):67–85 (1988).
4. Hauptmanns, U., Erfahrungen mit der Anwendung der Fechlerbaumanalyse bei der Untersuchung von Teilen einer Anlage zur Herstellung des Sprengstoffes Hexogen, Köln, Gesellschaft für Reaktorsicherheit GmbH (GRS), 1985 (in German).
5. Hauptmanns, U. and Sastre, H., J. of Chemical Engineering of Japan, 17(2): 165–173(1984).
6. Grace, T. M. and Taylor, M. L., Analysis of explosion data. Recovery Boiler Committee Annual Meeting Proceedings, American Paper Institute, New York, 1979.
7. Kepner, C. H. and Tregoe, B. B., The New Rational Manager, Kepner-Tregoe, Princeton, NJ, 1981.
8. Kletz, T. A., HAZOP and HAZAN, Identifying and Assessing Process Industry Standards, 3rd edn. Institution of Chemical Engineers, Rugby, Wartwickshire, UK, 1992.
9. Suokas, J. and Rouhiainen, V., Research Report 314, Technical Research Centre of Finland, Espoo, 1984.
10. Johnson, W. G., MORT Safety Assurance Systems, National Safety Council and Marcel Dekker Inc., New York, 1980.
11. Suokas, J., Incident Information as an Aid to Validating Safety Analysis, World Conference on Chemical Accidents Proceedings, CEP Consultants Ltd., Edinburgh, 1987.
12. Isännäinen, S., Rouhiainen, V., Koivisto, R., and Edelmann, K., Research Notes 1325, Technical Research Centre of Finland, Espoo, 1992 (in Finnish).

The author would like to thank Kaukas Oy, the Combustion and Thermal Engineering Laboratory of VTT, Metsä-Sellu Oy, Oy Metsä-Botnia Ab, Jaakko Pöyry Oy, the Finnish Technology Development Centre (TEKES), and the Tapiola Insurance Group for their cooperation and financing of these research projects.

Received for review April 24, 1992.

Accepted Nov. 6, 1992.


For complete coverage of the North American Market rely on...
PULP & PAPER CANADA
PONTIAC celebrates its 25th.
PROCESS CONTROL hits heights at Whistler
TS tunes up for PAPERWEEK '93
TOTAL CIRCULATION: 10,101
Tappi Journal
Pulping
TOTAL CIRCULATION: 46,114
For further details contact Tappi Journal's Advertising Department at 404/446-1400 ext. 248 or Pulp and Paper Canada's Advertising Department, at 514/339-1399.