DRILLING SOUR GAS WELLS,
RISK MANAGEMENT ALTERNATIVES FOR NORTHEAST CALGARY, ALBERTA

By
ROBERT IAN LAIRD ROSS
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Department of School of Community and Regional Planning

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

Date April 28, 1986
ABSTRACT

There is a growing public awareness of and opposition to the risks associated with the operation of hazardous industrial facilities near populated areas. Public concern escalates when the industrial activity possesses the potential for catastrophic consequences should a major accident occur. This study examines the risk of drilling a toxic, natural sour gas well near northeast Calgary, Alberta. The sour gas problem is indicative of the difficulties of finding socially acceptable solutions to such risky activities.

The sour gas industry in Alberta has been successfully drilling for sour gas reserves for over sixty years. Although there has never been a public death in the province as a direct result of exposure to the lethal hydrogen sulphide component of sour gas, recent uncontrolled accidental releases, or 'blowouts,' at sour gas wells have caused the public in Alberta to view the risks of drilling for the toxic reserves near residential communities too big to take. Because of the complexity and enormous array of uncertainties in predicting the likelihood and severity of a sour gas well blowout, the Energy Resources Conservation Board as the regulator and manager of Alberta's oil and gas industry is confronted with widely divergent opinions of the danger of drilling sour gas wells.
A risk management interpretation of the sour gas problem assumes a holistic approach, and utilizes knowledge—in depth, case specific information to help understand the uncertainties, the difficulties and implications of successfully drilling sour gas wells near urban centres. Personal work experience by this author on sour gas well drilling rigs enhances the validity and creditability of the risk management approach to sour gas. The main objective of this study, therefore, is to suggest alternatives to the manner sour gas wells are currently examined, regulated, drilled and managed in Alberta.

The thesis recognizes however, that in certain sour gas applications because potential consequences of an accident are extreme, that the risk cannot be effectively managed. In such instances, the proposal may have to be denied.

The risk management study begins by examining how the land use conflict between urban development and sour gas development materialized.

By understanding the uncertainties of safely drilling sour gas wells, especially with regard to the vital role that human error can play in contributing to a well control problem, the inadequacy of a technical solution to risky problems is emphasized.

Upon an extensive review of the literature relevant to risk research, the limitations of a quantitative, probabilistic approach to understand risky activities like
drilling sour gas wells is outlined.

Crucial to the risk management process is the need to recognize the legitimacy of the public's perceptions, concerns and fears of risks and to more readily include the public in discussions of the risks. Unless the public's point of view is understood, the principal difficulty of managing risky disputes, reconciling different opinions of the risks, will remain very prominent.

The sour gas industry in Alberta is at a critical point of development. The current sour gas proposal possesses the potential to represent the precedent for the manner the risks of sour gas will be managed.

The examination of this problem presents an opportunity to learn about the technical, moral, economic, social and psychological implications of operating hazardous industrial activities near residential communities. Unfortunately, this thesis has concluded that those involved in the sour gas problem have a great deal of catching up to do to assume a place in the classroom of understanding a holistic interpretation of the risks of sour gas.
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CHAPTER 1

1.1 Problem

Increasingly, public policy decisions to consider the siting of potentially hazardous industrial facilities near populated urban areas are coming under intense public scrutiny. The risk of a potential catastrophic accident like that which occurred at Bhopal, India, in December, 1984, emphasizes the growing concerns over the safety and compatibility of dangerous industries and urban populations.

In Alberta, the practice of drilling wells for natural gas containing highly toxic hydrogen sulphide ($\text{H}_2\text{S}$), or sour gas, to residents living in close proximity to these facilities, is representative of such a dangerous risk. Implicit in the drilling and development of any petroleum well is the possibility of an accidental release, or blowout, of hydrocarbons to the atmosphere. A sour gas well blowout occurring near of a populated area could expose residents to lethal concentrations of hydrogen sulphide, thereby placing their health and safety at risk. The Alberta oil and gas industry is very experienced and a world leader in obtaining and processing sour natural gas reserves. The industry is extremely well regulated, from a safety point of view, both internally and externally, and feels confident that sour gas wells can continue to be successfully drilled and developed near populated areas.
This thesis concerns an application by a Calgary oil company, Canadian Occidental Petroleum Ltd., to drill a sour gas well approximately two kilometres from residential communities in northeast Calgary, Alberta. The present application is a revised version of the original application made in the spring of 1984 to drill a well within 900 metres of the city's northeast boundary. Canadian Occidental's proposal represents one of the most thoroughly discussed and scrutinized energy resource development proposals ever considered in the province. A decision on the application has been temporarily deferred. The oil company's proposal is reflective of the difficulties in public policy making of coping with conflicting perceptions of risk, and how to best manage the problem when the positions of the disputing interests are based on widely divergent interpretations of the risk in question.

While interest in examining industrial risks has grown considerably in the past decade, the focus of most research has been on mathematical and engineering estimates of hazards and on attitude formation in individuals to explain why individual risk perceptions differ from engineering estimates. This research, while greatly facilitating the ability to assess the probabilities and consequences of a risk and to conjecture why people at risk respond in a particular way, does not provide a thorough understanding of
the uncertainties inherent in every risk problem and thereby negates the opportunity to effectively manage the problem.

1.2 Problem Statement

By identifying the nature and origins of the risks of drilling toxic natural sour gas wells near populated areas, and the difficulties of managing widely different perceptions of risks, this thesis explains where the risk management attention could be focussed to ensure a safer operation of sour gas wells and to account for public concerns over sour gas.

This thesis assumes that given the extent of sour gas reserves, facilities and investment in the province, some sour gas well drilling will continue to be part of Alberta's oil and gas industrial activity. A thorough risk management approach to particular sour gas wells may also mean in some instances, that the risk of potential consequences of an accidental release is so extreme that certain wells should not be drilled. Risk management, therefore, does not imply that sour gas well drilling will proceed in every application.

1.3 Scope

The practice of drilling for, producing, transporting and processing sour gas requires separate industrial
operations and cannot be simultaneously discussed as a single system. Each operation consists of a different potential for an accidental release of toxic hydrogen sulphide gas. Drilling a sour gas well represents the initial stage in obtaining the raw natural gas. Since the author of this study has extensive personal work experience in the drilling phase of sour gas wells in Alberta, and therefore practical insight into the existing problem areas, the focus of this thesis will be limited to the drilling operation in the discussion of risk management techniques.

1.4 Objectives

The objective of this thesis will be to examine the difficulties and uncertainties of drilling a sour gas well near northeast Calgary and to recommend alternatives in the manner the risk of sour gas is approached. The general objective will be achieved in the following ways:

1. Examining the planning policies that led to the formation of a land use problem between urban subdivision development and sour gas development;
2. Identifying the uncertainties of drilling sour gas wells;
3. Ascertaining the inadequacies of a quantitative approach to sour gas;
4. Revealing the limitations in the societal response to the risks of sour gas; and
5. Integrating a personal understanding of the risk of drilling sour gas wells to help formulate alternative risk management techniques that address the uncertainties of sour gas.

1.5 Methods

This thesis has been developed from a number of sources of data:

1. An examination of City of Calgary general plans and planning reports; Energy Resources Conservation Board decision reports, directives and information letters; public intervenor submissions to current well proposal; and an extensive survey of Calgary Herald newspapers,

2. A review of the literature in the field of risk;

3. Interviews, meetings and conversations with those individuals and groups actively involved in the sour gas well application; and,

4. Six years of personal work experience on sour gas drilling rigs in Alberta.

1.6 Definition of Sour Gas

Raw natural gas may be one of two varieties, either sweet or sour. By definition, a gas is termed sour if it contains a hydrogen sulphide ($H_2S$) content exceeding 0.05% by volume. Sweet gas, on the other hand is natural gas
without this amount of hydrogen sulphide. The principal hazard of exposure to \( \text{H}_2\text{S} \) is death by inhalation. The immediate effect of hydrogen sulphide is dependent upon the dose inspired, which is directly affected by both its concentration and volume. When concentrated, sour gas is an acute killer and odourless. In lesser concentrations, it is potentially hazardous and has an easily recognizable "rotten egg" or sour smell.

It should be noted that hydrogen sulphide may also be encountered in oil wells, but in this research, the focus is on the sour natural gas wells. For a more detailed review of the toxicity and properties of \( \text{H}_2\text{S} \), refer to Appendices 1 and 2.

1.7 **Purpose of Risk Management**

Decisions concerning the development and management of hazardous technologies raise several issues involving the evaluation of their impacts on society. To those residents exposed to the risk, the most immediate problem of sour gas wells near urban communities is the uncertainty of whether or not an accidental release of hydrogen sulphide will occur and if so, with what consequences. The difficulty to the decision-maker is the uncertainty whether or not and under what conditions should a potentially dangerous well be drilled in the first place.
While successful drilling, completion and production of the sour gas well would result in economic benefits, an uncontrolled release of H₂S at the well could result in severe health and safety costs. Neither benefits or costs are borne equitably by the parties involved. A risk management decision by Alberta's regulator of the oil and gas industry, the Energy Resources Conservation Board, on the proposal to drill a sour gas well next door to northeast Calgary could be aided by any of several analytic techniques, including cost-benefit analysis, social impact assessment and decision analysis. However, these techniques can provide only a limited amount of information, like what the monetary benefits of drilling the well are, what the social reaction of a well being drilled will be or what the key factors of a decision are. In this sense, risk management should not be viewed entirely as an end in itself but rather as an important decision tool in the consideration of Canadian Occidental's application.

In analyzing risk problems, the central need is to understand the uncertainties of the risk in question, and to evaluate, order and structure inevitably incomplete and conflicting knowledge so that the management acts can be chosen with the best possible understanding of the current knowledge, its limitations and its implications. Relying on quantitative predictions of the probability of risk to base decisions from entails a great deal of variability and
educated guesswork. Societal perceptions of risk on the other hand, are sometimes based more on emotion than a rational understanding of the problem. The ability to cope with the uncertainties of sour gas in this type of situation depends on the flexibility of both individuals, industry, and the regulators to understand the differing and varying perceptions of the influences created by sour gas; each party must be able to see the other parties' point of view.

In this study, personal work experience on sour gas wells provides an additional dimension to the risk management process, not ordinarily included in risk studies, thereby enhancing the understanding of the problem. The fundamental issue is not necessarily how to calculate, control or even reduce risk, but to understand the risk problem and manage it (Clark, 1979). The challenge of effective risk management in examining Canadian Occidental's sour gas well proposal is to act rationally in the face of uncertainty and complex, emotional concerns, where over-reaction and too much regulation can be costly, but where the cost associated with the occurrence of a sour gas well blowout could be disastrous.

1.8 Thesis Organization

Following this chapter's introduction of the content and intent of the thesis, chapter two discusses the simultaneous urban growth of Calgary with sour gas resource
development outside its northeast boundaries, resulting in an inevitable present day land use conflict.

Chapter three introduces the uncertainties and the risks associated with sour gas development including the technical aspects of drilling a sour natural gas well, the critical importance of the human factor, and the toxicity of \( \text{H}_2\text{S} \), and relates the problems to the current application by Canadian Occidental.

Chapter four explains current concepts of an objective analysis of risk and how risk has been studied in this manner in the past, elsewhere in the world and in the sour gas industry in Alberta. The difficulties and uncertainties of placing numerical measures on risk will also be discussed.

Chapter five examines how sour gas is perceived by the public. The limitations of a reliance on a social appraisal of risk will be outlined and management options identified.

The conclusions of the thesis incorporate an analysis of the findings of the risk management study with a practical insight to sour gas wells, as a basis to make recommendations from.
CHAPTER 2

NORTHEAST CALGARY'S LAND USE CONFLICT WITH SOUR GAS

2.1 Introduction

The oil and gas industry has had a tremendous impact on the growth and development of the Province of Alberta. Today the petroleum sector continues to be the backbone of the provincial economy. As a result of the oil and gas industry boom during the 1970s, rapid expansion of urban areas in Alberta has led to competing uses of land; residential, manufacturing, and commercial development have radiated out from, while oil and gas developments have expanded toward urban centres. The competition has been most severe near northeast Calgary (refer to Map 1) and, to a lesser extent in Edmonton, where urban expansion and development of toxic sour gas reserves are in conflict.

The Energy Resources Conservation Board (ERCB), as regulator of the oil and gas industry, has attempted to establish appropriate developmental guidelines of safe setback distances between sour gas facilities and urban development, in order to resolve existing and potential land-use conflicts, and to avoid unacceptable risks to the public. The regulations that are in effect today to manage the sour gas drilling industry are more attuned to the
potential danger of hydrogen sulphide natural gas to human safety than the regulations that accompanied northeast Calgary's rapid residential development from the mid 1970s to early 1980s, but are not extensive enough and are, in fact, in place ten years too late.

In 1974, a joint provincial government - oil and gas industry committee recommended stringent guidelines to control urban expansion toward sour gas reserves (A Report By The Alberta Industry-Government Sour Gas Environmental Committee on Guidelines For Urban Development in Relation to the Sour Gas Industry, October, 1974). Disregarding this report and the long term consequences of the close proximity of sour gas reserves to the northeast portion of the city, Calgary city council continued to endorse annexations of rural land to the city from 1976 to 1983 and to encourage residential subdivision therein (refer to Map 2). Consequently, a situation has surfaced where public concern for the risks of drilling potentially dangerous hydrogen sulphide gas outside northeast Calgary has stalled both urban expansion and sour gas development.

The chapter will commence with the economic importance of sour gas, thereby providing the industry's rationale for the current proposal to drill two sour gas wells within two kilometres of northeast Calgary. In the remainder of the chapter, by examining the manner in which Calgary and the
sour gas industry grew and expanded and how this ultimately led to a land use conflict, a lack of an effective method of reviewing surface and subsurface land issues will be made apparent.

2.2 Economic Significance of Sour Gas

Approximately 70 percent of Alberta is underlain by producible oil and gas reserves (ERCB Annual Review, 1983, p. 18). Of this total, approximately 23 percent of reserves contain hydrogen sulphide, ranging in concentration from only a trace up to 90 percent, with most sour gas wells having an \( \text{H}_2\text{S} \) concentration less than 30% (ERCB, Annual Review, 1983). Three-quarters of all sour gas reserves however, are located within ten miles of a village, town, or city (Alberta Government - Industry Committee on Guidelines for Urban Development in Relation to the Sour Gas Industry, October, 1974). With so much sour gas located near populated areas and a growing public concern in Alberta of drilling for potentially toxic hydrocarbons near urban areas, Canadian Occidental's application represents the standard from which future sour gas wells may be evaluated. Denial of CanOxy's proposal may ultimately cause a ripple effect throughout the province, thereby disrupting the vital economic role of the sour gas industry in Alberta. The importance of the sour gas industry's economic influence will be presented below.
Alberta has been a major beneficiary of economic activity from oil and gas development since the early decades of the century. A summary of its influence since the late 1940s was recently referred to in an article in the Canadian Petroleum Association Review (C.P.A. Review, August, 1984, p. 1-10). Since 1947, the industry's exploration and capital expenditures have totalled over $46 billion. Including operating expenses and royalties, the oil and gas sector has spent approximately $105 billion in Alberta. From 1973 to 1983, the number of oil and gas wells in the province increased from 27,000 to an amazing total of 65,000 (ERCB Annual Review, 1983, p. 14). In 1983, gross revenue from synthetic and conventional oil totalled $14 billion, while the marketable gas gross revenue was over $6 billion (ERCB Annual Review, 1983, p. 29-30). Provincial royalties from gas production for 1985 were forecast to be nearly $2 billion, nearly as much as personal and corporate income taxes combined, and not far behind oil's $2.7 billion contribution (Calgary Herald, November 2, 1985, p. A14). During the first seven months of 1985, oil and gas companies in Alberta spent nearly one half a billion dollars acquiring petroleum leases alone (The Financial Post, August 31, 1985, p. 21).

While it is obvious the oil and gas industry generates enormous revenues to the provincial economy, the industry
was only beginning to rebound from the drastic effects of the National Energy Program (NEP), devised in the autumn of 1980, when the recent decrease in the price of oil braced the industry for a second slowdown (Toronto Globe and Mail, February 18, 1986, p. B17). The Petroleum Incentive Program of the NEP gave rich grants to oil companies to search for oil and gas in the frontier regions of Canada (i.e., the Beaufort & East Coast of Canada). As a result, drilling activity was diverted from Alberta in late 1980, and the provincial oil and gas industry began a four year nosedive. During the oil and gas slump, drilling equipment use was far below its boom year levels. With recent changes in federal energy policies, markets rather than government regulation, became the dominant factor in industry performance (Calgary Herald, November 2, 1985, P. A4). In 1985, approximately 11,500 wells, or 20 percent more than in boom-time 1980 were drilled as a result of the Federal policy, the Western Accord, relaxing price controls, federal taxes and provincial royalties (Calgary Herald, February 22, 1986, p. A1,2). During the first five weeks of 1986, drilling continued its hectic pace with 441 rigs employed 85 percent of the time (Canadian Association of Oilwell Drilling Contractors, Rig Activity Map, Feb 15, 1985). The increase in drilling activity reflects the philosophy of the oil companies in that the quicker hydrocarbons can be found and
produced, the sooner they received a return on their exploration and development investment.

Yet drilling activity can fall as fast as it rises. With little more than a year of solid recovery under its belt from the last recession, the industry has little fat to help it through another slump as a result in the drop in the price of oil. Oil companies have been spooked by the suddenness of the recent drop and, with no sign that the soft oil market is ending, will set their current drilling budgets conservatively (Toronto Globe and Mail, February 18, 1986, p. B17).

The oil and gas industry energy critic of the Calgary Herald newspaper states that Alberta gas supplies 80 percent of Canada's natural gas needs and 25 percent of Canada's total energy needs (Calgary Herald, October 23, 1985, p. D1). In addition, the National Energy Board requires that a 25 year supply of natural gas is reserved for future use. To meet these requirements, Alberta has approximately 5,500 natural gas pools on production. According to Hans Maciej, technical director of the Canadian Petroleum Association, within 20 years, gas is forecast to be, with oil, the primary energy source in Canada, with the two fuels evenly splitting about two thirds of the market (Calgary Herald, November 2, 1985, p. A14). Although only 23 percent of Alberta's remaining established gas reserves contain
hydrogen sulphide (are sour), approximately 53 percent of the gas marketed in 1983 was derived from raw sour gas (ERCB Annual Review, 1983, p. 10). The growing influence of sour gas in the natural gas industry emphasizes the important role it plays in the Alberta energy situation. Figure 1 provides a graphic view of the comparison of sour gas reserves and production with sweet gas reserves.

By the end of 1983, 167 plants had been approved to process sour gas in Alberta, representing 65 percent of the total provincial raw gas processing capacity (ERCB Annual Review, 1983). Most of the gas was processed at large plants, but the trend in recent years has been toward greater use of small plants as a result of improving gas prices which have made it economic to develop small, more remote gas reserves.

Some oil patchers in Alberta claim that growing interest in sour gas is motivated more by the search for the processed by-product of hydrogen sulphide gas, sulphur, than for natural gas (Calgary Herald, July 23, 1985, p. C4). With an annual average production of 5 million tonnes of sulphur and a current historical high price of $150 per tonne, the assessment may be correct (Calgary Herald, September 24, 1985, p. E4). The total monetary influence of the sour gas industry to Alberta in 1983, comprised of both processed natural gas and the sale of sulphur, was $3.6

Sulphur is a very valuable commodity in international markets, especially in Third World nations, for its use in the manufacture of agricultural fertilizers. Sulphur also has a variety of uses in other industries such as non-ferrous metal production, petroleum refining, iron and steel production, rubber, paints, chemicals and pulp and paper (Terry, 1984).

Alberta controls 45 percent of the world's supply of sulphur with an inventory stockpile of 13 million tonnes (Terry, 1984). Brian Prentice, president of Agrichemicals Economic Research Inc., a Vancouver-based consulting company, says essentially all other inventories in the world have been used up and Canada is being depended upon to meet demand (The Financial Post, May 11, 1985, p. 50). Since 1979 Alberta's sulphur inventories have been depleted rapidly and the province is experiencing difficulty keeping up with the frantic world demand. The problems will persist if, as expected, Alberta sulphur sales hit 9.3 million metric tons in 1985 (Terry, 1984). New production will account for about five million metric tons, but the remainder will have to come out of the province's rapidly shrinking stockpiles.

Canterra Energy Ltd., one of Canada's largest oil, gas, and sulphur producers predicted that at the present rate of
activity in Alberta, the sulphur supply will be exhausted by 1988 (Canterra Energy Ltd., Annual Review, 1984). Unless new reserves are found by drilling additional sour gas wells in the province, Alberta's enviable share of the international sulphur market will drop dramatically by the end of this decade.

The sour gas industry in the Calgary region is an extensive economic force. Based upon proven and potential reserves, sour gas from the Calgary area is predicted to provide 10 percent to 15 percent of all gas and 30 percent of the total future provincial sulphur production (Calgary Regional Planning Commissn, Sour Gas Study - Final Report, June, 1984). Production in the Calgary area is expected to peak in the 1990s and decline thereafter. Currently there are nine major sour gas operators producing reserves in the Calgary region (Sour Gas Study - Final Report, 1984, p. 33).

Canadian Occidental Petroleum Ltd. (CanOxy) has been the operator of the Crossfield sour gas field, adjacent to northeast Calgary, since initial exploration and development commenced in the area in 1961 (Crossfield Wabamum A Pool Development Plan, April, 1984, p. 8). Petrogas Processing Ltd., owned 33.1 percent by CanOxy, operates a sour gas processing plant for the gas field approximately three miles northeast of Calgary (Canadian Occidental Petroleum Ltd. 1984 Annual Report, p. 8). The companies have approximately
90 miles of pipeline servicing 60 sour gas wells in the Crossfield field (refer to Map 3). As in other parts of the province, early drilling activity in the Crossfield field did not fully determine the extent of sour gas reserves but recent wells have indicated that substantial reserves of sour gas remain in this area. CanOxy, in the business of obtaining and producing oil and gas reserves, therefore wishes to expand its operations (Crossfield Wabamum A Pool Development Plan, 1984, p. 8).

In a personal conversation with me (April, 1985), J. Angus McKee, President of Canadian Occidental Petroleum Ltd., estimated the worth of the initial well to be in the vicinity of $50 million. Objectively this amount of money may appear miniscule in relation to the risks that residents of northeast Calgary may be exposed to, and the damage that could result if an accidental release of poisonous sour gas did occur. However, as noted earlier in this section, the proposed well in many ways represents the precedent from which future sour gas wells near urban areas will likely be planned and evaluated from. In this sense, disapproving CanOxy's well means much more to the sour gas industry in Alberta than the $50 million the oil company hopes to accrue from the well.

While the economic importance of sour gas may be one criteria in evaluating the well proposal, the more holistic
role the petroleum industry assumes in the Alberta way of
life should also be considered. According to studies by the
Canadian Energy Research Institute, an agency supported by
the federal, Alberta, Ontario and Saskatchewan governments,
the University of Calgary and the industry, almost every
individual in Alberta is potentially affected by the oil and
The Institute estimates that each well drilled in the
province contributes to jobs and incomes of 210 people,
ranging from roughnecks and truck drivers to consultants and
technical service contractors. The figure does not include
induced or indirect employment, such as keeping staff busy
at energy company head offices, or the benefits accrued from
oilfield workers having money to spend on clothes,
restaurants and cars.

When the oil and gas industry moves in Alberta, the
entire province flourishes. The sour gas industry is a
major part of this influence. The influence does not,
however, imply that economic benefits alone should take
precedent over a risk that could be detrimental to Calgary's
best interests. Instead, consideration of the economic
significance of sour gas is but one facet of the risk
problem that must be understood so that a balanced
representation of varying views of sour gas is possible.
2.3 **Calgary Past**

In the past 100 years the City of Calgary, Alberta, has expanded from an isolated police post into a burgeoning urban area with a population of over one half million (Census of Canada, 1981) (refer to Table 1). The rapid growth of Calgary has been closely associated with the development of a single industry, the petroleum based economy. To gain perspective on Calgary's remarkable expansion that accelerated with the major oil discovery at Leduc, Alberta in 1947, some aspects of Calgary's earlier development must be considered.

The critical turning point in Calgary's early development was the decision by the Canadian Pacific Railway Company in 1883 to take a southerly route across the prairies and to follow the Bow River valley into the Rockies (Foran, 1970). This decision placed the small police post and minor local trade centre of Calgary on the main line of east-west commerce. The first important consequence of the railway's plans was the rapid establishment of the cattle industry. Within a few years of the coming of the railway, Calgary had replaced Fort MacLeod, Alberta (90 miles southeast of Calgary) as the financial, administrative and social centre of the ranch country. By the late 1880's ranchers in the Calgary area were doing sufficiently well to become the most important local source of investment capital
for urban services (waterworks, electric light, telephone and street railway companies) (Foran, 1970).

While the social and economic blending of the town and country elites lent a special character to Calgary, it also allowed the city to interpret its position in the prairie west quite differently from other prairie centres (Rutherford, 1971). Calgary's location astride a key transportation route assured the growth of its beef manufacturing industry so much so that by 1911, accounted for nearly 25 percent of all manufacturing in the province (Census of Canada, 1931, Vol. VIII, p. 667). The city also assumed the role of the agricultural service centre for the thousands of farmers settling the southwest portion of the prairies. The agricultural based economy became so significant that it continued to dominate Calgary and the province until the 1940s. Confident in the future of their region, Calgarians commenced to exhibit expansive metropolitan ambitions. Growth during the first decade of the 20th century was so substantial that enthused city administrators in 1913, engaged a well known English town planner, Thomas Mawson, to draw up a city plan for one million people (Morrow, 1979, p. 2).

Until the turn of the century, city limits roughly corresponded with what now constitutes the downtown core (refer to Map 2). A 1907 annexation brought in territory
now accommodating such inner-city communities as Sunnyside, Hillhurst, Sunalta, and Mount Royal. In 1910 the geographical size of the city was doubled in another annexation. By 1913 however, escalating land values plummeted. Speculators lost money and the planned suburban developments distant from the downtown river valley were not to be realized until the mid 1950's when a rejuvenation of the oil and gas industry stimulated growth in Calgary again.

2.3.1 Early Evolution of Planning in Alberta

Alberta has one of the longest traditions of planning in Canada. The first enactment of planning legislation occurred in the early 1900s during the period of rapid settlement that followed the expansion of the railroad. Planning at this time in North America was viewed as a required feature of any progressive and growing city (Hulchanski, 1981, p. 17). Since planning would help to make a city like Calgary a much more efficient place in which to do business, the business establishment in Calgary was able to convince city council to establish a Planning Commission in 1911 to prepare a general plan for future development of the city (Hulchanski, 1981, p. 18). The Planning Commission was primarily concerned with matters relating to physical development of the city and to the coordination of municipal services capable of supporting
further growth and development. The objective was to become more efficient and effective at providing these services, and to help Calgary to keep up with and perhaps even outpace other Western Canadian cities, many of which were also becoming involved in planning.

With the amount of planning activity that was being generated in Calgary, and to a lesser extent in Edmonton, the Town Planning Act was adopted in Alberta in 1913 (Murchie, 1978, p. 1). However, Smith's (1979) study of the 1913 Act, notes that it was rushed through all legislative readings on the last day of the session, circumstances suggesting a low level of commitment to the planning legislation. The impression is further supported by the lack of originality in the Alberta Act in comparison to the British Town Planning Act of 1909 and the 1912 New Brunswick Act.

Smith also argues that although the planning movement in Alberta as in the rest of the country, enjoyed fairly extensive support during subsequent boom years, the support even at its peak, was very shallow. As long as conditions were such that greater coordination of urban development was seen to be necessary for the sake of the efficient functioning of the city as a place to do business, there was support for the concept of planning and planning legislation grew. Such a tendency to allow market conditions to
determine the form and extent of planning became the established manner in which planning was practised in Alberta. Land use planning as a rational process of identifying a city's goals and developing means of control over the use to which land is put, was not widely practised.

Although the business interests which initiated planning had very limited objectives, the early professional planners who frequented Alberta, such as Thomas Adams and Thomas Mawson, fully believed in the potential which planning offered to many societal problems. At the root of their beliefs was a strong element of environmental determinism: by simply applying some forethought to the development of cities, many problems could be avoided (Adams, 1917, p. 178). This required the use of state authority to limit, not the free functioning of the land market but only the excess of those who would take advantage of a situation to the detriment of the general public interest, such as land speculators and developers. In Alberta however, municipal councils and municipal planning commissions were almost always composed of pro-growth elements either directly from or representing the local business elite of the community, and it was they who decided the timing and content of any land use planning activity. The early history of planning in Alberta, therefore, implanted a continual gap between planning theory and planning practice.
2.3.2 Origins and Influence of the Oil and Gas Industry in the Calgary Area

Almost concurrent with early urban growth in Calgary was the commencement of the oil and gas industry. At Turner Valley, 30 miles southwest of Calgary, on May 14, 1914, the oil discovery known as "Dingham Number One," marked the birth of western Canada's petroleum industry (Hanson, 1958, p. 72). Over the following decade several hundred exploratory wells were drilled, some of which encountered sour gas reserves. In 1924, the first commercial scale gas processing plant in Alberta was built in Turner Valley, and from there supplied Calgarians with natural gas recovered from sour gas (Environment Views, December, 1984, p. 6).

Although the Turner Valley field became Canada's largest oil producer for more than thirty years until the Leduc discovery, approximately 25 kilometres south of Edmonton in 1947 (C.P.A. Review, August, 1984, p. 2), the oil field did not prove to be the immediate bonanza that Calgary had anticipated. The discoveries made by the oil and gas industry however, added an important new dimension to Calgary's economic base that began to differentiate the city from other western urban areas and communities elsewhere in Canada.

In 1938, in ultimate recognition of the importance of the hydrocarbon activity, the provincial government assumed
a more direct regulatory role in the industry by establishing in Calgary the Petroleum and Natural Gas Conservation Board, the grandfather of the present regulatory agency, the Energy Resources Conservation Board (ERCB) (C.P.A. Review, August 1984). Calgary's early involvement in and intimate contact with the oil and gas sector gave it an initial advantage over other cities. By the time significant oil discoveries were made elsewhere in the province after World War II, Calgary was already firmly entrenched as the administrative, regulatory, and financial centre of Canada's petroleum industry. The consequences of the long direct connection with the developing petroleum industry were of both socio-political and economic significance.

The Leduc oil discovery in 1947 sparked such an interest in the Albertan petroleum industry that it altered the entire structure of the provincial post-war economy. Follow up drilling in the Leduc field resulted in 131 producing oil wells from 147 wells drilled, important discoveries were made elsewhere in the province, and Alberta became an oil surplus region (Hansen, 1958, p. 72). Alberta changed from a predominantly agrarian based economy to an urban society stimulated by the oil and gas industry, and commenced a period of sustained growth that lasted for nearly 35 years. The oil and gas sector as the engine of
growth, attracted a continual influx of new residents to Calgary from 1947-1981 (Table 1). By 1951, Calgary's population had increased 45 percent over the previous decade to 129,000. Ten years later in 1961, one quarter of a million people were residing in Calgary and in 1981, the city's population was over 590,000.

The degree to which Calgary's phenomenal growth is tied to the petroleum industry is suggested by the presence in 1965 of the head offices of 886 oil and oil-related companies, in addition to branch offices of a further 336 (Smith, 1971, p. 4). In 1971, 74 percent of Canada's oil and gas exploration, development and producing companies had their head offices in Calgary, along with 84 percent of the nation's geophysical contracting companies, 87 percent of the data processing firms related to the oil and gas industry, 68 percent of petroleum related consulting companies, and 65 percent of the firms engaged in contract oil well drilling (Baine, 1973, p. 58). The benefit of being Canada's petroleum capital still accrues to Calgary for even though, apart from the tar sands in northern Alberta, the primary interests of western based oil companies, in the past five years, have expanded beyond Alberta to the "frontier" regions of the country.

The 1971 Census of Canada revealed that Calgary had one of the smallest manufacturing sectors of any major Canadian
city. Instead of workers in Calgary being dominated by assembly-line occupations, over 10,000 Calgarians were directly employed in the oil and gas industry (and thousands more indirectly) as compared to 2,050 in Edmonton and only 60 in Winnipeg (Census of Canada, 1971, Volume 3, Part IV). The ratio of managerial to unskilled labour in Calgary was approximately 3:1. Since there were so few factories in Calgary, it became very much a "brief-case" rather than "lunch-box" city. With the influence of the oil and gas industry on employment in Calgary, incomes rose relatively high (Census of Canada, 1981), and newcomers to the city sought to purchase single, detached homes. In order to satisfy the housing needs of the newcomers to Calgary, city council deemed it necessary to annex enormous parcels of rural land to the city for development.

2.4 Establishment of the Sour Gas Industry

After Leduc, extreme interest in locating additional oil fields in Alberta, and to some extent in northeastern British Columbia, led to increased exploration and drilling activity. As a result, more and more sour gas reserves were found to the extent where discovery, production, transportation, and processing of sour gas turned into an industry itself.

Sour gas processing accelerated after 1951 when Shell's
Jumping Pound plant, approximately 50 kilometres west of Calgary, became the first sour gas plant in Alberta to extract sulphur from the raw hydrogen sulphide gas. Previous gas plants had simply burned off the sour component to the atmosphere. The highest concentration of sour gas pools were found to lie west of the 5th meridian in an 80 kilometre wide stretch of foothills, running the length of the province just east of the Rocky Mountains (Map 4). By 1974, there were over 100 sour oil and gas fields in Alberta (Alberta Industry - Government Committee on Guidelines for Urban Development in Relation to the Sour Gas Industry, October, 1974; hereafter referred to as AIGSGI).

In the early 1970s, gas was deemed to be underpriced in relation to the value placed on crude oil, resulting in legislation changing the price of natural gas in subsequent years from 16 cents per thousand cubic metres to over 3 dollars today (Calgary Herald, November 2, 1985, p. A14). Production costs increased half as much, leaving potential for profits that triggered an outburst of gas drilling and provided much of the fuel for Alberta's 1970s energy boom. By 1976, there were over 3,700 producing sour gas wells in Alberta (ERCB Decision D76-15). The gas industry continued to expand so much that today there are approximately 600 gas producing companies in Alberta (Calgary Herald, November 2, 1985, p. A14).
The gas industry has had special problems with sour natural gas, as the technology of exploration, development and processing had to be almost entirely developed in Alberta, there being nowhere else in the world where such large quantities of sour gas were being used. Today, drilling sour gas wells has become a relatively routine operation in Alberta because of the experience and technological advances accumulated since the early decades of the century but the process remains a hazardous one due to the toxic characteristics of the sour gas and the complex interactions among mechanical drilling components, geostatic formation pressures and the potential for human error.

A turning point for the sour gas industry occurred in 1973 when a sour oil blowout near New Norway, Alberta, (southeast of Edmonton), forced the evacuation of the town's residents (AIGSGI, October, 1974). Although no residents were seriously injured, the incident instigated a concern over the lack of policies and regulations to adequately control the encroachment of population centres on to sour gas operations. The public in Alberta was becoming increasingly aware and sensitized to the potential health and safety impacts of the sour gas industry when industrial accidents like New Norway resulted in the uncontrolled release of toxic hydrogen sulphide.

Sour gas wells continued to be drilled however, and
sour gas plants continued to be built. When a particular sour gas well created a public controversy near a populated area, the well either had more strict drilling regulations placed upon it or a shorter producing period assigned by the ERCB. On only two occasions was a sour gas proposal completely denied by the ERCB; one involving a well near a Boy Scout Camp and the other, a pipeline through an environmentally sensitive area (personal review of ERCB Decision reports).

While New Norway informed some residents in Alberta about sour gas, an uncontrolled release of sour gas near Lodgepole, in the west-central part of the province, in the autumn of 1982, incensed the public of Alberta about the practicality of drilling such potentially dangerous wells near an urban area (Lodgepole Blowout Inquiry, Phase 1 Report, Energy Resources Conservation Board, December, 1984, p. 1-1). In spite of numerous measures to regain control, the sour gas blowout persisted for 67 days before the well was finally "capped" on December 23, 1982. Like New Norway, there were no public fatalities at Lodgepole, but two well control specialists from Texas died after being exposed to the lethal gas. The blowout has had a overwhelming impact on the public's perception of sour gas and the manner in which wells are presently drilled in Alberta.

Adding fuel to fire, a sour gas blowout at a producing
well near the town of Claresholm, approximately 150 kilometres south of Calgary in September, 1984, further tarnished the image of sour gas. Thus the safety of CanOxy's current proposal has become a major issue in light of recent accidents in the sour gas industry.

2.5 Rapid Urban Growth

1950 – 1974

Urban growth in Calgary assumed its accelerated pace in the 1950s. This led to the hiring of the first permanent planner in the city in 1951 (Calgary Herald, February 3, 1983, p. A8). In 1950, a series of amendments were made to the Town Planning Act (Murchie, 1978, p. 2). Provision was made for the formation of District Planning Commissions to oversee the process of urbanization and regional growth in an area like Calgary. These bodies were given the mandate to prepare a district plan governing land use for the entire area, but lacked political power and today remain in an advisory and intermediary role between the urban municipalities and the provincial government.

In 1956, the problems of rapid municipal growth in Alberta were seen as so extreme that a Royal Commission on the Metropolitan Development of Calgary and Edmonton was formed. One of the most serious consequences of the post-war population increases was the tremendous increase in
both Calgary and Edmonton's debt as the cities were obliged to provide expenditures on utilities, schools and other services. Increased municipal debt meant large amounts of provincial aid. Another problem addressed by the Commission was rapid population increases occurring in the fringe communities outside the cities. (Report of the Royal Commission on the Metropolitan Development of Calgary and Edmonton, Edmonton, Alberta, 1956, p. 1-5).

The Royal Commission subsequently made over 80 recommendations to deal with Alberta's growth problems. One major recommendation was that all urban development which forms one social and economic unit should come under one jurisdiction. Using annexation of rural land as a planning tool, the recommendation known as the "uni-city concept" (Calgary Herald, February 3, 1983, p. A8), sought to prevent the development of future satellite or fringe communities outside an urban area like Calgary, thereby reducing the number of local governments and the confusion that can result thereof. The basis for the concept was gleaned from experience in urban expansion in cities like Toronto. In 1911, Toronto had frozen its municipal boundaries, forcing additional residents into newly developed communities just outside its perimeter. The satellite communities became so numerous and large that the Ontario government was eventually forced to devise a metropolitan government to
sort out overlapping jurisdictions and services (editorials in East York and Leaside Advertiser, November 16, 1967).

Seeking to avoid the multiplication of local governments and their strain on the provincial coffer, annexations of rural land in Calgary in 1956 and 1961, provided enough urban space for subdivision development to satisfy the housing needs of the new residents of Calgary until the mid 1970s. Growth in the annexed portions of the city, referred to as outer suburbs, between 1964 and 1973 accommodated approximately 120,000 people (refer to Table 2 and Appendix 3). In the same period, growth in the remainder of the city experienced only a 2,800 population increase.

The substantial addition of land to the northeast portion of Calgary in the 1961 annexation, established the majority of the existing land found in this sector of the city today. The annexation occurred when sour gas reserves were beginning to be developed in the area adjacent to northeast Calgary (Crossfield Wabamum A Pool Development Plan, Canadian Occidental Petroleum Ltd., April, 1984, p. 8). As sour gas development in the area continued, the annexed land was simultaneously developed for residential subdivisions.

Formation of Land Use Conflict

The land use conflict between sour gas development and
urban development in northeast Calgary did not become immediately apparent, but evolved over time. However because there was no communication or coordination between the two types of development, a conflict was inevitable. For example, in the mid-1970s when an oil company planned a sour gas well outside northeast Calgary, consideration of possible future residential development within the adjacent part of the city was not required, nor was consultation with the municipality about the well proposal. Similarly, the route of gas pipelines in the province were chosen, not with public safety as the determining criteria but, for reasons of economics and ease of administration reasons. (Canadian Institute of Planners Forum, No. 6, November, 1984, p. 8).

Perhaps a more influential factor in the eventual controversy between urban and resource development was the manner in which Calgary grew and expanded. Calgary's seemingly insatiable hunger for spatial enlargement of its municipal boundaries in the northeast portion of the city, brought urban land closer and closer to the sour gas operations. The appetite was not satisfied with the massive 1961 annexation. Six subsequent annexations, although not as geographically as large, were added to the northeast part of the city between 1976 and 1983 (refer to Map 2). Each annexation, and residential development therein, increased
the risk to subdivision residents of a lethal exposure of hydrogen sulphide as a result of an accident at any of the numerous sour gas facilities operating in the area.

The Planning Act (1977) and its Subdivision Regulations are the main legislative tools for dealing with the use of land and its development in Alberta (A Study of Land Use and Sour Gas, Okotoks-High River, Alberta, February, 1983. p. 19). The Planning Act enables the preparation of Regional and General Plans, Land Use Bylaws, Area Structure Plans, etc., all of which influence the form and extent of urbanization. In terms of the oil and gas industry however, the Planning Act exempts wells, batteries and pipelines from the subdivision approval process and the development permit process (Alberta Planning Act, 1977, Application and Administration, paragraph 3 (b), (c)).

Energy and resource development fall under the jurisdiction of the Department of Energy and Natural Resources, with regulatory powers being vested in the Energy Resources Conservation Board. The ERCB works in close co-operation with Alberta Environment in terms of performance and safety standards. Pursuant to the Subdivision Regulations of the Planning Act, the ERCB makes recommendations to the appropriate Subdivision Approving Authority (i.e., City of Calgary) respecting any proposed urban developments near sour gas facilities. The City is
not however bound to follow ERCB recommendations. The ERCB, according to a directive revised in 1981, establishes safe setback distances between sour gas facilities and urban development in particular categories, according to the potential release rate, volume, and $H_2S$ content in the gas emitted from a facility, and the proximity or urban residents to the well or pipeline (Appendix 4).

The lack of an effective policy, or coordination by one government agency, to direct the growth patterns of the land development industry and the sour gas industry permitted the serious land use conflict to occur. Even though oil companies, like Canadian Occidental, consistently opposed urban developments and annexation proposals in and around Calgary (Calgary Herald, January 12, 1985, p. A10), the sour gas reserves were increasingly encroached upon. The following account will describe how Calgary planning authorities neglected the sour gas issue.

Planning Policies

Calgary City Council adopted its first general plan in 1963. The plan was essentially concerned with projecting the then current trends of Calgary's growth to 1980, and with sketching a scenario for the city at that date. In 1970, Council approved a second general plan, and it in turn was revised in 1973. The role of Calgary's general plan was
expressed in the 1973 report as:

The need for a general plan, or strategic plan, arises for a number of reasons. Amongst them is the fundamental belief that a community should seek to control its own fate, rather than simply allowing things to happen to it. This leads to the view that development, if it is to occur at all, should take place in a coordinated and rational fashion, and that it should respect the aims and aspirations of the community at large. (The Calgary Plan, 1973, p.2)

It soon became evident in the growth of Calgary that such assertions were not adhered to.

Because subdivision possibilities make land within an urban area considerably more valuable than land outside municipal boundaries, land development companies were frequently proposing annexations to the city. A land developer would purchase rural land and attempt to convince the City of Calgary how beneficial annexation of the land would be to the municipality. If persuaded, city council would, in turn, apply to the Local Authorities Board (LAB) for annexation approval. LAB was created in 1956 in response to the uni-city concept. Approval at a LAB hearing would usually result in a rubber-stamping by the provincial government. Once annexation was approved, development control and regulation would revert back to municipal authorities (Planning in Alberta, 1978, p. 3-7).

Part of the problem that was created from annexing land
and building new residential subdivisions was the belief that the correct economic conditions would continue to permit Calgary's unprecedented growth. The manner in which decisions were made on the use of land rested primarily with the land developers themselves who were the initiators of the annexation proposals. It reached a point where practically whatever was proposed by land development companies would be approved by Calgary city council.

By 1976, though remaining advocates of the uni-city concept, the provincial government wished to diversify Alberta's increasing population base away from the major recipients of the new residents, Calgary and Edmonton, to smaller urban centres like Red Deer and Lethbridge. To accomplish this objective, the provincial government established an eight-kilometre wide Restricted Development Area around Calgary (Calgary Herald, July 21, 1984, p. A14). Landowners in the restricted area had to obtain direct approval of the provincial government for any proposed developments. Implicitly, establishment of the restricted area indicated the provincial government had lost confidence in the regional plan and the ability of local governments to cooperate in planning for land use areas in the region. Future annexations were scrutinized much closer by the provincial government, but they continued to occur.

Absent in any of the planning documents up to and
including the 1973 *Calgary Plan* was any explicit mention of sour gas, even though exploitation of sour gas reserves north and east of the city had been occurring since 1961. As urban development proceeded in northeast Calgary communities (Map 5), an assumption prevailed that since natural gas is a non-renewable resource, it would have a relatively short depletion span (i.e., 15 to 30 years). Consequently, it was assumed that when urban growth reached the area of sour gas activity, the petroleum operators would be at a stage of winding down operations. This attitude is reflected in the *Calgary Regional Growth Study* (Calgary Regional Planning Commission, 1977, Chapter 1, p. 5).

Municipal planners and officials were in effect permitting the ERCB and the sour gas industry to control the development of sour gas reserves, without insisting on municipal input. In other words, there was no communication between those separately responsible for urban development and resource development. Eventually the lack of communication between the two entities and the lack of one policy to deal with both types of development, caused the serious land use conflict to materialize.

It wasn't until the 1977 *Calgary Plan* that any explicit mention was made of the sour gas reserves lying outside, and in one particular subdivision in the northeast portion of the city, within municipal boundaries. In contrast to the
attitude taken by the 1974 AIGSGI Report of urban development encroaching upon sour gas facilities, the Calgary Plan saw the hydrogen sulphide natural gas wells as responsible for hindering urban expansion. The policy recommendation stated, "encourage the early relocation of sour gas extraction facilities in and near the city" (The Calgary Plan, 1977, Part 3, Chapter 5). The manner in which this was to be accomplished was suggested thus:

The best way to eliminate the problem of a potential leak from a sour gas well is to move the well to a more suitable location, or, rather to cap the well and drill another elsewhere. (Calgary Plan, 1977, 3.5.11)

However, such a policy was not always economically sensible and not always possible from an engineering point of view. The sour gas problem was not really being addressed by city authorities but rather an attempt was being made to work around the issue and still allow urban development to occur.

Growth Explosion

As in other city quadrants, urban expansion in northeast Calgary moved progressively outwards from the earlier established areas and communities. This expansion was particularly intense from 1974 onwards. The Census of Canada (1981) reveals a 100 percent population change for most of northeast Calgary from 1976 to 1981. Acceleration
was encouraged by the incidence of major oil and gas related projects within the province and by the potential of northern resources. In addition, high levels of unemployment in the Maritime provinces together with the uncertainties of politically imposed problems in Quebec, precipitated a population explosion in which the influx of people into Calgary exceeded some 3,000 per month at its peak (Calgary Herald, January 12, 1978, p. B2). Significant land acquisitions at low rural prices by land developers facilitated the establishment of new residential communities in the northeast part of the city at a pace reflected by a city-core expansion of astounding magnitude.

Of the 160,347 housing units existing in Calgary in May, 1975, 56 percent were single family dwellings (Housing in Calgary, 1976, p. 2). Of the 5,650 housing units built in 1975, 78 percent were single family homes. Construction activity was obviously concentrating on the single detached home which required much more land than a higher density form of housing like appartments. The building boom precipitated a rapid escalation in land costs, housing prices, and in commercial rental rates. By 1978 Calgary had become the first municipal jurisdiction in Canada to exceed the $1 billion total in issuing building permits (Toronto Globe and Mail, April 20, 1981, p. B28). In contrast, building permits for 1984 in Calgary totalled
only $380 million (Calgary Herald, August 10, 1985, p. B3).

In 1979 there were 12,000 housing units built in Calgary (Toronto Globe and Mail, April 20, 1981, p. B28).

The 1977 Calgary Plan reflected the attitude that was accompanying Calgary's accelerating growth:

Growth, rapid growth, has in recent years come to be seen as a basic characteristic and condition of Calgary. Indeed, it is something of a cliche to point out that Calgary is one of the fastest growing of Canada's large and medium-sized cities. Yet the facts are indisputable and impressive. The preliminary results of the 1976 Census of Canada indicate that over the past decade Calgary has experienced a higher rate of population increase (38.5 percent) than any other major urban centre but Kitchener (40.3 percent). This is true whether it is the cities proper or the total metropolitan areas. If population within the municipal boundary is the criterion, then Calgary is now the third largest city in the country. Only Montreal and Toronto are larger.

The Plan continues emphasizing future trends:

Population projections, based on past trends, further suggest that the city may well accommodate three-quarters of a million people by 1996. The benefits of such rapid growth have long been recognized, and appreciated, and they are the source of much civic pride. As the city becomes larger, it becomes more sophisticated and better endowed, and its people more cosmopolitan. Growth permits the crossing of thresholds, with the result that many facilities and services become viable that are denied to smaller urban centres. The faster the rate of growth, the sooner those thresholds are crossed. (Calgary Plan, 1977, Part 1, Chapter 1; underlined statements are my emphasis)
These comments reveal a perception that rapid urban growth brings otherwise unattainable benefits to Calgary.

In 1978, the City of Calgary estimated it only had a six year supply of residential land left within its municipal boundaries (Calgary Herald, January 11, 1978, p. B1). Therefore to accommodate the increasing number of new residents, the City of Calgary adopted a Balanced Growth Strategy in 1978 which in effect stated the city should strive to maintain a thirty year supply of land for future development purposes (Calgary Herald, January 12, 1978, p. B2). Population projections, based on past trends, had suggested that the city could accommodate 750,000 people by the 1990s (Calgary Plan, 1977). Given such confidence for the future, the City of Calgary maintained that annexation of rural land is "urgently required" so that the city can cope with a surging population and development pressures. Annexation would enable the city to meet its long term requirements for growth by providing land that can be developed for all densities of housing, as well as land for industrial, commercial, institutional and open space requirements. The City also felt if land was not made available for residential development, housing prices would sour as a result of a dwindling supply (Calgary Herald, January 11, 1978, p. B1).

In mid-1978, Calgary city council proposed to annex 48
square miles to the city. Provincial Municipal Affairs Minister Dick Johnson argued there was already enough land within the city to meet demands for housing lots without seriously affecting a possible price increase of existing stock. Mr. Johnson explained,

There are 30,000 acres of developable land within the present city limits and 18,000 of those are available for use within the near future, so a decision to annex 48 square miles adjacent to the city seems to indicate there is no rush to add new land to the city at this time. (Calgary Herald, June 4, 1978, p. A1)

Within a year however, approval was given to annex 25 of the 48 sq. miles. The Director of the Calgary Regional Planning Commission called the city land hungry by pointing out the residential and industrial growth in Calgary was consuming 2.75 square miles per year yet Calgary City Council was making requests for annexation nearly twenty times that amount (Calgary Herald, June 4, 1978, p. A1).

By 1980, with Calgary city council continuing to respond to land development companies' requests for annexations and development of subdivisions within the land already annexed, serious concerns were being expressed of the manner the city was evolving. The Director of the Calgary Planning Department compared Calgary and its rapid growth in the 1970s to a . . .
gangly teenager. About all you can tell is that it is growing rapidly and is full of vim and vigor. But so far it has no idea what it will be as an adult with a population of one million in twenty years. (Calgary Herald, January 2, 1980, p. B1)

A 1980 city finance department report stated Calgary is "on a binge of construction spending which must be curbed" (Calgary Herald, May 11, 1980, p. A1). Former Toronto mayor John Sewell continued the criticism of Calgary's management of urban development by stating,

Calgary should slow its growth to take a look where it is heading— to add up what is happening and figure out if you want to do anything different. Calgary has an unique opportunity to critically examine its growth rather than wait until it is all over like other cities. Rather than letting the market dictate the city's growth, Calgarians should decide how big they want their city and what is an acceptable rate of growth. (Calgary Herald, May 5, 1981)

Despite a seemingly endless questioning of Calgary's municipal policies, city fathers as in the real estate boom at the beginning of the century appeared to be content to allow the private sector to determine the city's growth.

As early as some three years prior to 1981 evidence was becoming increasingly apparent (e.g., oil embargo overseas and national policy to Canadianize the oil industry) regarding an economic down-turn that could seriously affect the city's continued growth— an expansion hitherto related
to the oil and gas industries in the exploitation of provincial and northern resources. Late 1980 and 1981 became the crisis years when planned projects of very major magnitude like Alsands (i.e., a major heavy oil project in northern Alberta to be financed by a consortium of Canadian oil companies) were cancelled due to the political controversy of the National Energy Program and declining energy markets. The demise of the process engineering and contracting industries accelerated and critically affected industrial, commercial and housing projects. The drilling industry's decline affected all of Alberta. With the attendant pressures of increased unemployment levels, high interest rates, increased city taxes, an alarming increase in bankruptcies and house foreclosures and, rapidly declining property values, a serious recession in Calgary had manifested itself.

While these effects became more pronounced in the period after 1981, it is difficult to comprehend why City policy would have ever entertained the further extension of municipal boundaries and a continued commitment to accommodate further new developments in an increasingly more difficult market. All economic yardsticks progressively emphasized urgent need for a policy of restraint and of consolidation in the city's best interests. However city officials maintained that the city had to increase both the
supply of land and develop that land already within municipal boundaries, or housing prices would escalate as a result of a shortage of supply. An increased supply of land also represented a potential for an increased tax base. As long as the ERCB was managing the sour gas operations outside its municipal boundary, the City of Calgary felt confident in developing the land within its jurisdiction.

The subdivisions of Saddleridge, Martindale, Taradale, Burlington, Abbeydale and Applewood Park (refer to Map 5) are all locations close to which a string of nearly a dozen active sour gas wells and pipelines present a possible threat to the health and safety of the residential population. More significantly, five of these six northeast Calgary fringe community developments received initial approval between 1981 and 1984—despite the rapidly worsening economic climate (Calgary Herald, October 6, 1984, p. B1). In all cases, due to the recent economic uncertainty in Alberta as a result of falling oil prices, the new communities are likely to remain in an underdeveloped state for an extended period into the future.

In 1982 city council endorsed a massive annexation, known as Northridge, of approximately 4,500 acres of land (or 330 sq. km) northeast of Calgary (Calgary Herald, September 8, 1982, p. A1). This would have increased the then present size of Calgary of 507 sq. km by more than
half. The developer's plan was to eventually build housing to accommodate 55,000 residents. However the land contained in the proposed annexation area was downwind from two sour gas processing plants and contained over two dozen sour gas wells. The Chief of the City of Calgary Fire Department's hazardous goods department stated in the event of an accidental sour gas release, "it would be near impossible to evacuate that many people" (Calgary Herald, September 8, 1982, p. A1). One of the oil companies engaged in sour gas operations in the area, Petrogas Processing Ltd., suggested the city should wait up to 25 years when the gas fields are depleted before expansion should take place, and went on to proclaim, "Urban development and sour gas cannot co-exist safely" (Calgary Herald, September 8, 1982, p. A1, emphasis is mine). Surprisingly the ERCB stated development could safely occur given adequate setback distances, and city council voted 7-3 to approve the proposal. Public criticism of the city attempting to "gobble up valuable agriculture land" and a total disregard for sour gas facilities instigated an uproar in Calgary and on this occasion, bowing to public pressure not market considerations, the City withdrew the annexation proposal.

In addition to economic conditions implying no rationale for increased subdivision development in northeast Calgary was the occurrence of Lodgepole in late 1982, the
most serious and dramatic sour gas well blowout in the history of the Alberta petroleum industry. The negative public reaction to Lodgepole was overwhelming and the incident served as a catalyst for change; the public learned it could have a louder voice in determining new regulations to prevent a recurrence and suggesting improvements in procedures for dealing with such emergencies near populated areas (Environment Views, December, 1984, p. 29).

Despite the increased public awareness and fear of sour gas as a result of Lodgepole, the City of Calgary under pressure from land development companies, continued to develop land adjacent to sour gas reserves in northeast Calgary. In 1983, the ERCB was requested by city council to consider urban development plans within the northeast subdivision community of Saddleridge (ERCB Annual Review, 1983, p. 19) where existing sour gas wells and pipelines were in operation. Like the Northridge proposal, the ERCB again concluded resource and urban development could co-exist without seriously affecting the safety of the general public if specific setback distances were observed. Again after much public debate, the urban development proposal was halted until the sour gas reserves were phased out (ERCB Decision D83-6).

While it may appear the ERCB also played an integral role in endorsing very questionable urban development
proposals, it must be remembered that the city initiated the land development proposals. If the application conformed to sour gas regulatory guidelines, the ERCB felt compelled to recommend approval of the applications. The next section of this chapter will address the regulatory development of sour gas policies.

2.6 ERCB Regulation of Sour Gas

The establishment and general acceptance of regulatory measures in the Alberta oil and gas industry since 1938 originates from the initial regulations promoting conservation (i.e. preventing waste) of oil and gas reserves. As the petroleum industry grew and expanded, the legitimacy of regulations pertaining to well spacing, maximum production rates and prorationing schemes were also conceded to be necessary to maintain orderly marketing and stability in the industry. By the early 1970s, government regulation was viewed positively by the oil and gas industry (Thompson, 1985).

A turning point for the oil and gas regulatory agency occurred in 1971 when its mandate was enlarged to also include development and operating regulations of a range of other energy resources and activities, including coal, hydro and thermal power, and chemical fertilizer and ammonia plants (Millard, 1984). Initially this change was not
expected to have a major impact on the manner the Board functioned because new regulation simply extended to other resources, the same kind of responsibilities that had previously applied to oil and gas matters. Those duties included ensuring economic and orderly development, resource evaluation, market assessment, pollution control in resource development, safe and efficient practices, dissemination of information and providing advice to government (*Sour Gas Study*, 1984, p. 19, 20).

While technical issues continued to represent the major portion of the Board's responsibilities, the role of the citizenry in ERCB public hearings to consider applications for energy resource developments became a very crucial part of the provincial agency's evolving character. In carrying out its new regulatory obligations, the ERCB assumed the role of mediator between proponents of resource applications and those landowners, adjacent residents and environmental groups who have land use concerns with a project. In essence, it assumed the unenviable role of keeping all sides happy (*The Roughneck*, July, 1984, p. 16). For example, farmers who had previously quietly accepted oil and gas developments, were now seeking to avoid the land use constraint imposed by a well being located in the middle of their field with an elevated access road, or by an pipeline crossing the farm.
The primary reason for the current increase in public concern over resource development is the continual stream of energy projects taking place in the province. In the past five years alone, there have been nearly 29,000 oil and gas wells drilled, 95,000 kilometres of pipeline constructed and 65 sour gas plants built (Alberta Report, July 8, 1985, p. 28). Inevitably, this leads to land use conflicts. A review of the ERCB public hearings held between 1974 and 1983 indicates a two-fold increase in annual total hearings, with those applications for sour gas plants, electric transmission lines, and sour oil and gas pipelines eliciting the most public response (Millard, 1984).

In matters relating to the sour gas industry, the authority of the ERCB is very broad and extends to,

(a) the approval, denial, deferral, or modification of a sour gas application, thereby dictating the pace and extent of sour gas development,

(b) holding public meetings, hearings, and inquiries,

(c) establishing orders on proceedings, and

(d) recommending actions or studies to be undertaken in a specific time.

Initial public health and environment issues concerning the sour gas industry were focussed on the release of pollutants by sour gas processing plants, particularly sulphur dioxide emissions (Alberta Environment Conservation
Authority, 1972). Such concerns have subsequently had an especially high profile in southern Alberta near the town of Pincher Creek where an extensive Medical Diagnostic Study is currently underway to investigate the correlations of sour gas processing plants to public health. Unlike sour gas wells and pipelines, sour gas processing plants must comply in addition to ERCB guidelines, to the regulations of the Alberta Planning Act (Land Use and Sour Gas, Okotoks-High River, Alberta, February, 1983, p. 20). Sour gas processing plants must obtain proper land use classification and a development permit before operation can begin.

In the early 1970s, the ERCB possessed scant regulations to protect the populace from the hazards posed by potential direct releases of toxic hydrogen sulphide from sour gas wells and pipelines. Similar to what had been practised in the previous 50 years, the sour gas industry itself was ensuring their operations were safe. The ERCB's regulatory safe distance requirements that were in effect did not differentiate between sweet and sour gas (AIGSGI, October, 1974, p. 4.8), and special safety requirements on sour gas wells with a $H_2S$ concentration higher than 5 percent were very superficial (Section 7.050, Alberta Oil and Gas Conservation Regulations). In addition to the meagre restrictions placed on sour gas operations, the ERCB
was restricted in its ability to control the encroachment of urban or rural development on sour gas facilities.

Instigated by the New Norway, Alberta, sour blowout in 1973, the joint provincial government-sour gas industry study into the implications of sour gas development, concluded that insufficient guidelines and procedures exist to adequately control the growth of population centres on sour gas operations (AIGSGI, 1974, p.2). The report pinpointed the Crossfield sour gas field, northeast of Calgary, as posing serious hazards to the development of northeast Calgary.

The Crossfield boundaries encompass a substantial portion of the Calgary City boundaries. As the city expands further north and east, more and more development will be exposed to higher risk areas in the event of hydrogen sulphide releases. (October, 1974, p. 4-16)

As a result of the Committee's conclusion, the ERCB commenced a period of increased regulatory attention to the sour gas industry. However, the ERCB did not take charge of the emerging sour gas problem, and consistently reflect a concern for sour gas development near residential areas in its decisions. Their approach was piecemeal and strategies sometimes differed from application to application.

The lack of a major industrial sour gas accident in Alberta in over 50 years of operating history permitted the
existence of such an attitude. The potential danger of sour gas, although recognized in the 1974 Government-Industry Report, was not yet fully appreciated by either the ERCB or the public. Only the industry, who was directly involved in the drilling and production of sour gas, felt the lethal consequences of hydrogen sulphide. Despite infrequent but reoccurring accidental industrial deaths, as a result of exposure to H₂S, the sour gas industry was functioning well for the magnitude of its operations. The sour gas industry realized the dangers of the H₂S and did not have to be increasingly regulated into concern for safety. Because of the nature of the industry, operators actually owed their existence to maintaining their safe operating record.

The most influential regulatory concept adopted by the ERCB as a result of the 1974 Committee was that no new subdivision development be permitted within a boundary that could, by worst case calculation of an accidental release of sour gas, receive up to 100 parts per million (ppm) of hydrogen sulphide gas (AIGSGI, 1974, p. 3.1). The 100 ppm concentration of H₂S was selected as the safe dosage or exposure because it was neither life threatening or overly pessimistic. The 100 ppm boundary estimation became known as the isopleth concept (i.e. location of points of equal ground level concentrations of hydrogen sulphide), and resulted in restrictions on residential land subdivision in
existing sour gas areas and on the siting of new sour gas facilities. Where there was no reasonable data upon which to compute the complex $\text{H}_2\text{S}$ isopleth, the surface location of a well was to be not less than 1500 metres from an existing urban centre or not less than 600 metres from any existing permanent residence (ERCB Interim Directive 78-1, p. 2). Such separation distances were deemed to be able to cope with a sour gas accident.

The adoption of the isopleth concept to control land use near sour gas facilities was an innovative planning technique for the oil and gas industry. It represented an attempt to understand the factors influencing a sour gas well blowout's consequences, rather than simply relying on a non-substantiated safe setback distance regulation. In France, near the LACQ sour gas field, safe setback distances, although more restrictive than those used previously by Alberta, were still employed (AIGSGI, 1974, p. 4-11). However the Oil and Gas Division of the Railroad Commission of Texas, U.S.A. adopted Alberta's approach to sour gas regulation and enacted Rule 36 to regulate all sour gas development in the state through the use of the 100 ppm isopleth. The Rule became effective in April, 1975, six months after the ERCB's implementation of the concept (Railroad Commission of Texas, Rule 36, Reference Special Order N. 20-64973, April 17, 1975). Rule 36 continues to be
applied in Texas today, as well as similar regulations in other states developing sour gas (e.g. Wyoming, Mississippi, New Mexico) (Oil and Gas Journal, July, 1985, p. 56).

When the isopleth concept was applied to northeast Calgary in 1974, approximately 1,100 acres of land within the City were restricted to future residential development until the sour gas facilities responsible for the 100 ppm contour ceased operation (Calgary Herald, July 8, 1984, p. B4; Refer to Map 6). Complicating the land use restrictions, however, the isopleth contour also infringed upon existing residential homes. In the following years, attempts to refine the isopleth prediction model produced very divergent results, depending on who performed the study and what assumptions were used.

The ERCB became very flexible in the enforcement of the isopleth concept, and in certain instances allowed residential growth within the 100 ppm boundary (ERCB Decision D77-4). In other instances, the ERCB encouraged the removal of the isopleth from the area altogether. For example, a sour gas well immediately east of the northeast Calgary community of Falconridge, which was responsible for a major portion of H₂S isopleth within the City, was curtailing residential development therein. The land developer wishing to build in the restricted area paid approximately $2.5 million to relocate the well one mile
further east, thereby removing the 100 ppm contour from City (Calgary Herald, January 11, 1977, p. B1). In other instances, certain pipelines were abandoned and emergency shut-down valves installed in other lines. From an engineering and economic point of view, however, relocation of sour gas wells was not always feasible or possible, thereby denying an ERCB regulatory policy of remote siting of sour gas facilities from urban areas.

By 1979, amid continuing pressure from the large land development companies desiring to subdivide their land, private individual land owners wishing to sell or build on their land, and the City of Calgary wishing to provide housing for the increasing population of Calgary, the ERCB discontinued the use of the isopleth distance to separate urban and sour gas development. The ERCB viewed the use of an hypothetical worst case blowout situation to determine a safe distance from sour gas facilities as an unnecessarily restrictive method of ascertaining the potential impact of a sour gas accident (ERCB Decision 83-6, p. 6), and therefore represented an unrealistic restriction on use of land. Surprisingly, the ERCB continued to use the isopleth concept as the basis to determine the emergency planning zones around sour gas facilities in the event of an uncontrolled release of H₂S (ERCB Interim Directive 76-2).

The new minimum distance requirements separating new
sour gas facilities from residential and other developments that replaced the isopleth concept, were developed by Alberta Environment and the ERCB, and were applied in granting approvals for sour gas facilities near areas of public use (ERCB Interim Directive ID 79-2). With regard to encroachment of occupied buildings on existing sour gas facilities, the Subdivision Regulations of The Planning Act, 1977, were amended to require setbacks similar to the Board's separation distances (Province of Alberta Legislative Order in Council 382/79). The criteria used to affix one of four various classes of safe separation distances to a particular sour gas facility included, 

(a) the \( \text{H}_2\text{S} \) concentration in the gas,

(b) the potential sour gas release volumes, and

(c) the density of the population living nearby (Ibid, ERCB ID 79-2; Refer to Appendix 4). The separation distances increased as the above criteria increased for any particular proposal.

The isopleth concept from a public safety and development control point of view was much more restrictive and perhaps, given the potential danger of \( \text{H}_2\text{S} \), much more practical than the newly implemented setback policy. The elimination of the isopleth concept in the regulation of land use matters opened up the residential land development process again, and eventually resulted in residential
subdivisions being built within one kilometre of sour gas wells and pipelines adjacent to northeast Calgary. Consequently, withdrawal of the isopleth concept as a regulatory technique, facilitated the situation confronting northeast Calgary today.

In lessening the land use controls however, the ERCB was also placing much more responsibility with the sour gas industry to prevent sour gas accidents from occurring. Improved supervision and training of individuals working on sour gas wells, and stricter equipment standards and requirements were identified as necessary mitigative strategies.

Shortly after the land use regulatory changes, a changing ERCB attitude to the incompatibility of urban development and sour gas development became evident. In 1980, in a sour gas application for development in an area south of Calgary, the ERCB proclaimed that sour gas reserves should be depleted before land use conflicts became so extreme that the resources are lost (ERCB Decision D80-6). The Board also began to include mandatory public awareness programs as a responsibility of sour gas operators (ERCB Decision D 80-26).

Serious attention to the sour gas industry did not take place until the historic Lodgepole blowout occurred in the autumn of 1982. In the space of two months while Lodgepole
raged, sour gas was transformed from a long time, bread and butter industry in the province to a major public health and safety issue (The Roughneck, July, 1984, p. 14). Suddenly all sour gas projects were under increasing scrutiny from the affected public. Environmental pressure groups, which had long had difficulty gaining public sympathy and support, were being quoted daily and were even in demand as consultants in communities near sour gas developments (Environment Views, December, 1984, p. 14).

Subsequent to the findings of the extensive and expensive Lodgepole Blowout Inquiry (ERCB Decision D84-9, Phase 1 and 2 reports, December, 1984), the ERCB imposed strict new planning and operating procedures on companies wishing to drill for sour gas reserves. Where a well was to encounter a high H₂S concentration with the potential for a release volume more than two metres³ per second (i.e 2 M³/second) of sour gas, and was to be located within 1.5 kilometres of an urban setting, the well was to be identified as a "critical" sour gas well (ERCB D84-9). Critical sour gas wells subsequently became the primary regulatory targets of the ERCB. Increased regulation on such wells meant increased costs for the operators who could not quite understand how one sour gas blowout could have such a dramatic effect on the industry after an impeccable 60 year safety record of drilling for sour gas reserves.
In the autumn of 1982, prior to Lodgepole occurring, the ERCB gave approval to Canadian Occidental Petroleum Ltd. (i.e. CanOxy) to drill a sour gas well with a H2S content of approximately 31 percent, less than one kilometre from the outskirts of northeast Calgary (Crossfield Wabamun A Pool Development Plan, April, 1984, p.2). According to the separation distance guidelines of ERCB Interim Directive 81-3, the well was classed as a Level 2 sour gas facility, the second "safest" type of sour gas well of the four separation distance levels (Crossfield Wabamum A Pool Development Plan, 1984, p. 11). The well was successfully drilled and upon completion, indicated that the penetrated sour gas reservoir extended further to the south, approximately 2,800 metres underneath the City of Calgary. This well set the stage for the current application.

While the public of northeast Calgary views Canadian Occidental's present application as "a risk too big to take" (Calgary Sun, September 28, 1984, p. 6), the oil company feels confident the wells can be successfully drilled. CanOxy sees the government as lessor of the mineral rights, and as possessing the legal obligation to see that development occurs. The sour gas industry has spent money in good faith on mineral rights, exploration and planning, hence legally and morally expects support from the ERCB. However, the application is not a 'cut and dried' resource
development proposal; it represents the culmination of a serious land-use problem that could be neglected no longer.

The onus for the landuse problems must reside with Calgary City Council, who was so overwhelmingly pro-residential growth orientated, that it ignored the existence of a sour gas problem. City Council placed the financial benefits of developing land ahead of ensuring the public health and safety of its residents. For example, as recent as the autumn of 1984, Calgary city council informed the ERCB they did not object to Canadian Occidental's initial well application, despite its planned location within 900 metres of northeast Calgary. Concerned residents of northeast Calgary felt the well application should be opposed unless the well was shown not to represent a potential danger to their health and safety (Toronto Globe and Mail, September 28, 1984, p.A6). The ERCB did not immediately approve the well even though all explicit regulations were met, and the proposal continues to be debated.

For the ERCB, the existence of conflict conditions is a mixed blessing. On the positive side are the obvious advantages of having critical reviews of the assumptions and analysis on which public decisions are based. Equally important is the openness that comes from public scrutiny of the ERCB regulatory process. Only by understanding the viewpoint of risk from the public, oil company and the ERCB
perspective, can an understanding of the obstacles confronting the problem be provided. The disadvantages of increasing conflict are primarily operational. Decisions on the sour gas/urban development problem are delayed. Litigation or repeated technical modifications incur costs which would not ordinarily occur and investment in the sour gas industry is postponed.

From the viewpoint of the regulated, probably the worst feature of this mode of decision making is the problem of moving targets; that is regulatory guidelines are revised at a rate faster than industry can adapt (personal conversations with Angus McKee, president of Canadian Occidental petroleum Ltd., April, 1985). CanOxy feels it can adapt to a wide range of policies, even those seen as costly, provided the rules are clear and specific, and that policies controlling urban development will not suddenly change and jeopardize their operations.

Fortunately, unlike the limited focus of municipal authorities, the ERCB currently takes more into consideration in its sour gas decisions than simply approving or disproving a development application. With CanOxy's proposal, the sour gas controversy needs to be diffused rather than arbitrarily decided, and indeed an unhurried approach to this application has been the ERCB's forte. The agency should be commended for its patience, and
its elicitation of all sides of the story thus far. Such a procedure has not always been practised in the past.

2.7 **Inevitable Conflict**

Drilling for sour gas reserves is a location specific land-use activity, in that drilling is performed where the reserves are located. Being an entirely social creation, urbanization has more flexibility and through effective management and planning initiatives, urban growth should be able to proceed in an orderly fashion, making the best possible uses of the land. However, growth in Calgary was not based on a rigid examination of all the land-use alternatives; urban expansion did not occur in a rational comprehensive manner. Despite the identification of a potential conflict between surface and subsurface uses of the land in northeast Calgary over ten years ago, the City of Calgary, being responsible for planning within its municipal boundaries, generally disregarded the sour gas industry operating outside northeast Calgary. The City failed to develop any effective policies to prevent the visible encroachment of heavily populated areas upon a well known and active sour gas field (Land Use and Sour Gas, Okotoks-High River, 1983, p. 29). The City was not fulfilling its corporate social responsibility of ensuring the present and future well-being of its citizenry.
The oil and gas industry was the stimulus to Calgary's boom and growth explosion during the 1970s and early 1980s. During this period the sour gas industry had been successfully operating in the province for nearly 60 years, and outside northeast Calgary since 1961. Because the sour gas industry had never caused a public fatality and because Alberta did not endure a major sour gas accident until 1982, oil and gas meant positive benefits to Calgarians, and the industry was difficult to imagine as potentially responsible for negative influences. In Alberta there were no province wide scars of logging or waste heaps of mine tailings left behind, nor were there any Trail's or Sudbury's; rather the lingering symbols of hydrocarbon energy developments were the highrise office buildings of downtown Calgary.

The City of Calgary became so involved in its subdivision developments, annexations, and rapid growth that it did not seem to consider the consequences of an economic slowdown in the oil and gas industry. Planning policies like the Balanced Growth Strategy sought to maintain a 30 year supply of lands to meet the City's "continuing" growth needs. When the petroleum slump did occur, Calgary was confronted with the results of its rapid urban development, half developed subdivisions and unwarranted annexations abutting sour gas operations.

However, the City of Calgary, and to a lesser extent
some of the nearby municipalities, continued to intensify the land use conflict by proposing and approving urban and residential development in the vicinity of sour gas reserves. These events continued to occur not only after the petroleum industry decline in the autumn of 1980, but after the Lodgepole blowout in the fall of 1982 as well, and even after the current Canadian Occidental controversy began in the summer of 1984. For example, preliminary approval was given to a mobile home park project in the Burlington subdivision, the area closest to the original proposed sour gas well, because the application fell within municipal land-use guidelines and the presence of sour gas was therefore deemed not to be a planning matter. (Calgary Sun, October 28, 1984, p. 10). In another instance, just north of Calgary, planning guidelines of safe sour gas setback distances were relaxed so that a private home could be built next door to a Level 4 sour gas pipeline (i.e., the most dangerous level) (Calgary Herald October 23, 1985, p. A19).

In these and similar requests, the ERCB's opportunity to input into the land development decision making is limited to recommendations to the proposal. Comprehensive land development decisions near sour gas facilities have remained outside the ERCB's mandate. Because sour gas development and urban development went their own ways,
regulating themselves, there was a lack of effective communication between the two entities, and a collision was inevitable. Clearly the lack of a coordinated policy to make decisions on urban development-sour gas developments has contributed to the risk problem confronting northeast Calgary today.

Plans for more open spaces between sour gas wells and residential areas (*Calgary Herald*, January 5, 1985, p. B6) or a complete closure of the sour gas industry outside northeast Calgary (*The Financial Post Magazine*, May 1, 1985, p. 28) represent one view of resolution alternatives but to effectively address and manage the problems of sour gas, all views must be evaluated.

The following chapter will introduce the uncertainties involved in successfully drilling sour gas wells; uncertainties that emphasize the need for specific and in-depth knowledge of risk problems, and the difficulties of acquiring this information.
CHAPTER 3

UNCERTAINTIES AND RISKS IN SOUR GAS DEVELOPMENT

3.1 Introduction

The objective of any petroleum company engaged in exploration for oil and gas is to successfully extract the financially optimal amount of hydrocarbon reserves from the penetrated subterranean formation. While Alberta's experience in drilling oil and gas wells since the early part of the century and data from geological analogy can provide a degree of understanding of what to expect in a particular well, the unique characteristics of the circumstances accompanying each well to be drilled in the province, create an element of uncertainty in accomplishing this goal. For sour gas well operations, there are three primary areas of uncertainty present in the drilling of a well. These are as follows:

1. Uncertainty of engineered drilling systems functioning in complex subsurface geological formations;
2. Uncertainty related to the human factors involved in the drilling operation; and
3. Uncertainty in the toxicity and other health effects of H₂S.

This chapter will discuss these aspects of uncertainty and
establish their relevance to the current application by Canadian Occidental Petroleum Ltd.

3.2 Drilling Systems and Associated Uncertainties

Using engineered systems to drill wells into the surface of the earth in search of hydrocarbons is a technology that continues to improve. However the most feared and most costly operational hazard related to drilling a well persists: a well blowout or complete loss of control over the well's formation pressures, resulting in release of gases and/or liquids to the surface. Because of the toxic properties of hydrogen sulphide, an uncontrolled release of sour natural gas to the atmosphere is the most critical type of blowout.

Drilling to find and produce oil and gas in Alberta is accomplished using a rotary drilling rig system as illustrated in Figure 2 on the following page. The first deep well drilling rig embodying all the principles of the modern drilling rig was developed at Spindletop, Texas in 1900 (Hazlett, R., 1954). Other than routine interruptions and maintenance, drilling a well is a continuous, 24 hour per day process, day after day, until either total depth is achieved or a well problem halts drilling.

The essence of the process of rotary drilling a well involves rotation of the drill pipe in the hole and the
drill bit on the wellbore bottom, with successive additions of pieces or joints of drill pipe as the drilling progresses. The drill pipe is often removed from the hole (i.e., tripping out) to change a dull drill bit, and re-enters the well by running in the drill pipe to the wellbore bottom to resume drilling. The hole is drilled by simultaneous application of downward force and torque to the bit.

When drilling the well, the angle that the well bore takes is directionally controlled by performing either manual wireline or computerized deviation surveys, and altering the weight on the bit accordingly, or installing special bent housing assemblies and stabilizers just above the bit on the next trip out of the hole. By controlling the angle of the well, the well operator is able to drill into the formation where the hydrocarbons are thought to be. As a well becomes more angled, the difficulties of drilling the well increase. Some wells assume such an angle, or series of angles, that their bends resemble, and are referred to as, "dog-legs."

The depth of the wells drilled in Alberta range from less than 1,000 metres to over 5,000 metres, or 3 miles in depth. Similar to an increased angle in the well, as the depth of the well increases, and fairly substantially for depths greater than 3,000 metres, the risk of a well control
problem also increases (Bercha, 1983, p. 4.7; Refer to Figure 3). The length of time it takes to drill a well can vary from a matter of days to over one year, depending on the well depth and any problems encountered.

While drilling, drilling fluid or mud is continuously circulated through the pipe string, out through the drill bit, and back up the sides of the well hole to the surface (Figure 4). At surface, the drilling mud fluid is held in the mud tank, cleaned and treated with water, chemicals are added, and when required, weighted materials, to retain the properties necessary to successfully drill the well. Once cleaned and treated, the drilling mud is re-circulated through the system.

The functions of the drilling fluid include removal of formation cuttings from the wellbore, lubricating the drill bit, cleaning the bottom of the hole, slicking the sides of the well, and most importantly counteracting downhole formation pressures, thereby preventing blowouts. The essential concept of the mud circulation procedure is to create and maintain a constant bottom hole pressure at a value somewhat higher than penetrated formation pressures, thereby allowing the weight of the drilling mud to hold the gas in place down below. This denies an influx of formation fluids or gases the opportunity to blow from the well in an uncontrolled manner. Geological information of previous
wells in the area and wells drilled into the same formation elsewhere, provide the oil industry with the expertise to calculate what formation pressures are likely to be encountered. However until the "pay zone" formation (e.g. where the hydrocarbons are located) is penetrated and tested by oilfield specialists, the exact underground formation pressure in a particular well is unknown.

**Well Control Problems**

Well control problems consist of closely linked events in that a minor difficulty may ultimately lead to a major accident. A problem may begin when the weight of the drilling mud is no longer sufficient to keep down the formation fluid or gas pressures that may be present in the well. It is not feasible to simply use heavy, dense mud to prevent this problem because the use of too heavy a mud creates another set of problems which may in turn, result in a blowout. These problems are as follows:

1. Fracturing of the formation, leading to lost circulation (Refer to Figure 5);
2. Obstruction of the rotary motion of the pipe in the hole, possibly leading to the drill pipe becoming stuck in the hole; and,

The challenge of any drilling program therefore, is to find the optimal mud weight to counteract formation
pressures but to facilitate efficient drilling. Thus, in a drilling program, optimal mud weights are relatively close to, but barely exceeding formation pressures (Refer to Figure 6), providing a real possibility for a problem to occur if an unexpected pressurized zone is encountered.

Perhaps the most vivid example of a well encountering problems as a result of incomplete geological information is Mobil Oil Canada Ltd.'s troublesome West Venture N-91 gas well, two kilometers north of Sable Island, off the Nova Scotia coast in September, 1984 (The Financial Post, April 13, 1985, p. 33). The well penetrated an abnormally high pressure formation but the rig's blowout prevention equipment quickly contained the gas. However, the pressure was so great within the well that it began escaping into the adjacent rock formations and subsurface loss of control over the well continued for nine months, at an estimated cost of $167.7 million (Calgary Herald, June 22, 1985, p. E3). The well established itself as one of the longest, most difficult and most expensive corrective actions ever conducted on an oil or gas well. The well was permanently plugged after nearly 1,000 barrels of heavy mud and cement were pumped down the hole (Calgary Herald, June 22, 1985, p. E3).

When formation fluids or gases begin to flow into a wellbore, the condition is known as a kick (A Dictionary of
Petroleum Terms, University of Texas at Austin, 1980; Refer to Figure 7). It is not a highly unusual occurrence in the drilling industry and develops with a predictable sequence of events, while exhibiting several visible warning signs of its occurrence. The formation materials associated with a kick can be oil, gas, water or a combination of these. There are significant differences in the pressures associated with gas and liquid kicks with gas kicks being the most dangerous because of compressibility and volatility properties of gas (Blowouts: Well Control Insurance and Risk Management, British American Corporation, 1982, p. 135).

Unless the kick is controlled by circulating out the gas, the tremendous pressure that may build up in the well within a few hours can lead to the total uncontrolled release of gas to the atmosphere. Once the gas well is flowing out of control, the fluid inertia in the accelerating mud column is comparable to the momentum of a fully loaded freight train moving along a railway track at high speed (Bercha, 1983, p. 3.17). Because a kick warns of an impending blowout, the prevention or total control of kicks is the most reliable means of preventing blowouts.

The drilled well bore and mud volume are a closed circulating system, with mud being pumped into the well as mud is flowed from the well into the mud tanks. Any addition or influx of formation material to the system will
reveal itself as a change in the fluid-flow rate back to the surface and subsequently, an increase in total volume. A rapid change in the rate of drilling or a "drilling break" and variation in mud characteristics are also indicative of a presence of intruding formation fluids or gases. While these incidents reveal that trouble in the form of a kick is pending in the well, the short time period in which they reveal themselves before the blowout occurs [e.g., approximately 3 hours for the Lodgepole blowout (ERCB Lodgepole Report, D84-9, Figure 3.3)], sometimes causes inattentive well personnel or poorly trained crews not to recognize the warning signs.

The technical causes of loss of control over formation pressures fall into two categories, improper mud control and inappropriate surface control procedures (Refer to Appendix 5). The biggest contributor in the failure to control kicks however, is human error, either directly through the execution of incorrect well control response tactics, or indirectly, through operator induced equipment failures (ERCB Lodgepole Blowout Report, D84-9, p. 5.26).

The primary step in controlling a kick is shutting in the well mechanically with the hydraulically operated Blowout Preventor (BOP) assembly which is situated at the well head, beneath the substructure of the drilling rig. Essentially the BOPs consist of a series of large,
high-pressure valves. By mechanically sealing off the well, the hole is temporarily stabilized so that efforts can begin to increase the downhole pressure by circulation of a heavier mud than was in the well previously. As the heavy mud is pumped down the drill pipe, bottom hole pressure increases and formation fluids cease coming into the wellbore. The gas already in the well can then be circulated to the surface under controlled conditions. After the well is thoroughly circulated, cautious drilling can proceed at a slower penetration rate and with heavier drilling mud (Personal work experience knowledge acquired while employed on sour natural gas well drilling rigs).

The Lodgepole Blowout Inquiry Panel reconstructed the events that led to the initial kick in the Lodgepole well and determined that deficient drilling practices and the marginally adequate mud density being used, permitted the entry of reservoir fluids into the wellbore (Lodgepole Blowout Report, 1984, p. 1-2). The Panel also concluded that the kick was likely not controlled because,

1. The drilling crew did not immediately recognize the problem and therefore did not immediately apply and maintain standard kick control procedures;
2. Several pieces of vital equipment did not function properly; and,
3. Supplies of mixed drilling mud were not adequate during kick-control operations.
Kicks, such as that at Lodgepole, which are unresponsive to initial control efforts, or are incorrectly handled, may continue until the rate of flow of formation fluids into the wellbore becomes so extreme that their pressure can no longer be contained by the drilling mud and/or pressure control equipment, and they begin to vent to the atmosphere. As soon as this occurs, loss of control of the well has technically taken place, and a blowout is in progress. Highly trained well control personnel are then required to "kill" (i.e., regain control of) the well. Blowouts which are relatively quickly brought under control are known as minor blowouts, while ones which continue to flow uncontrolled for extended periods of time, threatening human life and the environment are for the purposes of this study, what is referred to when blowouts are discussed.

Regaining control of a sour gas well blowout may be achieved in one of two ways:

1. Capping the well by installing a new Blowout Preventer assembly on the damaged wellhead, while the well is either discharging raw sour gas or is burning as a result of ignition of the gas flow;

2. Drilling an adjacent "relief" well to intersect the blowout well and relieve its pressure.

The immediacy of the problem of a sour gas well blowout, especially when public safety or the environment is
at risk, compels most blowout situations to be resolved by the former method. Drilling relief wells can take considerable lengths of time and no assurance is provided that the relief well will not become a blowout victim as well.

The wild well capping technique of placing a new Blowout Preventor on the damaged well head is complicated by two factors, depending upon whether the well is emitting H₂S or is on fire. The first complication relates to the extreme lethality of the H₂S spewing from the wellhead where the wild well control specialists must work. Even though special air supply breathing equipment is used, a small puncture in an airline or a bump in the face mask, could produce a brief exposure to H₂S and result in instantaneous death. The second complicating factor is the extreme heat of up to 1,000° Celsius (Calgary Herald, December 5, 1982, p. F1) that may be present near the wellhead if the well flow is ignited. Evidence at the Lodgepole Blowout Inquiry indicated that prior to Lodgepole, successfully taming a blowout while it was on fire, had been accomplished only six times in the world before (ERCB Lodgepole Blowout Report, Summary and Recommendations for Report 84-9, Calgary, Alberta, December, 1984, p. 3; Refer to Figure 8).

Capping blowouts, or drilling adjacent wells, and their associated well control procedures are highly complex,
technical and controversial operations. Very few basic rules are universally accepted by the experts due to the unique characteristics of every well and blowout. Pat Campbell, a well-capping expert with the famous Houston-based Boots and Coots Inc. described his work as,

It's a specialized field, one where one mistake is deadly. But we don't make mistakes. (Vancouver Sun, February 27, 1984, p. A12)

Fortunately, the state of the art in controlling well blowouts has advanced in Alberta beyond the techniques employed in Poland in 1980, when a natural gas well blowout burned for 19 days before serious efforts were put forward to tame the well. The Eastern Bloc country, with assistance from Soviet troops, blasted the remnants of the burned drilling rig with anti-aircraft artillery, which subsequently caused the well to bridge over (i.e., seal off the uncontrolled release) (New York Times, December 29, 1980, p. 8).

DRILLING EQUIPMENT

The most efficient and effective risk management actions that can be taken to avoid accidents in a hazardous industrial operation are preventative (Risk Management,
June, 1985, p. 22-24). Preventative actions include both the technical (design, maintenance, quality control, and housekeeping) and the human (training, motivation, physical and mental well-being, instructions, and warnings). In a risky activity like drilling H$_2$S wells, the amount and extent of preventative actions can make the difference in whether or not undesired events like a well control problem will occur, and if so, whether the incident will become a minor accident or develop into an uncontrolled blowout. Subsequent discussion in this section will address the technical implications of preventative actions to ensure the safe operation of sour gas well drilling equipment.

Each of the approximately 390 drilling rigs presently contracted to drill sweet and sour oil and gas wells in Alberta (Oilweek, January 20, 1986, p.1), are required by the Energy Resources Conservation Board to install, maintain and control standard safety equipment which will prevent the undetected and continuing escape of any influx of hydrocarbons into the well. Due to the unique characteristics of sour gas, problems are more likely to occur while drilling a well that contains H$_2$S than a well which is not sour. The higher problem rate for sour gas wells can be attributed to a number of factors:

1. Because of the corrosive nature of hydrogen sulphide on metals, equipment deterioration unless
detected, inevitably leads to equipment failure;

2. Deeper wells, whether sweet or sour, experience a greater rate of drilling problems, and sour gas is generally found only in deeper formations;

3. In any potentially sour environment, well control procedures are complicated by the need for drilling crews to take greater precautions; and, 

4. The element of stress plays a very influential role in human error on sour gas well drilling rigs. Consequently, special "SOUR SERVICED" equipment and equipment provisions like corrosive mud inhibitors in the mud system and electronic testing for metal fatigue in the drillpipe are mandatory for all sour gas wells in Alberta. Equipment for both surface and subsurface monitoring of hydrogen sulphide is also required by the ERCB. At surface, state-of-the-art computerized monitors warn of the possible presence of H₂S, when specific minute concentrations of sour gas are exceeded, or when a well is exhibiting signs of a kick. Some of the monitoring equipment includes ambient and mud system H₂S detectors, and mud flow rate and mud tank volume monitors. When H₂S is found in the mud, special chemicals like iron oxide, which are known as scavengers, can remove H₂S from the hole (Journal of Petroleum Technology, June, 1979, p. 797-801).

The technical requirements of sour gas well control equipment are very stringent. For example, the Blowout
Prevention valve assembly and "casing" must be pressure tested at various stages of the drilling process to ensure they can withstand approximately twice the amount of the expected formation pressures in the well. Although the ERCB does not directly oversee all tests that are performed on equipment, the oil companies and drilling contractors are diligent in their compliance to well control standards. Consider the following pressure test I observed while working on a sour gas well in January 1986.

The initial 200 to 500 metres of a sour gas well, referred to as the surface hole, are drilled and subsequently enclosed with a string of steel tubing known as casing. The casing is cemented in the hole before drilling proceeds to the primary part of the well. The cemented surface casing serves as a security zone between surface and well head equipment and subsurface formations. A rule of thumb often used in selecting the casing seat depths in \( \text{H}_2\text{S} \) wells is that no more than 75 percent of the hole be unprotected by casing at any time (The Northern Miner, May 16, 1985, p. 85).

Pressure testing of the casing and the blowout preventative equipment is a crucial part of the drilling process, but usually only takes 3 to 6 hours to complete, depending on the number of leaks detected and how long it takes to repair them. In the referred to incident however,
because one valve would not seal properly, remedial attempts to resolve the problem took nearly 48 hours. The oil company's persistence to ensure that the well control equipment functioned properly was emphasized not only by the amount of time and expense that was spent rectifying the valve problem, but also in consideration of the amount of valuable drilling time that was lost or foregone in favour of ensuring the equipment was safe.

The initial two recommendations of the Lodgepole Blowout Report (1984, p. 12-1) dealt specifically with the need for sour gas well drilling equipment to be examined to ensure that it is adequate for worst-case conditions. The need to examine sour gas well drilling equipment further was made apparent upon review of the 1983 ERCB drilling rig inspection reports (Drilling Rig Inspection Committee, formed in accordance with ERCB Decision D84-5, June, 1984). Of the 4,616 oil and gas wells drilled in Alberta in 1983, there were 1,664 total rig inspections performed, with over one third (i.e., 560) being recorded as unsatisfactory. The Committee members subsequently reviewed all the unsatisfactory inspections to determine whether a "serious" deficiency condition existed, where a serious condition was defined as restricting the drilling rig crew's ability to safely detect, shut in the well, and/or circulate out a well kick and maintain control of the well (Oilweek, August 27,
1984, p. 32). The results of this review revealed that 56 percent of the unsatisfactory inspections and nearly 20 percent of all inspections had the implicit potential to encounter a serious well control problem. The most serious equipment deficiencies identified were concluded to be directly attributable to a lack of awareness, attitude and maintenance by those employed at the well site (Drilling Rig Inspection Committee, 1984, p. 10).

Despite these findings and the identification of human failings as a major contributor to the Lodgepole blowout, high standards for well control equipment and adherence to cautious drilling procedures in the critical H$_2$S-bearing zone continue to be the regulatory focus of attention to sour gas well drillers (A Report on an Application by Canterra Energy Ltd. to Drill a Critical Sour Well in the Sundre Area, ERCB D84-28, December, 1984, p. 19). For example, in the cited well, the expected hydrogen sulphide content in the sour gas was approximately 90 percent, representing the highest H$_2$S concentration ever drilled in the province, and higher than any sour gas well currently in production in Alberta (Edmonton Journal, August 3, 1984), and perhaps higher than any sour gas well drilled anywhere in the world. In effect, the oil company was not drilling for natural gas but mining sulphur. Because a well with such a high H$_2$S content had never been drilled before,
untested technology was being employed. In spite of appeals by furious local farmers near the well, who insisted they were being exposed to danger much the same as guinea pigs (Calgary Herald, March 28, 1985, p. A23), the controversial sour gas well was approved by the ERCB. Fortunately, at 3,900 metres, the targeted H$_2$S zone, sour gas was not found (Calgary Herald, November 19, 1985, p. A14), and the validity of relying on special well control equipment and cautious work practices to ensure the safe operation of the well, did not have to be evaluated.

Faith in the ability of engineered well control equipment and drilling procedures to overcome the uncertainties of drilling a sour gas well underscores the effect that other influences, like auxiliary well drilling equipment and human interaction with equipment and procedures, may have on the safe drilling operation of the well. In essence such an attitude attempts to make the sour gas well drilling system more tolerable to secondary variables rather than actually dealing with why well control problems occur.

Well control equipment is very dependent upon the efficient operation of auxiliary equipment on the drilling rig for its usefulness. Unless the boiler produces steam and keeps the BOP's from freezing during winter drilling, the diesel motors generate the electricity needed to run the
mud tank circulation pumps, and the air compressors continue to supply air power for the control mechanisms of the drilling and blowout prevention processes, the safety of the well may be placed in jeopardy. Poorly installed and maintained motors and pumps, and corroded mud circulation components can individually, or in conjunction with the other secondary equipment malfunctions or deficiencies, contribute to a more serious well control problem. Since many of the rigs contracted to drill sour gas wells in Alberta are over 25 years of age, the efficient operating condition of auxiliary equipment, which is not subject to stringent standards, is most often suspect. The oil industry term used to refer to a drilling rig with aged equipment that often breaks down is "junk".

The number of ways human interaction can effect the operation of well drilling and blowout control equipment are enormous, even when the most up-to-date equipment procedures and precautions are employed. Mistakes may originate in the initial design phase of the well, in the selection and preparation of the site for drilling and support facilities, in the selection of casing and mud programs, or in the choice of the drilling pipe string and BOP stack design. Since the sour gas well drilling experts do not possess the clairvoyance necessary to predict with certainty all the conditions and events that may occur while drilling a sour
gas well, the possibility exists for such preliminary engineering flaws and equipment deficiencies to create inadequate conditions in which to effectively respond to a well control problem. While equipment failure may result from off-site human error, well control problems are more likely to occur as a result of direct human error interacting with well control and well drilling equipment.

3.3 Human Failure

Although the direct detection and warning signs of a sour gas blowout generally occur in multiple redundancy, any of a combination of equipment failure, human failure, misinterpretation, and extenuating or unusual circumstances could result in failure to detect and control a kick until it has progressed to the point of becoming a major uncontrolled release. Thus, quick and competent action by the immediate employees on the drilling rig is essential to recognize and rectify a well control problem. Quick and effective response however, is sometimes constrained by the physical, social and psychological influences that exist in the work environment of a sour gas well.

In the account to follow in this section, based in a large part on personal knowledge and experience acquired while employed on approximately two dozen sour gas well drilling operations during the past six years, the
Contribution of human failure as a determinant in the risk of well control accidents will be discussed in relation to the influence exerted by eight different aspects of the work situation on drilling rigs. These work condition characteristics should not be viewed as indicative of all sour gas well rigs but representative of the flavour commonly found in the drilling industry.

Given that human failure on a drilling rig may vary considerably even during the most normal work conditions, human failure in this section is viewed as the righthand's inability or failure to perform the function or responsibility of his role because of extenuating circumstances at the well site and variable factors influencing individual performance. Failure to fulfill the task responsibilities expected of him, a rig employee may commit a human failure mistake that is detrimental to the safety of the well.

The key personnel parties involved in the drilling of oil and gas wells in Alberta include the oil company as the well operator, and the drilling contractor. Oil company personnel will generally make the decision on a drilling program, plan and engineer the well, and set detailed specifications within both their own requirements of successfully drilling and producing the hydrocarbons in the well, and those of the governing regulations. The oil well
operator is responsible for the life of the well, however long that may be (Lodgepole Blowout Inquiry - Phase 2 Report, 1984, p. 9). The drilling contractor's principal responsibility is to use its drilling rig, equipment and crew employees to drill the well according to the operator's requirements. Additional specialized maintenance, service and supply companies are also required as the need for expertise arises during the drilling of the well.

A list of the principal positions and their related task responsibilities on a typical sour gas drilling operation in Alberta is displayed on the next page. The configuration includes those employees associated with the oil company, the drilling contractor, the maintenance contractors, and a sampling of the varied service contractors. Minor variations from this list would occur if the sour gas well is classed "critical" since recent regulatory changes have made it compulsory to have two drilling engineers on site so as to provide 24 hour supervision, when drilling through a critical H₂S zone (Lodgepole Blowout Report, 1984). In addition, a specially trained H₂S safety crew and air breathing safety equipment must also be at the drilling location.
SOUR GAS WELL DRILLING PERSONNEL

1. Operator Crew

   **Drilling Engineer**: the on-site person in charge of the well; usually an experienced veteran of the drilling industry who communicates daily with head office drilling supervisors.

   **Geologist**: responsible for identifying formation cuttings and ascertaining where and when a H₂S formation will be penetrated.

2. Drilling Rig Crew

   **Toolpush**: manager of the drilling-rig and crew employees; responsible for ensuring the efficient functioning of all drilling operations, equipment, and personnel.

   **Driller**: senior member and on-shift supervisor of the six person drilling rig crew; responsible for operation of principal rig controls, and in essence, actually drills the well.

   **Derrickman**: second most experienced member of drilling rig crew; responsible for maintenance of mud circulation system and pumps; also works on a platform, 100 feet from the ground, called the "monkey-board" when drill pipe is being tripped in or out of the hole.
Motorman: the rig's on-shift mechanic, jack-of-all trades; responsible for maintaining and servicing power generation equipment, boiler, air, water, and hydraulic systems, and well control equipment.

Roughnecks: the core and brawn of the drilling rig crew; depending on rig size and conditions, 2 or 3 roughnecks handle the drill pipe on the rig floor, as well as performing general housekeeping and maintenance.

3. Maintenance Crew

Electricians, mechanics, and welders are called to the well site when a malfunction situation to drilling rig equipment cannot be rectified by the drill crew.

4. Service Contractors

Mud Engineers
Cementing Crews
Well Deviation Survey Personnel
Water Truck Drivers
Cooks
Etc.

The drilling rig crew (i.e., also referred to as righands), as individuals and as a unit are the most important component of well safety because of their constant 24 hour contact with the well. Because of this, the rig
workers are also the most susceptible human factor to an error capable of leading to a well control problem. Although the significance of human error as one of the primary causes of well blowouts has been identified by numerous studies since Lodgepole occurred in the autumn of 1982, a thorough examination of the effect of the human factors on a drilling rig to the safety of blowouts has never been performed in Alberta.

Analytical assessment of the risk posed by drilling a sour gas well depends upon understanding the possible chains of events which may lead from normal drilling operations to the state of an accident. Carnino and Griffith (1982) contend that one major difficulty hindering such an examination is that the analysis of human behaviour in a high risk industrial process is a very complex undertaking, particularly in relation to understanding how an accident can happen. Finding information on the human error mistakes that may lead to technical failure of a system, like equipment on a drilling rig, must be narrowed to those factors of direct negative influence. To successfully carry out a valid analysis of human behaviour in the workplace, Carnino and Griffith (1982) emphasize that special interviews with those employees directly involved in the risky process, knowledge of the work situation, and technical background are essential.
However, viewing human failure "from the outside looking in" has its drawbacks. Hunns (1982) notes the difficulties encountered in attempting to gain information of the workplace by monitoring workers engaged in a risky industrial process. For example, while drilling a sour gas well, if there is a continuously conscious awareness by righands of performance monitoring, performance is likely to be abnormal. Righands do not like being observed making errors because mistakes inevitably lead to connotations of blame and personal deficiency, and ultimately in the reality of the drilling industry, getting fired or "run off." Therefore rig employees, as potential subjects for personal performance monitoring, instinctively oppose anyone watching them perform their work. The only exception may occur when outside visitors like television crews or females, tour the rigsite. Overcoming such reluctance will be a major obstacle for the analyst attempting to measure human error on a drilling rig.

Only a minority of situations offer ready possibilities for "transparent" performance monitoring. Many human error mistakes may actually be corrected by the person concerned, before becoming evident to the third party. Furthermore, when an error is observed, not only must the event be recorded but also a comprehensive and objective account of the determining factors surrounding the event. Many of
these factors, and often the most critical ones, are bound up in the mind and psychology of the rig hands themselves.

Carnino and Griffith (1982, p. 174) assert that the primary negative influences which may cause human failure to occur are the characteristics of the work environment. For a sour gas well, these characteristics can be grouped into the following eight classes:

1. Operating condition of equipment;
2. Physical environment;
3. Time and duration of work;
4. Individual attention to task;
5. Individual characteristics;
6. Social environment;
7. Management approach; and,
8. Safety training.

By using personal knowledge and experience to interpret how these characteristics influence employee performance on sour gas drilling rigs, many of the deficiencies of a third party monitoring approach to understand the reasons of human failure are avoided. Personal experience and knowledge lessens the uncertainty, and provides an accurate estimation of the extent that physical, social and psychological influences are responsible for, and capable of creating and enhancing the risk of a serious well control problem.
OPERATING CONDITION OF EQUIPMENT

The first work situation characteristic considered to be influential in leading to human failure on a sour gas well is the operating condition of the drilling rig and its equipment. As disclosed earlier, only the rig's well control equipment must comply to rigorous safety standards and pressure tests. Auxillary drilling equipment, which exerts a tremendous influence on the entire safe operation of the drilling process, is not as rigidly inspected and is therefore, vulnerable to failure because of age, lack of maintenance and repair, or incorrect application of its use. When a drilling rig possesses equipment of inferior quality, but otherwise continues to operate by passing the mandatory pressure tests of its blowout prevention equipment, the rig employees are subjected to an additional workload of maintaining the faulty equipment. Poor work attitudes result, leading to a decrease in concern for the safe operation of all equipment, and consequently the possibility of serious well control problems.

During the drilling industry slump in Alberta between 1981 and 1984, many of the drilling rigs currently being used to drill sour gas wells, were sitting idle (i.e., rusting away in a farmer's field) and not generating revenue for their owners. Now employed, the drilling companies are attempting to quickly recoup their losses by cutting
costs of current drilling operations. Unfortunately, on some sour gas well drilling rigs, the cuts have extended to neglect in maintaining and ensuring the safe operating efficiency of all drilling rig equipment. The inevitable result is that a sour gas drilling rig may be continually subject to mechanical malfunctions.

Righands who must work with 'junk' equipment grow frustrated with the continual need to make repairs. Working with unreliable and aged equipment dictates that drilling rig crew members spend less time with the regular responsibilities of their role on the rig, and more time ensuring that basic equipment continues to operate.

"Running around like a chicken with his head cut off" is an expression which aptly describes a typical day of work on such a rig. When the situation is aggravated by a lack of back-up systems on the rig, or an absence of spare parts to keep the equipment operating, moods of anxiety lead to feelings of helplessness and ultimately to extremely high levels of stress. Worker fatigue and disrespect for equipment inevitably results. As a consequence, positive worker attitude to the safe operating condition of equipment deteriorates. For example, the following work habits are reflective of a righand's response to a continued exposure to drilling rigs with poor equipment:

1. When spare parts are not available, makeshift
repairs are often performed, sometimes with only half-hearted attempts and a hope that it does not fail again;

2. Hiding a problem, thereby permitting someone else to detect it and repair it;

3. A tendency to pass equipment problems on to the next shift; and,

4. An extreme but practised habit of sabotaging the faulty component so that management is forced to buy a new piece of equipment.

In essence, when the efficient operating state of a drilling rig and its equipment is uncertain, an atmosphere of negative worker attitudes towards equipment is created, and a work environment conducive to human error materializes. Unless the drilling equipment can be relied upon to successfully drill a sour gas well, the reliability of righands is even less certain.

**Physical Environment**

The second work situation characteristic which influences the human error factor is the physical environment of the workplace. The environment has the ability to affect a righand's physical well-being and his mental attitude, his mood, his desires, his actions and his efficiency.
The work environment on a sour gas drilling rig is dominated by a continuous noise level being emitted from the mechanical, air and electrical operating systems. Hard physical work for extended periods of time is performed in muddy, oily, greasy, dirty and damp work conditions. When these trying conditions are complicated and stressed further by exposure to extremes of winter and summer weather and temperatures, the physical environment of the workplace becomes very demanding. Compounding the negative influences is the necessity for a rig hand to be constantly aware of his physical environment to ensure his physical safety; moving mechanical parts and heavy objects being lifted overhead are common place.

Collectively the physical environment on drilling rigs can be described as noisy, dirty, physically and mentally demanding, and dangerous. Hard physical work under such physical and mental strains is representative of an occupation that can effectively "separate the men from the boys."

Individually, each of the characteristics of the physical workplace has the latent potential to inflict detrimental effects on efficient human performance at the rigsite. For example, Surry (1969) outlined four negative features of noise in an industrial work environment:

1. Damaging effects on hearing ability;
2. Interference with speech communication;
3. Interference with work efficiency; and,
4. Annoyance.

Despite the constant noise level on drilling rigs, rig employees seldom use hearing protection.

The dirty, cold, damp work conditions on a drilling rig are an accepted facet of the job. However when the uncomfortable surroundings are accentuated by the need for a righand to complete a task in a confined position for a lengthy period of time in severe weather conditions, and with a lack of assistance or the proper tools, frustration may exceed an individual's commitment to perform the task to the best of his ability.

With regard to the physical demands of a righand's job, a study that examined United Kingdom Offshore Drilling Safety (Oil and Gas Journal, December 10, 1984, p. 95-100), found that rig workers engaged in tasks such as the long periods required to trip drill pipe out of and back into the well (i.e. depending on the depth of the well, the time period can be up to 12 hours in length), experienced extremely high levels of physical exertion. The greater the effort needed to initiate an activity meant smaller remaining capacity was held in reserve to maintain control of a stitution if an unforseen event should occur. Capacity to perform hard physical work may be reduced as the
shift progresses, and because of fatigue, mental errors were seen as potentially occurring more often. The study also demonstrated that the physical demands that specific tasks placed upon rig hands can be quantified by recording maximum heart rates for each activity (refer to Appendix 6). The collection of such data can then be used to identify where the physical demands are greatest and whether changes in operating procedures or equipment design are needed to achieve a better match between task demands and the worker's capacity to perform them.

The element of danger to the health and physical safety of rig employees has become a well documented characteristic of the workplace on drilling rigs. Although well operators and drilling contractors conduct their practices with an honest intent of safety, in the quick-paced demands of oil and gas well drilling, over 2,800 worker accidents were reported in 1977 out of a total workforce of 7,500 (Canadian Association of Oilwell Drilling Contractors, Monthly Accident Reports, 1976-80). In 1978, there were an astonishing 4,307 accidents. From 1976 to 1979, 39 workers in the Alberta drilling industry were killed as a result of accidents like being crushed by heavy equipment, falls from the derrick, electrocution, wrapped up in the deadly spinning chain (i.e. used to spin drill pipe joints together), or from being exposed to a lethal concentration
of hydrogen sulphide. When the drilling industry wound down its hectic pace of the boom years, increased regulation made rigs safer, and more experienced crew members were the only ones fortunate enough to be still employed in the industry. Consequently, accidents were reduced but today, yearly deaths and monthly injuries continue to characterize employment on drilling rigs in Alberta (refer to Appendix 7).

Competent and lucky rig personnel avoid accidents, but many others, less experienced or not as lucky, lose their fingers, toes, eyes, and sometimes their lives. As the demand for drilling rigs intensifies in Alberta, crew experience declines; that is, because there have been fewer rigs working in recent years, there is presently a shortage of skilled righands in Alberta for the current demand of drilling activity. New employees dilute the quality of rig worker performance, longer hours requiring less crews are worked, and the potential for worker accidents and human error increases.

In Alberta, concern for worker safety by the drilling contractor is usually a result of company pride from competition within the industry, or as a result of the amount of pressure being applied by regulatory authorities. Their shared objective is to operate sour gas drilling rigs with "Accident-Free Days." Most drilling contractors employ
a token safety awards program of ball point pens, hats, duffle bags and winter coats to reward those righthands for working extended periods without a lost-time accident. When an accident to a worker does occur, as long as it is not too serious, drilling contractors go to great lengths to entice an employee to stay working on "light-duty" so that the safe-drilling record of the company will not be tarnished.

While the drilling industry proclaims to be advocates of safety, their sincere regard to hazardous work conditions on rigs is lacking. Tasks that entail working with electrical systems, or at dangerous heights, or on the drillfloor under very slippery, cluttered and muddy conditions are common. Whenever an accident occurs however, it is blamed on the righthand's carelessness, failure to follow correct procedures, or unwillingness to use precautions (CAODC, *Monthly Accident Reports*). There is no required formal training for employment on drilling rigs, in effect righthands must learn how to work safely by trial and error. To a certain extent righthands accept these conditions as an inevitable part of the job. However, it is a complacent compliance.

Two rig workers who first gained experience in Alberta and returned to Nova Scotia to work on offshore rigs, described the differences of drilling safety on rigs in the two locales (*Halifax Chronicle-Herald*, September 30, 1985, p. 4),
The offshore rigs are up-to-date, which is a big change from the 1950s-built rigs in Alberta. The training and equipment aboard offshore rigs is superior to that which we experienced in Alberta. It's more technical offshore, and takes more thinking, less labour. Formal training was not needed to get hired on rigs in Alberta in the late 1970s, all that was needed was common sense and a willingness to work hard.

Another offshore worker employed on a rig off the coast of Newfoundland, did not have quite so positive a view of drilling rig safety (Toronto Globe and Mail, November 13, 1985, p. A3), "the attitude out there is poor as far as safety is concerned: just get the job done and as quick as possible."

The final report on the Ocean Ranger disaster, in February, 1982, off the Newfoundland coast, in which all 84 employees of the rig perished, recognized this attitude problem within the oil and gas industry and emphasized that righands should get a much bigger say in decisions affecting their safety (Calgary Herald, July 13, 1985, p. E1). Yet safety on a drilling rig still remains in the hands of others, and workers must learn by experience or misfortune how to persevere.

**Time and Duration of Work**

The third feature of the drilling rig work situation which may be considered conducive to the occurrence of human
failure is the time and duration of the work. Righands routinely work scheduled cycles of 12 hours per day for 14 consecutive days before receiving one week off. One week of day shift (i.e. 8 A.M. to 8 P.M.) is followed by one week working the graveyard shift. Workers engaged in 12 hour shifts work more hours in a two week span than the average 'nine to fiver' works in an entire month. In addition, during periods of assembling or dismantling the drilling rig (i.e. beginning a new well or completing an old well), the amount of hours worked often extends beyond the maximum 12 hours per day standard as set by the Workers's Compensation Board of Alberta.

The sheer number of hours worked in a two week period connotes worker fatigue. Even one 12 hour shift may represent an insurmountable period of time if the workload on the rig has been abnormally high, if the weather conditions and temperatures have been severe, or if there has been a high degree of worker turnover, causing rig crews to work short-handed. If these or other common types of work conditions persist, and problems at the rig eliminate the opportunity for any type of coffee or relaxation break from work, maintenance of a high degree of alertness and attention to the problem situation for the entire 12 hour period is unlikely and uncertain. Correspondingly, the potential for human failure is increased.
The Canadian Association of Oilwell Drilling Contractors (CAODC), a representative body of approximately 100 drilling contractor companies in Canada that establishes and requests voluntary compliance to drilling standards as well as wage rates for righands, examined the 12 hour shifts as a factor in worker accidents (Maclean's November 12, 1979, p. 35). The CAODC proposed that 8 hour shifts should be worked on rigs, whenever possible, to reduce worker fatigue as an influence to employee accidents and deaths. When the drilling industry slump occurred, 8 hour shifts became the norm. Shorter shifts meant drilling companies could employ more of their workers (i.e. 4 crews instead of 3), and less overtime would have to be paid. However as the demand for drilling rigs increased again, the limited supply of experienced workers re-established the need for 12 hour shifts.

Righands vehemently oppose the shorter 8 hour shifts, especially when the rig is drilling in a remote area. Less hours at work mean more time is spent in camp, work cycles become 3 weeks on and 1 week off, and less money is earned. The situation is paradoxical in one sense; 12 hour shifts have negative causative effects but it is what rig employees desire.
Individual Attention to Task

While revelation of the inadequacies of the physical work environment on drilling rigs reveals the danger and constraints placed upon the righand, the content and amount of employee attention to the individual tasks performed in the workplace accounts for the fourth influence to human failure. When a well control problem arises or an equipment malfunction occurs, unless each concerned rig employee is knowledgeable in the tasks required of him in order to deal with the problem, or the necessary information is communicated effectively to him, the importance and degree of attention attached to the task may be insufficient to effectively respond to, and rectify the situation.

The immediacy of the task requirement will determine the amount of initiative the righand focusses on the problem. If the circumstances are a routine occurrence like a suspected washed valve in the mud circulation pump, a level of repetition and monotony may hinder the employee from looking for non-routine problems with the pump like a broken valve spring, and consequently the pump will not be repaired correctly. On the other hand, if a rig employee has never experienced an actual well control problem before, and training has been inadequate, human failure may occur quite easily. An infrequently performed task, suddenly required, does not always leave time for practise and memory
search. For example, if a motorman must manually bleed off the shut-in well pressure through the choke manifold, but has never actually done this before, inadvertently an error may be made. This causes the casing pressure to be exceeded, thereby rupturing the downhole geological formation and causing a series of subsequent well control problems.

The responsibility for diligent attention to the content of a specific task does not rest entirely with the righthand assigned its responsibility. The degree of concern expressed by management personnel to the task will influence the manner the rig employee approaches the problem. If concern is apparent, an employee wishing to fulfill his job responsibilities and impress upon the foreman that he is a good 'hand,' will perform the work in earnest. However if supervisory concern is not apparent, worker attitude may be similarly neglectful. On the other hand, if a driller as the supervisor of the on-shift crew, is over-assigning the amount of work he wishes to be performed in a 12 hour shift (i.e. referred to as a 'shit-list'), then the technical detail required of many jobs may be foregone so that completion of all the tasks is possible.

If human failure on sour gas well drilling rigs is attributed to a righthand's ignorance or a poor memory in how to correctly perform, what is implied is that righands are
not motivated to learn, to remember, to refresh themselves, or to really try to do a task the right way. However, individual motivation is sometimes very difficult to maintain in an industry like sour gas well drilling where operations are often continuously conducted for long periods of time without a well control incident. The boredom and complacency that grows out of this type of employment can lull even the most well-intended righand into mishaps.

As will be discussed more thoroughly in subsequent work situation characteristics, additional extenuating circumstances can influence the efficient performance of a righand and consequently an employee's attention to specific tasks.

**Individual Characteristics**

The fifth characteristic of work on a sour gas drilling rig deemed to be very closely related to the occurrence of human failure is consideration of the physical and mental makeup of those individuals employed at the rig. These traits can be examined in two ways; those characteristics needed under normal working conditions and those that may be present under abnormal circumstances. If the demands of either situation require more physical ability or mental strength than the individual possesses, human failure leading to accidents will develop.

One of the most obvious individual characteristics required by a righand is the physical ability to perform the
labour-intensive role of his job, day after day. In addition to physical strength, stamina, and agility, a righthand must possess good vision and hearing and be free of health impairments like a poor heart. The necessity of such characteristics would tend to imply that righthands be young and physically fit; but often employees are the opposite. Medical examinations, check-ups and health standards are not a part of the employment process on drilling rigs. As a result, the physical limitations and exhaustion point of many righthands is approached during routine operations, creating possibilities for human failure to occur when task demands of the work situation extend to abnormal physical requirements.

Approximately 65 per cent of the righthands currently employed on sour gas well drilling rigs began their oil patch careers prior to, or during, the drilling boom of the late 1970s and early 1980s (personal estimate). These workers have become experienced employees and form the core of the sour gas drilling industry. The remaining righthands in the industry have either been absent from rigs for a number of years or are new entrants to the drilling workforce. This element of inexperience on sour gas wells breeds uncertainty and becomes more crucial to the safe operating efficiency of sour gas wells when there is an unusually high degree of inexperienced workers on the rig.
Since well control problems can only be avoided and solved by individuals who are familiar in the precautions to be taken, and competent in the application of the correct procedures, the length of experience working directly on sour gas drilling rigs is a critical individual characteristic to consider when examining the possibility of human failure. More specifically perhaps, is the need to ascertain the number of years the righand has worked for the drilling contractor in question, or on the drilling rig under consideration. Loyalty biases to particular drilling companies are prevalent among righands and can influence the degree of initiative, conscientiousness, and dependability an employee possesses. Similarly, although all drilling rigs are basically the same structurally, every rig possesses its own particular equipment and mechanical intricacies. Unless a righand is aware of and familiar with the peculiarities of the rig, human failure mistakes can easily occur.

Some experts in the sour gas industry assert that any lack of experience or incomplete knowledge by righands can be supplemented and made better by:

... enhancing the qualifications of existing crews through training and preparation to ensure they are totally familiar with safe drilling procedures. (Blowout Prevention Review Committee, July, 1984).
However, once training to cover skill deficiencies is completed, there still remains the significance of a rig employee's mental attitude to his work, which in turn depends upon the extent and type of external and internal influences acting upon the individual.

Whether the right-hand is lazy, unhappy, excitable, easily distractable, impulsive, irritable, anxious or complacent, will determine the personal stability of the individual and his mental ability to successfully detect problem situations and exert an influence upon them. If a right-hand has personal problems and is constantly occupied with these concerns, his ability to concentrate on the demands of his job are impaired. Missing a wife, son, or girlfriend, or just the normal everyday things that the rest of society takes for granted (i.e. seeing different faces), can make a routine occurrence of getting mud splashed in the face at minus 30 degrees Celsius, just too much to take. Under such stressful working conditions, positive worker attitude may deteriorate, and unless motivated, lead to complacent work habits. Crew member turnover on drilling rigs has previously been, and continues to be very high for these reasons.

When the individual characteristics of right-hands are stressed with the actual occurrence of a well control problem, the uncertainty of human failure rests entirely
with how well an employee can perform under unfamiliar and potentially dangerous conditions. Bercha (1983, p. 31) describes the situation,

Although, in principle, the concept of well control is relatively simple, its implementation is carried out through a relatively sophisticated and complex series of procedures. The natural forces involved in the process are of extremely high magnitude—phenomena occur relatively quickly by comparison to human reflex periods, especially in operations that are carried out in a hostile environment of extremes in summer and winter temperatures by crews that are away from their homes and families for extended periods of time working on a rotating shift basis in a relatively uninteresting social setting.

A recent personal experience confirms the power of situational characteristics to influence the response to a well control problem. The incident is an example of how mental stress can cause even experienced and knowledgeable drilling personnel to misinterpret the content of a problem situation. Although the incorrect action did not prove to be of a serious nature, the incident exemplifies how easily human failure mistakes can occur.

The drilling contractor company to whom this incident refers, had in 1983 won the Canadian Association of Oilwell Drilling Contractors award for the best safety performance of drilling companies with 12 or more rigs (Oilweek, June 23, 1984, p. 20). The drilling rig crew members were very experienced with sour gas wells and the two oil company
drilling engineers that were managing the well, possessed over 60 years combined experience in the Alberta oil and gas industry.

The well was being drilled to a depth of approximately 4000 meters with an expected $\text{H}_2\text{S}$ content over 50 per cent. Since the well was located near a rural population, the well was classed 'critical.' At one point earlier in the well, a highly unusual underground fire had melted the drill pipe string. The well was obviously very dangerous and had gained the respect of management personnel. Concern for well safety was paramount. However because nerves were so keyed up to react immediately and positively to any indication of a well control problem, when an incident did occur, response was overreactive and what was initially identified as a problem, was really not a problem at all.

While drill pipe was being tripped out of the well, the driller was periodically performing the routine practice of keeping the hole full of mud by turning the hole fill pump off and on. A lapse in concentration caused the driller to forget to turn off the pump and mud was soon observed flowing from well. Management personnel were summoned and immediately assumed a kick was occurring. What ensued was 3 to 4 minutes of excitable confusion. The actual reason for the well flowing, detected after the 3 to 4 minute period had elapsed, was that the mud being pumped into the hole was
in excess of what was required. Consequently, the hole fill pump was shut off.

How well individual rig employees react to the physical and mental influences created by the work condition characteristics of a sour gas well underlies the uncertainty of human failure in successfully drilling a well. It is a wild card factor that always exists. Because sour gas blowouts occur so seldom, most righands and many drilling engineers have never experienced a serious well control situation before. Furthermore, the question of whether a righand would actually remain working on the rig for $12 per hour when their health and safety is at risk to exposure of \( \text{H}_2\text{S} \), remains unanswered.

In summation, while some individual characteristics may be enhanced through continued work exposure, training and from any experience gained from rare problem situations, individual reactions to workplace conditions on a drilling rig are unpredictable, and are therefore vulnerable to human error mistakes.

**Social Environment**

Apart from the physical and individual influences to human failure on drilling rigs, the sixth work situation characteristic which exists as a force having a psychological effect on employee performance is the social
environment in which righands must work and live. To appreciate the relevance of this characteristic to the safe operation of the well, the understanding of how individual rig employees function as components of the larger social group on the drilling rig must be conveyed. The social arrangement and interaction of all individuals within the group determines the social quality of life on a sour gas well drilling rig and its connection to human failure.

Individuals are lured to work on drilling rigs because of the illusion of high wages that drilling rig employees are paid. While righands were comparatively well paid 5 to 10 ten years ago, the unstable nature of the drilling industry in recent years has resulted in very modest hourly wage increases (i.e. two 5 percent increases in 5 years). An average net income for a righand is approximately $2200 per month. There are no shift differentials paid and overtime is paid at a rate of time and one half after 44 regular hours in a one week period. More interesting perhaps, is the absence of any type of financial benefit or incentive for working on sour gas wells. In essence, the wages a righand earns are a small sum in comparison to other industrial occupations and in terms of the long hours worked in dangerous and extreme conditions.

An article in Macleans, (November 12, 1979, p. 35) entitled "A Hell of a Way to Earn a Living" described
drilling rig crew members as the modern day equivalent of yesterday's cowboy. . . .

lean, tough, independent young men who work hard and live hard and are mysteriously attracted to one of the world's most romantic occupations of petroleum exploration.

In reality however, experienced righands are as normal as everyone else, working hard at a job and trying to make a living. Burdened by family obligations in an uncertain economic and employment climate, most rig employees feel they are locked into their work on rigs. Due to a lack of education, a lack of relevant experience in another occupation, or the fear of not being able to find a job that pays the same amount of money, righands see no viable alternatives to turn to. Few workers are willing to change their jobs or even risk being fired for speaking out about workplace conditions. For many, working on a rig becomes routine. Faulty equipment, poor working conditions, danger and insensitive management practices are accepted as inherent aspects of the job. Subsequently, righands lapse into attitudes of resigned compliance and passive adoption to workplace conditions conducive to risks. In doing so, righands make the necessary personal accommodations to conditions they have little chance of changing.

Despite its long history in Alberta, working on a
drilling rig is still not an officially registered trade. Although there exists a government-industry drilling rig training school located in Edmonton, Alberta, attendance is not required to obtain employment on a rig. While mechanical aptitude, a substantial level of intelligence, and motivation exist as essential requirements of the positions on a drilling rig, there is no apprenticeship training program affiliated with the drilling industry. There are no certificates issued for any of the jobs even though competency in repairs varies from small electrical motors to propane furnaces in camp, the steam generating boiler, pipefitting and plumbing, repairing the ballasts in fluorescent lights and numerous mechanical repairs.

Because of the nature of oil and gas well drilling activity, work locations are shifted regularly, and oil companies employ short term drilling contractors, making the possibility of organizing any type of worker union very difficult. In fact, only one drilling rig crew union has ever been formed in Canada (i.e. the Seafarers International Union successfully organized an union on an offshore rig off the coast of Newfoundland in the summer of 1985). Oil companies fear the notion of unions because the threat of work stoppages places their objective of drilling a well uninterrupted to total depth and making the well producible, in jeopardy.
Since righands do not possess the option of turning to an umbrella group to protect their best interests, there are no union contracts, no seniority rules, no job security, no grievance procedures, and very few promotions. In effect, the social quality of the work situation is dictated by the management philosophy practised by the senior personnel at the rig site, the drilling engineer and the tool push.

The different occupational roles on a drilling rig express the relationship between the management positions and those righands employed under them. In one sense, the roles are related to tasks which are related to each other. For example, even though righands are typically excluded from the decision making process on a rig, they are responsible in most instances, for physically carrying out the actions required of those decisions. In another sense however, the occupational roles clearly differentiate the social standing of each individual in the confined drilling rig community.

The successful drilling of a sour gas well depends critically upon a coordinated teamwork approach, working towards a common goal. Therefore employees must function and interact as a tightly knit unit. If the management approach practised at the well site is professional with regard for rig employees as individuals as well as workers, a positive social atmosphere will prevail on the rig. On
the other hand, if the rig managers are authoritarian with little regard to righands as people, a mood of anxiety and uneasiness is created and the social interrelations on the rig are tense. Any degree of social friction between supervisory personnel and the rig employees could represent a disruptive influence to the safe, efficient operation of the sour gas well.

While the two senior bosses at the rigsite will be the major determinents of the social quality of life for rig employees, additional social interaction problems are evident. The selection of employees to work on the drilling crews is based entirely on factors of availability and experience. Medical histories, family stability, education, criminal records, and social compatibility are not viewed as important hiring criteria. As a result, the majority of drilling rig crews consist of individuals from very diverse backgrounds and a melting pot of personalites. For example a typical crew may include two farmers from Saskatchewan, a motorcycle club member from Red Deer, a city guy from Vancouver, a roughneck from Newfoundland and an inexperienced 18 year old with a grade eight education.

While the sharing of a common work experience often forms an impermeable bond among righands, the difficulties posed by the integration of very different individuals into a close working unit sometimes results in a lack of
cohesiveness and social stability within the group. For example, the roughneck from Newfoundland may become the subject of ridicule and practical jokes, and the city slicker from Vancouver, unpopular to the extent that he is kept uninformed of the changing conditions of the drilling process. Unless righand feels he is part of the crew, his 'alignment' to the organizational goals of safely and successfully drilling the well may be distorted. Existence of personality conflicts may eventually lead to poor work attitudes and avoidance work habits. The incompatibility situation is stressed further when the drilling rig crew members work under the continual threat of being 'run off' or fired by the senior member of the drilling crew, the driller.

On occasion, the sour gas well may be drilled near an urban area, enabling the rig employees to commute each day to work. When this is possible, whatever the social atmosphere at the rig, employment can be tolerated because the righands have daily access to the 'real world.' The situation is enhanced when the employees are returning to their homes and families each day rather than a motel room. In many instances however, the well is drilled in a remote, desolate area where a camp of modular trailers is assembled to accommodate the rig employees. In effect, a self-sustaining community that provides facilities for working, eating and sleeping, is established.
Life in the typical drilling rig camp can be described as boring and monotonous, a repetition of sameness. Outside communication can only be established by radio phone, there are no daily newspapers and no mail deliveries. Unless an employee is seriously injured, a rig-hand in an isolated camp situation is implicitly locked into the well's proximity for the duration of his two week work cycle. This is especially true when the only transportation available is by air.

While some camps may provide superior recreational facilities like a satellite television, a pool table or a sauna, the norm is an ordinary television and a shuffleboard.

Because each day is a work day, they all become the same. The days of the week are not referred to as Monday, Tuesday, Wednesday, but by numbers, representing the number of days left before you go home. Even though a rig-hand spends two-thirds of his life in camps while employed on rigs, the situation never becomes an accepted, comfortable feeling. The employee's desires extend beyond the work and camp situation. When extenuating circumstances magnify the difficulty of coping with the social environment, especially if the rig's management approach is the most negative influence, the possibility of social discontent contributing to human failure is ripe with opportunities.

The consequences of a negative social setting on a sour gas rig should not be discounted, for to do so would be to
oversimplify the complexities of sour gas well drilling, and to deny the value of personal experience as relevant data in ascertaining the influences to human failure.

MANAGEMENT APPROACH

The seventh work situation characteristic on drilling rigs that is influential in contributing to human failure is the inadequacies of the human management approach to drilling rig employees. It is an approach that has been around as long as the industry and is aptly described in a portion of Scott's (1974) *Muscle and Blood* entitled "Oil Dealing with Men as Cattle." Probably no other management approach in Canada is as archaic as what is sometimes found in the drilling industry. To some, such assertions may appear outrageous, but in a thorough examination of the work situation characteristics influencing human failure, such considerations are an absolute necessity.

Disputes over occupational risk obviously divide labour and management, the traditional adversaries in the workplace. Their approaches to risk on a drilling rig reflect their economic interests; the drilling engineer and toolpush in ensuring the well is drilled as inexpensively, quickly and successfully as possible, and the righands in ensuring they do not get hurt, killed or fired. Identifying
faulty equipment, poor worker-manager relationships and inefficient work procedures can impose costs, allocating responsibility to the oil company or the drilling contractor to buy new parts and equipment, increase training, and to improve the work situation. By relying upon the most up-to-date drilling equipment and procedures, attention to the human resources management problem on drilling rigs is seen as either non-existent or secondary to the technical prevention of blowouts.

Drilling a sour gas well can be an expensive endeavour, sometimes costing up to $1 million depending on the depth of the well and any problems encountered. Time is of the essence in reducing costs. Consequently management's hurry-up attitude prevails on the rig. While the on-site managers are responsible for the successful day to day progress of the well, to the oil company executives sitting in downtown Calgary, the rig site managers are their rig hands. When things go wrong with the drilling, the head office holds them responsible. Ultimately however, the buck stops with the real rig hands, the drilling crew members.

While most other industrial occupations in Canada have received increased managerial attention in recent years, with the intent by improving the worker's situation, productivity will be increased, the oil and gas well drilling industry has been noticeably absent of innovative
practices. Good equipment, technical knowledge and hard workers remain the only ingredient thought to be necessary to successfully drill a well. If any of the components are deficient, they can be easily replaced. This type of managerial attitude is basic to the drilling industry.

One of the more popular mottos in the drilling industry is 'every rig needs a roughneck.' However the industry's need for roughnecks is not out of the respect for the knowledge and skill of the individual, but for the brawn and perseverance of the employee. Righands are seen as easily expendable and replaced by most rig managers because "ten more men are always waiting at the end of the cat walk for a job." Failure to recognize righands as professionals, as experienced and competent oil and gas industry employees, and treat them accordingly, has led to an implicit resentment felt by righands throughout the industry. In the real world, a company without a genuine concern for its employees first is a company absent of happy, motivated and dedicated workers engaged in a positive work environment.

The managers at the rig site, the oil company's drilling foreman and the toolpusher, are seasoned veterans of the oil patch, and most often, began their careers as roughnecks. They are usually very competent and knowledgeable about the technical aspect of drilling a well, but are not in tune with current innovative worker-manager
techniques. They assume total control of the rig's activities, although some responsibility is delegated to the drillers of each crew. In attempting to successfully drill "their well", the managerial approaches employed by these individuals may violate current Canadian labor law regulations and fair treatment to righands as people, provoking disrespect, discontent, distrust and inattentive worker attitudes, with the ultimate potential of inducing an action or behavior which could result in a well control problem. The type of manager-worker relationship I am referring to is certainly not representative of every drilling rig in Alberta, but in my exposure to the industry was experienced more than once.

To illustrate, I will refer to some management tactics practiced while I was employed on various sour gas wells in the past six years. The incidents are representative of extreme instances of worker abuse, but are also indicative of the general atmosphere sometimes common on sour gas drilling rigs.

A well that was drilled during the winter of 1982, when the drilling industry was very flat, remains to be one of my most vivid recollections of poor human resources management. The willingness of employees to remain in the negative conditions of this drilling rig reflected the righands' sense of limited alternatives for employment
elsewhere. The drilling engineer, in a very distorted manner, also detected the rig employees' precarious position.

This individual assumed complete dictatorial control of the isolated wellsite; he stalked the rig like a bear searching for food, verbally abusing and mentally punishing righands for their apparent mistakes, for their perceived tardiness or their incompetency. Threats of being fired were frequent. In one instance, while rigging up, prior to the establishment of the heating system on the rig, employees were forced to eat their noon meal outside in sub-20 Celsius weather, after having worked 18 hours the previous day. The drilling engineer, on the other hand, drove the short distance to the warm camp to eat his dinner. Due to the mood of tension and resentment that was prevalent on the rig, a sporadic turnover rate and a very high incidence of worker accidents occurred while the well was being drilled.

The mood was finally broken when the barking engineer fell from a suspended platform, while bellowing orders to a derrickman trying to open a frozen mud tank compartment door. The drilling engineer suffered injuries that disabled him for 3 months and in a cynical way this relieved the pressure cooker atmosphere on the drilling rig.

Two years later however, the same drilling engineer was
the target of a drilling rig crew mutiny as a result of his inappropriate use of authority. Resolution of the problem resulted in the driller, not the drilling engineer, being fired.

On another well drilled in the summer of 1980 near a small urban municipality, numerous problems with alcohol abuse were common. Because the well was also doing a lot of tripping, and other jobs on other rigs were readily available, worker turnover was high. Being a new employee on the rig, I was exposed to a very unstable work environment.

The toolpush had a drinking problem and rarely made contact with crew members. One evening while running in approximately 14,000 feet of drillpipe back into the well, the drilling engineer returned to the rig from town, drunk. He 'relieved' the driller of control of the operational levers and exposed the righands to dangerous work conditions while tripping. He was a big man and no one said a word.

A third incident, on a well drilled in the spring of 1985, exemplifies how worthless and insignificant management sometimes regards rig employees. The worker in question was an experienced, reliable and dedicated employee who requested and received one week off from his regular work schedule. Near the end of the week, the temporary worker who had replaced the righand, was injured. To the toolpush,
the injury represented a possible dent in the rig's unblemished "lost-time accident" record. Rather than help the injured employee file for a week or two of workmen's compensation payments, the rig manager decided to fire the experienced worker who had taken a week off and retain the injured employee working on "light duty"; thereby maintaining the rig's accident-free record. In this instance, neither employee was viewed as an individual in need of employment or medical attention, but as a number in a very superficial system used by the industry to reflect how safe its operations are.

Not wishing to dwell on the negative, an incident which took place in the summer of 1982 reinforces the notion that management on a rig has the ability to exert a positive influence on righands. While 'rigging-out,' a drilling engineer, sensitive to workers' struggle of performing their work in a torrential rainfall and mud to their knees, suspended work for the remainder of the day while still paying the employees for the entire 12 hour shift. Unfortunately, this type of fair treatment to righands as people has not been so demonstratively displayed to me since.

One of the most widely read books on management, *In Search of Excellence* (Peters and Waterman, 1982), emphasizes that successful companies listen to their employees and
treat them like adults. Motivation through positive reinforcement is a key concept advocated throughout Peters and Waterman's treatise, (1982, p. 68,69)

It seems to us that central to the whole notion of managing is the superior/subordinate relationship, the idea of manager as "boss," and the corollary that orders will be issued and followed. Thus management's most significant output is getting others to shift attention in desirable directions. The threat of punishment is the principal implied power that underlies it all. In short, negative reinforcement will produce behavioral change, but often in strange, unpredictable, and undesirable ways. Repeated negative reinforcement is usually a dumb tactic; it doesn't work very well. The person who has been punished is not likely to be simply less inclined to behave in a given way; at best, he learns how to avoid negative feedback or punishment. Positive reinforcement, on the other hand, causes behavioural change too, but usually in the intended direction. It also teaches and in the process enhances an employee's image of himself and the company and manager he is working for.

Mamchur, an industrial psychologist, explains that,

An employee who is working under the ideal conditions produces so much more than an employee who is under stress. A person who expends much of his energy in anger and resentment against his employer will not do nearly as good a job. Further frustration and unhappiness may impair their ability to work effectively. (Vancouver Sun, November 22, 1985, p. B1)

But the reality of work on the drilling rigs is nothing like these human resources management prescriptions. All too often, depressing environments, repetitive work,
boredom, meanness, snobbery and sudden dismissals are evident at well sites. All too frequently, management's preoccupation of 'just get the job done,' wins out over concern for drilling rig crew members as persons. Righands see themselves as the ones having to bear the brunt of the sweat, skinned knuckles, and dirty mud that accompanies the successful completion of a well, but seldom get praised for their work. Instead their contact with management is usually based on negativities.

**Safety Training**

The eighth work situation characteristic capable of inducing a very negative effect on efficient human response to a well control problem is the deficiency of blowout prevention training for rig employees. The seriousness of this deficiency, when an actual well control problem occurs, may determine the difference in whether or not a blowout situation materializes.

Part of the deficiency can be easily traced to the industry's limited focus of attention for appropriate training. While a drilling engineer, toolpush and driller must undergo extensive well control training and examinations, the remaining members of the drilling crew are excluded. The rationale is that if management personnel are well educated, they can interpret and manage the situation,
and delegate tasks, usually of the physical nature, to crew members to successfully contain the well problem. The responsibilities of specific tasks for each rig employee in standard well control procedures are currently maintained with on-the-job training.

As evident in the previous seven work situation characteristics, management's persistence in failing to recognize righands as an integral part of the well drilling process or as potential valuable sources of knowledge and information on how sour gas wells may be more safely drilled, permits a discriminatory attitude problem to undermine the competency of the industry's entire well control safety program. To emphasize the significance of the lack of attention to righands, reference will be made below to a shift in attitude to workers engaged in other hazardous industries.

At a recent conference held in Vancouver, British Columbia, for major international corporations and government agencies involved in managing hazardous industries (Air Pollution Control Association, November 4-6, 1985), a common theme became apparent; that the strength to avoid major industrial accidents lies not with the government regulations or the corporate headquarters of the company involved in the activity, but in acknowledging the crucial role of the workers actually engaged in the work.
Richard Scherr, the Conference Program chairman, summed up the three days of discussion by stating,

... safety is a byproduct of quality and one of the greatest enemies to risky industries is the complacency of management to employees directly involved with the hazards.

Although dramatic accidents in hazardous industries continue to occur, a change in management attitude to recognize the need for input from the base employees engaged in the activity is a progressive step in decreasing the likelihood of accidents. For the American chemical industry, a key component of this recent change in attitude from a reliance on engineered systems and procedures to ensure the safe operation of its system, is the innovative approach of conducting safety audits at its plants (New York Times, November 26, 1985, p. 1). Audits consist of interviews with every employee working at the plant to determine where the real safety problems in the facility are located. If mistakes or potential faults in the safe operation of the facility are identified, a constructive means to share, transfer and communicate learning experience and develop safety programs can be made. Safety audits signify a participatory management approach to safety (Toronto Globe and Mail, February 24, 1986, p. B4).

Employee safety training for sour gas well blowouts on
the other hand, is absent from any major innovations. While the chemical industry advocates safety training to begin in the classroom and two week refresher courses yearly (New York Times, November 25, 1985, p. 10), employee training for sour gas blowouts is predominantly achieved in much the same method as fire drills are practised in public schools. While in theory, the 'blowout prevention drill' may appear to be a learning experience for righthands, it is a formality that is not taken serious enough.

Blowout drills are intended to serve as replication of real-life events with each crew member possessing a responsibility to fulfill, to counteract a supposed well control problem. During the course of a blowout drill, the crew members act out these responsibilities with the objective of becoming totally familiar with well control procedures. However, knowing how to play-act and reacting to an authentic well control problem are two entirely different issues.

The mandatory weekly blowout drills are often pre-arranged with crew members and as a result, everyone approximately knows when they will happen. A real blowout is not so generous with its warnings. The objective of a drill is for all crew members to quickly report to the driller and then go to their preassigned positions, just as they would in a real blowout situation. A good performance
is when the response time is less than a minute. Seldom is a righand queried any further about how he would respond to any of several various problem scenarios. Yet this type of knowledge is the key to the entire blowout prevention program.

An article in *Oilweek* (March 19, 1984, p. 9) commented how the experience and knowledge of drilling rig crews varies enormously from one rig to another.

Some crews are well versed in blowout prevention programs, while others are not well organized or well versed to any extent.

One experienced sour gas well drilling engineer toyed with the inadequacies of current blowout prevention drills by noting that even the horn warning signal for a blowout is inappropriate (conversation with Mr. Ron Purcell, January 3, 1985, Morley, Alberta). He felt a special alarm, and in areas on the rig where extreme noise was a factor, flashing lights, should be employed so that the rig employees realize when a real blowout is occurring.

Besides the practice of well blowout drills, the second most emphasized aspect of well control training for righands is on knowledge of the air breathing apparatus which is to be used in the event of a sour gas well blowout. Implicitly this is saying . . . "Here's your safety gear--we wear it when things go wrong."
Unlike most other industries training programs, common use of simulators to portray accident scenarios is not available to crew members, only the senior personnel on the rig. With simulation techniques, a righand could conceivably practice handling a blowout situation over and over. Consequences are illustrated when response tactics are inappropriate, thereby establishing the exact ramifications of each response action. Response becomes quicker and more accurate and in a real well control problem situation, a righand is apt to be calmer and less frightened because he has seen it all before. In lieu of simulation, a more basic well control course, consisting of films and an exam, is available to rig employees above the position of roughneck, but the course must be taken on the employee's own time.

The deficiencies in current blowout prevention techniques should obviously be examined with a more comprehensive commitment to decrease the likelihood of human failure mistakes, because a poorly trained righand possess neither the competence or confidence to effectively respond to a serious well control problem. However, the drilling industry has continued to emphasize specialized training for its engineers, toolpushers and drillers, and rudimentary instruction for the remaining drilling crew members. The need to ensure a continuity of competence with righands
implies the need for a change in well control training. Unless such a change occurs, the drilling industry's "band-aid" approach to blowout training will continue to represent a major deficiency in the manner sour gas wells are drilled.

In consideration of the eight work situation characteristics commonly found on drilling rigs, the possibility of negative influences causing human error to occur should be apparent. By neglecting these influences, one of the major problems with sour gas wells, human failure, remains. If workplace conditions were improved, human performance should improve, but because a right hand as an individual cannot be changed as easily, human failure remains unpredictable and uncertain.

3.4 Uncertainty of Toxicity and Other Health Effects of Hydrogen Sulphide

Due to the unpleasant, rotten egg smell of hydrogen sulphide that lingered throughout Alberta during the Lodgepole sour gas well blowout in the autumn of 1982, there is probably no odour more readily identifiable to the average individual in the province than that of $\text{H}_2\text{S}$. While hydrogen sulphide is irritating at low concentrations in air, its health effects are thought to be minimal (National Research Council, Subcommittee on Hydrogen Sulphide, 1979,
p. 47). In higher concentrations, a strong scientific basis has developed for linking exposure of H₂S to lethal effects of individuals (Burnett, 1977; Greenhill, 1978; Haggard, 1925; Roffman & Bender, 1975). However, data is incomplete and there is a great uncertainty in the probability and magnitude of health effects associated with a particular dosage and concentration of H₂S (Reid, 1977). The lack of knowledge of the precise health effects of H₂S increases its danger, and heightens the public's fear of sour gas blowouts.

Hydrogen sulphide occurs naturally in coal, natural gas, oil, volcanic gases, and sulphur springs and lakes (National Research Council, 1979, p. 1). It is also a product of the anaerobic decomposition of sulphur containing organic matter, such as in a manure pile. A major industrial source of hydrogen sulphide in addition to the petroleum industry, is the kraft process for producing chemical pulp from weed.

Hydrogen sulphide was first recognized as a threat to human health in the sewers of Paris late in the 18th century (Mitchell & Davenport, 1924). The quantitative relationships between parts per million concentrations of H₂S in the air and the nature and severity of systematic effects were initially reported in 1892 by Lehman. He experimentally exposed men to concentrations of H₂S ranging from 100 ppm to 500 ppm, which resulted in severe
poisoning. Some years later, in 1925 Sayers et al., exposed "some men" for short periods to low levels of H$_2$S in the air. They concluded that men could not be used safely as experimental subjects because of the possible injury to the lungs and the narrow margin between consciousness and unconsciousness. This inability to test direct effects of human exposure to H$_2$S, has limited the validity of results of toxicity studies.

Using dogs as experimental subjects, Haggard (1925) confirmed the earlier observations made by Lehman. Haggard identified the role of H$_2$S as a highly dangerous asphyxiant and clearly described its effects on the nervous control of respiration. According to Haggard, hydrogen sulphide exerts a direct paralyzing effect on the respiratory center. Breathing is never re-established spontaneously following this H$_2$S-induced paralysis of respiration, but because the heart continues to beat for several minutes after respiration has ceased, death from asphyxia can be prevented if artificial respiration is begun immediately, permitting pulmonary excretion of the gas. Victims of acute hydrogen sulphide poisoning (i.e. exposure to high concentrations) who recover usually do so promptly, but long-term effects remain uncertain.

In the United States between 1925 and 1930, several published reports called attention to the role of hydrogen
sulphide as an occupational hazard (Mitchell and Yant, 1925; Avbes, 1929; Yant, 1930). The authors of each report cited the introduction into the United States of high-sulphur Mexican crude oil as the cause of numerous cases of $\text{H}_2\text{S}$ poisoning among oil processing workers. Aves (1929) gave a vivid account of hydrogen sulphide poisoning in the Texas oil fields. He estimated that during a 2 year period, 15 to 30 deaths had occurred. Yant, (1930) confirmed that the most hazardous occupational source of hydrogen sulphide in the United States was the petroleum industry.

Acute hydrogen sulphide poisoning was not confined to an occupation-related problem. Occasionally, accidents involving community exposures had also been reported (National Research Council, 1979, p. 47). The most dramatic and serious of such events occurred in 1950 at Poza Rica, Mexico, a city of 22,000 citizens located approximately 210 kilometres northeast of Mexico City (McCabe & Clayton, 1952). An accidental 20 minute release of hydrogen sulphide in concentrations ranging from 1,000 ppm to 2,000 ppm from a sulphur recovery plant resulted in 320 people being hospitalized; 22 of them died. Today the Poza Rica plant continues to operate (Oil and Gas Journal, September 16, 1985, p. 117). Unlike Poza Rica however, $\text{H}_2\text{S}$ disasters involving large numbers of people are infrequent.
Nevertheless industrial accidents involving hydrogen sulphide continue to occur. The recent mishaps noted below reveal the prevalence and extent of the danger potential of hydrogen sulphide:

1. In February, 1985, corrosion caused a leak in a sour gas pipeline at Kobes Pumping Station on the Alaska Highway, north of Fort St. John, British Columbia. Five horses in the immediate area of the pipeline were killed instantaneously and nearly 40 Westcoast Transmission Co. Ltd., employees had to evacuate their homes (*Vancouver Sun*, February 7, 1985, p. A2).

2. In May, 1985, a random puff of toxic hydrogen sulphide that emitted from a pulp mill machine instantly killed a factory worker in Thurso, Quebec (*Toronto Globe and Mail*, May 9, 1985, p. 4).

3. In late October 1985, a storage tank leak at an Exxon plant in Bayway, New Jersey, spread dilute hydrogen sulphide over 600 square miles of a densely populated area. There were scores of complaints of a foul odour and numerous cases of nausea, but luckily no fatalities occurred as a result of the accident (*New York Times*, November 25, 1985, p.10).

In Alberta, even though the sour gas industry has been operating for over 60 years, there has never been a public fatality as a result of an accidental exposure to H$_2$S. However in the ten year period from 1975 to 1985, more than
20 individuals involved in some capacity in the industry have died (Calgary Herald, March 16, 1985, p. A12). In November, 1984, within a one week period, four sour gas related deaths occurred in three separate accidents in Alberta, involving oil company personnel performing routine maintenance on sour gas facilities (Calgary Herald, November 23, 1985, p. A1, 2). Unfortunately, the workers were not wearing air supply breathing equipment. The combination of danger exemplified by occupational deaths and the possibility of threats to public safety as a result of uncontrolled blowouts like Lodgepole, and more recently, a release at a producing well near the northern Albertan community of Rainbow Lake in December, 1985, has caused sour gas to become a serious public health concern.

Aggravating this concern is the limited understanding of toxicity of hydrogen sulphide. The basis of current medical knowledge relating exposure of H₂S to human health has been derived from:

1. Old experiments of small control groups observed under laboratory conditions;
2. Inferences from experimentation with animals;
3. Reports of low concentration, nuisance complaints from residents living near H₂S facilities; and,
4. High concentration exposures in the workplace.

Since much of the knowledge is old and mainly laboratory based, the toxic effects of H₂S on individuals
remain uncertain, debated, and very much a subject of research. For example, while the current safe occupational exposure limit for hydrogen sulphide is 10 ppm for an 8 hour period (World Health Organization, Geneva, 1981), the results of a study performed at the University of Alberta in Edmonton found that exposure of individuals to H₂S concentrations greater than 2 ppm in the workplace could lead to muscular fatigue, which could result in a drilling rig worker becoming more susceptible to human error (Bhambhani & Singh, 1985).

Despite such uncertainty, there appears to be some agreement that concentrations less than 100 ppm, although a definite irritant, do not constitute a spontaneous serious health risk, and concentrations greater than 500 ppm may be fatal (Whittaker, 1976). The magnitude of each health effect and the levels of exposure at which these effects begin, differ somewhat from expert to expert and study to study, and in the real world from individual to individual. Dr. G.H. Bonham, Calgary's medical officer of health, asserts that even less is known about long-term low level exposures of hydrogen sulphide on certain high risk sub-groups within the population (Toronto Globe and Mail, October 13, 1984, p. 8). These individuals may include pregnant women, young children, the aged and individuals with respiratory problems.
When the Lodgepole blowout occurred several residents within 18 miles of the uncontrolled release, complained of numerous ailments (i.e. headache, eye irritation, sore throat, nasal irritation, pain on deep inhalation, some shortness of breath, nausea and nosebleeds in children) (Lodgepole Blowout Report, 1984, p. 7.1-7.22). Although concentrations of the deadly hydrogen sulphide were only emitted for 26 days, since the well was on fire for 41 days, and never remained at levels likely to produce serious health problems, people as far away as Calgary, 120 miles to the south, had similar health effects. The oil company responsible for the blowout, Amoco Petroleum Ltd., maintained that these individual were victims of psychological illness caused by stress. The members of the Lodgepole Blowout Inquiry Panel rejected the notion of a mass psychological illness as unlikely, but concluded that without a base group to compare health effects to, there was no scientific basis to make any definitive conclusions regarding effects of the well's H$_2$S emissions on human health (Lodgepole Blowout Report, 1984, p. 12-3).

While sufficient information on the seriousness of specific concentrations of hydrogen sulphide to an individual is obviously lacking, attempting to predict the toxicity of H$_2$S to a person located away from the emission source is even less certain. The concentration of the H$_2$S
in the gas being released, the volume and rate of the
release, the dispersion effects of wind and weather
conditions on the gas cloud, as well as whether the receptor
is inside or outside, will determine the toxicity of the gas
at a certain location. Nonetheless, predictions of safe
ppm concentration distances from sour gas wells are made to
determine:
1. An evacuation zone around an occurring blowout, and
2. An emergency planning zone around a sour gas well to be
drilled (Lodgepole Blowout Report, 1984, p. 7.1-7.22)

The method practiced in Alberta to identify serious
hydrogen sulphide concentration levels at an occurring sour
gas well blowout is to monitor air samples in the vicinity
of the blowout. In the Lodgepole air monitoring program, an
evacuation plan for nearby residents was established whereby
individuals would be advised to leave when concentrations
reached 10 ppm for 8 hours, requested to leave when
concentrations reached 15 ppm, and required to leave when
the H$_2$S reached an average of 20 ppm in air (Lodgepole
Blowout Report, 1984, p. 7-6). The rationale for the
exposure limits was contained in a booklet of health
information on H$_2$S issued by the Blowout Inquiry:

- at 10 ppm or less, effects are short-term and
  reversible if they occur at all;
- at 20 ppm or above, eye inflammation occurs in many
people and in some cases, could be irreversible if exposure continues over a long period of time; and below 140 ppm, irritant effects are not generally fatal but may lead to irreversible tissue damage.

The air monitoring program has several inherent weaknesses in attempting to determine when a situation has reached a serious enough to human health to warrant evacuation. Evidence submitted at the Lodgepole Inquiry indicated that when high concentrations were identified, mobile monitors would converge on the area to ensure that monitoring was sufficient to identify any potential danger (Lodgepole Blowout Report, 1984, p. 7.7). However, waiting for a high ppm level to be recorded does not safeguard against short peak concentrations of $\text{H}_2\text{S}$ in a gas cloud that may be fatal, or the possibility of the wind suddenly changing. In addition, the thoroughness of the monitoring program is suspect in its ability to record all concentrations, everywhere.

To determine the emergency planning zone around a proposed sour gas well, a hypothetical worst case analysis of a blowout is used to estimate the maximum extremity of a 100 parts per million contour of sour gas. Predicting the 100 ppm boundary is dependent upon the validity of the data and the understanding of the mechanisms involved in a potential accident sequence. By employing simplifying
assumptions, subjective judgments and dispersion models, an emergency planning zone can be estimated, but such techniques inevitably introduce uncertainties into the analysis.

Because of the nature of a blowout situation, a cloud of toxic gas that forms after being released into the atmosphere by a tremendous subterranean force, and subsequently diffused and transported by atmospheric forces, formulation of the emergency plan is very dependent upon the results of the dispersion model. The dispersion model attempts to simulate reality. Since any sour gas well near a populated area that blows will be immediately ignited, the primary consideration for toxicity effects are the uncertain, short-term concentrations of hydrogen sulphide, which in turn depend on the amount of gas that was released prior to the flow being ignited.

The uncertainty of the toxicity and other related health effects of hydrogen sulphide creates a major influence in the manner the gas is perceived. Since little is known of its exact danger potential at various concentrations, and what concentrations nearby residents may be exposed to, sour gas is regarded with fear, respect and vacillation.
3.5 **Canadian Occidental's Application**

Crucial to understanding the risks of drilling a particular sour gas well is knowledge of case-specific information. The geology and history of previous wells drilled in the area, the financial standing of the oil company and the drilling contractor, the condition of the drilling rig and equipment, the time of year the well will be drilled, and the \( \text{H}_2\text{S} \) content in the gas are vital factors to consider in determining the likelihood of a subsequent well control problem. Also essential is an assessment of the quality of managerial attention to rig employees and blowout training. The purpose of this section is to assess Canadian Occidental's application in light of such problems and uncertainties, and as discussed earlier in the chapter.

Canadian Occidental, which is owned 48 percent by the Occidental Petroleum Corporation of Los Angeles, California, is a diversified energy and chemicals company with assets of over $1 billion (Canadian Occidental Petroleum Ltd., 1984 Annual Report, p. 1). Oil and gas operations include the exploration, development and production of conventional oil, gas and sulphur in Canada, the United States Gulf Coast and South America, as well as investments in heavy oil development in northern Alberta. While not yet possessing a stature comparable to the major oil companies, William Ashly, an investment manager from Toronto, chose CanOxy as
one of the most favoured petroleum stocks to buy in 1985-86 (The Financial Post, December 7, 1985, p. 25).

Because of its expanding growth potential, CanOxy possesses a very strong financial incentive and commitment to conduct its operations successfully and safely, thereby avoiding potential liability lawsuits that may accrue from an accident like a sour gas well blowout. Because of the close proximity of residents in northeast Calgary to the proposed wells, the oil company also possess moral, legal and social obligations to prevent a blowout. With increased regulation and scrutiny focussed on the sour gas well drilling industry in Alberta, CanOxy has little choice but to drill the well with the most extreme caution.

Canadian Occidental is very experienced with sour gas wells in the Crossfield field, adjacent to northeast Calgary, having successfully drilled over 60 wells since operations began in 1961 (Crossfield Wabamum A Pool Development Plan, Canadian Occidental Petroleum Ltd., Calgary, Alberta, June, 1984, p. 2; hereafter referred to as Wabamum Development Plan). The company's close contact with the sour gas reserves provides it with immense amount knowledge of the underground geological formations and the type of equipment and technology that is necessary to safely drill sour gas wells.

One of the primary reasons why Canadian Occidental has never encountered serious well control problems in the
Crossfield field is the characteristics of the geological zone where the sour gas is located. The Crossfield formation, located at an approximate depth of 2,800 metres for the original well application, is the primary target for the new proposed wells (Canadian Occidental Petroleum Ltd., Drilling Plan, June, 1984, p. 1). The pores of this formation that hold the sour gas are said to be so tightly compressed that no significant well flow has usually occurred in the development of any previous wells, until the well has been chemically stimulated with nitrified acid to make it productive (Wabamum Development Plan, 1984, p. 17).

In other words, unlike the Lodgepole well, which was characterized by a high pressure, porous, sour gas formation, the geology of the area outside northeast Calgary is not as prone to sudden influxes of gas and well blowouts.

Canadian Occidental's impeccable safety record of successfully drilling over 5 dozen wells in the previous 25 years appears to confirm the oil company's expertise in, and control over, the sour gas field. However, upon closer examination of the geological history of the area, it is apparent that uncertainties remain. For example development of the southern portion of the Wabamum sour gas pool, where CanOxy is proposing to drill into, was stalled in 1965 when a well produced large quantities of water with the gas, and remedial attempts to resolve the problem were unsuccessful.
(Wabamum Development Plan, 1984, p. 2). In 1982, during the same time the Lodgepole blowout was occurring, a well located approximately 900 meters east of northeast Calgary, was successfully drilled on a westward angle to the fringe of the City. However, the well experienced a "relatively high bottom hole pressure" (Wabamum Development Plan, 1984, p. 2). While Canadian Occidental frequently mentions that the Crossfield zone requires stimulation with acid before the reservoir fluids can be expected to flow, others point to a well drilled in 1968 into the same geological formation near Hinton, Alberta (i.e. approximately 350 kilometers northwest of Calgary) (Environment Views, November, December, 1984, p. 27). This well experienced a blowout.

Another concern with the geological characteristics of the proposed wells is the relatively high H$_2$S content of 31 per cent expected in the sour gas. While Canadian Occidental operates other wells in the area with the same H$_2$S concentration, and in other wells with substantially less, a high H$_2$S content in a well implies increased danger if an accident should occur.

The drilling plan CanOxy intends to use in the wells will be developed from the practices and procedures successfully employed in the area's previous wells. After several requests of revision and upgrading by the regulator of the sour gas industry, the ERCB, CanOxy has addressed all
technical requirements of sour service specification for the
critical drilling equipment and procedures for BOP and
manifold testing (telephone conversation with Mr. Arley
Cocks, Senior Safety Coordinator, Canadian Occidental
Petroleum Ltd., May 9 1985). As a substantial history of
reservoir pressure data is available, the drilling fluid
programs will also be similar to those used on previous
wells.

Since the proposed new well is to be located another
900 meters east of the well drilled in 1982, and the
targeted formation remains the southern end of the Wabamum
Pool, beneath the City of Calgary, the well will have to be
directionally drilled at an increased angle and depth. Both
factors increase the risk of a well control problem. With
potential deviation problems in mind, extensive down-hole
surveys will be performed to maintain the required angle in
the well. However, unless a new computerized downhole
survey unit is used, the drill pipe may get "stuck" in the
hole as a result of a lack of movement in the drill string
as the manual wireline survey is being performed. In
addition, because directional drilling causes the drillpipe
to rub against the sides of the well, CanOxy will also
include in its application, a procedure to monitor casing
wear. In general terms, the drilling plan is designed to
achieve a high level of technical expertise to safely drill
the well.
It is anticipated that if a well licence is issued, the drilling rig to be utilized will be a National 610 mechanically powered drilling rig owned by Arrowhead Drilling Ltd. (letter from CanOxy to ERCB, May, 1984, p. 5). Arrowhead has been drilling wells in Alberta for approximately 6 years, with experience of successfully drilling 25 sour gas wells near Calgary (Canadian Occidental, Drilling Plan, 1984, p. 3). The company's equipment is therefore relatively new, and less susceptible to fatigue and failure, especially as a result of \( \text{H}_2\text{S} \) corrosion. It is a company characterized by "good iron" rather than "junk." Arrowhead Drilling is very selective in the hiring of new employees and maintains a policy of attempting to retain experienced personnel (personal work experience with Arrowhead Drilling, June, 1984). Arrowhead also employs a full time Manager of Training and Safety. In the period 1980 to 1984, Arrowhead won the CAODC safety award three times for the least amount of lost-time worker accidents with drilling companies that operate 6 or fewer rigs.

While Arrowhead's experience in drilling sour gas wells in the Crossfield field, the reliability of its equipment and selective hiring policy are positive attributes in consideration of the well proposals, the company, like most other drilling contractors in the sour gas industry,
possesses an inferior well control training program. In response to a letter from the ERCB requesting more information on employee training, CanOxy stated,

The level of supervision and training of all personnel employed on the proposed well will meet or exceed the ERCB guidelines respecting prevention of blowouts at sour gas wells. (May 10, 1984, p. 6)

In compliance to ERCB guidelines, Arrowhead maintains very high training standards for its rig managers and drillers, but the remaining drilling crew members are limited to "in-house H$_2$S awareness training" and "on-the-spot training" before drilling into a suspected H$_2$S bearing zone (Arrowhead Drilling Ltd., Training and Safety Program, 1984, p. 2). Well control training for all rig employees is supplemented by "... frequent BOP drills until crews are familiar with kick indications and control." While some crew members may actually possess additional training qualifications, these are usually acquired on the employees own initiative, not as a result of a concern by Arrowhead or the ERCB for high personnel training standards. Section 3.3 revealed the flaws in this type of approach to well control training.

The inadequacy of ERCB guidelines respecting well control training is reflective of the inadequacy of the sour gas industry's human resources management approach to rig
employees. Unless the drilling rig's work situation characteristics, that have been previously established as influencing human failure, are also recognized and accorded a similar type of examination in Canadian Occidental's application as is the drilling equipment, the well's geology and the oil company's expertise in drilling sour gas wells, then an understanding of the possible factors which may induce well control problems to occur, will not be complete.

For example, while Arrowhead usually employs its workers on 12 hour rotating shifts, the rig hands are paid one dollar less per hour than the CAODC wage guidelines, and are also short changed on the number of overtime hours by the manner the pay periods are scheduled (personal work experience with Arrowhead). Whether or not the discrepancy in the wages paid to Arrowhead employees in comparison to the higher hourly rates paid to other rig hands with other drilling companies, bears a negative influence on the manner a worker performs his job, is indicative of the type of uncertainty that is contained in CanOxy's proposal.

Reliance upon technical preventative action to reduce the frequency of blowouts fails to anticipate and recognize the possible ways in which human error may contribute to the occurrence of a well control problem, and inevitably causes the risks of the application to be underestimated and mis-managed.
Since Canadian Occidental has met the ERCB's technical requirements to successfully drill the well, the major regulatory obstacle yet to be resolved in gaining approval for the wells, is the establishment of an "air-tight" emergency response plan to accommodate approximately 70,000 residents of northeast Calgary, in the unlikely event of a sour gas blowout (Calgary Herald, November 4, 1984, p. C1). The primary purpose of emergency response planning is to ensure the protection of the public. Two major components of this uncertainty, ignition of the gas well to burn off the poisonous sour gas and possible evacuation of City residents, will be discussed below.

Ignition

The four closest wells to the proposed location have an H₂S content in the gas of approximately 31 percent (Wabamum Development Plan, Table 1, 1984), therefore by geological analogy, the expected H₂S content in the proposed wells is expected to be similar. Near the well site, if an uncontrolled release occurs, there could be poisonous concentrations as high as 310,000 parts per million (ppm) released, as compared to the above 500 ppm dosage considered extremely dangerous. Even though sour gas disperses as it spreads from its source, a concentration of only 20 ppm is considered to be the level at which people should be
evacuated on an emergency basis because reaction time and judgment are influenced to the degree that efficient human response to a dangerous situation is not certain (Environment Views, 1984, p. 27).

While the possibility of a well blowout from CanOxy's proposed well is deemed to be very remote, it is crucial to public safety that means be provided to prevent a widespread dispersal of toxic hydrogen sulphide if a blowout does occur. To ensure this, the ERCB is of the opinion that the most crucial action to be taken to protect the safety of nearby residents is the immediate ignition of the well (ERCB Decision D84-28, p. 21). Upon ignition, the H$_2$S is converted into sulphur dioxide (SO$_2$), which will be diluted with air and combustion products, and lifted high into the atmosphere by thermal effects (Greenhill, 1978). Sulphur dioxide, like H$_2$S, is a highly toxic gas, but the effect of burning so increases its dispersion that the concentrations of SO$_2$ where the plume (i.e. gas cloud) touches the ground are far below the hazardous level (Bercha, 1985, p. 4.5).

Current operating rules call for the most senior person at the wellsite to fire the well, after H$_2$S readings of 70 parts per million or greater are recorded at the edge of the wellsite or beyond, or after all attempts to stop the blowout with the BOPs and mud pumps have failed, and all workers are off the rig and accounted for (Emergency
Response Plan, Canadian Occidental Petroleum Ltd.
Application No. 840421, December 21, 1984, p. 3). Practical concerns over this "immediate" ignition criteria relate to several questions.

If the well is not simultaneously ignited as the well begins to blow, toxic concentrations of $\text{H}_2\text{S}$ will be released and may represent potential threat to residents of northeast Calgary. Time is of the essence to ignite the well, rather than relying upon a shot-gun type of flare device, which is usually located in the drilling engineers's trailer, one to two minutes away from the well head, an automatic, continuous flame ignition device should be built into the derrick or atop the BOP stack assembly. If the sour gas being released will not burn, natural gas or fuel should be injected into the blowing stream of $\text{H}_2\text{S}$ to aid combustion. Since any interruptions in the burning of $\text{H}_2\text{S}$ poses additional risk to the health and safety of those individuals near the blowout site, continuous ignition is very practical.

The actual decision by the senior person at the wells site to pull the trigger or push the button to ignite the flow, comes under intense personal pressure. Firing the well admits defeat in attempts to successfully drill and control the well. The resulting fire damage to the well control equipment will also likely lengthen the amount of
time necessary to kill the blowout, since burning wells have only been successfully capped seven times in the world before. At the Lodgepole well, fire damage was so extensive that the entire drilling rig was lost at an estimated cost of $6.5 million (Calgary Herald, November 11, 1982, p. C1). The financial loss of released hydrocarbons would also be substantial.

Since the proposed well is in close proximity to the City of Calgary, the question of public safety must take precedent in any type of decision to ignite a sour gas blowout. However the element of uncertainty in whether the well will be immediately ignited and remain burning, distorts assurance of this action.

**Evacuation**

Even though, immediate ignition of a blowout is required on all critical sour gas wells (ERCB Decision D84-5, p. 10), evacuation of nearby residents would take place as an extra precaution because of their proximity to the well and uncertainties that always accompany emergencies (ERCB Decision D 84-28, p. 23). The area to be immediately evacuated if an uncontrolled release occurs with CanOxy's proposed wells is the emergency planning zone determined by a worst-case 100 ppm isopleth contour (Environment Protection Department, ERCB, May, 1984, p. 5). If the
release continues, the hazard area may have to be expanded, and the zone that has been evacuated must remain isolated until the well is fully under control or, if the well is ignited, until monitoring of SO$_2$ and other relevant information clearly demonstrates that there is no safety reason for keeping the area evacuated.

There are major criticisms of the manner the 100 ppm isopleth is determined. A worst case analysis incorporates extreme assumptions that have to simultaneously occur in order to calculate the boundaries of the isopleth. Those assumptions for a sour gas well are:

1. That a complete well failure occurs (i.e., not a leak or minor failure but a 100 per cent flow of sour gas as a result of a complete failure of all safety systems);
2. That the well is not ignited;
3. That atmospheric and weather conditions are worst case (i.e., the wind is blowing in the worst possible direction for all receptors and there is a minimum of dispersion); and,
4. That all of the people are outside their residences, thereby having maximum exposure.

Because the probability of all factors applying at the same time is extremely remote, the practicality of its use is limited.

When Canadian Occidental originally applied to drill a sour gas well adjacent to northeast Calgary in July, 1984,
the maximum extremity of the 100 ppm H₂S isopleth, based on an average of weather conditions, was the edge of the City's boundary (Refer to Map 7). When Bercha (1985) applied a worst case analysis with the most unfavourable weather conditions to CanOxy's proposal the 100 ppm contour extended within the City. In a letter from the ERCB to CanOxy, the adjudicator of the application stipulated that CanOxy's emergency plan must include, "... personal contact with all residents within 2.5 kilometers of the well to ensure they are completely familiar with the plan" (Calgary Herald, January 28, 1985, p.3). In other words, CanOxy had to communicate with approximately 70,000 people. It became apparent to Canadian Occidental that such a request would be enormously difficult to comply to; not only would the initial contact with every resident be difficult, but informing them about the emergency plan could create an entirely different set of concerns. As a result, the ERCB deferred the application.

Deferment of the application did not solve the sour gas problem near northeast Calgary and efforts to find a solution continued. In July, 1985, the ERCB agreed to fund a Task Force comprised of public, industry, and government representatives, and an independent consulting firm, Sage Institute, to specify the priority components of an acceptable emergency response plan for dealing with a potential sour gas incident (personal conversation with City
of Calgary alderman, Les Pears, July 19, 1985). By December, 1985, the Task Force released nine recommendations of further action in need of studies.

Dissatisfied with the progress of their application, in January, 1986, Canadian Occidental proposed to drill a new well further east from the original well location, to a point nearly 2 kilometers east of Calgary's city limits (Calgary Herald, January, 11, 1986, p. B2). However, relocation of the well from city residents did not ease the concern over the emergency response plan, or the fears of a sour gas blowout.

Currently, an independent environmental group from Eastern Canada not associated with the sour gas industry, is examining a "Realistic Worst Case Scenario" of an accident at CanOxy's proposed wells (Calgary Herald, February 22, 1986, p. A6). The study's objectives are to identify whether the setback distances from sour gas wells and pipelines are realistic, whether CanOxy's assessment of evacuation needs are accurate, and if Calgary's plans for public evacuation in the northeast part of the City are adequate. Clearly, such deficiencies reveal the extent of uncertainties that remain in the consideration of an effective emergency response plan for sour gas well blowouts.

The state of emergency response planning to sour gas well blowouts is characterized by a severe lack of firm
direction and guidelines, resulting in a lack of coordination and communication. In response to a recommendation of the Lodgepole Blowout Inquiry, a holistic emergency plan was prepared by Alberta Disaster Services to direct the provincial government's response to a sour gas release anywhere in Alberta (Calgary Herald, November 16, 1985, p. A5). The major problems with the plan are its vagueness and lack of detail. The ERCB defends the plan by claiming it is meant to be generic, intended only to describe the roles and responsibilities of each party that will respond to a sour gas well blowout. In a recent application of the plan, during a "mock" sour gas well blowout, it took five hours to simulate the evacuation of people from the area affected by the blowout, an area substantially less populated than northeast Calgary (Calgary Herald, February 25, 1986, p. D1).

The need for specific emergency response details in Canadian Occidental's situation is apparent. For example, Environment Canada defines immediate evacuation as within four minutes (The Financial Post Magazine, May 1, 1985, p. 28), yet the urban design of the "crescents, cul-de-sacs, and drives" of the residential subdivisions in northeast has limited the number of access roads from this area, and therefore prevents any type of evacuation in such a short period of time. The Chief of Calgary's Hazardous Goods
Division of the Fire Department, today as in a 1982 annexation proposal, continues to maintain that immediate evacuation of northeast Calgary is impossible (Calgary Herald, January 12, 1985, p. A10). Who will notify residents of the need to evacuate, how will they be transported if they don't have a vehicle, where will the evacuated residents flee to, especially if it is during a period of extreme winter temperatures or if a much larger portion of the City has to be evacuated?

Almost without exception, papers about emergency planning stress the importance of simplicity and flexibility. Planning must be in depth not detail; excellence not perfection should be the goal (Underhill et al., 1976). A further general principle which has arisen from sociological studies of disasters, is to plan according to how people will react, not plan and hope that people will conform to the plan (Dynes et al., 1972). Because few people can be expected to act or think clearly in the confusion and tragedy of a disaster situation like a sour gas well blowout, simplicity should be maintained as far as possible.

While the necessity of a sound, workable emergency response plan is obvious, amid such uncertainties, the most valuable type of emergency plan would be a plan that never has to be used.
3.6 Summary

Because of the nature of the oil and gas well drilling industry, uncertainties will always be present in every well; if they were not, oil and gas well operators would successfully find producible reserves every time they drilled a hole. In a weekly column of the Calgary Herald newspaper entitled "Oil Patch," the Herald's energy critic Gordon Jaremko underlined this uncertainty (Calgary Herald, December 23, 1984, p. A10) . . .

Despite all the fuss and antagonism over the 1982 Lodgepole blowout, the bottom line is still the same for the Energy Resources Conservation Board and the petroleum industry; drilling for oil and gas remains a risky business. The deposits are deep underground. What is there and how it will behave when hit by a drill bit is still a matter for educated guesswork—and mistakes are possible.

To manage the uncertainty of drilling sour gas wells, knowledge must be acquired, shared and understood. In understanding the uncertainties, the objective should not be to rely solely on geological analogy, or information from past events, or key the studies of the risk of sour gas on consequences, because ascertaining safety in terms of results is a reactive approach, and not on an effective way to determine if things are safe or not (New York Times, September 1, 1985, p. 5). Missing opportunities to identify and correct problems, as in the managerial attention to
human failure caused by work situation characteristics, before they cause well control problems, represents an ineffective manner of managing a risk problem. Mitroff and Kilmann (Emergency Prepared News, September 10, 1985, p. 144) warn that unless companies involved in hazardous industries learn to think differently, tragedies will continue, and . . .

NO COMPANY TODAY CAN AFFORD THE LUXURY OF BELIEVING THAT THE WORST WILL NOT HAPPEN TO IT

The next chapter will explain the analytic approach of risk analysis, a technique which attempts to quantify the uncertainties inherent in risky activities like sour gas well drilling.
CHAPTER 4

OBJECTIVE ANALYSES AND RELATED UNCERTAINTIES IN ASSESSING THE RISKS OF SOUR GAS

4.1 Introduction

The word 'risk' implies the potential for something negative to happen as a result of an uncertain event or activity. While the natural environment has continually imposed risks like earthquakes and floods on society, since World War II man's technical interaction with the environment and the rapid pace of progress in hazardous operations like the chemical processing industry and the generation of nuclear power, have created an array of additional threats to society.

As new technologies were introduced, the lack of knowledge in whether or not a threat would materialize, or a given system fail, elicited concern for the need to estimate and evaluate the risks inherent in the new operating systems. It is against this background of systems vulnerability, that the field of study of risk analysis grew. It reflected a response to understand the probability of a risky accident occurring.

Subsequently, the field of risk analysis became a veritable industry, engaging professionals versed in
objective methodologies. Seeking a 'rational' means to make decisions about hazardous technologies, risk analysis initially sought to establish a quantitative basis to predict the probability of a major accident occurring and later, the magnitude of its potential consequences as well. With the numerical estimates, one risk could be compared with another, their relative costs and benefits calculated and acceptance criteria assessed.

Quantitative risk analysis has not become an exact science. The data base for predicting probabilities of occurrence is shallow and the ability to determine consequences is clouded by uncertainties, assumptions and unknowns. The ideological frameworks that shape the risk analyst's definition of the problem, that filter their perceptions, guide their judgments and influence their responses, also distort the validity and objectivity of the risk estimates. As a result, the growth of formal risk analysis has been described as fragmented, with conflicting views and a lack of agreement between the public, the regulators of risk, and the risk researchers themselves (Johnston, 1979).

Despite the difficulties, complexities and uncertainties of quantitative risk analyses, the technique's usefulness is acknowledged in examining potentially dangerous facilities like sour gas wells. The
significance of its application however, lies not in isolation, but as an integral component of the larger risk management process.

This chapter will commence with a historical account of formal risk analysis, and proceed to the use of risk analysis as an applied field of research in the sour gas industry. The limitations of a quantified interpretation of the probabilities and consequences of a sour gas well blowout will then be discussed in relation to attempts by risk experts to overcome these features. To conclude the chapter, the continuing problems and sources of uncertainty that accompany a quantitative approach to risk will be outlined, and in so doing, will reveal how the need for a more holistic approach to understand and manage risk problems came about.

4.2 History of Formal Risk Analysis

While attempts to comprehend and appraise the results of technological systems initially led to the development of formal risk analysis, it is important to recall that systematic analyses of risk have been carried out in the insurance industry, investment industry and public and occupational health fields for some time (Carnay, 1971). For example, insurance companies determine the potential for loss in calculation of their insurance premiums.
For the purposes of this thesis, the roots of formal risk research can be traced to the use of reliability analyses in the 1950s in technological advancements like the aerospace program (Drake, 1982). The demands of modern technology were creating the need to understand the failure rate function of machinery, its components and more sophisticated systems. Reliability analysis was based on the examination of failure to perform the normal, required function of the system (Rasmussen, 1975). Sir Christopher Hinton (1957) explained that engineering technologies advance not on the basis of their successes but on the understanding of their failures. The fatigue life in materials, reliability of electronic equipment and vibration problems in new jet aircraft were indicative of initial attempts of reliability analyses. For systems where someone had to sit down and design them, and feel comfortable that the system would work adequately, reliability analysis provided a methodology for systematic evaluation of safety and operability (Drake, 1982).

Reliability estimates focused on the probability of failure, without regard to the potential consequences of the event. If risk was evaluated to be present in a system, attainment of zero risk was the goal (National Research Council, 1982 p. 80). A critical first mistake in new technologies was to be expected, learning by trial and
error, but was not acceptable. Design and operating procedures for such hazardous facilities had to be right the first time (Farmer, 1981).

Consequently the designs of new operations like nuclear power systems were based on deterministic calculations, which showed that the reactor design, with its defense in depth safety features, was capable of bringing any risky incident to a satisfactory and safe conclusion (White, 1982). This was a deterministic assurance of the safety of a plant, and therefore a short-sighted, subjective assurance that the risk to the public was small. However because many components of engineered systems have failure modes which are stochastic, and because human interaction with technical systems is variable and unpredictable, the continued successful operation of hazardous facilities like nuclear plants could not be calculated with certainty by a deterministic evaluation. Risk researchers therefore began analyzing the risks of accidents probabilistically, in a quantified manner.

In 1967, Farmer published a paper in Britain that moved away from the vague idea of safe nuclear power plants to this more realistic, quantified study of public risk. Farmer's revolutionary paper was one of the forerunners to an approach of nuclear reactor safety which attempted to estimate the likelihood and consequences of various stages
of technical failure. The method was to postulate events which could initiate accident sequences, thereby establishing a whole spectrum of accident sequences depending on the various combinations of failures in the safety systems provided. From a knowledge of the operating performance of the components of the system, probabilities of failure were assigned. The full safety assessment was comprised of a variety of accident sequences with associated frequencies and associated consequences, and provided a rationale for safety based on the reliability of consequence limiting equipment.

As a result of Farmer's paper, the innovative engineering reliability emphasis in the 1970s was directed toward a methodology named fault-tree or event-tree analysis (Barlow, 1984). Fault trees are defined as graphical representations of all the sequence of events or faults in a system that could lead to the occurrence of an accident (Whittaker, 1980). Paul Slovic (1978), one of the world's leading risk psychologists, saw fault-trees as representing pathways to disaster. In the fault-tree analysis of interpreting risk, complex processes are decomposed into smaller events, a tree-like network of system interactions is developed and the overall probability of a system failure is determined by combining the estimated or empirical probabilities of the failure of each smaller event (Green
and Bourne, 1972). The essence of such an approach was that any complex event or process can be reduced to its component parts and the logical relationship between them clearly established.

Using a probabilistic model to predict worst possible case accident scenarios from the fault-tree methodology, risk analysis subsequently became an aid in the design of control systems for complicated facilities like chemical plants (Gibson, 1976) and nuclear plants (Rasmussen, 1975). However, since many hazardous industries like nuclear power didn't possess a lot of operating experience to draw data from, and there were no similar systems to extrapolate information from, the risk analyst calculating the component failure rates and accident probability estimates for the fault-tree, had to rely upon expert judgment and opinion to structure the mathematical model. In other words, subjective interpretations of the problem and therefore bias, were used in determining the failures that might occur, their relative importance and their logical interconnections. The validity of the data was therefore suspect, and revealed the limitations of a fault-tree approach to risk. Despite an appearance of objectivity, fault-tree analyses were inherently subjective.

Development of the field of risk analysis was part of a process of demonstrating to the public that risky endeavours
like nuclear power could be safely contained. The most famous early study that used a fault-tree approach to assess the probability and consequences of a major nuclear accident was the U.S. Nuclear Regulatory Commission's Reactor Safety Study, (1975), popularly known as Wash 1400. The Study which cost over $5 million (Griffiths, 1983, p. 25), greatly overstated the precision of its probability prediction of a part-in-a million chance of a nuclear disaster occurring. When the Three Mile Island nuclear accident occurred in March, 1979, such assurances were largely forgotten (Kasperson et al., 1980).

A major concern among critics of fault tree analysis was that important initiating event or sequence of events that may cause of failure may be omitted because of a lack of knowledge or experience with that system, thereby causing risks to be underestimated (Primack, 1975; Fischhoff, 1978). If a particular fault within a system had not yet been recognized or had not yet occurred, a complete understanding of all the possible ways an accident could happen was not possible. In addition, failure possibilities of a system that operated in unusual conditions, especially abnormal and unintended conditions like the operation of emergency equipment and procedures, further tarnished the practicality of predicting public safety by a fault tree approach. Equally of concern was the lack of knowledge in
ascertaining all the ways that human error can contribute to system failure. The implication of the possible existence of design flaws in a risky system called into question any assignment of probabilities for system success that depended on the absence of such flaws (Fairley, 1981).

Behind the apparent inadequacies of attempts to quantify risk, the continuing primary attraction of quantitative risk studies was the appearance of objectivity and of a factual basis for making a decision (Moss and Lubin, 1980). The use of precise numerical results in a quantitative risk analysis provided comfort by concealing the inherent and fundamental uncertainties found in most hazardous industries (Kunreuther et al., 1984). Some risk experts claimed a probabilistic approach to risk analysis was invaluable in assessing risky industrial activities because it identified where the most susceptible factors to failure were in a system (Whittaker et al., 1982).

Identification of the factors which affected the overall risk most strongly, helped to design improved systems. Risk analytic techniques also made maximum use of the available data, and even if the final numerical answer had a high degree of uncertainty, the process of finding it made all the alternatives, and the necessary remedial action, much clearer.

After the mid 1970s, refinement of risk analytic
techniques expanded to focus more on a quantified interpretation of the potential consequences that could result from a major accident. Site specific risk analyses had created the need to understand the atmospheric dispersion characteristics of hazardous chemical and gaseous releases to determine the probable effect on nearby populations (Griffiths, 1983). Worst case dispersion analyses (i.e. as discussed in 3.4) were simulated by computer models. The objective was to produce a hazard "foot print," or geographic extent of toxic concentrations, following an accidental release (Layton and Cederwall, 1985, p. 19). However since it was not possible to foretell the nature of the weather around a hazardous industrial site on the date of an accident some time in the future, the model's predictions of the influence of atmospheric diffusion, transport, deposition and plume rise on the accidental release, were uncertain. An average of the consequences for different types of weather was therefore used, each being weighted with relative probability of occurrence at the release site (White, 1982). While such computer programs for predicting public safety increased the understanding of risky accidents, the onus remained on the analyst to provide the computer programs with sufficient and valid information.

The ultimate objective of quantified risk analysis was
to produce a probability estimate of damage that could be
then used for comparisons with the numbers produced by other
risk analyses on various social risks that were readily
acceptable (Refer to Appendix 8). A concern with this
application of risk analysis was expressed in a report
15), which stated:

Science is strongly biased toward numbers for
when numbers can be justly employed they denote
authority and precise understanding of
relationships. Because this is so, there is an
equally important responsibility not to use
numbers, which convey the impression of
precision, when the understanding of
relationships is indeed less secure. Thus while
quantitative risk analysis facilitates comparison
or risks, such comparison may be illusionary or
misleading if the use of precise numbers is
unjustified.

Even though uncertainty was acknowledged to be present
in a quantitative risk analysis, risk analytic techniques
continued to be used and relied upon in determining the
scale and nature of hazardous installations. Kaplan and
Garrick (1981) pointed out that there weren't many options;
when there was insufficient data to make valid predictions,
there was nothing else to use but probability to estimate
risk. Making the best possible use of what data was
available, enhanced the quality of these estimates. Using a
probabilistic model to predict risk from a fault tree
methodology, risk analysis subsequently became a normal part of evidence at numerous public enquiries into a planning applications to locate risky industries near populated areas (Griffiths, 1983).

In many risk studies, analytic uncertainty was coped with by adopting conservative assumptions, then maintaining or implying that the risk measured is at the conservative end of the uncertainty error ban (Lathrop, 1981). Sensitivity studies were also employed in the risk analysis to test the effect of the assumptions on the final risk estimate and to identify factors that are major risk contributors. These studies considered variations in population density near a hazardous site, in different dispersion scenarios and fatality percentages, as well as the effect of various mitigative strategies to reduce the risk (Atwell and Andrews, 1979). Risk sensitivity analyses could arbitrarily either increase or decrease the probability associated with each risk cause and determine the effect of these potential changes on the resultant risk (Bercha, 1985).

Collectively however, the large gap in reliable information to derive probability estimates from, precluded a risk analysis from being definitive. The main difficulty in using a quantitative approach in risk studies, according to Van Reiden and Vinck (1980), was that almost every
technological risk in society is caused by human behaviour. The U.S. Presidential Commission on the nuclear reactor accident at Three Mile Island in 1979, popularly known as the Kemeny Commission, was quite direct as to the significance of human behaviour (Kasperson & Gray, 1982, p. 8-10).

... as the evidence accumulated, it became clear that fundamental problems are people-related problems and not equipment problems. (p. 8)

... wherever we looked, we found problems with human beings who operate the plants with the management that runs the key organization, and with the agency that is charged with assuring the safety of nuclear power plants. (p. 8)

The most serious 'mindset' is the preoccupation of everyone with the safety of equipment, resulting in the down-playing of the importance of the human element in the nuclear power generation. We are tempted to say that ... what the National Research Council and industry have failed to recognize sufficiently is that human beings who manage and operate the plants constitute an important safety system. (p. 10)

Despite the fact that the importance of human error had been well recognized, in comparison to the progressive growth of quantitative methods to assess risk in the past two decades, there has been a virtual drought in the development of analytical techniques to assess the human influence to risk (Hunns, 1982, p. 181). This imbalance, in progress, is a reflection of the complexity of the human factors problem as well as an indication of lack of effort
to understand factors that cannot be readily quantified.

Quantitative risk techniques have assumed that uncertainty is not constant with time. Confidence in operating hazardous facilities improves with continued experience, with continued analysis of risky activities and with improved regulations in the industry. Today, quantitative risk analyses are a crucial component of public policy decisions on hazardous industrial facilities. Despite the uncertainties that encompass its application, Fiksel (1985) maintains that risk analysis is the only available means of quantifying the probability and consequences of an industrial disaster, and will continue to be applied and refined as further experience is gained with toxic chemicals.

Since uncertainty is prevalent however, it is inappropriate to consider risks in rigid terms. Rather than relying upon an entrenched position to quantify and understand risk, the success of future examinations of risks depends on a comprehensive view to the problem situation. This will not make the task easier, but it will make for a more balanced basis for a risky decision, and hopefully, a greater understanding of what risk analysis can and cannot do.
4.3 Risk Analyses of Sour Gas

In reviewing the development of risk analytic techniques in the sour gas industry, it becomes apparent that similar patterns of evolution occurred in Alberta as what had been experienced in the growth of the field elsewhere. The ultimate goal of the analysis of the risks of a sour gas facility was to provide quantified data that would be used to make decisions regarding public safety. However like the quantitative studies employed in other hazardous operations, a numerical interpretation of the risks of a sour gas well blowout represent an incomplete attempt to understand the uncertainties of drilling a sour gas well.

In late 1973, when a H\textsubscript{2}S well blow out of control near New Norway, Alberta, a 100 square mile area was evacuated (Choukalos, 1980, p. 1). Although there were no casualties, the accident highlighted a growing conflict between the expansion of the province's residential areas near sour gas operations. As a result, a new regulatory policy was devised to control the competing uses of land (i.e. refer to section 2.6); no development was permitted within a boundary that could, by "worst-case" calculations, receive up to 100 parts per million (ppm) of sour gas if an accidental release occurred. However, it was also noted that the danger of sour gas is of finite duration, lasting only as long as a
given well produces gas, and that in perhaps 25 years the danger would have passed and the critical areas identified by the 100 ppm isopleth would again become eligible for subdivision and development.

Unfortunately this regulatory approach to the risk of sour gas contained complications, especially the problem of existing settlements within the critical areas of existing sour gas facilities (e.g. sour gas wells and pipelines). The available computer models that were determining the 100 ppm isopleths gave widely different answers, depending on the assumptions used, and planning bodies experienced difficulty in applying the information to specific situations, and in keeping the data up to date (Angle, 1982).

The principle result of preliminary examination of the risks of sour gas was frustration; not only were the basic data and knowledge lacking, but where were no accepted criteria with which to judge the situation. Specifically, little was known about the incidence and manner of accidental releases of sour gas. The process of altmospheric transport and diffusion was only partially understood, and the toxic effects of low concentrations of H$_2$S were largely unknown. In addition, little thought had been given to the type of land use controls that were consistent with society's reaction to technological hazards.
Perhaps the most complicated aspect of the 100 ppm regulation, given the extent of rapid growth that was occurring in Alberta, was the severe restriction placed upon development proposals near sour gas operations. For example, in 1975 the City of Calgary was wrestling with the problem of two large sour gas wells located near the northeast perimeter of the city (Choukalos, 1980). The 100 ppm isopleth from these wells constrained nearly 8 square kilometers of land within the city from development, at a time when considerable pressure was being put on the residential market. As a result, the City turned to another approach to interpret the risks of sour gas. Consultants determined that the probability of an accidental release at either of wells was 1 in 8000, a risk considered to be "fairly high" and in support of the 100 ppm restriction (D & S Petroleum Consultants, 1975). This represented the first attempt to apply probability concepts to the sour gas problem in Alberta, but since more refinement was required, no change in regulatory policy occurred.

Pursuing the idea of quantitative risk analysis, the ERCB and Alberta Environment expended considerable effort to become familiar with the technique. The Atomic Energy Control Board (AECB) of Canada was contacted to obtain the benefit of the nuclear industry's extensive experience in this area (Angle, 1982). The AECB, in turn, was interested
in the sour gas industry's experience and expertise in emergency response measures, as what had been practised with the New Norway well. With the base information of risk analytic techniques provided by the AECB, Alberta Environment engaged the services of Dr. Whittaker of the University of Alberta to document the rationale for using quantitative risk analysis and to develop a framework for its application in analysing the risks of sour gas facilities (Whittaker, 1976).

Whittaker (1976) proposed that the threat to public safety from a sour gas operation be assessed by a risk analysis that considers all possible cases rather than just the worst release with the worst weather as advocated by the isopleth concept. Whittaker's method was to determine the risk outcome from each type of release scenario, multiply it by the probability of the event occurring, and summing up the calculations, enabling a comparison with other risks that society readily accepts, to be made.

In the following two years, Whittaker (1977; 1978) applied his refined analytic techniques to two communities near Calgary, Crossfield and Okotoks, that were constrained in growth options because of the existing 100 ppm subdivision policy. In the Crossfield study, accident failure modes of the sour gas pipeline in question were identified and their probability of occurrence determined
from historical records. In combination with wind and weather stability data, the probability of experiencing hazardous-to-life concentrations (e.g. greater than 500 ppm) within town boundaries was calculated as so extreme (i.e. 1 in 3000), that the only mitigative measure that made a significant reduction in the risk was the relocation of the pipeline. In the Okotoks study, Whittaker (1978) extended his earlier work to include the probability of receiving a lethal dose during the passage of a gas cloud of a given average concentration. This accounted for concentration fluctuations within the plume and exposure time. With these calculations, Whittaker identified safe areas or control zones around sour gas facilities by a risk contour estimate. A risk level of $10^{-6}$ or one chance in a million of a fatality occurring, was attached to the control zone.

Although specific problem areas were being increasingly subjected to sophisticated risk analyses, the provincial policy continued to hinge on the worst case 100 ppm isopleth criterion. However confusion in isopleth calculations continued, and caused delay in both sour gas industry and subdivision applications. In fact, virtually all applications for sour gas facilities were being scheduled for ERCB public hearings, a rather protracted process that previously had been used primarily for major projects.

Not yet comfortable with risk analysis, research emphasis was placed upon improving dispersion models and
understanding the toxicity of sour gas (Clanaachan, 1979; Whittaker, 1980). In late 1978, the ERCB and Alberta Environment performed actual pipeline ruptures of sour gas as part of their earnest quest to gain a better understanding of the mechanics of an accidental release of $\text{H}_2\text{S}$ into the atmosphere (Report by the Alberta Industry-Government Committee on Hydrogen Sulphide Isopleth Prediction--Phase II--Pipe Burst Study, April, 1979).

As the risk experts in Alberta honed their skills in analysing the danger of sour gas, land-use zoning regulations near sour gas facilities were changed by the ERCB from the "worst-case" 100 ppm isopleth restriction to a technique, similar to what Whittaker.(1978) had proclaimed in Okotoks Study, which calculated risk as a function of distance from the sour gas hazard (Whittaker et al., 1982). This represented a major shift in the amount of restriction placed on land development near sour gas operations, and reflected a change in the manner the complexity of sour gas was approached. Instead of analysing the risks of sour gas with a series of assumptions involving extremes to produce a "very safe" risk estimate, an increased understanding of the process of drilling sour gas wells and the atmospheric dispersion of sour gas, lead to an appreciation of the statistically variable nature of the problem and a regulatory of commitment to the validity of using
probability concepts. An unintended consequence of the policy change however, was increased conflict between sour gas and urban development, as the City of Calgary continued to annex and develop more land near sour gas operations.

The objectives of a probabilistic approach to the risks of sour gas were to allow the maximum utilization of available data so that all the factors that may influence the risk are assigned a probability of occurrence. The joint probability of the entire sequence of events could then be determined. The typical sequence of probabilities leading to a fatal exposure from a toxic gas like H₂S were portrayed by the equation,

\[ P(X) = P(A) \times P(B) \times P(C) \]

where,
- \( P(X) \) = probability of a lethal exposure at point X
- \( P(A) \) = probability of failure resulting in release of H₂S
- \( P(B) \) = probability that a release will be transported to point X in lethal concentrations
- \( P(C) \) = probability that a person will be at point X.

While the equation seems to cover all the bases, an important component of the risk of a sour gas well blowout is missing, the uncertainty factor. As discussed and stressed previously in Chapter 3 the sheer number, variability and lack of knowledge of all the factors that
may influence the risks of a sour gas well blowout implies that reliance on quantitative estimates to get "the answer" may be short-sighted. Since uncertainty is difficult to quantify, discussion of the uncertainties of sour gas has previously taken place in a forum other than formal risk analysis, the ERCB public hearing process.

Risk analyses were never formally required by the ERCB in the discussion of sour gas applications, but rather evolved into an accepted role of providing technical evidence in support of an oil company's proposal. While an effective probabilistic risk analysis could identify in a fault tree description, the numerous events that had to simultaneously occur before a sour gas accident would occur, the risk analysis could not provide assurance to the ERCB that an accidental release wouldn't occur. Consequently the approach was limited to the applicant revealing the preventative strategies that were in place on a drilling rig to negate the possibility of the full sequence of events ever occurring. The most obvious flaw in this method of sour gas risk analysis was the reliance upon technical expertise to overcome deficiencies, without due regard to the variable nature of the uncertainties that influence risk, especially human error.

When the Lodgepole blowout occurred in late 1982, similar to the reaction in the nuclear industry following
its disaster at Three Mile Island, the low probability estimates of sour gas risk analyses were generally discarded. The holistic examination of the sour gas industry that followed the accident resulted in increased regulatory attention to the industry. Subsequent risk analyses continued to concentrate on identifying those factors most responsible for blowout risks and to determine what mitigation measures would be most effective in reducing total risk (Bercha, 1983; 1985).

While quantitative risk analysis techniques remain an important aspect of an oil company's plan to drill a sour gas well, residents living in close proximity to proposed well locations also began to utilize risk analysis as a basis to argue on their behalf against such applications. A risk analysis arguing against a sour gas proposal could identify the range of uncertainties inherent in drilling a sour gas well and emphasize the severity of damage that could occur if a sour gas well blew out of control near an urban area.

While risk analysis serves as the medium to examine quantifiable aspects of a risk problem, it is the public's acceptability of the results that remains to be the most difficult component of a quantitative approach to sour gas (ERCB Decision D84-28, 1984, p. 19). To more thoroughly understand the reluctance of the public to accept a
quantitative interpretation of the danger of sour gas, the remaining discussion in this chapter will focus on the manner numerical estimates of risk are determined, and how well or poorly this is accomplished. To facilitate the comprehension, the analytic technique will be examined in two ways,

1. Determination of the probability of a release,
2. Determination of consequences following a release.

4.4 Determination of the Probability of a Sour Gas Well Release

To estimate precisely the probability of an event, such as a sour gas well blowout in CanOxy's proposed new wells, is extremely difficult because of a lack of directly relevant data, and because it is virtually impossible to model all aspects characteristic to drilling a sour gas well. Therefore establishing a rational perspective from which to attempt to determine the likelihood of an uncontrolled release of sour gas entails understanding the specific nature of the well application and its component parts, acknowledging that some information may be uncertain and inevitably incomplete. Knowledge in depth of these limitations and implications permits a more meaningful educated "best guess" of the expected frequency of a sour gas well blowout.
To determine the probability of a sour gas well experiencing serious well control problems, an analysis of the engineered system of drilling a sour gas well must be performed. Traditionally, fault tree analysis has been utilized to ascertain the reliability of complex engineered systems. As mentioned in Section 4.2, the fault tree is an analytical tool which replicates how the system operates, and quantifies each component, or combination of factors, that lead to a resultant event (e.g. a blowout). Bercha (1985, p. 3.2) provides an excellent description of the fault tree,

The basic building blocks of a fault tree are the events and the associated network. The elements linking events are two varieties of logic gates, AND gates and OR gates, which define the logical interrelationship between events in the network. If two events are connected by an OR gate, the occurrence of either event will result in the occurrence of the subsequent higher event. If, on the other hand, they are connected by an AND gate, both events must occur together for the subsequent higher event to be realized. In developing a fault tree, it is usual to start with the top level resultant event and to define appropriate levels of subresultant events interconnected through appropriate logic gates. In this manner, a fault tree may be recursively developed by adding more and more basic events to the sub-branches of the tree.

In the fault tree devised by Bercha (1983), over 80 basic events that could contribute to a sour gas blowout were identified. A simplified version of the structure of
the sour gas drilling blowout fault tree is illustrated in Figure 9. The resultant event in Figure 9 is a sour gas well blowout and results only when the lower order sub events occur. Following the identification and definition of the event logic structures through fault trees probabilities of occurrence are assigned to each event and the sum of all event probabilities in a particular accident sequence, provide an overall estimate of the likelihood of a sour gas well blowout occurring.

The level of refinement, or the degree to which the basic set of events are portrayed, is heavily dependent upon the information availability and extent of knowledge of the system.

**Data Base for Predicting Probability**

The information base from which to derive numerical estimates of the probability of any event may be the result of three types of data: experimental, historical, or expert opinion. The three sources may simultaneously be used in the same risk analysis or individually as the means to derive probability estimates. Subsequent discussion in this section will address the appropriateness of each data source as the basis to determine the probabilities of occurrence to the events in the fault tree of a sour gas well blowout.
1. **Experimental Data**

The probability of a sour gas well blowout is expressed numerically as a ratio such that a blowout at every well drilled is considered 1, no blowouts is 0, and one sour blowout per thousand sour gas wells drilled is denoted as $1/1000$, $0.001$ or as $1 \times 10^{-3}$. However, it is impractical to estimate the risk of a sour gas well blowout by experimental means. Drilling one thousand gas wells to establish how frequently blowouts occur or permitting a thousand blowouts to take place and counting how infrequently a nearby resident survives is not feasible. The obvious recourse for quantification lies with historical data of previous sour gas wells drilled in Alberta and in the absence of this, expert opinion.

2. **Historical Data**

Previous sour gas risk analyses have generally relied upon statistical data from past well blowouts as the basis to predict future risk probabilities. Unfortunately, this body of knowledge is not sufficiently comprehensive to provide certain predictability for all the factors which may influence a future outcome. For example Section 3.3 explained the numerous ways human failure can influence risk. In a risk analysis based on historical data, uncertainty will also be present because data is derived
from a finite, not an infinite number of experiences with that risk and new, unanticipated unknowns may cause the risky event to occur (Andrews, 1981; Starr, 1976). Measuring risk in a historical manner rashly assumes what has happened in the past will occur in the future with the same frequency and intensity. Even with the best information of the past, the future cannot be predicted with certainty. Lee (1981) believes it is tempting but false to think of objective analyses that use historical data as an accurate way of arriving at the actual risk.

The primary benefit of information on previous well control incidents lies with technical data for geological analogy purposes, especially information of expected pressures in different geological formations. It is this type of information that allows the sour gas industry to successfully operate in Alberta. In addition, knowledge gained from previous blowouts can identify the most susceptible components of the drilling process to failure (e.g., low mud density, failure to keep hole full of mud). Spare equipment parts can be stocked accordingly, and remedial suggestions to deal with the problem areas can be made.

In another sense, historical sour gas blowout data may in fact be an useful aid in determining what to expect in a particular sour gas well. To assume this role however,
information of past occurrences must be specific to that risk being examined, rather than of a similar or more general representation of the risky activity. Consideration of the variables that influence the drilling process should also pertain to the risk in question. Using data in a generalistic manner is neither appropriate nor effective in a professional risk analysis.

To illustrate this point, reference will be made below to probability estimates calculated in previous sour gas studies in Alberta. The examples reveal how easily historical data can be manipulated and misinterpreted, and therefore, why historical data should be regarded with skepticism.

1. Bercha (1983, p. 5.20) calculated the probability of a sour gas well blowout from the fault tree methodology as 1 in every 62,500 wells drilled in Alberta.

2. The historical sour gas well blowout rate, estimated from 102,902 total oil and gas wells drilled in Alberta from 1924 to 1982 was 1 in every 6,700 wells (Lodgepole Blowout Inquiry--Phase 2 Report, 1984, p. 2).

3. The historical sour gas blowout rate for the period, 1974 to 1983, when 51,032 total oil and gas wells were drilled, was calculated to be 1 in every 2,900 wells (Phase 2 Report, 1984, p. 2).

5. Since only 30 percent of all the sour gas wells that are drilled are successful (i.e. obtain production), the ratio of 1 in 172 should be altered to 1 in 575 wells drilled (Dr. M. Leahey, Canterra Energy Ltd., Sundre, Alberta, August, 1984).

6. The frequency of sour gas blowouts between 1980 and 1982 was 3 in 220 sour gas wells drilled, or 1 in every 73 wells (Phase 2 Report, 1984, p. 3.1).

7. Canadian Occidental's blowout rate for the Crossfield sour gas field since operations began in 1961 is 0 for 60 wells drilled (Wabamum Development Plan, 1984).

Of the above examples, numbers 1 to 3 assumed that sour gas wells were no more difficult to drill than other oil and gas wells, and thereby aggregated all wells together. In actual fact, however, sour gas wells have an eight-fold higher incidence of blowouts than the average for all wells (The Roughneck, February, 1985, p. 12). Section 3.2.1 revealed the reasons why sour gas wells experience those difficulties.

The fourth example isolated sour gas wells as the data
base but assumes that all drilling contractors and oil companies operate with the same degree of competency and experience. In addition, no allowance is made for unique geological characteristics and formation pressures in particular areas.

The fifth interpretation of historical sour gas well data pertains only to a blowout probability per successful well completed. It does not distinguish between the success rate in different sour gas fields, and in effect attaches one probability estimate to another to obtain a historical rate.

The sixth blowout estimate is limited by its small sample size and does not reflect the possible effect that increased ERCB regulation since Lodgepole has had on the sour gas well drilling industry.

The seventh blowout estimate is the most pertinent to the risk under study in this thesis. However, to assume that because CanOxy's blowout record has been previously flawless, does not ensure a future blowout will not occur. Instead, historical data in this instance should reflect a degree of confidence in the oil company's ability to safely drill wells and in their knowledge of the geological formations.

The significance of the variance in these seven examples of historical sour gas well statistics is
emphasized when consideration is given to the tremendous effect that each blowout probability will have on an overall estimate produced by the fault tree analysis. For example, if a historical estimate such as 1 blowout in every 2900 wells is used in the fault tree network, the resultant risk probability will be much more conservative than if a historical ratio of 1 in every 172 wells is used. Bercha (1983) used the 1 in 2900 historical ratio to derive his 1 in 62,500 estimate from the fault tree. Therefore significant differences may occur between independent probability estimates of the same risk.

Collectively the examples reveal how different the blowout estimates are when holistic (i.e. examples 1 to 3) and specific data is used. In employing only sour gas well blowout data, examples 4 to 7 provide a degree of understanding of the seriousness of Allberta's sour gas blowout frequency, but this does not necessarily imply that future sour gas wells will adopt a similar pattern. The effects of increased regulation and equipment standards may improve the success rate of drilling sour gas wells, and a decrease in drilling activity will result in fewer inexperienced righands working on drilling rigs, thereby theoretically reducing the possibility of human failure mistakes leading to a well control problem.

However the bottom line remains the same; whenever a
new sour gas well is drilled in Alberta, previous well control incidents bear little influence on the outcome of the drilling; instead the probability of success depends more on case-specific influences. Perhaps Danenberger (1980, p. 5) sums up the relevance of past studies of blowouts the best,

Because of the differences in local geology and operating conditions, the complex human factors that are involved, and the continuous technological changes, one cannot realistically expect to forecast blowouts by analyzing historical records. Attempts to make forecasts and extrapolations are often misleading and should not serve as the basis for policy determinations.

3. **Data from Expert Opinion**

When there is not enough relevant information available, either from experimental data or historical statistics, to determine the probability of failure for particular components in the fault tree, expert opinion or judgment is relied upon to provide numerical estimates. The validity of these estimates is very dependent upon the risk analyst's knowledge of the operating system, or in lieu of this, the manner in which estimates are derived from others experienced with the system. Complicating the predictions further is the degree of personal bias and subjectivity involved in interpreting and assigning the probabilities to
the fault tree.

In Bercha's (1983) study of sour gas well drilling blowouts, an analytical approach that involved a range of estimated probability values was used. The estimates were determined by direct observation of the sour gas drilling operation, as well as consulting the opinions of experienced drilling personnel. The different range of values for those events of unknown operating failure rates was described so that sensitivity calculations of the estimates could be performed. The sensitivity of the overall risk to the varied estimates of the probability of component failure could then be determined (Bercha, 1983, p. 5.19).

Since individual risk experts may not be able to adequately quantify their personal observation of the drilling process because of their lack of intimate knowledge of the system, the combined judgments of a number of personnel directly involved in the operation may be a realistic estimate. Therefore, it appears Bercha's (1983) approach was on the right track. However since drilling supervisors, and not those rig hands directly working with the well's equipment and systems, were the sources of the risk estimates, a true evaluation of the operation may not have been made. In other words, a drilling supervisor may not realize how often a particular motor needs oil or water to ensure its continuing safe operation. A drilling
supervisor in the sour gas industry may also be unwilling to give entirely truthful estimates because disclosure of too many susceptible components may discredit the integrity of sour gas well drilling rigs.

Therefore, the reliability of expert opinion estimates will be influenced by the sample size and whom the sample respondents include. Other determining factors will be the choice and extent of the questions to be asked, issues to be considered, and methods to be used to obtain the numerical estimates.

Once probability estimates are obtained, interpretation of the results is not straightforward. Depending on whether a risk analyst is working for a proponent of a development proposal, for a community group opposing the application, or for a regulatory agency that is responsible for deciding on the proposal, expert opinion will reflect the interests of the client (Nelkin, 1985, p. 18-22). Because of the uncertainty of technical knowledge, individual values assume special importance in determining risk estimates; bias and subjectivity are personal attributes that can distort the validity of expert opinion.

Consequently, similar to experimental and historical data, data from expert opinion to determine probability estimates of unquantified fault due components, should be appraised with a degree of skepticism.
Collectively the large gap in reliable information from which to derive probability estimates for the fault tree methodology, precludes a risk analysis of sour gas well blowouts from being definitive.

4.5 Determination of the Consequences of a Sour Gas Release

The previous section of this chapter was concerned with the determination of sequences of faults in the sour gas well drilling process and with the estimation of the probability of occurrence of these faults. If an actual sour gas well blowout occurs, poisonous concentrations of hydrogen sulphide will be released into the atmosphere and may eventually result in exposure of the public to lethal or disabling dosages of H₂S. It is therefore also necessary to calculate the effect of a sour gas blowout on nearby residents in order to fully analyse the risk of sour gas. This section shall consider the quantitative manner of determining these consequences.

As with probability analysis, data restrictions make the determination of the actual consequences of a sour gas well blowout a very questionable endeavour. Because of the variable nature of this risk, a heavier-than-air cloud of toxic gas that forms often being released into the atmosphere by a tremendous subterranean force, and subsequently diffused and transported by ambient atmospheric
conditions, estimation of the potential consequences to individuals living in close proximity to the blowout site is very difficult. The analysis is hampered by uncertainty and incomplete scientific knowledge, and depends very heavily on the validity of results of computer dispersion models. For these reasons, the United States' educational leader in dispersion modelling, describes the process of understanding how atmospheric forces interact with toxic pollutants and the public as very complicated (Trinity Consultants, Inc., Richardson, Texas, November, 1985).

There are three factors that one must understand to attempt to predict the consequences of a blowout:

1. The magnitude of the sour gas release;
2. The dispersion effects of H₂S in the atmosphere; and
3. The characteristics of human settlements, which interact with time of release.

The manner in which risk analysts have attempted to make intelligent estimates of these features, and what continuing sources of uncertainty exist, will be the focus of subsequent discussion in this chapter.

1. **Magnitude of Release**

The magnitude of a potential release for Canadian Occidental's 1984 proposed well was discussed in the
application to the ERCB according to engineering estimates of the release rate, volume and H₂S concentration (Wabamum Development Plan, 1984, Appendix 2). Based on the reservoir characteristics of an adjacent sour gas well, the results predicted the maximum gas release of the proposed well as 0.88 cubic metres per second with an H₂S concentration of 31.12 per cent. In common language, although the hydrogen sulphide content in the gas is high, the well's release rate and volume are not, in comparison to other sour gas wells (e.g. it is classed as second safest of four types of sour gas wells).

Consequence analyses usually assume a steady state, maximum well flow condition to predict the magnitude of a sour gas release (Bercha, 1985, p. 4.2). For a well like CanOxy's however, where the formation flows best when the well is chemically stimulated, well flow rates during a blowout could be orders of magnitude less than the maximum prediction. In this instance, the oil industry expression of not knowing what is down below until it is out of the ground is very applicable. The phrase illustrates the uncertainty of attempts to precisely determine, in the event of a sour gas release, how big the gas cloud that forms will be, how long the release will continue, and the concentration of H₂S that the cloud will assume.

The most influential characteristic that can have an effect on the magnitude of a sour gas release is the success
of igniting the well flow, as discussed previously in Section 3.4. If the well is not immediately ignited as soon as an uncontrolled release occurs, accurately estimating the amount of $\text{H}_2\text{S}$ that is released is very difficult. Other variables which may influence the magnitude of the released sour gas include the downhole geological behaviour and possible effects of the sulphur component of the $\text{H}_2\text{S}$ solidifying as a result of temperature fluctuations in the well, the potential freezing effect of condensates in the gas, as well as the degree of pressure behind the release.

Since the magnitude of the risk source has a profound effect on the subsequent factors that influence the cloud's configuration and $\text{H}_2\text{S}$ density (Kaiser, 1982), the validity of magnitude estimates will determine the authenticity of subsequent dispersion model predictions.

2. Dispersion Predictions

Individuals would be at risk to a sour gas release if a hazardous concentration of $\text{H}_2\text{S}$ were transported by ambient meteorological conditions to the location of the exposed people. To facilitate an understanding of this sequence of events, numerous complex computer models have been developed to forecast the atmospheric dispersion of gases (Blackmore et al., 1982; Chatwin, 1982; Netterville, 1985), and to some extent, dispersion of sour gas releases (Choukalos, 1980;
Sakiyama, 1983). Recent advances in chemical dispersion modelling techniques allow a computer to be fed with release rate, volume, toxicity, topographical and meteorological data upon the occurrence of a toxic gas release, to produce a map, referred to as a "videograph," showing the nearby areas likely to be affected, and the distribution of levels of contamination (New York Times, November 26, 1985, p. 11).

However the behaviour of toxic gases in the atmosphere is a complex phenomenon, and there are considerable uncertainties in the mathematical modelling of atmospheric dispersion of dense gases like hydrogen sulphide (Kaiser, 1982). For example, the monitoring results of $\text{H}_2\text{S}$ concentrations from the Lodgepole blowout proved to be several times less than those predicted using a computer model (Bercha, 1985, p. 41). One major reason for the difficulties in estimating dispersion effects is the degree to which numerous variables can influence the eventual downwind characteristics of a sour gas release. As a result, a coherent treatment of uncertainty is not available, as it is for the description of errors of observation or variability in a body of physical data.

Another difficulty that McQuaid (1982) stresses is that the technology of heavy, dense gas dispersion estimates, such as that with hydrogen sulphide, is quite different from that of other more common atmospheric pollutants. Dense
gases have unique dispersion characteristics because they are heavier than the air into which they are released. Although the flow of heavy gases like H₂S have been studied in theory, and with a reliance on subjective assumptions, in dispersion modelling, the toxicity of H₂S negates the possibility of obtaining extensive experimental evidence from a well blowout to test the validity of these models (Griffiths and Kaiser, 1979).

Although each consequence analysis of a sour gas blowout may differ somewhat, it is not unusual for dispersion calculations to include several types of atmospheric and meteorological models to simulate the behaviour of sour gas in the atmosphere. The application of these models to determine the dispersion characteristics of sour gas will be outlined below.

When a buoyant release like an uncontrolled sour gas well blowout occurs, the momentum generated by the well will determine the initial height that the emission rises to. The release height, or plume rise, will have a profound effect on the characteristics of the toxic cloud that is formed, as well as the ground level H₂S concentrations that result (Kaiser, 1982, p. 513). Plume rise models are used to calculate these effects and to determine the radius of the cloud (Buggs, 1975). Because dense gases are heavier than air, McNaughton and Berkowitz (1979) claim such gases
have negative buoyancy, and therefore do not rise very high in the atmosphere. Photographs from the Lodgepole blowout however, clearly show the release height well above the top of the derrick of the drilling rig, a height of approximately 50 meters (Lodgepole Blowout Report, 1984). The higher the height of a gas cloud, the greater its downwind distance will be.

As the release climbs in the atmosphere, turbulent mixing with air occurs. To quantify the dilution effect of this turbulence, an entrainment hypothesis must be applied (Picknett, 1978). Entrainment refers to the volumetric rate at which air is pulled into the cloud. As more air mixes with the sour gas cloud, the toxic concentration of H₂S is greatly reduced. A review of literature on dense gas diffusion (Bander, 1979) indicates that although some data from field experiments (e.g. pipeline failures) are available for modelling, initial dilution and entrainment models for dense gas releases are not generally available.

Complicating the release analysis further, is prediction of the ambient weather conditions at the time of the release. The weather stability, wind speed, and wind direction will affect both the diffusion and dispersion of the sour gas cloud (Bercha, 1985, p. 4.2). Since atmospheric diffusion and atmospheric transport interact, the concentration of H₂S at ground level decreases with increasing distance from the sour gas release source.
However in general, all model estimates of $H_2S$ concentrations at distances within one kilometre of a sour gas release source are subject to great uncertainties due to the effects of meteorological and source condition variations (Wilson, 1979).

Atwell and Andrews (1979) modelled the risk of a sour gas release at a given location by summing the risks for each possible atmospheric condition under which a release could occur. In their analysis, 6 possible atmospheric stability conditions, 6 potential winds speeds, and 16 possible wind directions, were employed. Together these three parameters provided 576 different weather conditions in which a release could take place. The consequences for each set of atmospheric conditions were evaluated using the concept of a population in a particular location being exposed to constant concentrations of $H_2S$. Exposure areas were defined by contours of constant $H_2S$ concentration, or isopleths.

The effect of varying the weather parameters is to alter the size and shape of the isopleth. A "multiple puff" dispersion model, developed by the ERCB, calculates the isopleth sizes and shapes (ERCB, 1978). By overlaying the scaled isopleths on an urban area map, exposure areas are identified.

For Canadian Occidental's proposed well, weather data
probabilities may be derived from multi-year statistics compiled by Environment Canada ("Weather Conditions—Calgary International Airport 1972-1982," 1984). Wind direction frequency is noted in Table 3. In order for residents of northeast Calgary to be directly at risk from an accidental release of sour gas, the wind must be blowing from the east, which occurs only 7.1 per cent of the time on average. While such data provides a reliable indication of what the weather near northeast Calgary has been like in the past, the data is not so informative to predict the wind and weather conditions that will be prevalent on the day of a sour gas well blowout, sometime in the future.

Collectively the enormous number of ways the dispersion process is modelled, make on attempt to determine the consequences of a sour gas blowout appear to be a well understood science. However, given the wide range of uncertainties involved, the exercise may be more aptly described as forecasting fuzzy futures.

3. Interaction of Release with Residents of Northeast Calgary

Perhaps the most difficult and crucial aspect of the consequence analysis is to predict and quantify the ground level concentration level of $\text{H}_2\text{S}$ at any given location once a blowout has occurred. Harris (1985) notes that the
problem of variation in ground level concentrations of toxic
gases is much more complicated in the case of instantaneous
releases which occur under great pressure, like blowouts,
since concentrations rise and fall from the lack of
uniformity in the structure of the gas cloud. Equally as
important to estimating these uncertainties is determining
an individual's response to various concentration levels.

The lethality of a substance refers to the quality and
degree of its potential adverse effects. A toxic substance
like \( \text{H}_2\text{S} \) does not necessarily constitute a health risk
unless people are exposed to it. However once exposed,
individuals may experience an acute (i.e. immediate) effect
or a chronic effect which develops over a period of time.
The individual response relates both to the concentration of
\( \text{H}_2\text{S} \) in the air that the person is breathing and the
physiological condition of the exposed person (refer to
Section 3.4). The concept of a dose-response relationship
is therefore fundamental to understanding and determining
the lethal effects of exposure to sour gas. To predict the
degree of acute toxicity of \( \text{H}_2\text{S} \), past research has assumed
that there is a level below which exposures carry minimal
risk. In other words, as the level of exposure decreases,
so too does the likelihood of any adverse effect. However,
attempting to quantify this relationship is very difficult.

Usually a cloud of sour gas is modelled to assume an
average concentration but in reality, the cloud may also contain short peak concentrations, much greater than the average which are instantaneously fatal. For example, a small cloud of $\text{H}_2\text{S}$ may have an average hydrogen sulphide concentration of 400 parts per million (ppm). According to available toxicity data, most individuals can withstand short exposure to 400 ppm. The cloud may also carry brief $\text{H}_2\text{S}$ concentrations as high as 1100 ppm, in which case a single breath is fatal. Only by modelling various diffusion scenarios, each of which may or may not occur, can a probability estimate of peak concentrations be measured.

Bercha (1985) predicted the ground level concentrations of $\text{H}_2\text{S}$ by assuming a gas cloud has a midpoint or centreline of high $\text{H}_2\text{S}$ concentration with lesser concentrations in other parts of the cloud. Concentrations were interpreted as decreasing rapidly away from the cloud's centerline, even though probabilities existed for this average to be exceeded by up to a factor of 8 (Bercha, 1985, p. 4.8).

Therefore for ease in mathematical handling in the consequence analysis, and in the overall risk model, lethality criteria are established, whereby instantaneous concentrations in excess of a given threshold value of hydrogen sulphide are assumed to be fatal (R. Angle, 1983, p. 7). Different risk analyses performed in Alberta have employed different lethality models; for example,
1. In the lethality model adopted by Angle (1983), both the 500 part per million (ppm) and 1000 ppm criteria were used in a sensitivity test. This simplification was consistent with observation that at the high concentrations fatal to white mice, time of exposure was not a major factor (Whittaker et al., 1982).

2. In another sour gas risk study (Atwell et al., 1979), different concentrations of H₂S were assumed to produce a different fraction of fatalities at varying distances from the release source.

3. For the purposes of Bercha's (1985) risk analysis, a 6-second dose to a couple of breaths of 860 ppm H₂S was the instantaneously lethality criterion used. This criterion was converted to an average 435 ppm to account for averaging the assumptions used in the dispersion models.

Although the above mentioned three forms of lethality criterion were utilized in the analysis of potential casualties, an accurate estimate of the actual consequences from a chemical release are difficult to obtain because the exact concentration of any toxic material released into the atmosphere is not known and not constant (Boykin, Freeman, and Levary, 1984). Another problem is that there is no known threshold dose below which any response is impossible
for every single individual. Exposure to concentrations lower than the lethal dosage estimated may result in health hazards which can include irreversible tissue damage (Greenhill, 1978). For example, as mentioned in Section 3.4, certain segments of the public such as infants, the elderly and those with respiratory conditions would likely be at greater risk in all concentration of H₂S (Bercha, 1985, p. 4.13). Therefore the assumption of lethality models of a linear response to certain concentrations is invalid.

The existing population density and configuration in relation to potential sour gas release sites determines the potential public exposure to H₂S risks. The population densities of the communities of northeast Calgary are shown in Map 5. The residential population of the rural area outside northeast Calgary, within 2 kilometres of the initially applied for well, was reported as 279 in Canadian Occidental's application (Wabamum Development Plan, June, 1984). The number of rural residents near the new well proposals would be considerably less since the new facilities are proposed to be located further away from the City.

For a given population density, the probability of casualities is dependent on both the probability of residents being home and the probability of residents being
inside the home (Bercha, 1985). Depending on whether it is the summer or winter, day or night, weekend or weekday a person may or may not be either at home or inside their home. Studies have shown that a well sealed house acts as a filter to reduce indoor concentrations of a pollutant like \( \text{H}_2\text{S} \), an order of magnitude lower than outdoor concentrations (Sakriyama, 1983).

In addition, consideration of the reaction of a resident to the initial smell of hydrogen sulphide must be evaluated. If an individual as a result of noticing the odour, goes outside to determine its cause, as was reported in the response to methyl isocyanide gas in the Bhopal disaster and the 1950 incident involving hydrogen sulphide in Poza Rica, Mexico, then that person is risking exposure to a higher toxic concentration of \( \text{H}_2\text{S} \).

Yet another factor to consider in the consequence analysis is the effectiveness of an emergency response plan to remove residents from the potentially contaminated area. If residents can be quickly evacuated, the probability of casualties will be less than if residents are not removed from the danger area.

In summation, similar to techniques that attempt to determine the probability of a sour gas well occurring, prediction of the probable consequences following a release, are very difficult because of the overwhelming influence of
uncertainties, variable factors, and a lack of precise data. This dilemma in risk analytic techniques leads to a questioning of their effectiveness.

4.6 Problems and Uncertainties in Formal Risk Analysis

In a risk analysis of sour gas well blowouts, the use of complex computer models and probability estimates may resemble powerful predictive statistical tools. However, an ongoing criticism of quantitative predictions is their limited applicability or meaning to a real life situation. Since the assignment of probabilities of occurrence and of likely results to uncertain events of catastrophic potential are difficult to specify with any precision or completeness, individuals have feelings about probabilities that are not usually directly expressed in terms of probabilities. Quantitative risk analysis does little to relieve the anxieties, fears and tensions of living with a risk of uncertain and unknown consequences.

When a probability of occurrence estimate such as 1 in 172 is presented, it implies that future sour gas well blowouts will occur at an average frequency of one in every 172 sour gas wells drilled. The probability estimate may also be interpreted as 99.35 per cent of future sour gas wells will not experience an uncontrolled release of sour gas. The probability prediction does not inform when the
actual blowout will occur however. It could be the next well drilled, the 50th, the 100th, the 172nd, or the 300th.

Holloway (1985) explains that just a little knowledge of probability theory can be dangerous. For example, when the odds of something occurring are 50-50, then one half the time, on average, the event is supposed to happen. But few people realize that the average nears 50 per cent only after a large number of events take place. The meaning of probability estimates becomes even more elusive when the risk of an individual living in northeast Calgary becoming a casualty due to an H₂S release is represented by low probability values of 1 in 10 million and 1 in 100 million (Bercha, 1985, p. 4.22).

Slovic (1981) feels that individuals have great difficulty in dealing intuitively with probabilistic terms. If a person fears something but is informed by a risk analyst that there is nothing to worry about because the possibility of the bad event occurring is only one chance in a million, how comforting is this assurance? Psychologist Amos Tversky claims people's inability to cope with probabilities makes certainty appealing, (Science 85, October, 1985, p. 35).

... a high probability such as 85 per cent seems insufficient. Likewise the desire for impossibility sometimes makes a five per cent probability seem like a lot. The result is that low probabilities seem greater than they are and
high probabilities seem less. . . . If we can't be certain about the risk we face, we at least want to have some control over the technologies and activities that produce them.

Because of such an array of controversy over the ability of risk analysis to predict the probability and consequences of a rare event, some critics question whether such probabilities can ever be adequately assessed. For example, Holdren (1976, p. 21) stated:

I am among those who believe it to be impossible to support numbers as small as these ($10^{-5}$ or $10^{-9}$) with convincing theoretical arguments. The probability that the risk analysis contains serious errors is so big as to render meaningless the tiny computed probability of an accident.

Risk analysis seeks to smooth over these differences of opinion in interpreting risk probabilities by comparing the danger of the risk under study, to risks posed by other societal activities and events that individuals are more familiar with, such as the risks of smoking, of driving a motorcycle, or those emanating from airplane crashes, gasoline truck accidents and fire. Bercha (1985) compared the results of his risk analysis to those from natural phenomena of lightning and tornadoes. Typically, such comparisons are characterised by elaborate tables, or even "catalogues of risks" (Cohen and Lee, 1979), in which diverse indices of death or disability are displayed for a broad spectrum of life's hazards.
However the comparative approach fails to recognize each risky event as comprised of its own distinct features. Comparisons fail to observe that there are different ways to mitigate and manage each type of risk, at varying costs, and also ignore differences in uncertainty, in benefits, equity, necessity, controllability, and catastrophic potential that are attributable to each.

McGinty and Atherley (1977, p. 324) are very critical of the comparative approach, saying among other things:

Just because the risk of a particular industry is no greater than, say, that of being struck by lightning, is no reason for claiming that both are acceptable . . . it may be that the risk of being killed by lightning is not accepted, but tolerated only because of the expense of any remedial strategy.

In light of the many uncertainties involved in the quantitative derivation of the probability and consequences of risky events such as with hazardous accidents (Salz, 1982), it became apparent that risk research had to account for social, psychological, and political issues as well (Slovic, Fischhoff, and Lichenstein, 1977). The new qualitative perspective to risk debates revealed that while the technical risk experts may be better at seeing fault trees, the public may be better at seeing the forest. Consequently, examination of the subjective concerns of risk, referred to as Risk Assessment, become an increasingly studied aspect of risk.
Lee (1981), a psychologist remarked that it is often assumed that accurate scientific measurement is a reflection of the actual frequency of occurrence of events, and that if public perceptions are discrepant, they are presumed to be irrational. He points out, however, that objective analyses generally subsume a limited range of variables, ignore interaction effects, and are biased to factors that are readily quantifiable. Even when statistical data is plentiful in a risk analysis, the hard objective facts of the past have a limit on their usefulness. At some point, human judgment is necessary to interpret the findings and determine their significance. The seriousness of risk should be seen as distinct from its numerical probability estimate because in the view of Lee (1981, p. 5),

"... only the public can judge, since social and moral values and emotional considerations are more compelling to those in authority making the decisions on risk than the 'so-called' objective scientific knowledge."

Rowe (1977), in the same vein emphasized that the assessment of risk, or societal response to risk, is as important as the quantification aspect. Furthermore proclaimed Rowe, the subjective perception of risk is the basis for risk acceptance regardless of the objective or quantified evaluation (Rowe, 1977, p. 25).

Farmer (1981) admits complex mathematics is generally
only a small part of the real examination of risk. Farmer maintains however, that there are major advantages in undertaking a formal risk analysis, if the public can develop a sophisticated appreciation of the analysis. Farmer explains that the purpose of analysing risk lies not only in the derivation of a numerical risk estimate, but also in the better understanding of the characteristics and special features of the problem. As long as the uncertainties and assumptions that are employed to predict the probability and consequences of a risk are understood, the method's usefulness can be appreciated.

For example, when the fault tree methodologies are utilized, a systematic and logical development of accident scenarios allows quantification of the components and stages that determine the risk, thereby improving comprehension of the safety of the system. Separation of important from non-important accident possibilities identifies the relative prominence of those functions most susceptible to failure and those possessing the potential for large adverse consequences. In this sense, the process of analysing risks quantitatively provides conceptual insights into the reasons for the risk. By pointing out where the most preventative maintenance and safety engineering should be directed, particularly with regard to redundancy and diversity in equipment, and where continual inspection and testing should
be frequently performed, as well as similar attention to the human error factor, effective design and procedural changes can improve the operating system. Conceivably such an approach could make an operation like drilling sour gas wells less risky after the study is carried out.

Individuals directly at risk to sour gas however do not understand this aspect of risk analysis. Many individuals in northeast Calgary and other parts of Alberta automatically assume that drilling a sour gas well implies negative and possibly, disastrous consequences. When sour gas is mentioned, memories of the 67 days of Lodgepole, of the Claresholm blowout in 1984, and most recently of a sour gas blowout at a producing well near Rainbow Lake in northern Alberta in late 1985 (*Calgary Herald*, December 11, 1985, p. A2), are almost immediate. When sour gas blowouts occur, the validity of formal risk analysis estimates and the ability of risk experts to predict what will happen at a particular well, are largely forgotten. In addition to not understanding risk analysis, the public has lost faith in quantitative predictions of sour well blowouts.

With such a skeptical attitude, the positive benefits of risk analysis are ignored. However an effective communication of the techniques of analysis could reveal the many diversified factors and conditions that must be simultaneously present in order for any adverse consequences
to materialize. By educating the public, risk analysis possesses the capability to better inform individuals of a more realistic interpretation of risk. In this manner, risk analysis and risk assessment could complement each other. However, the gap between the two has not yet been bridged.

Lathrop (1982) deems it necessary to examine risk from two perspectives, the technical and the societal. He explains that risk analysis provides single-number evaluations of risk that do not incorporate societal concerns very well, yet political processes are sensitive to the societal perspective. Lathrop goes on to point out the need for studies of risk to express their results in a language that the political decision maker can understand. Starr and Whipple (1984), like Lathrop, unravel the confusion of risk by re-stating it is helpful to separate the problem into one aspect which deals with questions of fact concerning the level (or probability), and character of risk, and one that which explores the social significance of risk. While in practice it is impossible to make a distinct separation, the boundary is useful to define questions which can be addressed scientifically and questions involving individual, social and political considerations.

One possible direction for reform of risk analyses that could accommodate both dimensions of risk was discussed by Ackerman et al. (1974). They note that differences of
subjective and objective interpretations of risk are often exacerbated by simultaneous studies of the same phenomenon and that traditional approaches, such as agency hearings and judicial reviews, are inherently limited in evaluating these conflicting assessments. Ackerman et al. advocated establishing uniform rules for the way analyses are conducted so that the debate can focus on the alternatives themselves rather than on the particular assessment promoted by an interested party.

Lathrop and Linerooth (1982) provide a suggested set of guidelines with respect to establishing rules of evidence. In particular, they stress the importance of defining the specifics of the risk being assessed, and clarifying the assumptions and error bounds, as well as indicating the conditional nature of many of the analyses which are undertaken. As yet, no consensus in the manner risks should be examined has established itself.

Summary

The blurring of the distinction between the possible and the probable produces an immense gap between the views of the residents living in northeast Calgary and the oil company wishing to drill the well near northeast Calgary. Therefore perhaps the most beneficial contribution of risk analysis is not to provide precise estimates, but to serve
as a first attempt at problem understanding (Hertz and Thomas, 1983). It should encourage controversy and allow those affected by the risk to discover where basic differences exist about problem assumptions, values and uncertainties. Used in this way, formal risk analysis does not promote the "tunnel-vision" that it is often accused of possessing.

While efforts to understand the risks of sour gas have expanded in different analytical directions, there is a tremendous amount of uncertainties left unanswered. Research emphasis on ascertaining the public's perception and perspective of risk has generated the need for another dimension of risk to be understood, but this addition like risk analysis has not solved the risk dilemma. Risk assessment like risk analysis is but one part of the larger whole.

The next chapter will explore this subjective side of risk and explain some of the psychological mechanisms that are responsible for the manner an individual in northeast Calgary understands the risks of sour gas, as well as discussing the criteria for accepting or rejecting risk, and the alternatives that are available to manage the problem.
CHAPTER 5

SUBJECTIVE DIMENSIONS IN ASSESSING THE RISKS OF SOUR GAS

5.1 Introduction

The fundamental uncertainties about the nature and extent of the risks inherent in many hazardous operations near urban populations often defy systematic analyses, and efforts to quantify the risks simply mask these uncertainties. Typically, quantitative risk analyses assume that because the preservation of life is an important criteria, a simple estimate of the predicted number of deaths from a hazardous accident should prove a valid index of the risk on a linear scale of severity. However Green (1980) revealed that there are 'fates worse than death' in the public's view, and Slovic (1979) has suggested there is considerable dread associated with risky activities of uncertain consequences as well.

By ignoring these non-quantifiable, fragile public values and feelings, risk analysis failed to consider that political and social acceptability of risk. Consequently, the need to understand public attitudes and behaviour in response to potentially dangerous industries, encouraged research into the factors that determined the subjective dimension of risks (Nelkin, 1985). Although attempts to
comprehend these intangible concerns have proven to be more
difficult than placing numerical estimates on risks, the
field of study into individual cognition and perception of
risk has grown. It has become apparent however, that the
public's feelings of risk are often very different from the
estimates predicted by objective, quantitative analyses, and
that the real problem in risk disputes is reconciling 'how
safe is safe enough?'

An important group of studies, organized by Slovic and
other psychologists in the field of decision theory, has
described the characteristics of different kinds of risk
that seem to influence judgments about their acceptability
(Slovic et al., 1980). This work suggests that risks that
are involuntary, uncertain, unfamiliar, and potentially
catastrophic are the most difficult for people to accept.
However this type of reasoning is limited by the assumption
that perceptions depend mainly on the characteristics of the
risk itself.

Other perspectives on the subjective dimension of risks
view perceptions as a social comment, indicative of the
social setting and social arrangement in which individuals
are involved (Douglas and Wildavsky, 1982; Nelkin and Brown,
1984). This approach assumes that debates about risk
reflect concerns about economic, political and ideological
differences, and that debates are controversial because
groups have competing interests and conflicting social outlooks.

Both approaches appear to be very applicable to the sour gas controversy in northeast Calgary. Concerned residents interpret and characterize the risk of sour gas differently than the oil company wishing to drill the wells, and both groups are prisoners of rather different experiences.

While risk experts in Alberta continue to rely upon sophisticated analytic techniques like the current 'realistic worst case analysis' to determine the likelihood and severity of a sour gas well blowout, the subjective side, or the public's view, of the risks of drilling a well has been so overwhelming that the application has been stalled for nearly two years. The ERCB, in its decision making role of 'ensuring the orderly and economic development of Alberta's petroleum resource,' is also obligated to consider these other important, hard-to-quantify variables in their search for resolution of this sensitive and crucial problem. However the major problem confronting the ERCB in making a decision is the difficulty of managing conflicting perceptions of the risks of sour gas.

In this chapter, after a general preliminary discussion of the disparity in risk perceptions, the focus will turn to
the judgmental biases that comprise the public's interpretation of sour gas. The serious implications of these faulty perceptions in arriving at policy choices of an acceptable risk will outline the complexity of the ERCB's decision. The final section of the chapter will discuss how this type of perception problem has been approached in other risky activities, with the objective of revealing possible risk management strategies that the ERCB could employ in attempts to balance competing perceptions of risk, and to optimize the potential of a legitimate decision under uncertainty.

5.2 Disparity of Risk Perceptions

Perception of risk is an idiosyncratic process of interpretation, a process of making sense of a complex world in order to plan, choose and survive in the world (Thomas, 1981, p. 36). Risk perception may also be viewed as a function of one's subjective probability estimates of the likelihood of occurrence of an unpleasant event. Tversky (1974) argues that the notion of rational choice under risk also depends critically on the individual's interpretation of the consequences, should an unpleasant event occur. Thus the manner in which a person perceives risk may depend on how the risk is defined and what its outcome may be.

Research into this subjective side of risk has revealed
that individuals do not internalize these interpretations of risk in a consistent manner (Elliott, 1983). Consequently, a major problem with the subjective concept of risk is a set of confusions that exist even in discussion of the subject, confusion that involves the reality of the risky situation, the analysis of the situation, and the perceptions of the risk. Keyes (1985) admits the odd thing about risk is that when examined, its meaning becomes elusive. Differences are created at even the most elemental level since the term 'risk' has many highly individualistic interpretations. For instance, some people would never consider sailing around the world in a small boat, but for many others, this represents a colossal personal dream.

Many everyday risks such as crossing a busy street are routinely accepted, perhaps because they are well known. However, individuals differ in their point of caution or daring in personal risk taking contexts, in their choice of sports, in their driving habits and in pursuit of their occupations. Assuming that intangible benefits like the thrill of climbing a mountain (Calgary Herald, October 5, 1982, p. A1) or the excitement and challenge of working in a dangerous job do exist, the controlling parameter appears to be the individual's perception of their ability to manage the risk creating situation (Starr, 1969). If the individual believes the risk can be handled safely, braving
the unknown or taking a chance is normal behaviour (Toronto Globe and Mail, July 29-30, 1985; two part article on dangerous occupations in Canada).

While individuals may bring risks upon themselves by their own decisions and actions, their perception changes markedly when an external entity imposes a risk upon them. In such cases of involuntarily imposed risk, unless the unpinged upon party perceives an immediate personal benefit in return for being exposed to an undesirable risk (e.g. a proposed nuclear plant in Cape Breton, Nova Scotia, an area of high unemployment, would provide jobs (Toronto Globe and Mail, December 6, 1985, p. 7)) then disagreements can erupt among experts and various publics over the likelihood of a mishap and its diverse impacts, the margins for safety that the government ought to ensure, and appropriate government response in light of uncertainty (Elliott, 1983).

Locating hazardous industrial facilities like nuclear plants, chemical processing plants and sour gas wells near urban populations exemplifies an involuntarily imposed risk. Residents living near such facilities fear for their health and safety in the event of an accidental uncontrolled release of toxic gases and chemicals. The disaster in Bhopal, India, in December, 1984 which claimed over 2,000 lives, was the latest in a series of major industrial mishaps around the world. In November, 1984, a liquefied
natural gas explosion claimed 452 lives near a Mexico City shanty town (Time, December 17, 1984). As the list of such man-made tragedies grows, people are becoming more and more concerned with risks, especially risks of catastrophic potential (Lave, 1980). Although Bhopal represents the world's most severe industrial accident, it does not necessarily reflect the worst or maximum accident that could occur, as it is always possible to invent a situation that is worse than any previously devised (Farmer, 1981).

The reality of the world is such that there exists an enormous difference in both individual and societal response to risks which are well-known and frequently encountered and those which are relatively unknown, infrequent and possessing potential for grave personal danger. The concern for the latter type of risk goes beyond its potential to cause death; there are more subtle aspects to worry about as well:

- How well do we understand the risk?
- Is this risk necessary?
- How will it affect us?
- Could it wipe out an entire community?
- Would it affect some individuals more than others?
- What can we do about this risk?

In discussion of industrial risks, the debates vary. They may be about whether a particular risk is acceptable,
or as safe as is reasonably achievable or is similar to risks already accepted, or in the case of the petroleum industry in Alberta, the risk of alternative sources of energy at the expense of a loss of a considerable amount of jobs. Kasper (1979) sees the root of such discrepancy problems in the tendency of the technical experts involved in the risky activity to view calculated, objective characterizations of a risk problem as somehow more real or more valid than the perceptions or subjective assessments of the problem by the rest of the public. However, it is tempting but false to think of objective analysis as a moderately accurate way of arriving at the actual risk, and of public perceptions as dealing only with 'imaginary' or 'irrational' risks, a process subject to bias and error. Such an argument is difficult to sustain because regardless of what can be done to establish the probability or risk by extrapolating from the past, there is no way in which the adverse effects of a risk like drilling a sour gas well near a populated area, can be fully evaluated except in terms of human values and emotions.

Russell (1985) goes one step further to state that government regulators overseeing hazardous operations are servants of the public, and even if a cold, objective analysis identifies a risk as being not very serious, if the public worries, regulators should also worry because part of
their job is to relieve anxiety. Slovic (1985) adds that if
the public looks at a hazardous activity with a skeptical
eye, they may know something the experts don't.

With Canadian Occidental's proposed wells, the oil
company is concerned about the risk of not being able to
deplete the sour gas reserves before urban growth creates an
even more insurmountable obstacle to resource extraction.
CanOxy feels confident the wells can be successfully and
safely drilled. The community associations of northeast
Calgary have formed an alliance in opposition to the wells.
The claim that since there are numerous less hazardous sour
gas locations in the province, as well as an abundance of
"capped" natural gas wells in Alberta, CanOxy's only motive
in applying for the wells is not out of an urgent need to
procure energy sources, but to maximize their company's
profits (East Calgary Sour Gas Investigative Committee,
intervenor submissions to Wabamum Development Plan,
September, 1984). The northeast Calgary residents also feel
that the proposed drilling sites are so close to their
residential subdivisions that no amount of safety
precautions and/or emergency evacuation planning can assure
them of their safety. Both parties are relying on a
language of risk in relation to their broader set of values,
interests and objectives.

The usual initial reaction of analysts when conflicts
of perceptions reach such proportions has been to assume
that some of those involved have not seen the problem
correctly, and that educated by further information, they
would become more aware of the real risks (Wynne, 1982).
Drilling sour gas wells entails a high level of technical
details, and in most cases, these details are either not
known or understood by residents of northeast Calgary.
Finding an appropriate way to inform the public of these
technicalities is very difficult since one must be a
specialist to understand many of the aspects of safely
drilling a sour gas well.

Nonetheless the ERCB has maintained and emphasized the
need of the sour gas industry to go to the public to allay
the skepticism and misunderstanding of the risks of sour gas
prior to making applications for sour gas development
(Millard, 1985). This view tends to believe that as
evidence of the positive attributes of the sour gas industry
is conveyed to the public, the public and the experts will
come to share a common knowledge of the problem and
eventually their perceptions would converge towards one
appropriate view. However, studies into the subjective
dimension of risks, have indicated that once formed,
people's beliefs change very slowly, and are extraordinarily
persistent in the face of contrary evidence (Ross, 1977).
Of particular concern for policy making purposes is the potential inaccuracy of perceptions relating to low-probability, high-consequence events (Cole and Whitney, 1981). The next section of this chapter will explore the judgmental biases that characterize risk perceptions of a sour gas well blowout, a low-probability, high-consequence event.

5.3 Judgmental Biases in Characterizing the Risks of Sour Gas.

Slovic et al. (1981) found that the study of human cognitive processes indicates that making an intelligent decision about risky activities is a very difficult task. When individuals are asked to evaluate risk, they seldom have statistical evidence on hand. In most cases, individuals must make inferences based on what they have experienced, or on what they remember hearing or observing about the risk in question. A number of general inferential rules that people use in such situations have been identified (Tversky and Kahneman, 1973). These rules, known as heuristics, are employed to reduce difficult mental tasks to simple ones. Although heuristics are valid in some circumstances, in others they lead to large and persistent biases with serious implications.

One inferential strategy that has special relevance
for risk perception is the 'availability' heuristic (Tversky and Kahneman, 1974). Availability refers to the ease with which instances can be remembered or imagined, and is employed to judge the frequency of an event or the plausibility of it occurring. Since frequently occurring events are generally easier to imagine or recall than rare events, availability is often an appropriate mental strategy. However, memorability and imaginability are also affected by numerous factors not related to the frequency of occurrence. As a result, this natural way of thinking leads individuals to exaggerate the probabilities of events that are particularly recent, vivid, or emotionally salient (Slovic, Fischhoff and Lichtenstein, 1980).

Availability bias is very evident in regards to the manner residents of northeast Calgary, as well as other people in Alberta, perceive the risks of sour gas. Consider the following explanation of this claim.

As mentioned in Chapter 2, the sour gas industry began in Alberta over sixty years ago. The sour gas sector of the petroleum industry in Alberta has become the world leader in producing and exporting sulphur, the by-product of processed sour gas. The drilling sector of the sour gas industry is also a world leader in innovative technology as a result of its extensive drilling experience. Despite the magnitude of its operations, there has never been a public fatality in
Alberta as a direct result of exposure to hydrogen sulphide from sour gas facilities. It is an impeccable safety record for any industry, let alone an extractive industry dealing with a highly toxic gas. In short, the sour gas industry has had a very positive effect on the province.

When the individuals who currently live in northeast Calgary purchased their homes during the boom years of the late 1970s and early 1980s, they were unaware of the presence of the sour gas industry in their area (The Financial Post Magazine, May 1, 1985, p. 28). They were unaware of its presence because sour gas was not well known, yet. Even in 1982, when Canadian Occidental drilled a sour gas well 900 meters east of the City, residents were not concerned with the potential danger of sour gas that they currently so readily identify. However in the autumn of 1982, their knowledge of sour gas increased tremendously; the Lodgepole sour gas well blowout elevated sour gas from an industrial odour to a major public health concern (The Roughneck, July, 1984). None of the parties involved, the public, the industry, the provincial government or the ERCB were really prepared to deal with what this issue would eventually entail.

The Lodgepole blowout dramatically altered the public's perception of sour gas; it was from that point on viewed as a risk to be avoided. When Canadian Occidental applied to
drill its wells in the summer of 1984, they were greeted with an overwhelming public reaction, an opposition emanating from the bad impression another oil company's mistakes had created for the entire industry. If Lodgepole had not occurred, or had not persisted and remained uncontrolled for over two months, or had not killed two well control specialists from Texas, it is not likely sour gas would be the dirty word it is today. The most damaging effect of the Lodgepole blowout was that the industry had lost the confidence of the public in its ability to continue to drill sour gas wells in the same manner it did before the Lodgepole incident (The Roughneck, February, 1985, p. 14).

The availability heuristic highlights the vital role of memorability as a determinant of perceived risk. If one's memory is biased, one's perceptions are also likely to be inaccurate. By reviewing the press reports across Alberta during the 67 days that the Lodgepole well blew wild, it becomes easier to understand how the general public's concern and negative perception of sour gas grew so fast. The newspaper media did not inform the public how well the industry had been operating in the 60 years previous to Lodgepole and how rare an incident like this was, but rather emphasized the negative and uncertain effects of hydrogen sulphide on individuals. The sensationalized news coverage contributed to the public's heightened fears of H₂S.
Research into the effects of the media on the perceptions of risks confirms this view. For example, Zebroski (1976) notes that 'fear sells' and therefore the media tends to focus on catastrophes and potential danger, not on the successful day-to-day operations of hazardous plants. Similarly, Coombs and Slovic (1979) found that biases in newspaper coverage of risks closely matched the biases in people's perceptions of the same risks. Slovic (1978) concluded the biases in perception could be predicted moderately well from the amount of media coverage devoted to the risk.

By examining the number of major news items on sour gas reported in the Calgary Herald newspaper (e.g. listed in the Canadian Newspaper Index under the heading 'Alberta-environment'), for the two years prior to Lodgepole and the two years after the blowout, an interesting trend is noted, as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>News Stories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>0</td>
</tr>
<tr>
<td>1981</td>
<td>2</td>
</tr>
<tr>
<td>1982</td>
<td>51</td>
</tr>
<tr>
<td>1983</td>
<td>107</td>
</tr>
<tr>
<td>1984</td>
<td>83</td>
</tr>
</tbody>
</table>

From this table, sour gas may be interpreted as not an issue in the years prior to Lodgepole, but in 1982 when the
blowout occurred, coverage escalated. It is interesting to
note that over 70 percent of the stories in 1982, were
reported in the autumn after the uncontrolled release
began. In 1983, sour gas was a very hot topic, but subsided
somewhat from saturation of sour gas stories in 1984. Today
sour gas news continues to command headlines, but not to
inform the public of the success rate of the number of sour
gas wells being drilled in Alberta; the story is usually
about a sour gas dispute, industrial death, or the
inefficiencies of attempts to resolve CanOxy's proposals.
Since news reports, and the odd odour of H₂S, are often the
only means through which the general public becomes informed
about sour gas, the media can be assumed to have played a
significant role in the discourse on risk.

Risk perception is therefore derived, in part, from
fundamental ways of thinking that lead people to rely on
fallible indicators, such as biased memorability. Another
subtle and disturbing implication of the availability
heuristic is that any discussion of sour gas, regardless of
its content, will increase the memorability and
imaginability of blowouts like Claresholm and Lodgepole and,
hence, increase its perceived risks. This possibility poses
a major barrier to open, objective discussions of sour gas
safety. Consider a drilling engineer demonstrating the
safety of blowout prevention well control procedures by
using the fault tree to point out the improbability of the various ways a kick could lead to a well blowout. Rather than reassuring the audience, the presentation might lead them to think: 'I didn't realize things could go wrong in so many different ways.'

Whereas the availability heuristic implies that educational attempts may often backfire, another likely outcome is that information designed to educate people will simply have no effect (Slovic, Lichtenstein and Fischhoff, 1979). Once formed, initial impressions like those which resulted from Lodgepole, tend to structure the way that subsequent evidence is interpreted. New evidence appears reliable and informative if it is consistent with one's initial belief; contrary evidence is dismissed as unreliable, erroneous, or unrepresentative (Mazur, 1973). From a statistical standpoint, convincing residents of northeast Calgary that the sour gas blowout they fear is extremely unlikely is difficult because neither the ERCB nor CanOxy are so bold to provide concerned individuals with absolute assurance of sour gas safety. They, unlike the public, understand the concept that admits nothing is absolute safe (now termed the zero risk concept) (Giovacchini, 1983).

However, recognizing the enormous lack of knowledge the public has for sour gas, a group of oil companies in Calgary
issued approximately 10,000 information pamphlets to inform residents about the positive aspects of the sour gas industry (Calgary Herald, September 25, 1985, p. B5). It represents the first time the companies have ever tried this type of communications program with the public. The effort was positive but the real needs of the sour gas problem outside northeast Calgary go beyond a brochure; residents must be included in the discussions of risks.

To a certain extent the ERCB and Canadian Occidental have accommodated the representatives of the northeast Calgary communities in their examinations of the well proposals. For example, over one half of the two dozen members involved in the Task Force that examined the requirements of an emergency response plan for CanOxy's wells, were residents of northeast Calgary (Calgary Herald, June 22, 1985, p. B2). However the lack of flexibility in the attitudes of some of the community groups denies the opportunity for an objective discussion of the problems to take place.

Discussion in this section has focussed on the influence of the availability heuristic, the media and education in the public's perception of sour gas. However it is apparent that there are many more varied intangibles that determine the way individuals of northeast Calgary feel about sour gas. Research has verified the existence of the
other psychological dimensions of risk that characterize perception (Slovic et al. 1980; Linnerooth 1978; Kunreuther 1980). Emphasis in the remainder of this section will address these multidimensional aspects of perception that are usually ignored by traditional risk equations, but are essential in understanding how the public feels about risks.

**Potential For Catastrophe**

Beliefs about the catastrophic nature of sour gas are a major determinant of public opposition to Can Oxy's wells. For example, the Abbeydale Community group, representing those residents closest to the proposed wells, are very explicit of their fear of a potential catastrophe. In their intervenor submission to the ERCB public hearing that was scheduled for late January, 1985, the residents stated:

> The majority of our residents feel the main risks are a blowout during the drilling phase of the well. The issue, however, is not so much the risk but the consequences of an accident. Must there be a major catastrophe in N.E. Calgary before we reconsider the risk of sour gas development so close to urban areas?

Another independent submission, also pinpointed the threat of a catastrophe,

> ... the emphasis on risk analysis studies being used as the major criteria for allowable development situations discourages a common-sense approach in recognising the possibility of a
catastrophe and the resultant consequences, which would be severe. (Intervenor Submission of Mel and Linda Maschmeyer, p. 3, January, 1985)

Bercha (1985) estimated a one in one million probability of over 300 casualties as a result of an $\text{H}_2\text{S}$ release from the proposed facilities. This risk has been compared to the chances of being hit by lightning while standing in an open field; northeast Calgary residents view approval of Can Oxy's wells similar to forcing over 70,000 people to walk out into that field during a lightning storm (Environment Views, December, 1984, p. 27). Therefore the critical factor in the perception of a catastrophic result of a well blowout appears to be the simultaneous loss of life. The large scale catastrophe at Bhopal, India, is a vivid reminder that disasters can occur, especially when residents visualize another Lodgepole type of blowout occurring, next door to their subdivision communities.

While the idea of a possibility of catastrophe from a sour gas well blowout may be intuitively clear, this is not a comforting conclusion because the rarity of sour gas disasters makes it extremely difficult to resolve disagreements by recourse to empirical evidence. In addition, because the low-probability implications of what causes a blowout are not well understood by the residents of northeast Calgary, they are usually not given significant weight in an individual perception. Consequently, emphasis
on accident consequences can lead to distortions of perception.

**Equity**

The equity concern of involuntary risks is based on identification of who takes the risks and who gets the benefits. Since residents of northeast Calgary see no readily quantifiable monetary benefit to them, and realize Alberta has surplus volumes of 'shut-in' gas awaiting market, they cannot comprehend the need to drill the wells and expose so many people to even a remote chance of a sour gas accident (*Abbeydale Intervenor Submission*, January, 1985, p. 4). On the other hand, if Calgarians were being subjected to a lack of natural gas fuel in minus 35 degree Celsius weather, the cost of avoiding the blowout risk against the imposed risk may be seen as more balanced.

Another important feature of the equity concept is the ease with which residents of northeast Calgary can be identified as the group at risk, but because of the nature of sour gas, certain identification of who the victims may be is more difficult. Consequently, by completely opposing the applications, no one has to worry whether the victim will be he/she, their children, or the next door neighbour.
Degree of Control

The concept of degree of control over the risk of sour gas has two different aspects:

- an impacted individual's participation in the ERCB decision on the well proposals;
- an individual's control of the risk of blowout if the wells are approved.

The former aspect addresses the process which has the ability to create or deny the risk, and the importance of public participation in the deployment of the risky technology (Fischhoff et al. 1980). The overwhelming public response to the initial well application in the summer of 1984 has caused the proposal to represent the most scrutinized sour gas application ever made to the ERCB, but until the wells are disapproved, residents of northeast Calgary will not feel safe and therefore, not in receipt of control over the situation.

The second feature pertains to the manner northeast Calgarians feel about the risks from the wells if approval is granted, and is aptly described below:

... living next to Canadian Occidental's sour gas facilities is an involuntary risk that thousands of people will be faced to expose themselves to 24 hours a day, 7 days a week, 365 days a year until the facilities are abandoned. (Abbeydale Submission, January, 1985, p. 2)
Accidents as Signals

As stressed earlier, the occurrence of Lodgepole has had a major influence on the manner the public perceives sour gas. More specifically however is the manner that blowouts like Lodgepole and Claresholm have led residents of northeast Calgary to question the ability of sour gas technology to control the risks. If the sour gas experts have been negligent in the past, the public feels the same results could occur again, in their backyard.

The public's reaction to the Claresholm blowout—reveals this mood:

We fought like hell to keep it out of here. They told us a sour gas well blowout would never happen. They told us it is as safe as can be. We heard that quite a few times. There's nothing to worry about. Is tonight's blowout nothing to worry about? (Lethbridge Herald, September 25, 1984)

When Claresholm occurred, CanOxy's application was only three months old. For residents of northeast Calgary, the timing of the accident was rather opportune; it added ammunition to their mounting opposition of the proposed wells and allowed them to say, "so there, I told you so" (Calgary Herald, September 26, 1984, p. A1).

Although neither blowouts caused public fatalities, the public of Alberta continues to view the risks of sour gas as unknown and possibly immense, and therefore
they react strongly to actual accidents. To residents of northeast Calgary the blowouts provided proven information about the nature and controllability of the risks of sour gas and provided signals of future trouble. Even more worrisome to people living in northeast Calgary was the fact that Claresholm had occurred while the sour gas industry was under the regulatory microscope of the ERCB as a result of the Lodgepole blowout less than two years before.

**Fear of Sour Gas as a Killer**

Because sour gas is advertised as a toxic killer with different effects at different concentrations and to different individuals, an immense amount of uncertainty accompanies the perception of health effects of hydrogen sulphide. When residents of northeast Calgary saw the drastic effects of methyl isocyanate at the Bhopal accident, the uncertainty increased. A resident of northeast Calgary explained:

> The thing about sour gas is first you smell it and then it numbs your senses so you can't move anymore. The next thing you know, you've collapsed on the floor. ([The Financial Post Magazine, May 1, 1985, p. 25](#))

When Calgary's medical officer of health pinpointed the serious potential for human disaster, particularly with effects on children, old people and pregnant women, as a result of an uncontrolled release of sour gas, some
residents felt they were living on a 'time bomb.' Since one-fifth of Abbeydale's population is under five years of age, the fear of sour gas is enormous (1983 Calgary Census).

**Dread**

The list of immeasurable intangibles relating to the public's perception of sour gas continues, but in essence, all add up to feelings of dread, worry and anxiety. Dread connotes a very high perceived risk, a need for reduction of risk and the need for strict regulation to reduce and control the risk (Slovic, Fischhoff and Lichtenstein, 1981, p. 29). This type of dread may be a very real decrement in the public's quality of life, regardless of how safe the sour gas industry sees its operations, and how safe risk analysis measures it. The psychological effect of such anxieties pervades the issue of the risk for residents of northeast Calgary.

The most important general finding from the brief examination of how residents in northeast Calgary perceive the risks of sour gas is that they appear to conceive risk issues in differentiated terms, taking into account several substantive dimensions, which include an assessment of probable benefits as well as unpleasant outcomes. The study also stresses that a subjective view of sour gas leads to issues that must be addressed by the ERCB.
From personal experience with sour gas and from personal communications with many of the individuals involved in this dispute, I am not convinced that residents of northeast Calgary or anywhere else in the province, would vary their perceptions in every separate sour gas application. In other words, the uncertainties and risks of sour gas are perceived as so extreme, I am not sure if the residents have enough objectivity to see both sides of the coin.

Permit me to explain. The sour gas drilling industry is very experienced and has proven its competence and success for over six decades. However one sour gas well blowout at Lodgepole, discredits their entire operating history, a blowout, in hindsight, that should not have occurred (Lodgepole Blowout Report, 1981, p. 1-2). Mention is limited to one blowout because the accidents at Claresholm, and at Rainbow Lake in December, 1985, were not drilling well blowouts, but at unmanned sour gas production wells. The public however, doesn't either realize this, or understand the difference; to the concerned residents of northeast Calgary, a blowout is a blowout.

In effect, the immense reaction to Lodgepole is reflective of a worst-case scenario mode of thought. This is a counterproductive way to view sour gas since the low probability potential of CanOxy's wells is not
acknowledged. Recognition is not given to the oil company's vast experience, knowledge and success of drilling in the area, the 'tightness' of the geological formations outside northeast Calgary, and the advanced regulatory and technological safeguards currently employed on sour gas well drilling rigs.

The intent is not to imply that a blowout won't occur, but to provide an objective account of the case specific situation which residents of northeast Calgary, because of their lack of knowledge or faulty perceptions, do not apparently consider in their psychological examination of sour gas. Slovic, Fischhoff and Lichtenstein (1976) sum up what I am referring to quite well:

Intelligent individuals do not always have accurate perceptions about the risks to which they are exposed. Hazards that are easy to imagine or recall, that are certain to produce death (rather than just injuries), that take multiple (rather than single) lives, and that have particularly dread consequences, are overestimated.

Perhaps this is why we tolerate approximately 5,000 automobile deaths per year in Canada but apply the brakes to an industry that has never caused a public fatality.

Similar to attempts of understanding risks in a quantitative manner, subjective appraisal of hazardous industrial operations do not provide many definitive answers of what to do about perceived risks. Few of the results of
work by psychologists like Slovic et al. have found
application in policy design or decision making. What is
left from the research on risk is a partial understanding of
the critical components of risky operations from analytical
techniques like the fault tree and the notion that
individuals as 'intuitive scientists' react to risks as they
perceive them.

A fundamental question that remains with the subjective
dimension of risk is where the balance lies with
quantitative estimates. More specifically the difficulty of
risky decisions is whether and to what extent, emotional
worries and fears, should be considered in making choices
about what is an appropriate and acceptable level of risk.
A correlation of this problem is how to reconcile
conflicting perceptions of risk. The final two sections of
this chapter will address these vexing difficulties in
determining policy decisions of risky choices.

5.4 Acceptable Risk

'How safe is safe enough' is a dilemma that permeates
the issue of sour gas. The question addresses the
acceptability of the risks of drilling a sour gas well that
may endanger the safety of the public. Traditionally in
sour gas well decisions, safe has been a relative word. The
fact that a particular sour gas well met all regulatory
requirements of the ERCB did not mean the well was 100 per
cent safe, but rather it meant there was a risk which had been calculated and was taken to be acceptable. Since Lodgepole however, the lack of absolute knowledge of whether a particular well would result in a blowout has caused the public to question the ERCB's regulatory criteria in judging acceptable risks.

Derby and Keeney (1981) note that perhaps the biggest difficulty in determining an acceptable risk is that the solution in any particular problem depends on so many complex psychological, ethical, social, political and technical factors. Furthermore since the decision of an acceptable level of risk for the sour gas problem outside northeast Calgary affects so many different people, an enormous array of both public and expert values and points of view must be simultaneously considered. Regardless of how democratic the ERCB decision attempts to be, certain individuals and groups will inevitably be unhappy with the final determination of what an appropriate level of risk should be. As a result of these complexities, many risk researchers claim that an acceptable risk solution is a chimera (Dowie, 1983, p. 83).

For the ERCB, public safety is the predominant concern in considering the sour gas well application (Calgary Herald, August 7, 1984, p. A4). However efforts to identify, define and reduce the risks of sour gas to the public are hampered by a dearth of scientific data in the
danger potential of hydrogen sulphide and a regulatory commitment to the development of the province's petroleum resources. Thus the problem of acceptable risk becomes one of balancing competing social objectives. These include economic growth as well as ensuring public health and safety.

In some cases the ERCB is fairly specific on what risk of sour gas is acceptable. For example, in the sour gas processing industry sulphur dioxide emission rates of 0.17 parts per million for a one hour period are among the highest air quality standards in the world (Canadian Petroleum Association Review, 1984, p. 4-6). In other cases however, the ERCB has struggled with and continually redefined what constitutes an acceptable risk to the public living near sour gas wells. In the mid-1970s, the isopleth concept served as the regulatory tool to determine the safe distance between sour gas and the public. By the late 1970s, this rather restrictive form of acceptable risk was replaced by standard "setback," separation distances, which did not necessarily ensure public health but did accommodate Calgary's burgeoning urban sprawl. When the disaster at Lodgepole occurred in 1982, acceptable risk of sour gas to large urban populations was redefined by identifying the need for increased regulatory requirements and restrictions for "critical" sour gas wells.
In addition to these explicit guidelines for ensuring an acceptable risk to the public, the ERCB has often 'conditioned' specific sour gas well applications with additional regulatory rules. For example, the length of the operating license could be restricted or a applicant may be required to obtain additional approval from the Department of the Environment.

The integrity of the ERCB's regulatory definitions of acceptable risk remained valid as long as public opposition to a particular application did not escalate. With the changing fears of sour gas however, the ERCB has had to open up its dictionary of acceptable risk again. Unfortunately, with CanOxy's application, the ERCB has not turned to the correct page yet.

A recent, very controversial sour gas well decision near the town of Sundre, Alberta, exemplifies how questionable determining the acceptable level of risk can be (ERCB Decision D84-28, December, 1984). Despite the well's extremely high \( \text{H}_2\text{S} \) content and the close proximity of rural residents to the drilling site, approval was given to drill the well on the condition that the oil company maintained the most up-to-date drilling procedures and precautions. In this decision, acceptably low meant:

\[ \ldots \text{that the probability of an uncontrolled release is judged to be low enough to make it unlikely that residents of the area would have to endure an evacuation and other inconveniences.} \text{ (ERCB D84-28, 1984, p. 1)} \]
In the unlikely case of an uncontrolled release, public safety could still be maintained by resorting to the immediate ignition criteria. It has been this type of faith in the technical ability of the sour gas industry to safely drill wells and of the ERCB to predict the distances from sour gas facilities that are safe, that has previously determined an acceptable level of risk. The technical ability of drilling contractors should not be underestimated because the practise of drilling sour gas wells has established itself as a competent industrial activity. However the reliability of the ERCB in arbitrarily establishing safe distances from sour gas wells is very questionable.

The situation in northeast Calgary is much different from the Sundre sour gas well because the proposed wells are closer to a larger populated area. Even though the ERCB believes CanOxy's wells can be safely drilled (personal conversation with Vern Millard, Chairman of the ERCB, April 26, 1985), exclusive reliance on technical features to determine acceptable risk is insufficient because:

1. The potential disastrous consequences that may result in the unlikely event of a sour gas well blowout are extreme and uncertain, and

2. The ERCB must therefore become much more socially accountable to a large number of people's concerns and fears of sour gas.
Unlike residents near the Sundre well, residents of northeast Calgary cannot be treated as guinea pigs (Calgary Herald, March 28, 1985, p. A23).

Residents of northeast Calgary feel the only decision that can assure them of their health and safety is for the ERCB to:

1. Reject the applications;
2. Buy back the oil company's drilling rights; and,
3. Cap the existing wells in the area. (The Financial Post Magazine, May 1, 1985, p. 28)

If the ERCB followed through on these suggestions and effectively shut down the sour gas industry outside northeast Calgary, then the direct safety risks to the public from these facilities would obviously be zero. However what the public fails to understand in their preference of a No-Go decision is the indirect consequences as a result of this action, consequences which could eventually impose additional costs and risks upon them. In other words, risk can never be totally eliminated, the probability of a particular loss may be reduced to near zero, but only by changing some of the circumstances surrounding the risk, thereby creating a new set of risks, which may be either greater or less than the risk that has been eliminated. Consider the potential repercussions of completely disapproving CanOxy's application.
Since the majority of the population in Alberta live within a few kilometres of the approximately 7,700 sour gas wells in the province (Toronto Globe and Mail, January 18, 1985, p. B6), and the majority possess uncertain and bad feelings about sour gas, denial of CanOxy's proposals could instigate a precedent setting trend to shut down the sour gas industry throughout the province. Conceivably, smaller centres than Calgary could argue their case on discrimination due to population if their situation was judged differently than northeast Calgary's.

The seriousness of this hypothetical consequence has special relevance to the recent downturn in Alberta's petroleum industry as a result of the drop in oil prices. Since drilling oil wells is no longer an attractive investment, and drilling sweet gas wells offers no special incentives, it may turn out that because sour gas wells yield both natural gas and a sulphur by-product, the oil companies may deem drilling sour gas wells is their most viable financial option. Denying CanOxy's proposal may begin a snowball effect that could jeopardize this option. Restricting the petroleum industry in this manner has the potential to inflict numerous negative costs on the public in Alberta. Specifically residents of northeast Calgary may someday have to pay higher costs for their heating fuel, a provincial sales tax may be introduced to make up for lost
petroleum revenue, jobs may be lost, values of homes may plummet, and eventually residents may have to move away from northeast Calgary because the vibrant province has lost its economic backbone of the petroleum industry.

While such suggestions may be labelled as extreme assumptions, the point that is put forward is the significance of the uncertainty of any decision that may disrupt the petroleum industry in Alberta. The petroleum industry is the province's way of life, the importance of its influence is enormous. The key aspect of the reality of an acceptable risk decision with CanOxy's proposal is therefore not an arbitrary 'yes' or 'no'. Instead attempts should be directed to the solution found by choosing the best combination of advantages and disadvantages from among several alternatives. Acceptable risk in this sense, becomes the risk associated with the best of the available alternatives, not with the best of the alternatives which some would hope to have available. However when public opposition to a sour gas well proposal is so extreme that risk management alternatives cannot alleviate public concern, an acceptable risk decision may have to deny the well application.

One apparent difficulty with the ERCB's decision of determining an acceptable level of risk is the manner in which the decision is to be made. Unless the decision process itself is acceptable, it is unlikely the choice of a
particular alternative will be acceptable. However, there is no prescribed course of action for addressing these complexities. The provincial government has not provided any specific sour gas policy objectives to strive for, and as a result, the ERCB's goals of ensuring public safety remain vague and general and left open for the agency to interpret itself. Because a sour gas application has never reached this magnitude of controversy before, the criteria for ascertaining acceptable risk becomes uncertain.

Ethical and democratic considerations imply that the affected residents in northeast Calgary should participate in the decision. A collective decision is meant to reflect both the judgments and perceptions of each resident and their values. The problem then becomes one of determining how much weight should be attached to the public's values in the final decision. Residents of northeast Calgary want to see evidence that their interests are first and foremost in the mind of the regulatory authorities, not in the interests of big oil companies.

The residents view the sour gas proposals as 'sheer insanity' because no guarantees can be given that they won't experience an increase in the risks that they are currently experiencing as a result of existing operations in their area, and because no assurances can be provided that the proposed wells won't experience problems (Calgary Sun, September 27, 1984, p. 10). Lichtenstein et al. (1978)
found problems with this type of an attitude in making uncertain choices. Lichtenstein concluded that the most common form of error by the public is 'overconfidence' in their prediction of the outcome they perceived as most likely. The public of the northeast Calgary communities perceive the imminent threat of a sour gas blowout most likely.

The decision of an acceptable level of risk therefore remains a dilemma; a problem that has been discussed, analysed, deferred and debated for over two years. The public is in need of a more sensitive understanding of the technical details of drilling a sour gas well so that they can more fully appreciate the low probability of a blowout ever occurring. The sour gas industry must become more attuned to the social reality of residents' fears and make their drilling practises more open to changes and improvements, to satisfy the public's anxiety and to ensure their operations achieve a higher standard of safety than previously thought necessary.

The primary role of the ERCB will be to bridge the gap between the public's fear of sour gas and the drilling industry's overconfidence with sour gas so that a mediated conflict solution on how safe the chosen alternation should be, can be attempted. While some obvious choices may be available, a more acceptable risk solution may be determining whether a more creative set of alternatives can
be identified to reconcile divergent perceptions of risk. The final section of this chapter will address various risk management techniques that have previously attempted creative solutions, and those which are more likely to be successful in identifying acceptable risk alternatives and managing the risks of hazardous activities like drilling a sour gas well near an urban community.

5.5 Risk Management of Sour Gas

Because risks cannot be entirely eliminated, they must be managed. The term 'risk management' is used to describe the total process of examining and evaluating risks, which encompasses the formal quantitative analysis of the risk, the societal implications of the risk and the uncertainties inherent in the problem. The objective of risk management is to formulate alternatives to provide the safest route between social benefit and social loss (O'Riordan, 1979, p. 23). In this manner, risk management should be viewed as a societal investment.

In the case of hazardous industrial facilities, like sour gas wells, located near urban communities, defining and managing risk is fundamentally controversial. Divided groups with competing values, visions and views interpret the problem of 'how safe is safe enough' very differently. Numerous issues of social and philosophical questions pervade the dispute. The limitations and uncertainty of
valid information from the risk analysis and the difficulty of reconciling divergent perceptions of risk emphasize the significance of risk management and the decision process.

In this, the final section of the chapter, the characteristics of a risk management approach to hazardous industrial operations will be explained. Some of the risk management approaches that have been practiced elsewhere in the world will be discussed in relevance to the possible creative alternatives may be available for a better approach to coping with the sour gas-suburban conflict near northeast Calgary.

A safe co-existence of sour gas development and the Province of Alberta seems to be a reasonable goal to strive for and a holistic risk management approach to sour gas may be able to facilitate this process. A thorough management approach involves the allocation of available resources for the prevention or mitigation of the foreseeable risks and their consequences (Starr and Whipple, 1984, p. 454), as well as identifying potential strategies for coping with divergent interpretations of risk, thereby assisting policy makers in devising decisions about safety.

In support of this objective, formal risk analyses attempt to disclose the relevant cause and effect relationships on a drilling rig which give rise to well control problems, to describe the approximate magnitude of consequences of a sour gas well blowout and their
distributions, and help to identify management opportunities for risk reduction. Despite the enormous uncertainties in these calculations, the advantage of a risk analytical approach is to provide an explicit structure for addressing the problems of drilling a sour gas well that can be exceedingly complex. This type of methodology, in the minimum, can highlight the associated weak-links, unknowns and imponderables of a case specific situation.

In a similar sense, risk assessments include consideration of the societal evaluation of risk, and in this respect are concerned with interpreting public attitudes and values. A risk management approach to sour gas becomes aware of these perceptions and where they come from, and can thereby attempt to alter those attitudinal factors that are controllable, rather than wasting effort trying to change an individual's psychological makeup. Like uncertainty, over time if the risk can be shown to be less risky than it is perceived to be, perceptions of sour gas may change.

Collectively, risk analysis and assessment of sour gas have many appealing features for aiding a risk management approach to the problem. To exploit this potential value however, the technical and human factor aspects of drilling a sour gas well, and the social, political and ethical complications of the problem must be explicitly recognized and addressed in the risk studies. With this type of
information, risk management is able to select responsible courses of action concerning risks.

Noticeably absent in the examinations of the risks of sour gas is study of the public's perception of the benefits of developing sour gas. Mention has been made earlier in this chapter of the public's knowledge of an abundance of natural gas in Alberta but their understanding of the wider role of sour gas in the petroleum industry is less certain. Knowledge of how the residents of northeast Calgary perceive the benefits of sour gas may provide a clearer understanding why so many individuals elect to oppose the sour gas well applications. Starr and Whipple (1984) explain that although uncertainty is inherent in all risk studies, it need not be a deterrent to effective decision making if benefits and risks are examined with equal emphasis and in the same time frame.

There are additional problems in developing sound risk management policies. For example, once the health, safety, perceptual and economic impacts of the sour gas problem are specified, a system for evaluating these impacts is necessary. Regardless of whether this evaluation is done informally or formally, value judgments are essential to determine the definition of available options and option selection in the risk management process. The ERCB, as the decision maker, must somehow pinpoint the level at which acceptable safety has been achieved. The more directly
accountable the ERCB is to residents of northeast Calgary, the greater the likelihood that public perceptions of risk will play an important role in the setting of value priorities.

The ERCB must also anticipate that societal values may change, and that what is considered unsafe today may be viewed as safe tomorrow. For example, if the petroleum industry continues to downscale its operations as a result of the decreasing price of oil, many residents of northeast Calgary who depend either directly or indirectly on the petroleum sector for their livelihood, may see the benefits of the sour gas operations outside their residential neighbourhoods in a different light. A risk management approach to sour gas, must attempt to formulate values in the policy alternatives that will be consistent with the real values and risks of the problem.

A thorough risk management approach to the problem of sour gas in Alberta has yet to be performed. A unified, detailed risk policy is difficult to achieve because of the many uncertainties involved and the inflexibility of the actors involved in the dispute. The distressing result of this difference in views of risk is the continued erosion of trust and respect between the public and Canadian Occidental, and to a certain extent, a lack of confidence in the ERCB to assume a leadership role in the problem and answer the central question of 'how safe is safe.' The
result is confusion, disaffection and confrontation.

Traditionally the ERCB's management approach to sour gas has been an adversial approach with the different groups arguing things out. Events unfold this way because of the 'muddling through' manner sour gas wells are handled. For example, an oil company applies to drill a sour gas well but provides no alternatives to the application. The ERCB either responds or reacts to the industry's initiatives. After the sour gas industry was exhaustively scrutinized following the Lodgepole blowout, both the ERCB and the industry felt the technical deficiencies of drilling sour gas wells were taken care of. However, what the ERCB failed to consider in the Lodgepole study was the adequacy of the setback distances used to locate sour gas facilities near populated areas. Consequently, the ethical issue of safety was not fully resolved to the satisfaction of the public living near such facilities, and the antagonism between the proponents and opponents escalated.

With all of these difficulties working against any type of compromises for this, or similar types of hazardous industry siting problems, what pathways are available to a risk management approach? Previous management approaches to the risks of sour gas have taken one of two directions, either a preventative mode or reactive response, or a combination of both. The preventative approach would
include identifying the origins of the risks, and adopting policies to more safely work with the hazard. The reactive approach would assume the attitude that disaster is imminent, and adopt contingency procedures to cope with the impending event. The feeling that being unprepared could mean more serious consequences following an accident, sustains this type of approach.

Part of the preventative mode may include increased regulation upon the industry to ensure public safety. However, ill-conceived regulation could have serious effects. For example, over regulation could impede growth within the industry and could entail such high costs that only the giant industrial corporations would be able to survive. This turn could lead to less competition and less potential for innovation.

An alternative to additional regulation in regards to the sour gas industry, would be to delegate more responsibility to sour gas well operators to ensure the safety of drilling wells. Positioned at the source of the sour gas hazards, the drilling industry possesses an imposing array of technical knowledge and expertise, which neither the ERCB or public can expect to replicate. However to allow the sour gas industry to formulate regulatory changes, appears to be fatally flawed because of its inevitable ambivalence between profit maximization and social responsibility.
On the other hand, a very effective spur to sour gas safety could be corporate liability to ensure a company is competent and responsible in its actions, and to effectively compensate for any damage that may occur. At present in Alberta, sour gas blowout insurance is not required by the ERCB for companies drilling sour gas wells. Instead the regulator imposes legal obligations on the well operator to prevent and control blowouts, and to protect the public in case of an accident (ERCB Decision D84-28, 1984). The oil company must also assume financial responsibility for any damage that may be caused by its operations. Amoco, the oil company responsible for the Lodgepole blowout has had to incur costs estimated at $50-million, including the cost of bringing the well under control, conducting the public inquiry and compensation for damage to livestock and property (Toronto Globe and Mail, January 8, 1985, p. 8).

Many residents of the Lodgepole area however, claim they have not received full compensation for their losses. For example, one farmer says his cattle lost weight, his soil was damaged and the sulphur laden gas corroded equipment and metal sheds on his property (Toronto Globe and Mail, January 5, 1985, p. 8). He unhappily accepted a $30,000 settlement for his estimated $150,000 in losses.

Part of the hesitancy of the ERCB to impose mandatory blowout insurance on the drilling industry is the extreme
financial burden every company wishing to drill a sour gas well would have to assume (ERCB Decision D84028, 1984, p. 28). Recent blowouts like Lodgepole and the West Venture off the coast of Nova Scotia (Refer to Chapter 3.2), have driven up the cost of drilling insurance by as much as 400 percent (The Financial Post, April 13, 1985, p. 33). Other insurance underwriters have responded to major accidents by getting out of the hazardous industry business altogether (Toronto Globe and Mail, November 11, 1985, p. B11). It would appear that after disasters like Bhopal and realising the stakes involved in northeast Calgary, that blowout insurance would be a necessity, not only for compensation purposes but to add another component to the risk management process of ensuring public safety by maintaining a high degree of responsibility for all the actor's actions.

Although liability insurance possesses a powerful dual purpose, it maintains a resemblance of a reactive approach to the hazard. The reactive mode connotes that the problem itself is not being addressed, only the consequences of a problem. Admittedly planning for unintended accidents either in the form of insurance or emergency procedures is essential to any management approach to risk, but a valid risk management strategy must be more thorough than waiting for accidents to happen and then be prepared to deal with them.
The reality of the current situation in northeast Calgary demands that a creative alternative a set of alternatives be devised. To attain such creativity, there is a need for an increase in the amount of "give and take" that the public, the oil company and the ERCB is willing to provide and accommodate. Ronge (1982, p. 120) proclaims that the answers to risk disputes are ruled by compromise. To find and accept compromises is the most frequent way of reaching a peaceful settlement of conflicts (e.g. Union contract negotiations). Examples of different institutional arrangements which have been used elsewhere in the world to manage the risks of hazardous industries and to reach agreeable compromises may provide an indication of the type of innovative techniques required to appease controversial disputes. They will be discussed in brevity below.

Informed consent is a policy tool that is used before a risky situation reaches a major conflict. Informed consent is a process whereby a person who is properly informed about a potential hazard and chooses to expose himself to it, for whatever perceived benefit, is taking a voluntary risk (Rowe, 1979, p. 10). Thus informed consent implies a transfer of an involuntary risk to a voluntary one under the control of the individual himself. As an example, in 1979, the United States Department of Housing and Urban Development required that all persons in the emergency
response designated safety area adjacent to the Rocky Flats plutonium plant in Colorado be formally informed of the existence of the emergency plan before entering into a Federal Housing Authority mortgage loan (Rowe, 1979).

If such a policy had existed in northeast Calgary in the 1970s for sour gas, many of the subdivisions would not likely have been built. In a current application, such a policy could properly inform all prospective residents to an area of existing sour gas operations, and would ultimately result in fewer land use conflicts between residential subdivisions and sour gas development.

When a conflict situation has materialized, different groups will possess different desires and objectives in judging the appropriateness of a particular hazardous industrial location. One form of conflict negotiation that has been successful is developing policies for sharing the gains and the losses from a proposed project. By arranging for winners to compensate losers, by either monetary payments or by payments in kind such as a recreational park for nearby residents, all parties may feel they are better off after the siting of the new technological facility (Kunreuther et al., 1984, p. 475).

While it is not logical to consider that northeast Calgary residents would be receptive to a recreational park in exchange for permitting CanOxy's wells, another form of
compensation may have some appeal. For example, if natural gas rates to residents of northeast Calgary were drastically reduced, a more tangible form of monetary benefit from the sour gas industry may be recognized. Such a system has recently been introduced in France with respect to nuclear power plants (Kunreuther et al., 1984, p. 482). People living within approximately 15 km of a facility can apply for a reduction of up to 20 per cent in electricity.

Although most of CanOxy's processed sour gas is contracted to Westcoast Transmission Ltd., and not to Calgary consumers, (Wabamum Development Plan, 1984) the regulatory flexibility of the petroleum province should be able to accommodate such alternatives. Impracticality is valid to risk alternatives only when more effective options are offered.

Rather than attempting to prevent the risk problem from occurring by 'informed consent' or by buying off the public by monetarily compensating residents living near the risky facility, the attainment of compromise in the sour gas situation needs to be approached more directly.

Environmental policy and dispute resolution research at the Massachusetts Institute of Technology, (MIT) in Boston, Massachusetts has been responsible for the adoption of a novel hazardous facility siting law in the State (Bacow, 1982). The law seeks to create consensus between competing
parties of a controversial siting problem by requiring face to face negotiation among all interested groups. The objective of the negotiations are to lead to compensation and mitigation guarantees on a case-by-case basis that will be viewed by all parties as protecting the rights of local residents while ensuring that regional needs are met.

Research shared by MIT and Harvard University (Elliott, 1983) advocates that more must be known about risk perception in public policy debates before coming to the bargaining table. Elliott (1983, p. 2) states that consensus on crucial governmental decisions will not emerge until conflict perceptions of risk can be brought to a point of convergence. To determine how to best achieve agreement among disputing interests when their positions are based on widely divergent perceptions of risk and not just on the adverse reactions to the potential costs that they might be forced to bear, Elliott proposed repeated and controlled simulations of hypothetical hazardous facility siting situations involving the public, industry, environmentalists and government representatives. With the simulation analysis, the objective is to clarify:

1. the patterns of risk perception that emerge;
2. the sensitivity of those patterns to various public policies aimed at altering those perceptions; and,
3. the possibility of developing consensus when
perceptions of risk vary widely (Elliott, 1983, p.5).

Unfortunately the conclusions of Elliott's work are not currently available, but are indicative of the direction of risk management efforts to effectively cope with risky disputes.

Baram (1985) views the principle problem with risk perceptions and therefore risk management, with the industry which generates the risks. Baram (1985, p. 373) explains that research on the public's perception of risk is research that can too readily lead to 'blaming the victim' for the problems caused by industry's failure in risk management, and too readily lead to corporate public relations initiatives to make the public more acquiescent about industry activities that have risk potential. The public's response to risk may indeed be irrational or emotional in many instances, but when remedies are sought in the courts or agency hearings by concerned citizens, factual evidence and findings are usually needed to establish a basis for the concerns. The reliance by industry on cost-benefit and other objective analyses of risk provide such definitive conclusions, but the public's perceptual fears and anxiety do not. Baram emphasizes however that given the spiral increase of harms, claims, and liability imposed by hazardous industries, and given the industry's decrease of loss coverage and the stimulation of regulators to enact new
burdensome laws, the most critical target for perception research should be directed at industrial managers whose decisions lead to these consequences so harmful to the public and to their own firms.

Perhaps the most positive direction that risk management techniques in Alberta have taken to resolve sour gas disputes is to include public, industry and government representatives in the discussion of sour gas risks in a forum headed by an independent, consultant research group. Such an approach was utilized in an analysis of the perceptual factors associated with the health of residents living near sour gas processing plants near the communities of Pincher Creek and Twin Butte in southwestern Alberta (Sage Institute, 1983). The objective of the study was to document the various perceptions of all the participants into a cause-effect format of a subjective fault tree so that the major factors preventing resolution of the problem can be identified (Sage Institute, 1983, p. 6). The findings of the research indicated the following general areas of concern:

1. Inadequate communication.
   a) Government departments and agencies have not communicated adequately within their own structures, with industry or with the public.
   b) Industry has not communicated well with either the government or the public.
c) The media has not communicated all of the facts that are available or that are relevant to the issues.

2. Inadequacy of studies.
There is significant dissatisfaction with the nature and extent of health and environment studies in the past and in the present.

3. Involvement of appropriate individuals and groups.
There is a widespread perception that resolution of the sour gas problems will not occur until and unless affected individuals, knowledgeable groups from the community, and appropriate experts concertedly address priority issues.

Although the sour gas controversy continues in southern Alberta, the ERCB has continued to rely on the objectivity of outside consultant groups to direct studies into the problems of sour gas outside northeast Calgary. For example, the current 'realistic worst case analysis' is under the direction of a group from Eastern Canada not associated with the sour gas industry (Calgary Herald, February 22, 1986, p. A6). An independent group can more readily place all of the issues into a common perspective.

The major deficiency of risk management remains however, that of creating viable alternatives to the current status of CanOxy's application. Management has failed to
enhance the public's understanding of sour gas, and as a result the public's fear of sour gas has become a greater problem than the hazards themselves. Workable public policies for drilling sour gas wells near urban communities are not likely to be forthcoming in the absence of a workable detente over what is possible, desirable and acceptable. The problem of sour gas is not a wrinkle that can be ironed entirely out of the social fabric; starching must also be applied to the sour gas industry, the ERCB, municipal planning authorities, the media, and the technique of risk management itself. Collectively, the willingness of each entity to become much more accountable for their role in contributing to the management of a serious societal problem will determine whether or not the issue will be managed, or deferred and avoided.

The summary that concludes this chapter will touch upon how the responsibility for coping and managing the risk problem among the different entities should be allocated. The final chapter of this thesis will provide a more detailed set of recommendations. However, the following comment illustrates the type of mental roadblock that must be overcome to enable these responsibilities to be fulfilled:

After about 10 months of study of the Lodgepole blowout, the joint industry-Energy Resources Conservation Board blowout prevention review committee recommended softening the wording of an
ERCB regulation imposing stringent procedures on companies wanting to drill 'critical' sour gas wells. The word 'critical' in the regulation needs to be changed to 'special' because 'critical' tends to raise public concerns rather than provide the desired assurance (Calgary Herald, April 20, 1985).

Such an attitude fails to visualize the problem of sour gas in a holistic sense. It is an attitude that has influenced and characterized the entire history of this industrial activity, and is an attitude that defies and mystifies any attempt to reach a compromise solution.

**SUMMARY**

There are clearly major changes that must be implemented to avoid, change and manage the conditions that led to and are part of the risk of a sour gas blowout near northeast Calgary. The required changes will not come easily.

Obviously, land use controls devoid of sour gas risk considerations must be altered to accommodate a more coordinated and communicative approach in approving, regulating and managing land in, around and near sour gas reserves.

A major responsibility for improving the risk management strategy for sour gas wells lies with the sour gas drilling industry. Technical changes in equipment and
procedures are required, but more importantly, attention to human error aspect must be committed. A qualitative change to effect the general character of work on drilling rigs will help to bring about a social as well as a technical whole in the manner critical sour gas wells are drilled.

In conjunction with a sincere effort to make significant changes in the industry, the Calgary Herald newspaper, as the most accessible source of information on sour gas must become much more responsible in their communication of information to the public; the newspaper must become part of the risk management solution, rather than a major contributor to the problem. Dr. Timothy Earle, a researcher in the communication aspect of risk information, believes if special advisory boards are established to review the validity of the information on public risk stories before the stories are published, the public's understanding of risks could be influenced into a more thorough appreciation of the problem (Air Pollution Control Association, Vancouver, British Columbia, November, 1985).

A safer and more efficient drilling industry, and a more informed public, may then be able to make progress at risk negotiation exercises, with the objective of formulating creative, constructive and effective alternatives. At this point, the strength and ability of
the ERCB to assume a leadership role in managing the risk will play a significant role in the final decision on the fate of sour gas wells near populated areas.

The final chapter, to follow, will pinpoint the areas of uncertainty and deficiency where those involved in the sour gas dispute must make a honest and detailed look at, and admit they have a contribution to make to the risk management process by exerting an influence upon those areas of uncertainty and deficiency.
6.1 Conclusions

Drilling sour natural gas wells near the residential subdivisions of northeast Calgary, Alberta, like so many other hazardous technological activities located near populated areas, was an established, industrial development trend until a major accident within the industry occurred. The Lodgepole well blowout finally rang the bell of how serious a problem sour gas really was. Similarly the Three Mile Island incident awoke the nuclear industry, and Bhopal shocked the entire world of the risks and horror of chemical processing plants near urban areas. The initial reaction to the Lodgepole blowout was increased regulation but perhaps more dramatic, was the tremendous impact on people's perceptions of danger and dread, and the risk of another disaster occurring. The extreme differences in opinion between the sour gas industry and the public over the likelihood of another similar accident occurring, sustains the continuing debate concerning the extent to which—and the ways in which—the public should participate in discussions concerning the practice of drilling for sour gas reserves outside northeast Calgary.

In April, 1985, during an interview with me the Chairman of Alberta's ERCB, Mr. Vern Millard made reference
to the suggestion that 'critical' sour gas wells be re-named 'serious' sour gas wells. Mr. Millard felt that there was no reason to change the terminology, but there was "an urgent need to get serious with critical sour gas wells."

His comments were indicative of the amount of accountability regulatory authorities feel responsible for, in ensuring that risky operations function safely near populated communities. In the United States, the Occupational Safety and Health Administration is becoming more stringent with risky industrial operations, especially with the chemical processing industry. In its largest enforcement action ever, the regulatory agency is reported to be seeking more than $1.3 million in fines against Union Carbide Corporation for 221 alleged safety and health violations at its institute, West Virginia, chemical plant, where a toxic leak in August, 1985, affected 6 workers and 129 residents (Toronto Globe and Mail, April 2, 1986, p. A12).

A potential solution to the sour gas dilemma however, extends beyond a management approach that is based entirely on punitive or reactive policies. The inherent difficulties and uncertainties of the controversy with sour gas must be diffused by focussing attention to three philosophical questions:

1. How safe is safe enough?
2. How equitably should societal risks be distributed?; and,

3. How reliable are scientific measures of risk and technological assurances of safety?

Finding conclusive answers to these questions is extremely difficult. However, the recommendations that follow in this chapter have been organized into two subsections, and each of the above questions will begin to be addressed by acting on the full range of these recommendations.

More specifically, examination of the sour gas problem must be improved in significant ways to provide criteria to address these questions. For example, simplistic solutions to safety on drilling rigs should be replaced by changes identified by site specific, knowledge in depth. This reflects a 'proactive' approach to risk. To properly address the entire issue of sour gas however, the problem must be viewed as comprised of separate, component problems, much like those described by fault trees. Management attention to each of the problem components becomes the holistic process of risk management.

Although ethical and methodological analyses and assessment can improve the current practice of examining risks, philosophical scrutiny alone is inadequate to accomplish the reform necessary with sour gas. The ERCB, as
the risk managers responsible for decision-making, must be prepared to implement regulatory changes to alter some of the difficulties, deficiencies and uncertainties of drilling sour gas wells, as discussed earlier in the thesis. To address the problems associated with the human error aspect on drilling rigs, the ERCB needs to make changes to a human resources management philosophy that has been part of the sour gas industry for over 60 years. Unless both the ERCB and industry make a total commitment to safety, such changes will be ineffective and will appear as window-dressing, or won't occur at all.

This thesis does not pretend to offer a how-to manual to resolve the problem of sour gas and suburban developments in Alberta, but rather is concerned with emphasizing the obstacles and complexities that must be managed. Morgan (1985), one of the world's most respected experts in risk research, stresses that knowledge of risk is limited and no one has all the answers yet. Comprehending how residents of northeast Calgary enumerate and rank their perceptions of sour gas, and the lack of an effective policy making mechanism that can simultaneously address the concerns of the public and the sour gas industry, exemplifies such problems.

Consequently, the recommendations that conclude this chapter are for a number of remedial steps that must
individually address separate but specific problem conditions before the risk management process can attempt to bring about a compromise between the Calgary residents and Canadian Occidental. Currently, the sour gas proposals are stalled by confrontation and animosity, without any significant indications of progress. In this sense, the recommendations may provide a fresh outlook on the problem and add openness and confidence to the discussions.

On the other hand, there exists the possibility that such management recommendations will have no effect on the very negative perception the public holds for sour gas. The recommendations may also be viewed as too costly or unduly restrictive to the sour gas drilling industry, which has already undergone an extensive re-writing of the manner it conducts its operations. The sour gas dilemma in northeast Calgary may require an even more creative set of alternatives to facilitate the ERCB's decision. The reality of the controversy may also mean that a more arbitrary decision must be made to appease the public's opposition, such as the Alberta Liberal Party's suggestion that all sour gas operations within five miles of an urban area be banned (Taylor, 1985). Conceivably the ERCB could also go out on a limb and approve the wells as is, but to attempt to reduce the risk of sour gas to purely technical issues of the most-up-to-date drilling equipment and procedures, is to
ignore the value dimension of policy analysis and to disenfranchise the residents of northeast Calgary who, in a democracy, should have some input into decisions that affect their homes and lives.

The range of alternative solutions is representative of the array of opinions, possibilities and uncertainties that have characterized this thesis.

6.2 Recommendations

The recommendations are divided into two subsections. In the first (e.g. 6.2.1; 1-5), the recommendations are general ones that would help to bring the sour gas industry, the public and the ERCB closer to the point where they could at least sit down and talk about options without the fear, anger and resentment that currently characterizes the application. The second subsection (i.e. 6.2.2) represents the author's views on what should be done about the CanOxy application in particular. It deals with the fundamental question of how a decision should be reached and especially what should be done if everyone remains totally at odds on the application.

6.2.1 General Recommendations for Improving Sour Gas Risk Management

The following recommendations about general improvements in managing the risk of sour gas development
are offered under the assumption that since most sour gas in Alberta is located within ten miles of a village, town or city (i.e. as stated in Chapter 2.2), some sour gas well drilling will continue near populated areas. It is possible however that urban residents and the ERCB might decide that sour gas anywhere near cities is not worth the risk; despite small probabilities of a well blowout, the consequences are so large that it is just not worth it. The author recognizes that this is a possible political decision. If a decision were taken, there is little that anyone could recommend in terms of improved risk management. Therefore the assumption is that it is worthwhile to consider ways of doing a better job of proceeding with some drilling.

1. Land-Use Planning

In hindsight, it is easy to recall how the current conflict and risk situation occurred with northeast Calgary. A list of specific policy changes that would address all the criteria necessary to resolve the land use conflict between sour gas and urban developments would be too detailed for the purposes of this thesis, but the need for a more coordinated, communicative approach in approving, regulating and managing land in, around, and near sour gas reserves is obvious. There may also be a need for a provincial perspective on sour gas reserves near urban areas.
to determine whether sour gas reserves should take priority over future surface development. This perspective must be based on the understanding the sour gas reserves will be depleted as soon as possible to free up the land for residential development, without the risk of sour gas.

My recommendations for land use planning, are as follows:

1. Amendments should be made to the Planning Act to ensure explicit treatment of the sour gas hazard issue in areas where sour gas activity exists or is likely to;

   Relatedly,

2. Consideration should be given to extending the mandate of the ERCB to give this agency a role of authority and responsibility in general land use planning on designated sour gas reserves.

The thrust of these recommendations is to bring together the planning and regulatory responsibilities for the colliding land uses of urban development and sour gas exploitation.

2. **Risk Analysis**

   There are three very important considerations if risk analysis for sour gas is to be improved and more fully used. First, analyses must be more comprehensive and
complete, and especially must go beyond looking at the technical end, to include all of the human and psychological factors described in chapters 3 and 5. This means looking, in the analysis at the human factors on-site and complementing this with qualitative assessment of how residents nearby think about the risks.

Second, it must be always remembered that any risk analysis should be attuned to the specific situation. Broad policy guidelines are, of course, essential, and the ERCB has completed extensive work in this area. But a "Cookbook" risk analysis is not possible or relevant. Instead each major new development must be looked at detail in light of particularities of the situation.

The objective of analysing the risks of Can Oxy's application is to go beyond appraising historical blowout statistics to examine where the real potential problems may lie. This includes examining the daily drilling records of Can Oxy's previous 60 wells outside northeast Calgary to ascertain whether the company has had any well control problems that were quickly brought under control, and therefore not recorded as blowouts. A similar type of knowledge-in-depth analysis should be performed on the Arrowhead drilling rig as well as evaluating those personnel who will be employed on the well. By seeking to acquire case-specific information, the purpose of risk analysis will
become clearer and will hopefully increase the understanding of where the real problems lie.

The third and final consideration in improving risk analysis is that to be credible to all, the analysis may have to be performed and structured by someone other than the regulatory body, the ERCB. In the United States, the Environment Protection Agency has come to recognize the importance of separating controversial regulatory decisions from the underlying analyses (Ruckelshaus, 1984). The real or perceived danger of too close a relationship between regulators and the regulated industries has been well-known for many years (e.g. Bernstein, 1955). When a decision is made about very dangerous, risky developments, the feeling of fear and mistrust are almost certain to lead to accusations that the regulator is too friendly with the regulatee. As discussed in Chapter 5, some such feelings are very much present in Northeast Calgary with the CanOxy case. Anything that can be done to make risk analyses appear more independent of all the parties in this situation, will help to make the analyses more useable.

Given these considerations, the following is recommended:

1. Separate the risk analysis examination of sour gas from the ERCB so that what is seen by everyone as a truly independent review, can be produced. Some
ways of accomplishing this by creating independent expert committees have been discussed by Ozawa and Susskind (1984). The main principle is to ensure that both sides trust at least one of the experts responsible for the risk analysis.

2. Include all of the factors that influence the successful and safe drilling of sour gas in these risk analyses. This would mean less emphasis on computer $H_2S$ dispersion models as the focus of current risk analysis and greater attention to on and off site human factors.

3. After appropriate public review of the risk analysis report, the ERCB should attach specific conditions to the well license based on the detailed and independent risk analysis.

3. Sour Gas Well Drilling Industry

Extensive personal work experience on drilling rigs in Alberta has informed me that the probability of a sour gas well blowout is very unlikely if the drilling equipment is in good operating condition, if working conditions are not extreme or intolerable, and if the drilling operation is approached in a professional managerial manner. However, work experience on sour gas wells has also made me much more aware of the enormous potential for serious well control.
problems if those physical, psychological and social influences, as discussed in Chapter 3, are not addressed by the sour gas industry. Unless the drilling industry is willing to acknowledge the existence of these and other problems, and admit that total well safety and a successful drilling process are one and the same, and be receptive to radical changes in the manner sour gas wells are managed, the potential for human error to remain the number one influence to blowouts will not change.

The objectives of implementing innovations to the work place on sour gas well drilling rigs are to increase the effectiveness of a risk management approach to sour gas, to achieve a safe operating level above the upper limit customarily achieved by competent drilling rigs, and to reveal to the public that the sour gas industry is willing to make large sacrifices to ensure their operations are safe, thereby ensuring public safety.

Recommendations to the sour gas industry focus on three remedial areas; equipment, human resources management, and blowout training. The recommendations are directly applicable to 'critical' sour gas wells, but are indicative of the needs of the entire industry. They are as follows:

1. Equipment inspection emphasis should be placed upon the safe operation of all well drilling components, rather than limited to only well control equipment,
with the objective of providing more backup equipment systems on a drilling rig to compensate for failures when they do occur (e.g., two sets of mud-separation degassers).

2. Wireline deviation surveys should be eliminated and replaced with downhole computerized survey equipment to reduce the possibility of getting stuck in the hole.

3. Winter drilling should be eliminated to avoid the possibility of extreme weather conditions influencing an equipment malfunction or a human error.

4. Employee hiring procedures for all sour gas wells should be revamped to include:
   - medical examinations
   - in-depth past work history analysis
   - compulsory pre-employment orientation program.

5. For sour gas wells like CanOxy's, specially trained teams of righands selected by an application process from the existing sour gas workforce, should be formed to ensure a high quality of experience and knowledge among rig employees working on the well.

6. Rig employees should work only 8 hour shifts and receive a substantial increase in hourly wages for employment on critical sour gas wells.
7. Consideration should be given to increase the fringe benefits currently available to a drilling rig employee (e.g., annual paid vacation).

8. An apprenticeship type of program should be established whereby an individual with two years employment on drilling rigs could be accredited with, for example, one year of a pipefitting or heavy-duty mechanic training program.

9. Drilling rig crews should consist of six employees, including an experienced assistant driller to oversee any drilling decisions that the senior member of the crew, currently makes by himself.

10. Blowout prevention training and education should be increased substantially for all employees on drilling rigs, with fully paid courses and simulation exercises available.

4. **Emergency Planning**

Emergency response measures should not have to be employed if drilling operations are managed effectively but the nature of drilling sour gas wells near populated areas demands that workable plans be devised to deal exclusively with the central issue of coping with a sour gas well blowout. Excellence not perfection should be the guiding light with attention to the inevitable realities of an
emergency situation (e.g., traffic disruption resulting from mass exodus of residents leaving the area; arranging alternate forms of accommodation for the evacuees). Correspondingly, the focus of emergency planning should be directed to:

1. A policy that is simple and flexible, but one which also is extensive in its application to the reality of an evacuation of over 50,000 people, and is proven effective by testing it before the well is drilled.

5. Managing Public Perception

Perhaps the most difficult problem to manage in the sour gas dispute is to facilitate to the public an increased understanding and appreciation of the low-probability risks a sour gas well possesses. Public acceptability has long been regarded as one of technology's most difficult problems (Weinberg, 1976). Unless the residents of northeast Calgary can develop a more thorough understanding of the risks, public opposition to the well proposal will remain, and prolong the difficulty and length of the decision making process.

Although some risk researchers have maintained that educating the public about risks is very difficult, (e.g. Ross, 1977), by providing residents with information about
the other side of sour gas, the positive attributes may prove to be beneficial. For example, by implementing the recommendations for risk analysis, positive steps in reducing opposition would be made because expert analysis would be seen as more credible and independent. In addition, since the newspaper media has been largely responsible for the formation of the public's negative perception of sour gas, the newspaper as the information medium may also be able to become part of the solution to the problem rather than part of the problem (Millard, 1986), by publishing a factual interpretation of the safety of drilling sour gas wells. To emphasize the validity of this suggestion, consider that the daily newspaper in Bellingham, Washington, has appointed an independent, advisory panel to monitor the authenticity on all stories published in the newspaper about risky or hazardous activities (e.g. nuclear power) (Earle, 1985). The recommendation follows that:

1. Efforts be directed to encourage the Calgary Herald newspaper to be more responsible for telling the other side of sour gas, so that the public may become better informed, more knowledgeable, and more likely to be able to rationally discuss alternatives for the manner sour gas wells are currently drilled.
To facilitate the implementation of this recommendation does not imply that the newspaper should be manipulated, but rather that its important role in risky stories should be understood. Consequently the newspaper might want to consult a risk communication expert like Dr. Earle from Bellingham to come to Calgary and address some of the pros and cons of such an approach.

6.2.2 CanOxy Application — The ERCB Decision

The ERCB is capable of performing a much more effective role in coordinating and managing the risks of sour gas than at the present. The provincial agency needs to assume a more dynamic leadership role in managing sour gas and become a much more visible presence on drilling rigs than the Board's well license displayed at the rigsite, and the periodic inspections during pressure testing of equipment. Exclusive reliance upon technical solutions and a 'band-aid' management approach to blowout prevention training is insufficient to ensure public safety or to appease public dissatisfaction. To implement some of the recommendations in this thesis, will also require a more holistic and committed regard for safety on sour gas well drilling rigs.

The ERCB presently is of the impression that the sour gas industry and the public must work out their differences before an ERCB hearing is held. However, unless the regulators, like the planning authorities, risk analysts,
sour gas industry, and the public, become proactive and seek to avoid and manage the risks of sour gas, an attempt to find an amicable resolution by conflict negotiation and compromise among the alternatives, will not be available.

The enormous range of uncertainties and complexities of a decision in the Canadian Occidental proposal are representative of the increasing debates of whether or not the benefits of operating hazardous industries are worth the risks should a major accident occur.

In this particular application, it is crucial that the ERCB deal with public perception. More specifically, public input into the decision making process must be enhanced. The recommendation that follows, suggests how this may be accomplished.

1. A decision making group comprised of:
   - two community representatives of northeast Calgary;
   - the northeast Calgary city alderman (i.e. Mr. Les Pears);
   - the mayor of Calgary; and,
   - Vern Millard, the Chairman of the ERCB, should be established with the goal of reaching a decision on the application. The recommendations of this group would then be implemented in a ERCB decision. In essence, the group would be performing a form of mediated negotiation.
Critical to this group is possession of a veto power on the well application. Such an approach may begin to shift the public to a more voluntary type of acceptance of risk (i.e. as discussed in Chapter 5.2) since they would have more control and more of a say in sour gas well decisions.

In other similar types of risky conflicts, and similar attempts to reach an agreeable solution on the acceptance of risks, results have not always been positive. For example, as discussed in Chapter 5.5, the formation of a State Law in Massachusetts in 1982 that requires face to face negotiation between competing parties of a controversial hazardous waste facility siting problems, has yet to resolve a single facility site (conversation with Mr. Normal Dale, Ph.D. candidate at Massachusetts Institute of Technology; Thesis research advisor, April, 1986).

It may turn out that the sour gas decision-making group will not be able to reach an agreeable solution. In this case, the ERCB as manager of the oil and gas industry, remains the decision maker and must make a decision. The criteria that is ultimately used to make the decision will come from one of two different points of view:

1. An utilitarian approach based on the choice which provides the greatest benefit to the greatest number of people (i.e. economic benefits of sour gas to entire province), or
2. No one should have to live with the risks of extreme consequences from a hazardous industrial activity.

Which point of view should be chosen is beyond the consideration or intent of this thesis, and is a decision that the author has no definitive answer to.

In summary the conflict between sour gas and Calgary's urban growth is one of unusual complexity and, since the Lodgepole incident, great fear and emotion. There is no guarantee that action on the recommendations will solve the problem. It is the author's belief, however, that the probability of resolving the conflict may be enhanced if some of these measures are given serious consideration. Further trouble in Northeast Calgary for CanOxy, nearby residents groups and above all the ERCB, if the present situation continues, is perhaps the most unacceptable risk of all.
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MAP 1
Land Use Conflict Between Urban Development and Sour Gas Development

ANNEXATION MAP

MAP 2

Boundaries of City of Calgary as of January 1, 1985

City of Calgary Planning and Building Department January 1, 1985

North
MAP 3
Canadian Occidental's Sour Gas Operations Outside Northeast Calgary

- current proposed sour gas well

Source: Canadian Occidental Petroleum Ltd.
Principal Sour Gas Areas in Alberta
100 Part Per Million H₂S Isopleth Contour Inside Northeast Calgary (1974)

City of Calgary Boundary

1974 Extent of Urban Development

H₂S Isopleth from Existing Sour Gas Operations

MAP 7

H₂S Isopleth Contours - CanOxy Proposal 1984
(Average Weather Conditions)

RESERVES

INITIAL RECOVERABLE RESERVES

SOUR 26%
SWEET 74%
TOTAL - 2.9 $10^{12}$ m$^3$

REMAINING RECOVERABLE DECEMBER 31, 1982

SOUR 23%
SWEET 77%
TOTAL - 1.9 $10^{12}$ m$^3$

PRODUCTION

CUMULATIVE PRODUCTION

SOUR 32%
SWEET 68%
TOTAL - 1.0 $10^{12}$ m$^3$

1982 PRODUCTION

SOUR 45%
SWEET 55%
TOTAL - 0.06 $10^{12}$ m$^3$

Figure 1. Comparison of sweet and sour gas reserves and production.

Source: ERCB Report 82-D.
Figure 3. Problem occurrence by depth of wells
Figure 4. Drilling mud circulation system
Figure 5. Fracturing of formation - lost circulation
Figure 6. Drilling mud weights and formation pressures
Figure 7. Petroleum well 'kick'
Figure 8. Well capping technique while well flow is on fire

Failure to Ignite Blowout

Blowout

Sour gas

Minor Blowout

Failed to Control Minor Blowout

Kick

Failure to Control Kick

Circulating

Testing

Corning

Tripping In

Drilling

Tripping Out

Logging

Running Casing

\(\Box\) - And Gate

\(\bigcirc\) - Or Gate

Figure 9 - Sour gas drilling blowout fault tree
<table>
<thead>
<tr>
<th>Year</th>
<th>Population</th>
<th>Numerical Change</th>
<th>Percent Change</th>
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<tr>
<td>1891</td>
<td>3,876</td>
<td>-</td>
<td>-</td>
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<tr>
<td>1901</td>
<td>4,398</td>
<td>522</td>
<td>13.5</td>
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<td>1911</td>
<td>43,704</td>
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<td>83,761</td>
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<td>88,904</td>
<td>5,143</td>
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<td>129,060</td>
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<td>249,641</td>
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<tr>
<td>1976</td>
<td>471,397</td>
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<tr>
<td>1981</td>
<td>592,743</td>
<td>121,346</td>
<td>25.7</td>
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Source: Census of Canada, 1981.
### TABLE 2

**OUTER SUBURBS POPULATION GROWTH**

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<tr>
<th>Time Period</th>
<th>Net City Growth</th>
<th>Outer Suburbs Growth</th>
<th>5 of Total Growth</th>
<th>Growth in Remainder of City*</th>
<th>% of Total Growth</th>
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<tr>
<td>1964-1968</td>
<td>50,548</td>
<td>41,201</td>
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<td>1968-1969</td>
<td>14,179</td>
<td>11,523</td>
<td>81.3</td>
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<td>1969-1970</td>
<td>16,723</td>
<td>16,129</td>
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<td>594</td>
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<td>1970-1971</td>
<td>12,484</td>
<td>12,893</td>
<td>103.3</td>
<td>-409</td>
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<td>1971-1972</td>
<td>14,804</td>
<td>18,847</td>
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<td>1972-1973</td>
<td>11,945</td>
<td>17,247</td>
<td>144.4</td>
<td>-5,302</td>
<td>-44.4</td>
</tr>
</tbody>
</table>

Source: City of Calgary Civic Census, January 1, 1968, 1969, 1970, 1972 and 1973; and,

Calgary Transportation Study, Volume 1, City of Calgary Transportation Department (1967).

*Downtown, Inner City, Inner Suburbs and Industrial-Urban Reserve.*
<table>
<thead>
<tr>
<th>Direction</th>
<th>Percent of Time</th>
</tr>
</thead>
<tbody>
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<td>North</td>
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<tr>
<td>Northeast</td>
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<tr>
<td>East</td>
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<td>South</td>
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<tr>
<td>West</td>
<td>15.6</td>
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<tr>
<td>Northwest</td>
<td>17.8</td>
</tr>
</tbody>
</table>

APPENDIX 1
TOXICITY OF H₂S

Using the sense of smell to detect hydrogen sulphide (H₂S) is unreliable and extremely dangerous. The toxic gas attacks the nerves in the nose and kills the sense of smell within a few seconds. Small concentrations of H₂S are dangerous, therefore, it is normally measured in parts per million (ppm)

One ppm  = .000001
One percent  = 10,000 ppm

TOXITY TABLE

<table>
<thead>
<tr>
<th>ppm</th>
<th>Effect</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Odour of rotten eggs can be smelled clearly</td>
</tr>
<tr>
<td>3-5</td>
<td>Irritable to respiratory sensitive individuals</td>
</tr>
<tr>
<td>10</td>
<td>Eight hours maximum exposure time</td>
</tr>
<tr>
<td>over 20</td>
<td>Severe irritation to eyes</td>
</tr>
<tr>
<td>100</td>
<td>Kills sense of smell 3-5 minutes</td>
</tr>
<tr>
<td></td>
<td>Burns eyes and throat</td>
</tr>
<tr>
<td></td>
<td>Increased in pulse rate</td>
</tr>
<tr>
<td></td>
<td>Hazardous if exposed for more than 1 hour</td>
</tr>
<tr>
<td>200</td>
<td>Sense of smell lost rapidly</td>
</tr>
<tr>
<td>500</td>
<td>Irrationality, anoxia resulting in death from asphyxia</td>
</tr>
<tr>
<td></td>
<td>Dangerous if exposed for more than 30 minutes</td>
</tr>
<tr>
<td>700</td>
<td>Unconscious very quickly</td>
</tr>
<tr>
<td></td>
<td>Breathing stops</td>
</tr>
<tr>
<td></td>
<td>Prompt rescue required</td>
</tr>
<tr>
<td></td>
<td>Can be rapidly Fatal</td>
</tr>
<tr>
<td>over 700</td>
<td>Fatal</td>
</tr>
<tr>
<td>Sub-Acute</td>
<td>Prolonged exposure to concentrations between</td>
</tr>
<tr>
<td></td>
<td>15 and 100 ppm may produce:</td>
</tr>
<tr>
<td></td>
<td>nausea, gastric disturbance, diarrhea,</td>
</tr>
<tr>
<td></td>
<td>characteristic smell on breath, coughing,</td>
</tr>
<tr>
<td></td>
<td>disorders of balance mechanism, blurring of vision, headache.</td>
</tr>
<tr>
<td>Long-Term</td>
<td>Exposure to low levels are unknown</td>
</tr>
</tbody>
</table>

APPENDIX 2

PROPERTIES OF H$_2$S

Hydrogen sulphide has the following characteristics:

1. Classed as a highly toxic gas. It is extremely poisonous to man. No one is immune, no gradual exposure tolerance will be developed, and it will kill in high concentrations in a short time span.

2. Colourless at normal ambient temperature and atmospheric pressures.

3. Heavier than air . . . specific gravity of 1.189.

4. When mixed with air from 4.3 percent to 46 percent volume, H$_2$S is extremely explosive.

5. Soluble in water and liquid hydrocarbons.

6. H$_2$S is corrosive to all metals.

7. When ignited, H$_2$S will produce another toxic gas: sulphur dioxide (SO$_2$).

8. H$_2$S may produce skin irritation when combined with perspiration where H$_2$S and sweat combine on skin surfaces to produce sulphuric acid in a weak solution.

When H$_2$S is released, it can cause the following symptoms in man:

1. Skin irritation
2. Eye irritation
3. Fatigue
4. Nausea
5. Headache
6. Loss of appetite
7. Dizziness
8. Irrational behaviour
9. Dryness in nose, throat
10. Coughing
11. Loss of consciousness
12. Cessation of all life processes

The above symptoms may be hours in forming or may run their course in seconds if the H$_2$S concentration is extreme.

APPENDIX 3

CALGARY'S OUTER SUBURB GROWTH 1964–1973

<table>
<thead>
<tr>
<th>Year</th>
<th>Total City</th>
<th>Inner City</th>
<th>Inner Suburbs</th>
<th>Outer Suburbs</th>
<th>Industrial - Urban Reserve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1967</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Population

0 10,000 20,000 30,000 40,000 50,000 60,000 70,000 80,000 90,000 100,000 110,000 120,000 130,000 140,000 150,000 160,000 170,000 180,000 190,000 200,000 210,000 220,000 230,000 240,000 250,000 260,000 270,000 280,000 290,000 300,000 310,000 320,000 330,000 340,000 350,000 360,000 370,000 380,000 390,000 400,000 410,000 420,000 430,000 440,000 450,000 460,000 470,000 480,000 490,000 500,000

### APPENDIX 4

**SUMMARY OF MINIMUM DISTANCE REQUIREMENTS SEPARATING NEW SOUR GAS FACILITIES FROM RESIDENTIAL AND OTHER DEVELOPMENTS**

<table>
<thead>
<tr>
<th>Level of Sour Gas Facility</th>
<th>Sour Gas Well Release Rate $m^3/s$</th>
<th>Minimum Distance to Various Developments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 0.3</td>
<td>- Minimum distance for wells 0.1 km as stated in Section 2.110 of the Oil and Gas Conservation Regulations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- No minimum distance for other sour gas facilities except that associated with easement for right of way, unless otherwise specified by the Board.</td>
</tr>
<tr>
<td>2</td>
<td>0.3 - 2.0</td>
<td>- 0.1 km to individual permanent dwellings and unrestricted country development.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 0.5 km to urban centre or public facility.</td>
</tr>
<tr>
<td>3</td>
<td>2.0 - 6.0</td>
<td>- 0.1 km to individual permanent dwellings up to 8 dwellings per quarter section.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 0.5 km to an unrestricted country development.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 1.5 km to an urban centre or public facility.</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 6.0</td>
<td>- As specified by the Board, but not less than Level 3.</td>
</tr>
</tbody>
</table>

APPENDIX 5

TECHNICAL CAUSES OF LOSS OF CONTROL

Improper Mud Controls

1. Failure to keep hole full during pipe withdrawal;
2. Failure to keep hole full during other operations;
3. Lost circulation (natural or induced);
4. Reduction in hole pressure of mud when pulling pipe;
   and,
5. Insufficient drilling fluid density.

Improper Surface Equipment

1. Insufficient blowout control equipment;
2. Improper well casing and cementing practice;
3. Improper installation of blowout preventor equipment;
4. Improper fittings for blowout preventor equipment; and,
5. Improper design or manufacturer of blowout preventor equipment.

APPENDIX 6

MAXIMUM HEART RATES

<table>
<thead>
<tr>
<th>Activity</th>
<th>Maximum Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripping Work; Subject 1</td>
<td></td>
</tr>
<tr>
<td>Tripping in</td>
<td>135</td>
</tr>
<tr>
<td>Tripping out</td>
<td>139</td>
</tr>
<tr>
<td>Assembly change</td>
<td>158</td>
</tr>
<tr>
<td>Stair climbing test</td>
<td>135</td>
</tr>
<tr>
<td>Resting</td>
<td>75</td>
</tr>
<tr>
<td>General Drill Floor Work; Subject 2</td>
<td></td>
</tr>
<tr>
<td>General tidying up</td>
<td>124</td>
</tr>
<tr>
<td>Climbing and working on BOPs</td>
<td>122</td>
</tr>
<tr>
<td>Making a connection</td>
<td>128</td>
</tr>
<tr>
<td>Taking mud sample</td>
<td>102</td>
</tr>
<tr>
<td>Stair climbing test</td>
<td>139</td>
</tr>
<tr>
<td>Resting</td>
<td>80</td>
</tr>
<tr>
<td>General Drill Floor Work; Subject 3</td>
<td></td>
</tr>
<tr>
<td>General work on drill floor</td>
<td>135</td>
</tr>
<tr>
<td>Making a connection</td>
<td>149</td>
</tr>
<tr>
<td>General cleaning work</td>
<td>137</td>
</tr>
<tr>
<td>Handling ladders</td>
<td>165</td>
</tr>
<tr>
<td>Stair climbing test</td>
<td>143</td>
</tr>
<tr>
<td>Resting</td>
<td>100</td>
</tr>
</tbody>
</table>

ACCIDENT REPORTS FOR DRILLING INDUSTRY
FROM SEPTEMBER, 1982 TO JULY, 1985

<table>
<thead>
<tr>
<th>Type of Injury</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amputations</td>
<td>35</td>
</tr>
<tr>
<td>Burns</td>
<td>61</td>
</tr>
<tr>
<td>Eyes</td>
<td>26</td>
</tr>
<tr>
<td>Fractures</td>
<td>307</td>
</tr>
<tr>
<td>Strain/Sprain/ Bruises</td>
<td>577</td>
</tr>
<tr>
<td>Wounds/Lacerations</td>
<td>168</td>
</tr>
<tr>
<td>Other (i.e., paralysis, infection, dental)</td>
<td>45</td>
</tr>
<tr>
<td>Fatalities</td>
<td>16</td>
</tr>
</tbody>
</table>

Source: Monthly Accident Reports, prepared by The Accident Reporting Sub-Committee of the Accident Prevention Committee of the Canadian Association of Oilwell Drilling Contractors, Calgary, Alberta, 1982-1985.
APPENDIX 8

COMPARISON OF RISK ESTIMATES

Bercha (1985) concluded the annual human risk from an H2S release outside northeast Calgary to be less than one in one million.

A one in one million risk of death corresponds to:

- 1 1/2 cigarettes
- 1 1/2 minutes rock climbing
- 6 minutes canoeing
- 20 minutes being a man aged sixty
- 50 miles by car
- 250 miles by airplane
- 1 or 2 weeks typical factory work

Source: Environmental Risk Assessment, edited by Anne V. Whyte and Ian Burton, Institute of Environmental Studies, University of Toronto, Canada, 1982.