# Results from the Deepwell Disposal Workshop

November 7, 1991

INFORMATION SERIES 118



ALBERTA RESEARCH COUNCIL
Alberta Geological Survey

# Contents

# DEEPWELL DISPOSAL WORKSHOP

## EXECUTIVE SUMMARY


The workshop on Deepwell Disposal of Waste was held November 5-7, 1990 in the auditorium of the Alberta Research Council in Edmonton. This workshop was the result of a cooperative effort between Alberta Environment, ERCB, and industry. Recognizing that it is a major opportunity the workshop was held to discuss issues. The major conclusion of the workshop was that deepwell injection of wastes in Alberta was both environmentally and technically sound when properly operated and monitored. However, the workshop reached a number of conclusions which it believed to be important. In addition, it was recognized that there were some additional things which could be done to ensure regulators, industry and the public that the practice was reasonable and safe. Those conclusions and recommendations were drawn from the discussions and summaries provided by the four workshop study groups.

Conclusions

1. Properly monitored and operated deepwell disposal is an environmentally sound disposal method and should remain as a disposal option for specified liquid wastes. It is recognized, however, that waste stream reduction is an expectation prior to disposal.

2. A one-window approach for deepwell disposal approval and enforcement processes should be maintained. The roles shared by Alberta Environment and ERCB are believed to be adequate.

3. Although it is acknowledged that responsibility for the waste remain with the generator, the workshop felt it could not reach consensus on what party should assume financial responsibility in whole or part for risk assessment.

Recommendations

1. Disposal wells should be classified according to the type of waste being injected. A well classification system similar to U.S. EPA is suggested. Technical and monitoring requirements would be commensurate with the hazard nature of the well. For disposal wells injecting wastes (U.S. EPA Class 1 equivalent) additional requirements to establish and maintain physical integrity would be appropriate. Monitoring to ensure mechanical integrity should be reviewed and upgraded commensurate with well classification.

   Detailed chemical analysis such as that required or implied under the Hazardous Chemicals Act or the Transportation of Dangerous Goods Act are not appropriate and should not be applied to wastes destined for deepwell disposal. Broad waste stream descriptions and compositions are necessary to ensure that the appropriate waste management option is utilized and to allow easy waste description and entry on a waste manifest system.

Action by the ERCB on the well classification system is suggested. Action by Alberta Environment is recommended on the waste stream classification with review by all workshop participants on both issues.

2. Industry and Regulators should consider the following public awareness programs:

   - Information brochures on disposal and safety considerations. (Regulatory & Industry).

   - Develop and distribute code of practice for operations at disposal wells. (Industry).

   - Follow-up discussions and/or presentations from workshop participants with interested parties such as special interest groups, Alberta Environmental Network, community groups, etc.

   - ERCB and Alberta Environment should publish guidelines outlining disposal policy and application processing procedures.

3. Industry and Regulatory agencies should make an effort to promote technical knowledge and excellence by the promotion of research in the following areas:

   - Long-term well bore integrity.

   - Long-term formation integrity.

   - Fate of typical injected wastes.

4. Baseline data now being collected should be reviewed to ensure that all appropriate and necessary information is being collected and retained. Further, the feasibility of centralizing the storage of baseline data should be investigated and if feasible, instituted.

## GROUP SUMMARY

### WORKSHOP GROUP NO. 1 ROLE OF REGULATORS/STAKEHOLDERS

The Workshop participants agreed in summary to the following:

Conclusions:

- o Deep well injection of liquid hazardous wastes should remain a disposal option as it is acknowledged to be an established safe practice. It is recognized however, that waste stream reduction is an expectation prior to disposal.

- o Although it is acknowledged that responsibility for the waste remains with the generator, the group believed it could not reach consensus on what party should assume financial responsibility in whole or in part for risk assessment, believing that decision instead to require a political solution.

Recommendations:

- o Maintain the current one-window regulatory process. This should apply to the enforcement as well. The roles currently shared by Alberta Environment and the ERCB are believed to be adequate.

- o ERCB and Alberta Environment publish a joint guideline outlining disposal policy as well as application processing.

- o Because deepwell disposal is safe practice, Regulators should not necessarily require in-depth and expensive risk assessments of a disposal scheme, nor request operators to spend time and money trying to find alternatives to deepwell disposal. The Regulators instead should concentrate efforts on high-risk wells by asking operators how they would identify if a failure occurred, what would be the consequence of such a failure, and how they would react to such a failure.

- o In the interest of environmental protection, decisions on waste management should be made on the basis of "best available and best practical technology" (jointly) and not on the business interests of the hazardous waste management facilities or reclaimer disposal options.

- o Regulators should encourage operators to minimize, recyle, recover and reuse waste streams.

## GROUP SUMMARY

### WORKSHOP GROUP NO. 2 AWARENESS

The main conclusions and recommendations of the group were:

Main Recommendations:

- o For general public awareness, it is recommended that regulatory agencies (Alberta Environment/ERCB) provide a brochure describing deepwell disposal operations and safety considerations.
- o For owners and operators, it is recommended that industry develop and distribute (code of best practice) to inform and emphasize safe operating to employees and contractors.
- o It is recommended that the following actions be considered for follow-up by the steering committee:
  - further workshops
  - speakers bureau (?)
  - contact with Alberta Environmental Network to determine level of concern
  - one-day seminars to address specific concerns, e.g. Drayton Valley, Cold Lake, etc.
- o Deepwell disposal is an important, safe and viable option for some waste.
- o A well-classification system is recommended (US EPA type classification).
- o A disposal well injection criteria guideline should be developed.
- o Deepwell disposal should be considered in conjunction with other alternative waste management options.

## GROUP SUMMARY

### WORKSHOP GROUP NO. 3 RESEARCH

The participants in the discussion group concentrating on the research aspect of deep well disposal reached a general agreement that even though it was believed that deep well technology was environmentally acceptable, certain issues should be addressed by focused research.

It was recommended that consideration be given to research in the following areas, in order of decreasing priority:

1. Long-term Wellbore Integrity (includes production wells)

   o includes matters of cement and/or casing degradation, monitoring methods for continued wellbore integrity, and establishment of risk/failure assessment.

2. Long-term Formation Integrity

   o includes regional fluid migration, chemical/physical changes to formation characteristics, and the integrity of caprock and baserock over the long term.

3. Waste characterization and Fate of Injected Fluids

   o includes the suitability of existing technology to characterize wastes, subsurface treatment potential, and fate and effect of organics.

Much of the present information has been assembled through literature studies, further field research is required but was not delivered.

## GROUP SUMMARY

### WORKSHOP GROUP NO. 4. PHYSICAL/OPERATIONAL/ISSUES

1. Detailed chemical analysis such as that required or implied under the Hazardous Wastes and Chemicals Act or the Transportation of Dangerous Goods Act are not appropriate and should not be applied to wastes destined for deep well disposal.

2. Broad waste stream descriptions and compositions are necessary for two reasons:

   - to ensure that the appropriate waste management option is utilized, and
   - to allow easy waste description and entry on a waste manifest system.

3. The baseline data now being collected should be reviewed to ensure that all appropriate and necessary information is being collected and retained. Further, the feasibility of centralizing the storage of baseline data should be investigated and if feasible instituted.

4. Disposal wells should be classified according to the type of waste being injected.

5. For disposal wells injecting wastes (US EPA Class 1 equivalent) additional requirements to establish and maintain physical integrity would be appropriate. Monitoring to ensue physical integrity should be reviewed and upgraded commensurate with well classification.

CONCLUSION:

Deepwell disposal of wastes is appropriate providing that suitable technology has been applied to the drilling, completion and operations of the well. Other disposal or treatment options which are technically and economically feasible, and equally reliable should always be considered.

## WORKSHOP GROUP #1

GIVEN TOPIC: ROLE OF THE REGULATORS/STAKEHOLDERS

GIVEN QUESTIONS:

(Q) **What role/roles do you think Alberta Environment, Environment Canada, and the ERCB should play with the respect to deepwell disposal?**

Present role shared by ERCB & Alberta Environment believed adequate.
Environment Canada shares an interest, but should work with other two Regulatory bodies to prevent duplication of efforts.

Group believed that it would be beneficial for ERCB & Alberta Environment to publish a joint guideline outlining disposal policy and application process.

(Q) **What should their role be with respect to risk assessment of deepwell disposal (i.e. U.S. EPA proving the 10 000 yr criterion)?**

The group stated that a full-blown Risk Assessment was not the way to go.

Recommended instead:

Consequence evaluation on high risk wells; that is, the Regulators at the application stage could ask the operator how he would know if his disposal well failed, what would be the consequences of that failure, and how he would react (i.e. what would he do) if a failure occurred.

(Q) **What is the role of the regulators, regarding the recommendation or enforcement of risk assessment for alternate solutions of waste disposal streams?**

Regulators should encourage operators to minimize their waste streams rather than prohibiting deepwell disposal of them.

Large and expensive risk assessments on deepwell disposal or their alternatives not necessary because:

- deepwell disposal is believed to be a safe practice.
- the alternative solution to deepwell disposal would not necessarily be less risky.

(Q) **Financial responsibility. Who has it? How should it be implemented?**

The group did not reach agreement on a recommendation to the issue of financial responsibility; the Group believed it was more an issue that required political solutions.

The group put the responsibility of the waste with the waste generator.

(Q) **Should we indeed have deepwell disposal and when?**

Yes, we should have deepwell disposal.

When:

- It ensures environmental protection.
- resource conservation has been taken into consideration, i.e., can the waste stream be recycled?

  Waste stream should be minimized where economically and technically feasible.

(Q) **What should the role of other stakeholders be? (i.e. Alberta Special Waste Management Corporation, reclaimers).**

We believe that the legitimate business interest of the Hazardous Waste Management Facilities and reclaimers should not be the prime driving force on waste disposal options in Alberta.

Industry should do more public education about deepwell disposal where applicable.

## WORKSHOP GROUP #2

GIVEN TOPIC: AWARENESS

GIVEN QUESTIONS:

**(Q) How best could we inform the public on the deepwell disposal practice?**

Deepwell disposal is an important waste management option for all stakeholders to ensure protection of human health, safety and environment!
All stakeholders must continue to operate the deepwells in a responsible manner.
We endorse EPA type well classification system.
We endorse the establishment of injection criteria for industrial disposal wells for Alberta.

**(Q) What role can industry/regulators play to promote awareness to the public as well as their own employees?**

Alberta Environmental Network to be contacted to confirm level of concern over D.W.D. and what specific concerns they have.

Two types of groups

- General public awareness.
- Operators/owners of deepwells to understand importance of proper operation and downside of mismanagement, including employees and contractors.
    - Alberta Environment brochure.
        - i) Further workshops.
        - ii) Speakers bureau (Alberta Research Council independent)? independent group.
    - Operators communicate with neighbours on an as needed basis.

**(Q) What sort of "follow up" should be arranged in the future for this meeting?**

Follow up workshops (if required?).

- Deepwell Disposal Steering Committee to determine if follow up is required.
- One day seminars to address these concerns.
- Drayton Valley/Cold Lake/Grande Prairie or Edmonton/Calgary.
- Who pays for workshops/public participation?
- Timing?

**(Q) Should we indeed have deepwell disposal and when?**

Deepwell Disposal cannot be decoupled from other Waste Management Alternatives:

- Incineration
- Landfill
- 4 R's
- Transport of liquids to Swan Hills
- or other disposal facilities.

} Cost and reliability

## WORKSHOP GROUP #3

GIVEN TOPIC: RESEARCH NEEDS

GIVEN QUESTION:

(Q) What are some of the aspects of deepwell disposal that require further research (i.e. aspects for further research)?

1. Demonstrate that deepwell works

- by monitoring
- on a reservoir basis - no cross contamination
- effects on regional flow - how far, fast, etc. within reservoir formation
- after injection stage (discontinued)

2. Identify potential problems

3. Safety of target zone

- movement in non-target zones
- monitoring/detection

4. Long term integrity re: formation

- changes over time
- chemical change in
- caprock/basement/well bore-cement, integrity

5. Chemical characterization of injected wastes

- is the available technology suitable?
- is suitable technology available?

6. Fate and effects of organic species - modelling

7. Risk assessment - Models

- reservoir, well bore
- evaluation, - input data
- models need to be validated

8. Long term effects

- effects and interaction between wells
- regional effects
- cumulative effects
- integrate existing data to assess impact (200 K production wells - failure history)

9. What wastes can be allowed for deepwell disposal - fate and effect

- long term effects

10. Long term safety of disposal

- degree of certainty
- communicate to public
- how to demonstrate safety or impacts

11. Fundamental research on transformations (chemical, physical) in reservoir, cap and base rock

    Subsurface treatment and disposal

- use of disposal reservoir as a reactor;
- enhance interactions between wastes, rock, etc. to reduce undesirable properties.
- start with lab scale study
  (pilot scale) operational scale

12. Suitability of extremely deep zones?

13. Effect of injection induced uplift/ground movement on well or formation integrity

14. Identify public concerns and perceptions that need to be addressed by industry

- what are the concerns that should be researched

15. Characterization

- injected wastes
- formation waters
- non-production zones
- physical characteristic and properties of caprock/baserock

16. Long-term integrity of well bore

- casing cements/casing
- cementing practices
- especially surface/shallow casing
- testing/evaluation for failure

    Who should fund such research and how?

    Who should be responsible?

- to carry out research

- identify priorities etc?

What is the <u>mechanism</u>?

- by regulation
- by committees, associations (voluntary)

**(Q) Discuss some of the viable alternatives to deepwell disposal (i.e. other technologies)?**

Alternatives to deepwell disposal - depending on the nature and amount of waste:

- incineration
- recycling
- treatment and discharge (surface)
- ion exchange adsorption
- focus on one waste stream
- waste minimization
- treatment
- concentrate/resource recovery

**(Q) Should we indeed have deepwell disposal and when? Should deepwell disposal be done at all?** <u>Yes</u>

Impacts of alternatives

- only option in some cases
- e.g. large volumes saline water
- yes - for naturally occurring reservoir fluids - brine
- maybe not - man made synthetics
- deepwell 'storage'
- deepwell (subsurface) 'treatment'

# WORKSHOP GROUP #4

GIVEN TOPIC: PHYSICAL/OPERATIONAL ISSUES

DISCUSSION

GIVEN QUESTION:

THERE ARE TWO PERCEIVED PHILOSOPHIES BY WHICH ONE CAN JUSTIFY THE INTEGRITY OF A DEEPWELL DISPOSAL STRATEGY (1) ENGINEERING/GEOLOGICAL AND (2) CHEMICAL COMPOSITION. WHICH ONE WOULD BE BEST SUITED TO ALBERTA USERS/REGULATORS/PUBLIC?

There was a consensus that:

1. Engineering and geological criteria needed to be met to qualify for approval of any subsurface disposal.

2. Detailed chemical composition criteria is not required for the disposal well operation itself.

3. Some typical waste stream compositions * are necessary for the following reasons:

   o to choose appropriate waste management technology
   o to provide guidelines and information to operations to ensure workplace safety, well compatibility and general accountability.

*It should be noted that waste stream compositions refers to broader material classifications and not extremely detailed constituent analysis.

Summary and Recommendations

The group consensus is that detailed chemical analysis such as that currently required or implied under the Hazardous Wastes and Chemicals Act and Transportation of Dangerous Goods Act does not apply to wastes destined for deepwell disposal or even perhaps for other disposal alternatives.

The group was in agreement that some level of information was necessary to ensure a basic level of knowledge by the operator and regulatory agencies for a number of reasons. An increasing level of analysis may be required to assess the possibilities of alternative treatment and disposal methods.

o It is recommended that the disposal well approval process not be based on detailed compositions but rather on broader general material classifications.

o It is recommended that allowable or guideline treatment/disposal options be clearly published and communicated to the petroleum and other potentially affected industries. Where other waste treatment and/or disposal options preclude deepwell disposal, some degree of flexibility should be written into the policy to provide for transition economics and technology transfer.

(Q) WHAT BASE LINE DATA SHOULD BE COLLECTED?

There was consensus that a full suite of baseline data is necessary with respect to both the well itself and geological information. Geological information would include base line information on shallow aquifers (usable waters) as well as deep geological features to ensure regional geological integrity. Well data should include all drilling and completion data pertinent to well mechanical integrity. The following lists were developed by the group but are not meant to be fully inclusive.

Formation

- hydrology - both regional and local
- geology - aquifer/aquitard
- cores should be cut from injection zone
- water chemistry/quality for all zones
- logs - E-log, gamma log, etc.
- downhole pressures/temperatures in formation
- insitu injectivity and pressure tests to verify permeability and fracture pressures

Well

- depth of packer and perforations
- cement type
- surface casing depth
- annulus fluid
- tube design and type
- drilling mud
- cement and casing integrity tests (isolation tests, casing inspection logs)
- surface facilities
- cathodic protection baseline
- centralizers
- previous history
- data base of all above
- cement top

<u>Summary and Recommendations</u>

It was acknowledged that much, if not all, of the information is already collected. However, there was some concern that the information is contained in a number of locations or databases. It is recommended, therefore that the baseline information be reviewed to ensure that all pertinent information is being obtained and retained as appropriate. Secondly it is recommended to review the feasibility of collecting and storing the baseline data on one database.

## (Q) SHOULD WE INDEED HAVE DEEPWELL DISPOSAL AND WHEN?

### Summary and Recommendation

The workshop group was unanimous in agreeing that deepwell disposal was appropriate under two conditions:

1. when appropriate technology has been considered and applied to the siting, drilling, completion and operation (including monitoring) of the well, and

2. when other waste treatment and/or disposal options were not technically or economically feasible.

It was agreed that there were some areas of risks, but it was also agreed there were likely some additional completion and operational procedures which could be applied (which are not now being done, e.g., cathodic protection) which could reduce the risks even further. It was generally agreed that the well bore system was the area of greatest risk but at the same time can be monitored and controlled. Risk of migration from the formation in a properly located well was seen as being low and even the consequences were not believed to be high.

<u>Some Specific Recommendations</u>*

a) Wells must be classified according to the type of waste injected.
b) For waste disposal wells (US EPA Class 1 equivalent)
    o run casing inspection logs every 5 years
    o apply cathodic protection from the outset
    o special logs (e.g. tracers, temperature, etc.)

* Recommendation not necessarily a complete list.

## (Q) WHAT SORT OF DATA SHOULD OPERATORS BE MONITORING FOR AND AT WHAT FREQUENCEY?

### Recommended Monitoring for Waste Disposal Wells

- volumes disposed (metering)
- tubing and annulus pressure (chart or equal continuous)
- bottom hole pressure (reservoir pressure)
    o new wells/formations - quarterly 1st year
    o annually thereafter
- annulus pressure test quarterly
- surface casing/production casing annulus monitoring

## (Q) ABOVE GROUND OPERATIONS (i.e. manifesting, record keeping)

### Recommendations

It is recommended that records of volumes and corresponding waste descriptions be required and kept. Records of volumes and waste descriptions shall be kept and maintained in a consistent form prescribed by the appropriate regulatory body.

For deepwell disposal operations accepting wastes from more than one source by truck it was agreed that it should be a consistent manifest form identifying the waste generator, transporter and receiver.

# ISSUES

## DEEPWELL DISPOSAL WORKSHOP

November 7, 1990

1) ROLE OF THE REGULATORS/STAKEHOLDERS

a) What role/roles do you think Alberta Environment, Environment Canada and the ERCB should play with respect to deepwell disposal?
b) What should their role be with respect to risk assessment of deepwell disposal (i.e. U.S. EPA proving the 10 000 year criterion).
c) What is the role of the regulators, regarding the recommendation or enforcement of risk assessment for alternate solutions of waste disposal streams?
d) Financial responsibility. Who has it? How should it be implemented?
e) Should we indeed have deepwell disposal and when?
f) What should the role of other stakeholder be? (i.e. Alberta Special Waste Management Corporation, reclaimers).

2) AWARENESS

a) How best could we inform the public on the deepwell disposal practice?
b) What role can industry/regulators play to promote awareness to the public as well as their own employees?
c) What sort of follow up should be arranged in the future for this meeting?
d) Should we indeed have deepwell disposal and when?

3) RESEARCH

a) What are some of the aspects of deepwell disposal that require further research?
b) Discuss some of the viable alternatives to deepwell disposal? (i.e. other technologies).
c) Should we indeed have deepwell disposal and when?

4) PHYSICAL/OPERATIONAL ISSUES

a) There are two perceived philosophies by which one can justify the integrity of a deepwell disposal strategy: 1) Engineering/Geological, and 2) Chemical composition. Which one would be best suited to Alberta users/regulators/public?
b) What baseline data should be collected?
c) Should we indeed have deepwell disposal and when?
d) What sort of data should operators be monitoring for and at what frequency?
e) Above ground operations (i.e. manifesting, record keeping).

# Attendees at the Deepwell Disposal Workshop
## November 7, 1990

GROUP 1
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# UNIFARM

AN ORGANIZATION OF ALBERTA FARMERS AND THEIR ASSOCIATIONS

14815 - 119 AVENUE
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November 5, 1990

Stakeholders Forum
Deepwell Disposal

Dear Participants:

As we indicated to Mr. Stuhec of the Alberta Research Council by telephone last week Unifarm will not be making an in-person presentation to the Stakeholders Forum.

We had come to the conclusion that although our members have a genuine interest in the matter, these concerns could be stated briefly, by letter, without taking much valuable time during the Forum. Our limited resources preclude scientific analysis or argument we might have been expected to present to the Forum. Furthermore, the sponsorship of the Forum and technical Workshop and the details of the program lead us to believe that their purpose is to exchange information and views on the subject, with groundwater protection as a major objective.

Unifarm would appreciate having this letter made part of the proceedings and we look forward to hearing of conclusions reached during the event.

With regard to the subject of the Forum and the Workshop the concern of Alberta's farming community is obvious and simple: The contamination of groundwater must be avoided at all cost, whether such supplies are at risk because of procedures followed in the drilling, operation, and subsequent abandonment of oil and gas wells or by disposal of un-related waste substances. It should be recognized that contamination of groundwater supplies results in much more than an inconvenience. In many cases it would be catastrophic. The dependence of the vast majority of rural Albertans on a reliable supply of potable water for human consumption, a safe supply for livestock production, etc. is obvious. Contamination as a result of error or of indiscriminate disposal of waste is most often, if not always, irreversible, as we understand it.

Please accept our good wishes for a useful Forum and Workshop which will meet a common objective.

Yours sincerely,

W. J. Plosz
Executive Director

WJP:op

# ALBERTA ENVIRONMENT PERSPECTIVE ON DEEPWELL DISPOSAL

Silver Lupul-Alberta Environment

## REGULATORY AUTHORITY

Regulatory control on the use of deepwell injection schemes resides in the Oil and Gas Conservation act. This Act requires that an approval from the Energy Resources and conservation Board is required by anyone that uses a well for injecting gas or a fluid into an under ground formation for storage, hydrocarbon reservoir pressure maintenance or for waste disposal. The Oil and Gas Conservation Act also requires that the Board refer applications to the Minister of Environment for approval with respect to impacts on the environment. Alberta Environment's approval issued by the Minister forms part of the Board approval.

## GOVERNMENT POSITION

Alberta Environment accepts deepwell disposal of waste as an alternative waste management option available to Albertans. In consultation with other government agencies and industry, standards for well design and reservoir selection have been developed so that wastes can be disposed of safely in this matter.

## PROTECTION MEASURES

### Geology

Most of Alberta is geologically suitable for deepwell disposal. An individual site for an injection well is chosen for geological characteristics which make it both safe and economically viable. From the standpoint of protecting the environment, the injection zone must be isolated by aquitards which will prevent the injected fluid from migrating upward.

### Well Design

An injection well must be constructed to exacting specifications so that wastes are injected only into targeted reservoirs.

Controlled Operation

The rate and pressure of injection are limited to levels below those which would cause fractures in the receiving formation or the impermeable confining layers.

The operation of the well is monitored to provide an early warning of any failure , so that corrective action can be taken.

## WHY USE DEEPWELL DISPOSAL?

The ultimate repository of all waste is either the atmosphere, sediments in the lakes and the rivers, the oceans or the earth's crust. Deepwell disposal provides a means of disposal which isolates the waste from man's food , air and water, permanently.

When compared to treatment and disposal alternatives, it requires less energy and minimizes environmental impact.

It also provides for greater flexibility in siting industrial plants.

## WHY THIS WORKSHOP?

Although we are quite confident that deepwell disposal as practiced in Alberta is protecting our environment and human health , it is appropriate that we review the practice to determine if there is something we may have overlooked in the past which could result in unanticipated impacts in the future. Furthermore there is the new emphasis on waste minimization and recycling which has to be factored into the decision making regarding waste going down deepwells

The discussions that will take place during the next two days will lead to a better understanding of deepwell disposal, could lead to the identification of required changes and should lead to greater confidence in the practice.

## KEYNOTE SPEAKER

FRANCOISE BRASIER

# INJECTION OF INDUSTRIAL WASTES IN THE UNITED STATES

DEEPWELL DISPOSAL WORKSHOP
ALBERTA RESEARCH COUNCIL
NOVEMBER 5-7, 1991

# INJECTION OF INDUSTRIAL WASTES

# IN THE UNITED STATES

# LA INYECCION DE RESIDUOS

# INDUSTRIALES EN LOS ESTADOS UNIDOS

Michael B. Cook
Francoise M. Brasier

Paper delivered at the Seminar
La Inyeccion En Sondeos Profundos
Una Alternativa En La Lucha
Contra la Contamination

Madrid, Spain

November 1989

# INJECTION OF INDUSTRIAL WASTES IN THE UNITED STATES

The U.S. Environmental Protection Agency (EPA) is charged under the Safe Drinking Water Act (SDWA) with regulating injection of fluids in order to protect underground sources of drinking water (USDWs). Among the facilities covered under this program are injection wells used for industrial waste disposal commonly referred to as deep disposal wells. This paper will give an overview of the underground injection control (UIC) program, examine the evolution of requirements governing the deep wells used to dispose of industrial wastes and the current status of these wells with an emphasis on hazardous waste injection. In addition, it will touch briefly on shallow injection wells which are the issue facing EPA today.

## I. HISTORICAL PERSPECTIVE.

The practice of using injection wells to dispose of waste started in the oil fields in the 1930s. Played out portions of the fields were used to dispose of oil field brines and other waste fluids resulting from oil and gas production. The first report of injection of industrial waste is in an article published in 1939 (Harlow, 1939). Published literature indicates that only four such wells were in existence in 1950. A 1963 inventory by the Bureau of Mines listed 30 wells (Donaldson, 1964). Most of these early wells were converted oil production wells. By the early 1970s, the number of injection wells had grown to approximately 250 (Warner, 1972) and they were being used to dispose of sewage effluent as well as a variety of industrial wastes.

Concerns about the practice led the U.S. EPA to issue a policy statement in 1974 (39 FR 12922-3 April 9, 1974) which opposed storage or disposal of contaminants by subsurface injection "without strict control and clear demonstration that such wastes will not interfere with present or potential use of subsurface water supplies, contaminate interconnected surface waters or otherwise damage the environment." In December 1974, Congress enacted the Safe Drinking Water Act which ratified EPA's policy and required the Agency to promulgate minimum requirements for State programs which would prevent endangerment of underground sources of drinking water by well injection.

## II. OVERVIEW OF THE UIC PROGRAM

Pursuant to the mandate established by the Safe Drinking Water Act, EPA promulgated Federal regulations establishing minimum requirements for State UIC programs in 1980. These regulations are implemented either by the States where State laws and regulations are adequate or by EPA.

The regulations require protection of current and potential sources of drinking water which they define as aquifers or their portion which supply any public water system or contain water with less than 10,000 mg/l total dissolved solids (TDS) in sufficient quantity to serve a public water system.

The regulations establish 5 Classes of wells:

Class I - injection of municipal or industrial waste (including hazardous waste) below the deepest USDW;

Class II - injection related to oil and gas production;

Class III - injection for mineral recovery;

Class IV - injection of hazardous or radioactive waste into or above a USDW;

Class V - all other wells used for injection of fluids.

The regulations are tailored to the different Classes of wells. In general, for Classes I, II and III wells, the regulations establish siting, construction, operating, testing, monitoring and reporting requirements. In addition, owners and operators of these injection wells must demonstrate the financial ability to properly plug and abandon the wells upon completion of operations. The regulations are very stringent and specific for Class I wells, particularly those that inject hazardous wastes, they are much more flexible for Class II wells. They ban Class IV wells with the exception of wells used for remediation of aquifers which have been contaminated with hazardous wastes. At this time EPA has not developed specific regulations for the shallow Class V wells.

By far the largest group of injection wells is Class V. They include many practices which are not normally thought of as injection wells, such as certain types of septic tanks, sumps, and cesspools for which the technical requirements developed for the conventional forms of wells are not adequate. The official EPA inventory contains records for approximately 180,000 Class V wells, however the Agency believes that this is a gross underestimation of the actual number of Class V wells.

The second largest group of wells is the Class II group which contains approximately 150,000 wells. The largest number of these are used for enhanced recovery of oil and gas mainly through waterflooding.

Class III wells are used mainly for recovery of uranium by in-situ leaching, sulfur by the Frasch process, and for solution mining of salt. In 1989, there were 192 active Class III facilities with approximately 20,000 wells among them.

Except for Class IV wells which are essentially banned, Class I is by far the smallest class of injection wells. In 1989 there were 554 Class I wells. Of these 245 were used to inject hazardous wastes and 233 to inject other forms of industrial wastes. Seventy-six were used to inject treated sewage.

In addition to requiring EPA to establish minimum requirements, the SDWA empowers the Agency to enforce the requirements by providing it with several authorities. The Agency (or its representatives) has the right to enter and inspect facilities where injection wells are located as well as records pertaining to injection even if they are not located at the site. The Agency can impose administrative fines up to $125,000 without recourse to the judicial system, for violations of the UIC regulations. Finally the Agency can pursue civil or criminal actions against violators. The Act provides for civil or criminal penalties of up to $25,000 per day of violation and imprisonment of not more than three years for criminal violations. These cases, however, must be referred to the U.S. Justice Department.

The requirements prescribed by the regulations are imposed on specific facilities through the issuance of permits, except in the case of Class II enhanced recovery wells which are governed by more general rules. In order to obtain a permit the owner or operator must submit an application with detailed plans for siting, construction, operation, testing, monitoring and eventual plugging of the well as well as evidence of financial responsibility. The Agency reviews the information and makes a tentative determination to issue or deny the permit. This determination is subject to public scrutiny through publication in newspapers and mailings and the Agency must consider public comments before making a final determination.

In addition to specifying construction requirements, the permits identify the zone into which injection can take place. The permits also include special terms and conditions and testing, monitoring and reporting requirements for the well. Permits for Class I wells are valid 10 years, while permits for Class III and Class II salt water disposal wells are valid for the life of the well.

The regulations governing these wells are either applied by the States or by EPA where the States have chosen not to run the program. The States can also elect to run only the portion of the program dealing with Class II wells or alternatively only the portion which does not apply to Class II wells. In all 36 out of 56 States and Territories run a complete program, five States share the program with EPA and EPA runs the program in the remaining jurisdictions.

In order to be given the responsibility to enforce a UIC program, the States must demonstrate that they have in place a set of requirements at least as stringent as those spelled out in the Federal regulations and enforcement authorities comparable to those established in the SDWA. The States and the Agency enter in formal agreements which spell out respective responsibilities and provide for Federal oversight of the State programs. If a State fails to enforce requirements the Federal government can take enforcement action and if the situation warrants it withdraw the State's authority to run the program. Federal funds are awarded every year to the States responsible for the UIC program.

## III. INDUSTRIAL WASTE DISPOSAL

### A. The 1980 Regulations

In order to develop the UIC regulations, the Agency gathered information on the practices involved, particularly on deep disposal wells. Most of the information available at the time was compiled in a report entitled "An introduction to the Technology of Subsurface Wastewater Injection" by Don L. Warner and Jay H. Lehr (Warner, 1977). The regulations which the Agency promulgated in 1980 were based on the premise that injection wells if properly sited, constructed and operated, can be an environmentally acceptable method of waste disposal.

In order to ensure that injection wells are properly sited, the UIC regulations require the submission of very detailed geologic and hydrologic data. These are used to determine that injection will take place in a receiving formation that is relatively homogenous and continuous, free of faults, and separated from USDWs by at least one, but preferably several thick and relatively impermeable strata (Figure 1). In addition, the Agency considered what possible avenues there could be for accidental escape of formation fluids or injected wastes during injection when pressures are increased in the receiving reservoir. Since waste disposal often takes place in areas of oil and gas activity, a major concern was other wells penetrating the injection interval. The regulations require the applicant to demonstrate that all wells in the vicinity of a proposed injection well are properly completed, and plugged if no longer

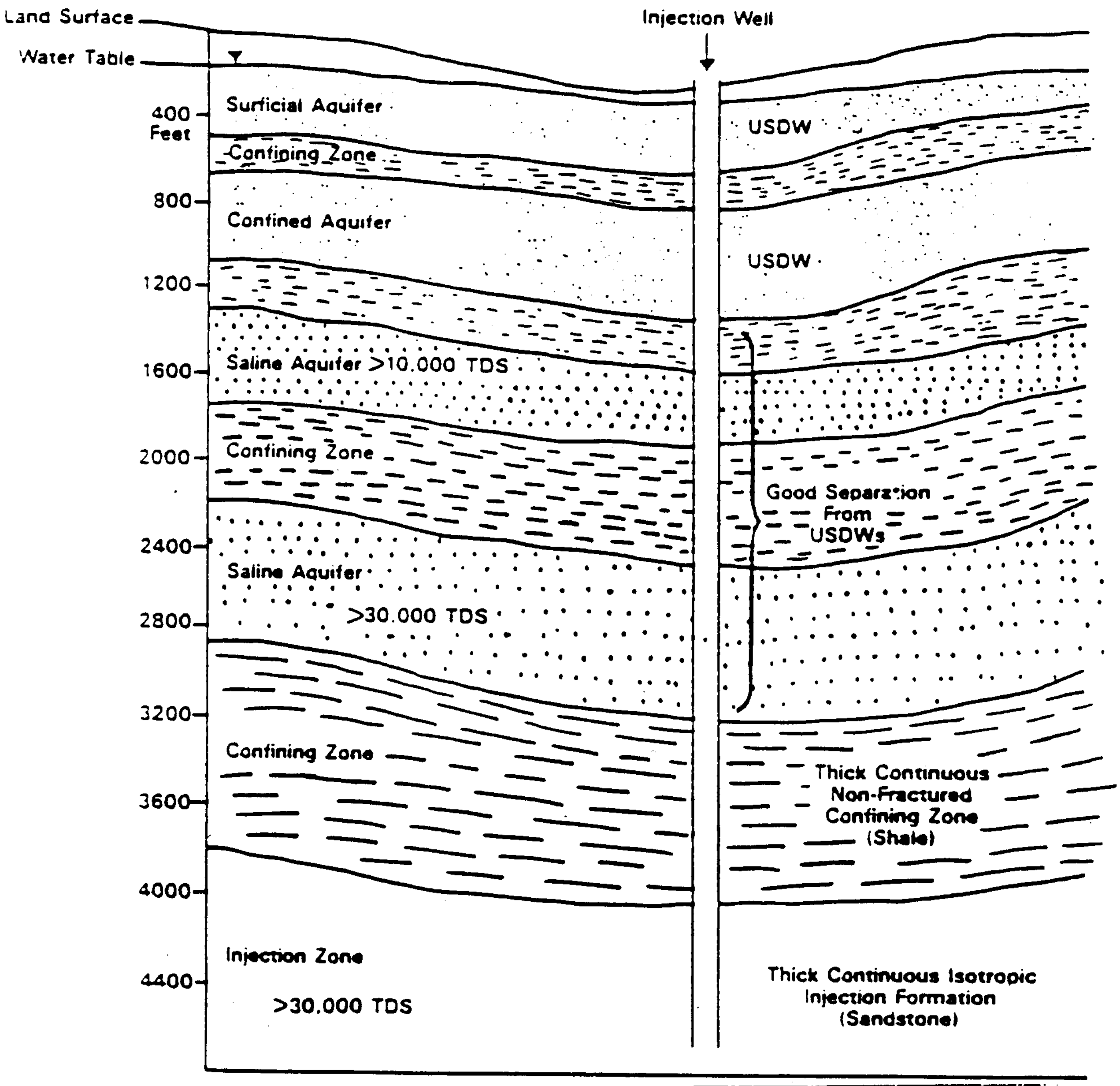



Figure 1. Ideal Class I HW Well Setting

in use, so that they will not serve as a conduit for injected waste or displaced formation fluids. The regulations require that these data be submitted for wells within one quarter mile (400 m) of a proposed facility. Some States have adopted more stringent requirements, for example, Texas requires data on wells within 2.5 mile (4 km) of the site. Other States use a formula to calculate the probable radius of pressure influence of the proposed wells and require data of all wells within this radius.

Another important factor in successful waste disposal was determined to be proper well construction. The UIC requirements were designed to achieve two goals: protection of USDWs and successful emplacement of the waste in the chosen injection interval. A typical hazardous waste injection wells constructed according to the UIC requirements (Figure 2) has at least two strings of casing, the surface casing designed to protect USDWs and the long string casing extending to the injection zone. These casings must be cemented in order to prevent movement of fluid into or between USDWs. The wells must be equipped with an injection tubing set on a packer located above the injection zone

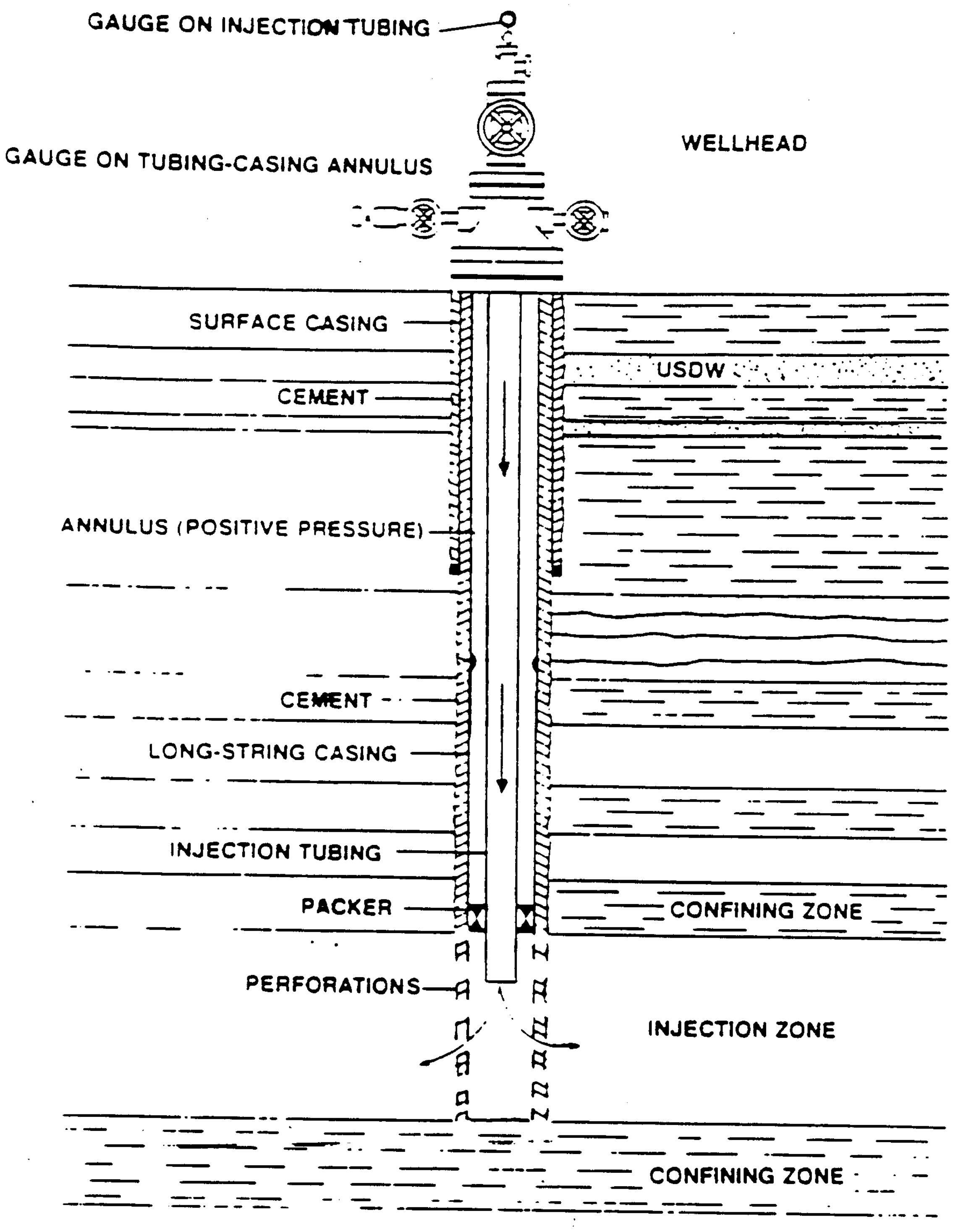


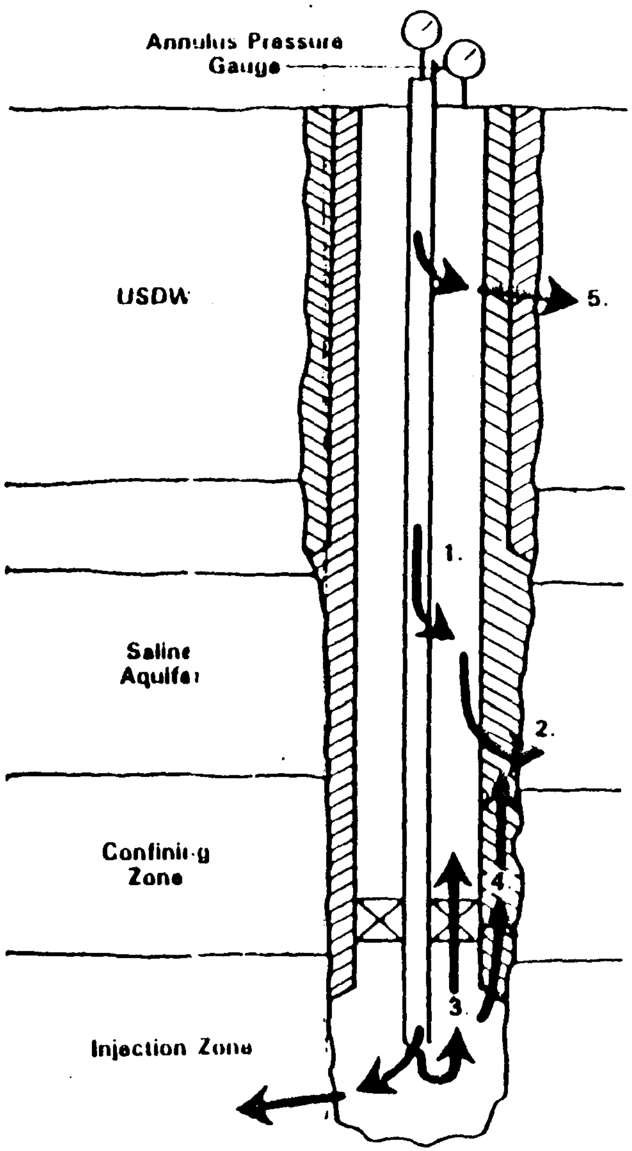

Figure 2. Typical Class I HW Injection Well

to prevent back flow of injected waste into the well. Materials used in well construction must be resistant to the prospective injected waste and to formation fluids. Before a well is put in operation, the effectiveness of the cementing program must be verified by "logging" the well, i.e., lowering electrical sensors into the well which measure such variables as temperature, noise, or particle emissions. The integrity of the well's tubular goods must be similarly verified by running pressure tests.

For a proper operation of the wells the Agency considered that injection pressure had to be regulated to ensure that there would be no damage to the well or the confining formations. The regulations require that the maximum injection pressure be set below the fracture pressure of the injection zone which ensures that no fracture of the confining zone could possibly occur. Injection pressure must be continuously monitored as well as injection volume and flow rate as a change in the relationship between these variables could be an indication of down-hole problems. The tubing-casing annulus must be filled with fluid upon which a positive pressure is applied. Continuous monitoring of this pressure is required in order to detect leaks in the tubing, packer or long string casing. If a pressure change indicates a possible leak, the well must be shut-down, the director of the UIC program must be alerted and further testing be conducted to verify the cause of the change in pressure must be done. The well must remain shut-down until all problems are resolved. It would take a simultaneous failure of at least two of these elements in order for waste fluid to escape the injection well, and the conditions under which these failures could lead to contamination of a USDW are highly unlikely (Figure 3).

A final aspect of proper operation is that the injected waste must be compatible with injection formation matrix and fluids. This requirement often works to the advantage of the operator, since incompatibility between these elements mostly could lead to formation of precipitates which plug up the formation face and reduce the useful life of the well. In some cases, however, such as injection of acid waste in carbonate formations, which can result in the formation of gases, the injection of the waste must be managed in order to prevent sudden releases of gas and blow-out of the well.

Finally, the Agency considered that proper plugging and abandonment of the wells was an important factor in ensuring that injected wastes would not travel back to the surface once the injection was terminated. The regulations require that the operator submit a plugging and abandonment plan that must be approved as part of the permit application. This plan must identify the number and method of placement of plugs in the well.




1. Tubing Leak ► Annulus Pressure Change ► Well Shut Down Injected Waste Contained in Tubing-Casing Annulus – No Waste Movement into USDW

2. Leak Through Long String Casing/Cement ► Annulus Pressure Change ► Well Shut Down – No Effect on Injected Waste

3. Leaky or Unseated Packer ► Annulus Pressure Change ► Well Shut Down Possible Back Flow of Injected Waste in Tubing Casing Annulus – No Waste Movement into USDW

4. Channeling in Cement – Channels Would Have to Extend From Injection Zone to USDW to Cause Movement of Injected Waste into USDW

5. Simultaneous Leak in Tubing, Long String Casing and Cement, Surface Casing and Cement ► Annulus Pressure Change ► Well Shut-Down Some Injected Waste Could Migrate into USDW

Figure 3 – Consequences of Mechanical Integrity Failures

The operator must also demonstrate that he has and will maintain the financial capabilities for properly plugging the well.

The information which must be submitted in a Class I permit application is extensive and requires the use of sophisticated geophysical methods and tools. In general, permit applicants must employ special consultants or teams of consultants to put the information together. Only very large companies are likely to have the necessary in-house expertise. The cost of obtaining the information and going through the permitting and construction process can range from several hundred thousands to a million dollars and more.

B. The 1983 Survey of Hazardous Waste Injection Wells.

The regulations described above apply to all Class I wells regardless of the type of waste they inject. For the subset of these wells injecting hazardous wastes, the regulations must also take into account the requirements of the Resource Conservation and Recovery Act (RCRA) which was first enacted in 1976. In 1983, Congress began a process to amend RCRA and it became evident that a study of hazardous waste injection would be mandated. In the Summer of 1983, the Agency conducted a survey and assessment of hazardous waste injection and issued a report to Congress on its findings (U.S. EPA, 1985). Although these data are now 6 years old, few new hazardous waste facilities have been constructed in the last 6 years and they still are representative of the hazardous waste well universe today.

General Information

All of the wells are privately owned and operated. More than 90% of these wells are "on-site" wells; that is they are owned and operated by the waste generator. Only 10% of the wells are commercially operated facilities that collect a service fee for the disposal of a variety of wastes. These are usually referred to as "off-site" wells, and active ones are located in Louisiana, Ohio, Oklahoma and Texas.

Wells used to inject hazardous wastes are concentrated in a few areas of the country (Figure 4). A vast majority of the wells are located along the Gulf Coast and near the Great Lakes. Louisiana and Texas alone account for 62% of the wells. Other States with sizeable numbers of hazardous waste wells are Michigan, Indiana, Ohio, Illinois and Oklahoma. In general, the wells are located in areas of oil and gas production where data on deep formations are readily available.

The majority of the wells active today were drilled in the mid-1960s to the mid-1970s (Figure 5). There was a peak in start-up of injection wells in 1973, 1974, and 1975, probably as a result of implementation of the Clean Water Act which established stringent pollution control requirements for discharges to surface water.

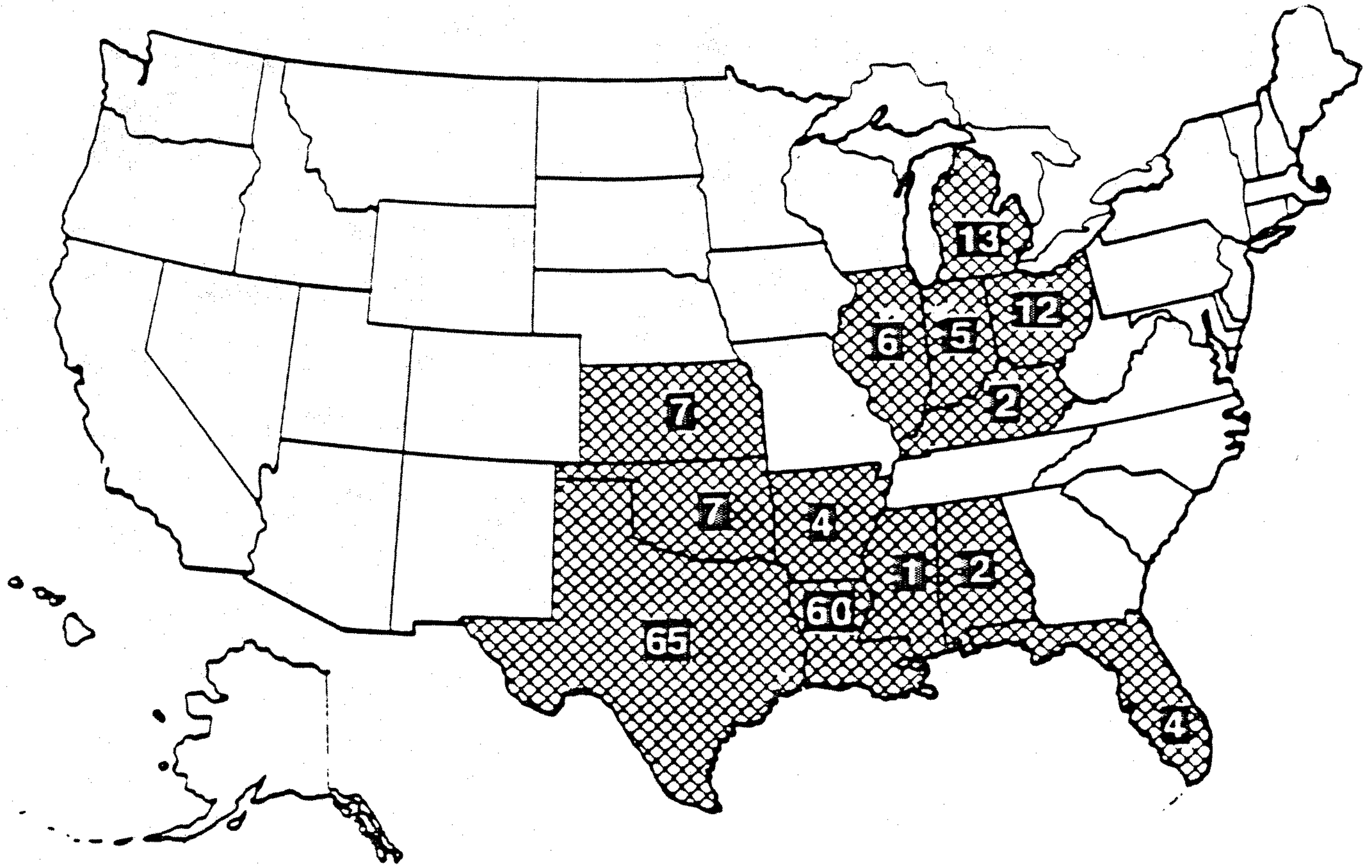
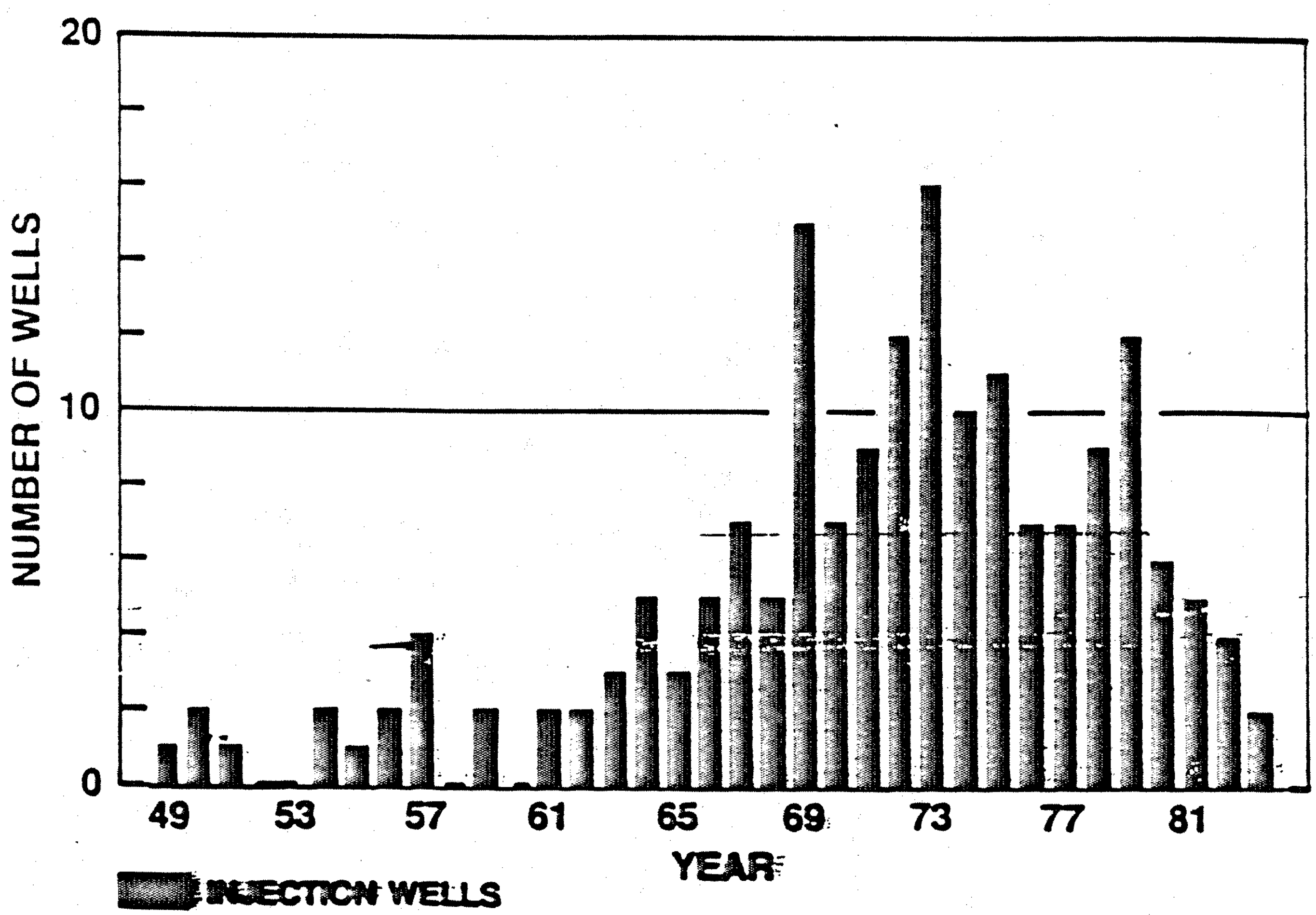



Figure 4. Distribution of HW Wells in 1983



The biggest user of hazardous waste Class I wells is the chemical industry (Figure 6). Manufacturers of organic chemicals account for 43% of the injected wastes, while the petroleum refining and petrochemical industries account for 20% of injected volumes. Twenty-eight percent of the injected wastes are generated by other chemical manufacturers. Only four percent of the total volume of injected waste is handled by commercial (off-site) waste disposers.

The study found that 11.5 billion gallons (43.7 billion l) of wastes were injected in 1983. This number has remained relatively constant. The waste are highly aqueous, approximately 96% of the waste streams is water.

Well Design and Construction

The inventory revealed that Class I hazardous waste wells are in fact, deep injection wells (Figure 7). With a few exceptions, these wells are completed below 2,000 ft (600 m) The average depth of all wells is approximately 4,000 feet (1,200 m). The deeper wells are found in Texas and Mississippi where the depth usually exceeds 4,500 feet (1,350 m).

The study found that most hazardous waste injection wells are constructed with redundant protective features. All the wells are constructed with at least two strings of casings. The surface casing extends below the base of 10,000 mg/l TDS water in 57% of the wells, is usually carbon steel and is cemented back to the surface. All the wells also had long string casing extending

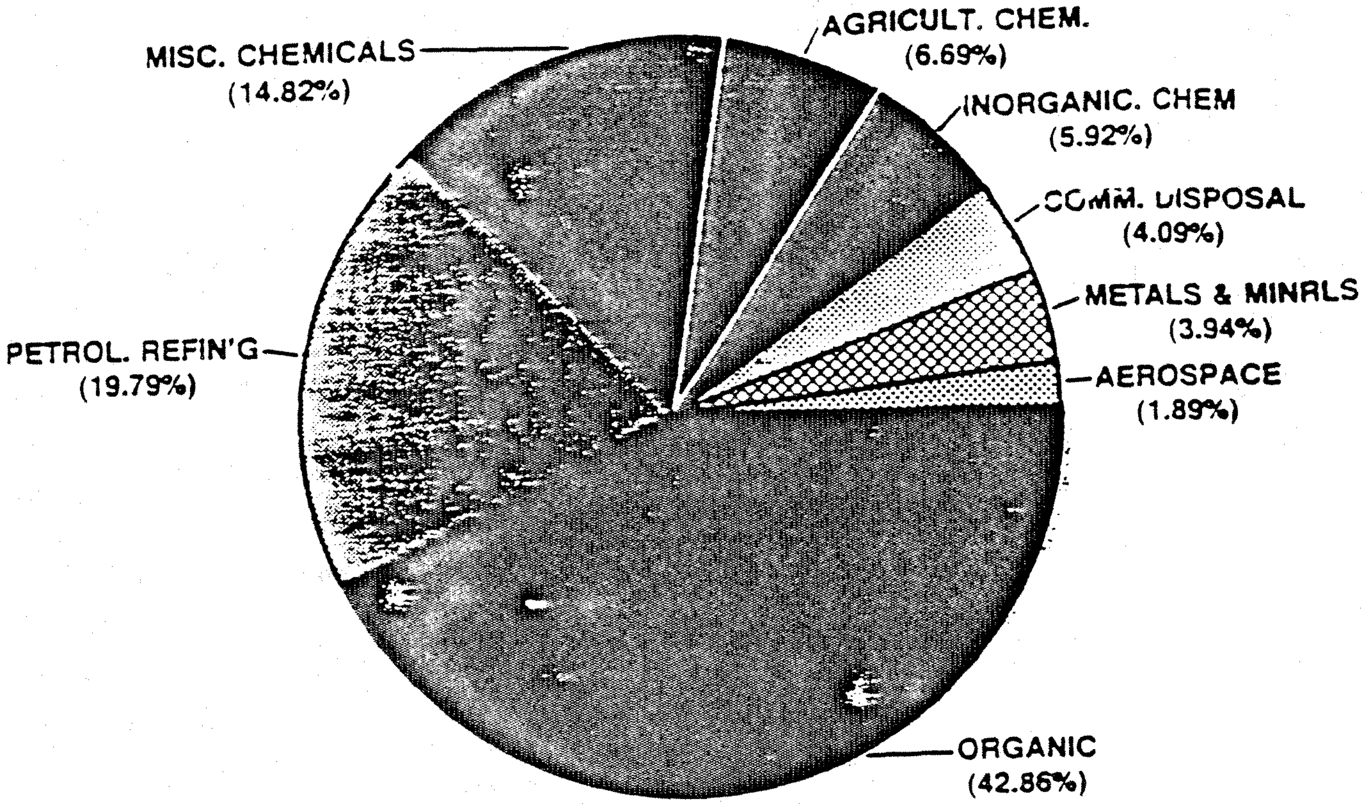



Figure 6. Users of Class I HW Injection Wells

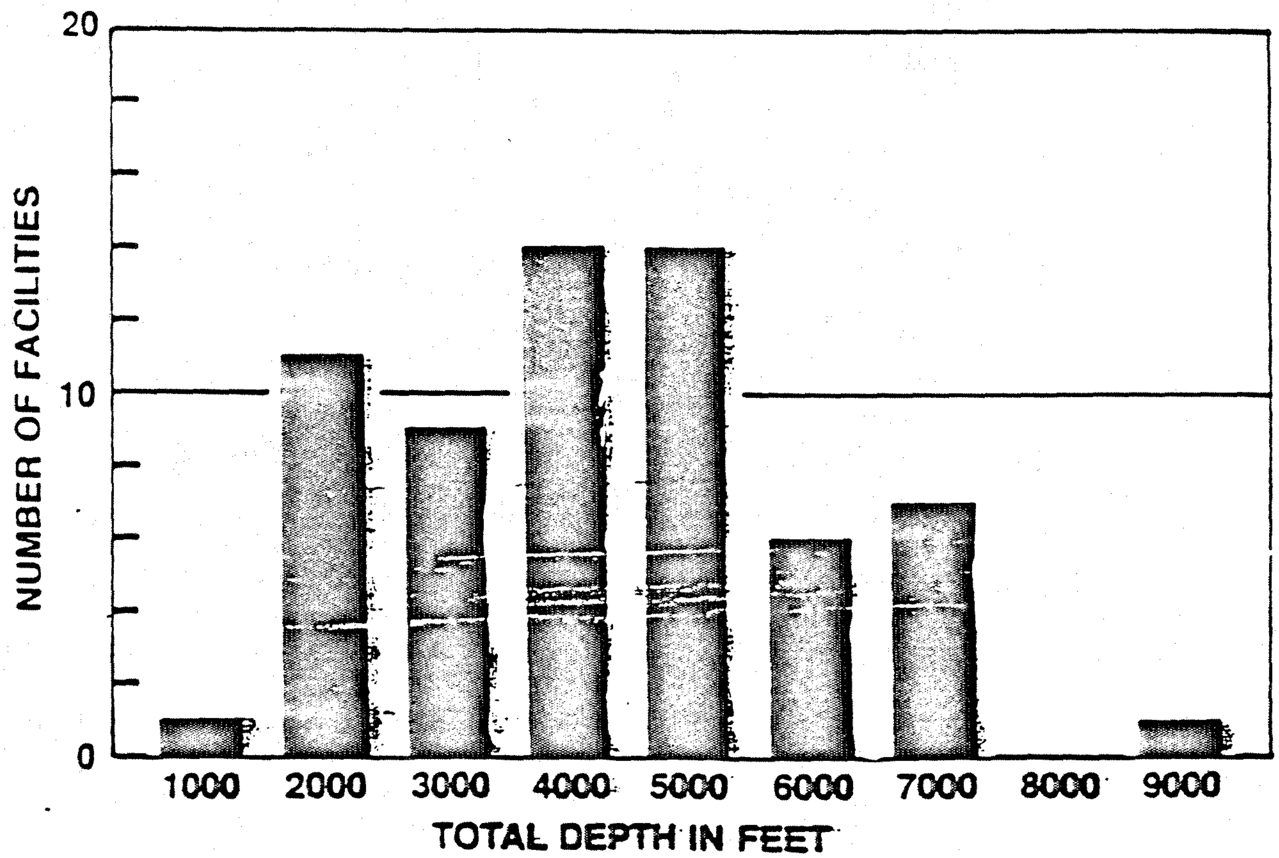



Figure 7. Depth of Cl

to the injection zone. This casing is cemented all the way to the surface in 74% of the wells. It is usually carbon steel although other materials such as stainless steel, special alloys and fiberglass were also encountered. In addition, thirty five percent of the wells have an intermediate string of casing. In all cases injection is through a tubing. The typical injection tubing is 5.5 in. (8.25 cm) in diameter and is carbon steel. Thirteen percent of the wells had fiberglass tubing, 10% fibercast and 5% stainless steel. In 93% of the wells the tubing is set on a packer at or near the injection zone, the other wells use a fluid seal.

Hydrogeologic Setting

A vast majority of the Class I hazardous waste injection wells (71%) are completed in sand and sandstones formations, 15% are completed in carbonate formations (limestones or dolomites) and the remainder in shaley sandstones. Most of the confining zones are composed of shales (66%), followed by shaley sandstones(14%), and shaley limestones (12%). Other examples of reported confining zones are silt, clay and dolomites.

In the Great Lakes Area, the disposal zone is usually a 600 to 700 foot (180 to 210 m) thick sandstone found at approximately 3,000 feet (900 m) of depth. Confining beds of limestone, dolomite and siltstone approximately 1,300 foot (390 m) thick separate the injection zone from the base of 10,000 mg/l TDS water. In Texas and Louisiana, the injection zones are typically unconsolidated sediments of tertiary age and are more than 4,000 feet (1,200 m) deep (Figure 8). They are separated from the base

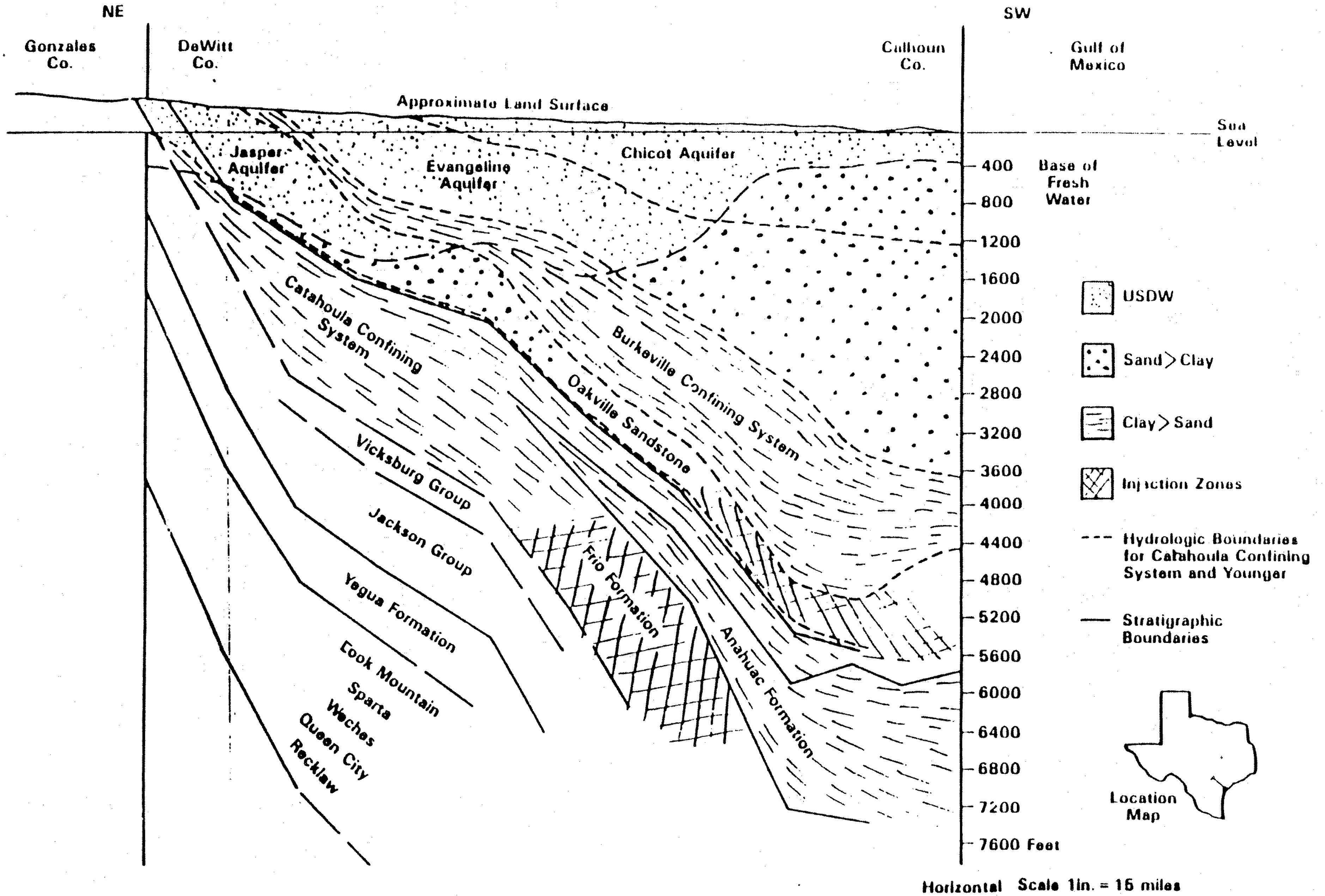



Figure 8 - Stratigraphic and Hydrologic Setting - Texas Gulf Coast
(After TDWR Report 236)

of fresh water by one to two thousand feet (300 to 600 m) of sediments that include silt and clay intervals.

The data show that in most instances there is good separation between the injection zone and the base of 10,000 mg/l TDS water (Figure 9). In more than fifty percent of the cases this distance is more than 2,500 feet (750 m). There is, of course, greater separation from the base of 3,000 mg/l TDS water, the outer limit of water usually considered usable as a source of drinking water. This distance is greater than 2,500 feet (750 m) in approximately 70% of the wells in the inventory.

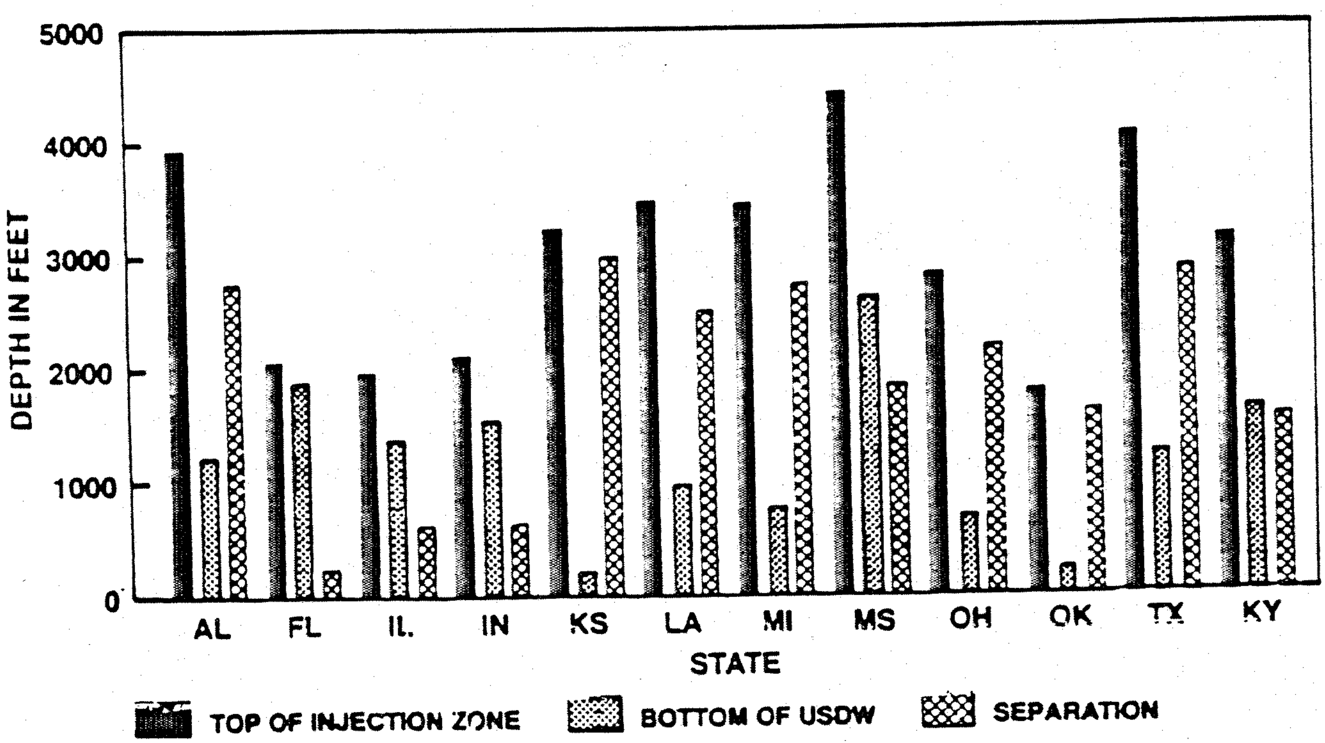



Figure 9. Average Depths by State

Well Operation

All injection wells have a limitation on the injection pressure. This limitation is in all cases set below the fracture pressure of the receiving formation, and is usually calculated based on a hydraulic fracture gradient. Twenty percent of the wells in the inventory injected waste by gravity flow.

All operators are required to monitor injection pressure, flow rate and cumulative volume in most cases using continuous monitoring devices. In approximately 90% of the wells the tubing-casing annulus is filled with fluid upon which positive pressure is applied. The pressure is monitored continuously to detect leaks in the tubing, casing or packer. The majority of the assessed facilities had an automatic shut-off system that is activated whenever one of the monitored parameters reaches a given level.

The data show that wells are extensively tested prior to being put in operation in order to ascertain the mechanical integrity of the well. The integrity of the tubular goods was tested by pressure tests, caliper logs or radioactive tracer surveys. In general a log such as cement bond, velocity or temperature had been run to confirm the soundness of the cementing job. In addition, all but a few of the assessed facilities have implemented corrosion control methods in order to preserve the integrity of the well materials. These include use of corrosion resistant material and addition of corrosion-inhibiting fluid to the annulus.

B. Well Failures

As part of the Report to Congress EPA had to provide information on wells at which enforcement actions had been initiated "by reason of well failure, operator error, ground-water contamination or for other reasons". In addition pursuant to a published report by the Natural Resources Defense Council (Gordon, undated) the Agency commissioned a study of all reported well incidents (EEI, 1986). An independent study was conducted on behalf of the Underground Injection Practices Council (CH2M Hill, 1986). According to these studies, only nine wells have had significant problems which could have resulted in contamination of fresh water. However, of the nine, only two actually contaminated an underground source of drinking water.

- Leakage of injected wastes caused contamination of an underground drinking water source at a refinery site in Louisiana in 1980. The well did not have tubing and wastes were injected directly through casing. The contamination was confined to within a 100-foot (30 m) radius of the well in the uppermost portion of the drinking water aquifer. A ground water recovery system was installed. Between July 1982 and early 1986, the system had removed 250,000 barrels (39,900,000 l) of contaminated ground-water and considerably reduced contamination levels. As of May 1987, the company had spent $400,000 on restoration.

- Leakage of injected wastes at a chemical plant in Texas caused contamination of an underground source of drinking water (4,000 mg/l TDS) at a depth of 665 to 680 feet (199 to 204 m). The well was constructed without tubing and packer with injection occurring directly through the casing. Leaks were discovered by pressure testing. Water quality in the aquifer was restored by groundwater pumping.

These two cases would have been avoided had the wells been constructed according to the regulatory standards now in place.

There is one case where injection has been suspected as a source of ground-water contamination.

- In the early 1970s wastes from a papermill were suspected to have migrated about five miles (8 km) from the injection site and up the unplugged well bore of abandoned gas well. All injection wells were plugged and abandoned in 1972. Field tests and investigations conducted between 1979 and 1982 were inconclusive and failed to determine the source of fluid seeping from the gas well.

None of the other major incidents caused any contamination of fresh water.

- An off-site facility in Ohio did not discover leaks in the bottom part of the long-string casing of the wells until large amounts of waste were injected into an unpermitted zone. That zone however was still separated from the base of USDWs by more than 1,500 feet (450 m) of which 1,000 feet (1300 m) were an impermeable shale. The problem was detected when the company conducted tests to obtain information to apply for a UIC permit. The company was fined $12.5 million for these and other violations at the site not related to the wells.

- Leaks in the wells of an off-site facility in Oklahoma were discovered as a result of mechanical integrity tests. These leaks did not affect underground sources of drinking water.

- Another off-site facility in Louisiana discovered leaks in a wells allegedly resulting from disregard for compatibility problems between the wastes and the well materials. The leaks did not result in migration of waste into USDWS.

- A commercial facility in Texas suffered a well blow-out when injection was stopped precipitously allowing gases to come up the tubing. No ground water contamination was involved.

- At a facility in North Carolina, waste migrated to a shallow formation because of inadequate cement in the borehole. The facility was shut down.

All of these cases point out to the need for proper siting operation and monitoring of injection wells.

C. The 1988 Amendments to the Regulations

When RCRA was finally amended in 1984 it imposed a new burden on hazardous waste injection wells. The amendments specifically prohibited the continued injection of untreated hazardous waste

beyond specified dates unless the Administrator determines that the prohibition is not required in order to protect human health and the environment for as long as the wastes remain hazardous. The UIC regulations were amended in 1988 to comply with this new mandate. Operators of hazardous waste injection wells must now demonstrate to the Agency, through the use of models, that hazardous wastes will not migrate out of the injection zone for at least 10,000 years. This demonstration can be based either on flow modeling or on modeling of the waste transformation within the injection zone. At this time, 54 demonstrations have been submitted for review by the Agency. Two tentative decisions to approve a demonstration have been published.

IV. SHALLOW DISPOSAL WELLS

At this time, we believe that deep disposal wells are in general very well regulated and the decisions which the Agency has to make regarding hazardous waste disposal wells will ensure protection of human health as well as is humanly possible. One very large remaining concern is that of shallow disposal wells which are found in every State and are probably also numerous in Spain. These wells are, in fact a greater concern than deep wells because they affect the surficial aquifers which are most likely to be used for private wells. The Agency recently completed a Report to Congress on these shallow wells and identified several types of practices which need to be addressed.

Industrial drainage wells - shallow wells located in heavily industrialized areas which primarily receive storm water runoff but are susceptible to spills, leaks or other chemical discharges;

Shallow industrial process water and waste disposal wells - they are used to dispose of a wide variety of wastes and wastewaters from industrial, commercial or utility processes. Industries involved include refineries, chemical plants, smelters, pharmaceutical plants, laundries and dry cleaners, tanneries, laboratories, petroleum storage facilities, car washes, electroplating industries, photo development and other light industries.

Automobile service disposal wells - inject wastes from repair bay drains at service stations, garages and car dealerships.

Our first concern is that some of these wells may be injecting hazardous wastes and should be shut down. We intend to devote a major effort in the next two years to enforcing the ban on shallow injection of hazardous wastes. We are also developing guidance on best management practices to reduce the amount and toxicity of wastes generated by these users of Class V wells to try and eliminate their use for disposal of industrial wastes.

CONCLUSION

Disposal of industrial waste in deep wells has become a highly sophisticated practice in the United States, subject to very stringent demonstrations and technical requirements. It is only feasible for highly aqueous wastes which can easily be injected in porous zones. We believe that the governing factor in deciding whether injection should be allowed is the geology of the site. The geology should be well understood and relatively simple. It also should provide for containment of the wastes. This is the reason why areas which contain oil and gas reservoirs are generally considered suitable in the United States. We have large sedimentary basins with little post-depositional tectonic activity. Their containment properties have been demonstrated by the fact that oil and gas have been trapped for millions of years. Naturally-occurring fluid movement in these basins is actually slow and down-dip away from any discharge point. There are, however, also vast portions of the United States which would not be considered favorable for deep injection because they are seismically unstable, because the geology is complex or because they would not contain the wastes for long periods of times. For example, one concern that we have at this time is the increase in injection of sewage in the coastal areas of Florida. The residence time of the injected fluids in the injection zone may be comparatively short because these zones have high permeability and may allow discharge of injected wastes into the Ocean. In many cases, however, injection can be done in a manner that is protective of human health and the environment. Currently, shallow disposal wells are a greater threat to the environment. They are probably ubiquitous and must be addressed in any type of ground water protection effort. The Agency is now turning its full attention to those practices.

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# DEEP WELL INJECTION : AN OIL & GAS PRODUCTION INDUSTRY PERSPECTIVE

IPAC

CANADIAN
PETROLEUM
ASSOCIATION


Canadian Petroleum Association

Independent Petroleum Association of Canada


*November 5, 1990*

# INJECTION / DISPOSAL WELLS : BACKGROUND

- *The Oil and Gas Industry in the province of Alberta operates approximately 5350 disposal / injection wells*
  - *1350 wells are classified as disposal wells (no EOR objectives other than voidage replacement or pressure maintenance)*
  - *4000 wells are classified as injection wells (used in waterfloods or EOR projects)*
- *According to the EPA UIC Program Classification Scheme, all these wells can be classified as Type II*

| | |
|---|---|
| *Class I :* | *Industrial Waste Disposal Wells* |
| *Class II :* | *Petroleum Industry Produced Brine Disposal and EOR Wells* |
| *Class III :* | *Mineral Extraction Industry Disposal Wells* |
| *Class IV :* | *Waste Disposal into A USDW (Banned)* |
| *Class V :* | *All Other Types of Disposal Wells* |

# INJECTION / DISPOSAL WELLS : BACKGROUND (continued)

- *The 5350 injection / disposal wells operated by CPA and IPAC member companies are used to return salt water that is co-produced with oil and gas to the subterranean formations where it originated.*
- *In 1989, 225 million cubic meters of fluids were returned to formations of origin via disposal / injection wells.*
- *As oil and gas fields in Alberta continue to mature, it is anticipated that the volume of produced water that requires injection / disposal will increase.*

# INJECTION / DISPOSAL WELLS : BACKGROUND (continued)

- *In addition to 5350 salt water injection / disposal wells, CPA / IPAC member companies operate 67 wells which are <u>approved</u>* to dispose of certain materials along with produced water. These materials, which are generated during the production and processing of oil and gas, are:*

*Spent Acid*
*Spent Caustic*
*Boiler Blowdown Water*
*DEA Filter Backwash Liquids*
*MEA Filter Backwash Liquids*
*Water Softening Filter Backwash Liquids*
*Water Treatment Filter Backwash Liquids*
*Hydrocarbon Removal Wastes*
*Hydrotest Fluids (methanol-containing)*
*Ion Exchange Resin Residues*
*Laboratory Chemicals*
*Process Waste Waters*
*Water-Based Wash Fluids*
*Acidic Well Workover Fluids*
*Brine-Based Well Workover Fluids*

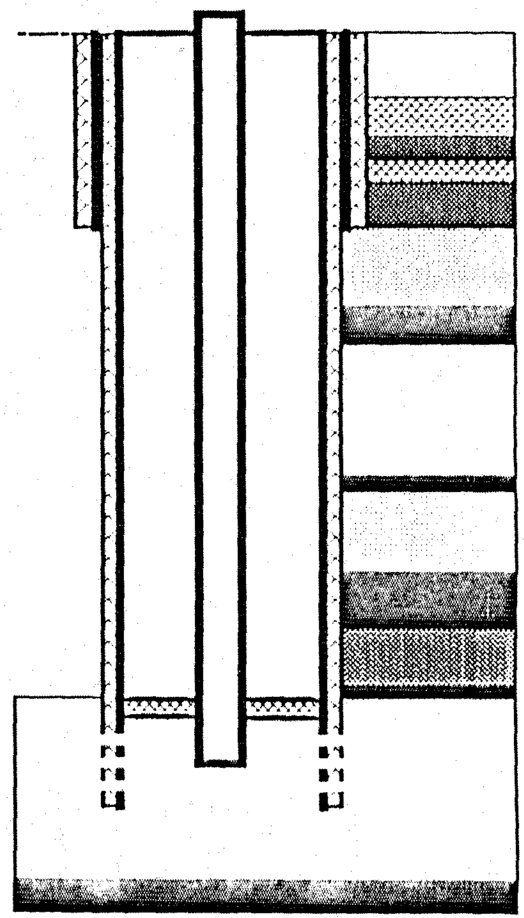
** Each well is individually approved to accept only <u>specific</u> materials from the list above*

# INJECTION / DISPOSAL WELLS : REGULATORY SAFEGUARDS

- *ERCB TECHNICAL REVIEW : NEW WELLS*
  - *Hydrocarbon Conservation*
  - *Reservoir Continuity & Integrity*
  - *Reservoir Fracture Gradient*
  - *Geology / Stratigraphy*
  - *Injectivity*
  - *Reservoir Voidage Replacement*
  - *Min. 180 m Surface Casing*
  - *Cement Quality*
  - *Injection Tubing Type / Integrity*
  - *Casing Type / Integrity*
  - *Packer Type, Placing, & Integrity*
  - *Monitoring Hardware & Schedule*
- *ALBERTA ENVIRONMENT REVIEW (if deemed appropriate by ERCB)*
- *MONITORING (all disposal / injection wells)*
  - *Class II Wells : Annual Packer Isolation Pressure Test*

# INJECTION / DISPOSAL WELLS : ENGINEERING SAFEGUARDS

- *A Stable, "Deep" Injection Zone is Selected*
- *Injection Zone Overlain by Impermeable Rock*
- *A Minimum of 180 m of Surface Casing is Set and and Cemented to the Surface*
- *Full Length Casing is Set and Cemented to Surface*
- *A Packer is Set Just Above The Injection Zone*
- *Injection of Materials Occurs Via a Full Length Tubing String*
- *The Integrity of The Tubing / Casing Annulus is Checked Annually*
- *Injection Occurs at Pressures Below the Fracture Pressure of the Injection Zone*
- *Wells are Abandoned According to ERCB Regulations*



# CLASS II INJECTION / DISPOSAL WELLS : CPA / IPAC POSITION

- *Alberta's geology is very well suited to the use of injection / disposal wells*
- *Returning salty water that is co-produced with oil or gas to the formation of its origin via an injection / disposal well is entirely appropriate and, in fact, preferable to all other treatment / disposal options*
- *A detailed knowledge of local geology, the rigorous use of conventional wellbore / completions technology, and on-going performance monitoring assure that disposal wells deliver materials to a target zone, that these materials are contained in the target zone, and that USDWs are protected*
- *The present-day ERCB procedure that reviews, approves, and monitors Class II injection / disposal wells is sound*

File: 4004

PRESENTATION TO THE WORKSHOP ON

DEEPWELL DISPOSAL

5 NOVEMBER 1990

MARK POLET

ALBERTA SPECIAL WASTE MANAGEMENT CORPORATION

Thank you for inviting us to the Alberta Environment Sponsored Workshop on deepwell disposal. It's great to see some old friends and acquaintances here after many years away. It is also heartening to address this issue at this time as it indicates industry's continued willingness to improve their already excellent record in waste management.

WHO ARE WE?

Before I go into the Alberta Special Waste Management Corporation's views on downhole disposal, I think it be worthwhile for the audience to gain a clear understanding of our reason for existence.

> Our Corporation mandate is: To promote the establishment and operation of cost-effective special waste management solutions in Alberta which globally demonstrate excellence in protecting public health and enhancing environmental quality.

This means that we are responsible for developing and maintaining the best system capable of handling all special wastes that are not able to be treated on site. The strategy designed to meet our mandate is a unique combination in North America of:

1. encouraging private enterprise to meet Alberta industry needs;
2. developing service programs such as the Household Hazardous Waste Program, and the Pesticides Container Program, and;
3. at the core, a utility based system to handle the most complex of special wastes at the Alberta Special Waste Treatment Centre in Swan Hills.

This Centre is the only integrated treatment centre of its kind in North America and should be capable of handling any special wastes generated by Alberta industry, excluding radioactive and explosive wastes.

WHAT IS OUR STAND?

What is the position of the Corporation with respect to downhole disposal? Alberta Special Waste Management Corporation does not see downhole disposal as a viable option for the disposal of untreated concentrated special wastes. The oil industry is now well past the time where it can be considered acceptable to "stuff down" disposal wells anything that will flow. I believe that this position is consistent with good oil industry operating practice. There have been enough sad cases in the past where injection wells used to maintain pressure in producing reservoirs have had materials pushed down their wells which have later soured that formation resulting in an increase in production costs. We do not have any problem with putting produced water back from where it came, nor with injection wells required to maintain pressure in producing reservoirs, as long as we view disposal of any kind without treatment as a last resort.

SO WHAT ARE THE SOLUTIONS?

The Corporation is committed to finding minimization and treatment solutions for Alberta industry.

Part of our mandate is to promote waste minimization. Again this is consistent with industry's drive toward improved production. Many of the companies represented around here have gone a long way in waste minimization, improving their recovery rate and reducing the loss of valuable product down disposal wells. After waste minimization programs have been put in place and after treatment options on site have handled what they can, then it's time to turn to us to provide a solution to handle your other special wastes. If our System is not meeting your needs and by this I mean not just Swan Hills, the whole system in Alberta, then Tom Thackeray and I look forward to hearing your comments today and in the future to find out how we can improve.

The Corporation is here to provide treatment solutions, not disposal solutions. I am sure that the audience here has the same goal. If more facilities are required, please let us know. As many of you now know, an expansion is planned to handle an increased volume of incinerable solids and if there are other waste streams that also need increased capacity we would like to hear from you. We now regularly update our strategic analysis and marketing surveys and we look forward to your participation in those.

## SUMMARY

The Corporation believes all substances produced by Alberta industry should be treated as a resource, even though some of these products are now considered waste.

We actively encourage Alberta industry to apply the following ranked strategy to their waste management practices:

1. Waste Minimization - applying process optimization, product recovery, and the principles of reduction, reuse, recycling and recovery where best practicable;

2. Onsite Treatment - wherever reasonably practicable;

3. Offsite Treatment - of residual concentrated wastes requiring special handling off-site and after these options have been exhausted;

4. Disposal - including deepwell, as a final option for certain dilute wastes requiring special handling.

The Corporation is committed to working with Alberta industry to provide valid minimization and treatment options that would ensure the disposal wells remain in good operating condition for the waste for which they are intended, such as produced water.

Some of you may see our position on deepwell disposal as strong, but please remember an analogous situation just a few decades ago when the ERCB first started insisting the oil industry reduce the amount of sour gas going to flare and the amount of resources going up in smoke. Their strictures against flaring led to improved production and the development of an important sulphur market. We are now in the same position now with potentially valuable resources and in some cases dangerous wastes going downhole. The same ethics and farsightedness needs to be applied to the way we manage our downhole disposal option.

Thank you for your attention.

# DEEP INJECTION OF LIQUID WASTES; ENVIRONMENT CANADA'S PERSPECTIVE

Presented to: The Deepwell Injection Stakeholders' forum
Alberta Reseach Council, 250 Karl Clark Rd, Edmonotn, Alberta
5-November-1990

by:

D. C. McNaughton
Senior Regional Hydrogeolog
Environment Canada
Conservation and Protection,
Edmonton

## 1.0 GENERAL STATEMENT

Environment Canada's mandate with respect to the protection and enhancement of water resources is set down in Section 109 of the Constitution Act, which distinguishes between legislative and proprietary rights regarding natural resources, including water. In this context, recognizing that the provinces own the ground water resources and have a clear mandate to manage them, there are some matters with respect to ground water for which the federal government has a degree of responsibiltiy.

The Canada Water Act permits the federal Minister of the Environment to "...conduct research, collect data and establish inventories respecting any aspect of water resource management or the management of any specific water resources...". As there is no distinction made between ground and surface waters, the section gives the Department and hence its agencies wide-ranging authority with regard to ground water related activities.

The federal department of the Environment is mandated to take part in or initiate research or data collection activities around projects where federal funds are involved, or for which federal property is required.

The Federal government is committed to monitoring the quality of international, interprovincial, Indian Reserve, national Parks, and other waters in Canada.

Environment Canada may take part in environmental impact assessments of projects falling directly within its mandate, or where requested to by other departments or provincial agencies.

In areas not falling directly under federal jurisdiction, the department may enter into agreements with the Provinces whereby water related projects are cost-shared. Such projects, whether falling under the classification of monitoring, research, or database maintenance, are generally designed to meet mutual objectives of the agencies involved.

In is also the responsibilty of Environment Canada to identify water management research needs and, in response, to implement appropriate research on hydrological processes. Research implemented by the Department has been directed at improving the methodologies, instruments, and mathematical models used in addressing ground water related problems. One of the ultimate goals of research is the transfer of resulting knowledge to potential users.

The federal Department of Energy Mines and Resources provides funding (PERD) for studies relating to environmentally sustainable energy development. The purpose of deep injection studies proposed for this and ensuing fiscal years is for impact assessment and guidelines development. It is necessary for both industry and regulatory agencies to work from the same set of assumptions, so that guidelines or regulations concerning deep injection are environmentally feasible, and fair, but nevertheless stringent enough to fully bring about the desired end, which is the environmentally safe disposal of waste fluids, and the rejection of this means of disposal where conditions indicate that it is environmentally unsafe.

## 2.0 CONCERNS

Environment Canada is interested in the deep injection of wastes because of the potential for:

-contamination of potable water supplies

-degradation of in-place mineral, hydrocarbon, or thermal resources

-discharge of contaminants or formation waters to surface regionally, or locally

and because of:

-current lack of environmental effects guidelines for monitoring

-the lack of knowledge as to regional and long-term effects.

When fluid is injected into a confined aquifer, there is an increase in pore pressure within the injection formation, which moves outward from the injection well over time. This causes compaction of the fluids in the formation (both native and injected), and compaction of the aquifer matrix. If the intergranular pore pressure becomes large enough, fracturing of the formation matrix may result. The zone of increased pressure spreads out beyond the zone of actual fluid invasion, and the distance from the injection point that this pressure transient spreads out is dependent on the compressibility of the fluid and the matrix, the porosity, and intrinsic permeability of the formation. The pressure transient will have the potential to induce flow in the aquifer, and if the aquifer is not totally confined, or the transient encounters an "easy way out", there can be movement of ground water out of the formation. This might drive formation water and eventually, injected water into shallower aquifers, or to surface discharge.

3.0 ENVIRONMENT CANADA-SPONSORED RESEARCH

In 1983, a contract was let to the Alberta Research Council (ARC) to do fluid rock interaction studies, consisting of four phases:

(1) a regional reconnaissance of deep aquifer systems beneath the oil sands and heavy oil areas to determine the depth and extent of aquifers, and to determine hydraulic characteristics of both aquifers and aquitards in the Cold Lake area

(2) characterization of wastewaters injected in the Cold Lake area

(3) investigation of phenol partitioning

(4) evaluation of long and short-term impacts of injection

In 1987, INTERA Technology Ltd. was retained to conduct a feasibility study for a field sampling program aimed at monitoring impacts resulting from in situ heavy oil subsurface disposal practices.

In 1988, the Alberta Research council conducted a study to identify data gaps in the shallow and deep hydrogeology of the McMurray area, relating to the operation of the Underground Test Facility (UTF) near Ft. McKay. The UTF, which is operated by AOSTRA, uses the Shaft and Tunnel Access Concept (SATAC) for bitumen extraction, which was pioneered in Canada by AOSTRA.

In 1989, Stanley and Associates Engineering Ltd was retained to identify suitable existing wells in the Cold Lake area, whereby a field sampling program as envisaged in the INTERA report might be done. The investigators found that there were not many suitable existing wells. They also found that the ERCB pressure/volume data were unsuitable for input to ARC's model for predicting the hydrodynamic effects of injection. Pressure/volume data from the injection well at the Swan Hills Special Waste Facility were then tried in the model and found suitable. The model outputs, consisting of predicted pressure response to injection scenarios closely matched actual monitoring results.

Future research initiated by Environment Canada will focus on gaining an understanding of the hydrogeological and geochemical conditions in an injection zone, and in monitoring the effects of actual injection in a well drilled and instrumented for the purposes of research. It will ultimately be necessary to have a comprehensive understanding of the deep aquifer systems, so that predictions can be made of contaminant transport and geochemical behaviour.

## 4.0 CONCLUSIONS

Deep injection of liquid waste is commonly practiced in Alberta and to a lesser degree, in Saskatchewan. To date, there has been very little work done to assess the actual subsurface effects of this practice, and with the increasing use of deep wells for injection, the need for better data has become apparent. The aquisition of the necessary data through field oriented research has been a high priority of Environment Canada since 1983, but as yet has not been successfully done. Future research sponsored by the Department will be aimed at acquiring high quality monitoring data from one or more wells in the tarsands/heavy oil areas, to allow predictive modelling to be done. The overall goal of the research program will be to gather quality subsurface data, to develop a database for deep basin hydrogeology, and to develop guidelines for the assessment and monitoring of future injection projects.

# PUBLIC PERSPECTIVE

Don Appleby

Deepwell Disposal Workshop
Alberta Research Council

November 5, 1991

## DEEPWELL DISPOSAL WORKSHOP

## ALBERTA RESEARCH COUNCIL

**November 5, 1990**

It has been well shown through polls and studies that the adult public, for the most part, receive their basic daily information from newsprint or the television tube. There is probably not a large portion of the population who can discuss with experts, take courses or study technical papers so they might understand something about the specific technology of deepwell waste disposal.

The approach of both media is usually to try to tell the whole story in one short, dramatic headline. As a hypothetical example this is what it might look like:

"Deep Disposal Well Dumps Its Poison On Children's Playground".

There should be a headline reported, perhaps even quite dramatic. Unfortunately, this might be the only report of the incident a member of the public sees. However, on the basis of this they could probably decide that these wells are not the way to dispose of anything.

I think that due to the short, as well as the long-term effects of such incidents, the story should also include as many of the specific details as possible of why the leak occurred.

Far from being a local issue, quite often the problems associated with disposal wells may be far reaching. There is probably some form of underground disposal in every province. Some might be considered shallow or deep and that could also be a question for discussion. Any report should provide enough technical material to cause the operators of all other disposal wells to check the equipment and monitoring systems under their control to be sure that the conditions present in the offending well were not being duplicated.

I should point out that what I say here comes from **my personal, yet limited** knowledge of deepwell disposal, the geological formations and other operations associated with the oil sands in the cold Lake region. I feel it is best for me to say just how I gained some knowledge of the subject. I would also suggest that you can add to my understanding of a deepwell disposal system and the geological formations used for the purpose.

My basic interest is first set up through the review of a proposal. Understanding is then influenced by listening and asking questions. Then, I try to combine what I understand with that of other interested residents.

An important factor to remember here is the response I and others receive to questions we might ask. If a geologist, engineer or government member tells us something, we can only hope they are being accurate, and most of all honest.

If we are misled, for whatever reason, it is usually only a temporary setback and a short matter of time before any discrepancy will come to light. It has been my experience there are more honest than dishonest people living on this planet. So this simplifies things. It is relatively easy to add a name to a short list, and from then on not place too much trust in those people again.

We have found at Monthly Public Meetings that there is respect for the person who says "I don't know the answer to your question but I know who does, and I will get the answer for you". To the contrary, there is a general distrust of those who would make up an answer, rather than concede there was something they did not know. I believe it is good to remember the possibility that the person asking the question may already have the answer; what they are really seeking is agreement.

It has been know for many years there were tar sands in parts of Northern Alberta. In recent years there has been a variety of technologies employed in the attempt to produce this oil. All of which require the disposal of produced waste.

At Cold Lake there are a number of extraction experiments being piloted, however, the primary technique has been to steam the oil-bearing formations, generally the Clearwater Formation. This process creates an emulsion of oil, water and sand, plus any other substances or chemicals that may have been used in the cyclic steam and/or well drilling operations, or any that may be natural to the formation.

Once this emulsion reaches the surface and the oil separated from the rest of the mess, there is a need for some method of disposal. This brings us to the geological formations which are the target for deepwell disposal. Geologists have in the past, and will continue to spend a lot of time impressing upon us that they have core samples, that there are studies and seismic data which should totally convince us that the formation they are choosing for disposal has all the best properties for containment of the waste the industry needs to dispose of.

We look at it very simply, yes indeed, the formations have been in place for millions of years, and with the variety of types and thickness of the overburden in place, there is a good chance these formations have not leaked to the surface or developed communication from one to the other.

There is also a good chance that if we do not intrude upon these formations they will continue to contain or restrict the flow of whatever is presently in them for the next million years.

However, we are not going to leave them alone; we are going to increase the temperature and pressure in them. We will drill holes through them vertically, horizontally, we will pump the fluids out of them, we will flush them with jetting tools and water pressure, we will dig them from the surface. They will also be set ablaze, to name a few of the plans.

The Public will be asked for opinions on a variety of things that will hopefully determine what is acceptable or unacceptable. We will be provided with the actual locations of the pilot or commercial projects being planned. We want our involvement to occur **BEFORE** not **AFTER** there has been some commitment to approve these projects.

Of course, this is when the questions will begin. There are lots of questions, in fact, there are many questions the Public would not even know to ask! I will list some of the questions that I know have been asked:

Are the "FORMATIONS" with the best qualities for disposal found in close proximity to the project site? Or will we settle for a lesser quality formation just because it **IS** present at the site?

Will the chemical characteristics of the waste be compatible with what is presently in the formation of choice, or will the mixing create the third chemical which perhaps we don't know anything about? Could the waste be transported to another location to take advantage of a better formation. If transported to a better formation, what means of transport would we use? Is this transportation method safe, and could we recover from a spill if one was to occur?

Then there is the actual depth of the formation, the public may choose the deeper ones for disposal. After all when it comes to choosing sites for other types of waste disposal, everyone wants them as far away from where they live as is possible. The public may feel that deeper **IS** better, and deepest is best.

Then there is the evaluations, assessments and calculations of the volume that can be disposed of to a formation, and where the formation outcrops. These figures can be used to estimate that if the waste did migrate to the outcrop, say 200 miles away, then at the migration or flow rate of the formation, it would take perhaps a zillion years to get there. Of course by that time it would be only unpolluted water that surfaced.

However. this may not be so reassuring when it takes a matter of minutes or hours for fluids to reach the surface up the side of a broken well casing or through a poor cement job.

Will there be an exact list of the chemicals contained in the waste being disposed of? If a leak to the surface were to occur, could you test the leaked material and identify the chemicals it contained and by this possibly determine where it came from? If a disposal well does leak into upper aquifers how would this be known? How would you restore the aquifer to it's original quality?

When the casing is installed is it cemented equally from the surface to the bottom of the hole, or are there spaces along the length of the casing that may not be cemented at all? How is the casing kept an equal distance form the side of the hole being cemented? If the cement log shows gaps then what action is taken?

At what intervals are the vertical length of casing stabilized from surface to the bottom? How are the threads on the pipe cleaned, and are they treated with any type of sealant before they are tightened? Are the connections between lengths of casing torqued by the strongest person on the crew, or are these connections torqued by computer? How can we be assured that the quality of all material used in a deepwell disposal is the best available?

How is the effect of possible earth tremors or other seismic activity that occur near the well monitored? What is the distance between the injection or producing wells and the nearest disposal well?

Are there any resources in the disposal formation that may be of value now or in the future? Would disposal of waste to the formation at present affect possible future recovery of other resources from the same formation, at the same location?

Of course, there is also a threat to the geological formations from natural causes like earth tremors or real quakes, however, these are uncontrollable and not nearly as frequent as the continuous lifting and subsiding of the surface area around wells that are steam injected.

If the pressure at 1400 feet causes the surface are to lift 8 or 18 inches, then is it not reasonable to assume that each formation or layering between also lifts the same amount? When the lifting subsides do all the layers return to their original position, like elastic? Is there any cracking or gaps created by a process where formations continually elevate and subside?

Could communication between formations be established by these actions? Is it prudent to locate a disposal well in the formation next to the one that is the producing zone, considering the activity the production zone is being subjected to?

A big topic, and one I believe is directly related to deepwell disposal particularly in the Cold Lake Oil Sands, and that is water reuse or recycle. To date, there is no requirement for water recycle in Pilot Projects.

The normal position for a Company is that while they will not be recycling water in their pilot project, they will recycle when they proceed to a Commercial venture. So, we have potable ground water and surface water resources in the region being reduced to a totally non-renewable resource that is being lost from the systems at the rate of approximately 4 barrels of sludge for each barrel of oil produced.

There are a number of thoughts locally with respect to this situation. Recycling would reduce the volume of waste water to be disposed of. Less for disposal would obviously put less demand on the receiving formations used for disposal. Every Pilot Project reinvents the water recycle process. If the intention of a pilot project is truly an experiment in technology to determine the feasibility of a commercial venture, then **ALL** elements of the process should be part of that experiment.

Let me summarize my feelings, yes, I have confidence in the ability or capacity of the geological formations to contain what has naturally occurred in them. I can also be convinced some of these formations will retain or contain waste material that might be injected into them. I have confidence in the workers that perform the installations.

I just don't have the same confidence with the things that might be considered **COMPANY** policy or attitude which may be lax in providing the quality of casings and the cement jobs or the monitoring systems. More often these are the things, that in the final analysis are the reported cause of leaking disposal wells.

Sometime one has only to listen to the dedication to details and the attitude displayed in a discussion of developing the facilities required to produce the oil and get it to market, then compare the details and attitude toward the stuff left over that has to be disposed of somewhere. A person's confidence can be reduced pretty quickly in these cases.

However, my confidence is reduced to its lowest level when I read or hear that a major factor in a Company choosing a formation or waste disposal well system is because it is the most economic...... and after all we **ARE** here to make money.

# ABSTRACT

## GEOLOGICAL HISTORY OF THE WESTERN CANADA SEDIMENTARY BASIN


Grant D. Mossop
Alberta Geological Survey
Alberta Research Council


On the most elementary level, the Western Canada Sedimentary Basin can be viewed as a simple wedge of Phanerozoic strata above Precambrian crystalline basement. The wedge tapers from a maximum thickness of about 6000 metres in the axis of the Alberta Syncline (just east of the foothills front) to a zero edge in the northeast along the Canadian Shield. In point of fact, however, the succession reflects sedimentation in two profoundly different tectonic settings - a Paleozoic to Jurassic platformal succession, dominated by carbonate rocks, deposited on the stable craton adjacent to the passive margin of ancient North America; overlain by a clastics-dominated foreland basin wedge deposited in mid-Jurassic to Paleocene times, during active margin orogenic evolution of the Canadian Cordillera. Net erosion and sediment bypass have prevailed in the region since the Paleocene culmination of the Laramide Orogeny.

The platformal succession consists of four major sequences, each representing more or less continuous internal deposition but separated from adjacent sequences by pronounced unconformities. Sequence 1 records transgressive onlap of the craton from the west in the Cambrian-Ordovician; Sequence 2 Ordovician-Silurian sedimentation in the Williston Basin; Sequence 3 Devonian-Carboniferous transgression from the north and sedimentation over the whole of Western Canada; and Sequence 4 Carboniferous-Jurassic onlap of the craton from the west and south. For most of the interval embraced by the platformal succession, patterns of marine inundation, sedimentation and erosion were strongly influenced by epeirogenic movements on various intracratonic arches, that episodically differentiated the region into a complex array of sub-basins and uplifts.

Beginning in the mid-Jurassic, as North America began to drift westward with the opening of the Atlantic, the western margin of the continent was subjected to at least two major episodes of compressive tectonism, as a result of collision with large oceanic terranes that accreted to the continent in what is now British Columbia. As a result of these collisions, sedimentary rocks deposited outboard of the ancient passive margin of the continent were compressed and displaced eastward over the continental margin. In turn, platformal cover rocks were thrusted and folded to form the Canadian Rockies and Foothills. Emplacement of the imbricate thrust slices, progressively from west to east, produced tectonic thickening of the crust and isostatic downwarp of the foreland, forming an eastward migrating trough that trapped clastic detritus shed from the developing mountains. The foreland basin wedge is characterized by upward coarsening progradational cycles capped by extensive non-marine deposits.

A multi-institutional, multi-disciplinary project to produce a new atlas of the subsurface geology of the Western Canada Sedimentary Basin is currently underway.

ABSTRACT

# EVALUATION OF EFFECTS OF DEEP WASTE INJECTION IN THE COLD LAKE AREA, ALBERTA

1. S. Bachu, E.H. Perkins, Brian Hitchon, A.T. Lytviak, and J.R. Underschultz

The regional and local effects of underground injection of wastewater from insitu oil sands pilot plants have been evaluated at sites in the Cold Lake area, Alberta, using projected injection rates up to the year 2015. Geochemical effects were investigated in a suite of cases representative of the injection aquifers and conditions of injection in the Cold Lake Oil Sand Deposit. Although water-rock reactions will take place between the injected fluids , formation waters, and minerals in the injection aquifer, only those reactions involving quartz and calcite are significant. Based on calculations of the amounts of these minerals precipitated or dissolved, the most important change that should be made to wastewater before injection is softening or the removal of carbon dioxide.

Fracturing thresholds were evaluated at several sites, based on the geomechanical properties of the rocks. The regional effects of deep waste disposal were simulated on a large scale in terms of pressure buildups at 27 sites. Under the assumption that average values of the hydraulic parameters characterize the hydrostratigraphic succession, the numerical simulations revealed no interferences between the different injection sites for the projected duration of operations. The results of regional scale simulations allowed for the individual treatment of each injected site. Local scale simulations were performed for the same sites as were the evaluations of geochemical effects and fracture thresholds. The results show that vertical fracturing will occur close to the respective injection well at some sites, but overlying strata are expected to prevent fracture propagation to the top of bedrock. As a general conclusion, the effects of deep injection of wastewaters in the Cold Lake area are felt only in the area adjacent to the injection wells.

1. Alberta Geological Survey/Alberta Research Council

WORKSHOP ON DEEPWELL DISPOSAL

November 5-7, 1990

Alberta Research Council
Edmonton, Alberta

# WASTE SUITABILITY
# FOR DEEPWELL DISPOSAL

by

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Industrial Wastes Branch
Wastes and Chemicals Division
Alberta Environment

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## 1. BACKGROUND

Based on a survey conducted by the Canadian Petroleum Association in 1989, 90% of all oilfield liquid wastewaters (process and produced) are currently disposed of by deepwell injection. This corresponds to approximately 263 million cubic meters of waste. The total wastewater potentially suitable for underground injection is summarized in Table I.

TABLE I

Liquid Waste Suitable for Deepwell Disposal
Oil and Gas Exploration (CPA data and AE assessment)

| Nature | Quantity ($\times 10^6$ $m^3$/year) | Number of Streams | Percentage |
|---|---|---|---|
| Hazardous | 36 | 6 | 12.3 |
| Non-Hazardous or unclassified | 256 | 10 | 87.7 |
| TOTAL | 292 | 16 | 100.0 |

Of all liquid oilfield waste, the volumes potentially suitable for deepwell injection could be as high as 292 million cubic metres representing almost 98% of the total. To put some perspective on these numbers, it should be noted that process wastewater and produced water represent over 99% of the total suitable for injection with 36 and 250 million cubic meters, respectively.

Another survey conducted by Alberta Environment in 1988 identified a total of 22 wells being used strictly to dispose of industrial wastewater. The majority of the wells are used by refineries and chemical and fertilizer plants. Those wells are responsible for injecting approximately $7.6 \times 10^6$ cubic meters of industrial effluents (Table II).

Table II

Deepwell Injection by Major Industrial Plants

| PLANTS | QUANTITY ($X\ 10^6\ m^3/yr$) |
| --- | --- |
| Chemical | 4.0 |
| Refineries | 2.4 |
| Fertilizer | 1.2 |
| | 7.6 |

A detailed characterization of four liquid effluents discharged from some of these plants is shown on Table III.

Table III

Wastewater Characteristics Major Industrial (1988 data) Plants

Plant A. Volume injected: $2.2 \times 10^6\ m^3$/year

methanol, acetone, ethyl acetate, acetic acid, acetaldehyde, acetonitrile, methyl formate, methyl acetate, butyl acetate, lime, tank car cleanings, runoff, COD 14,000 ppm.

Plant B. Volume injected: $1.1 \times 10^6\ m^3$/year

Unit 1: NaCl 1-5%, chlorinated phenols 0.01-0.1%, NaOH-0.5%, pH 10-13, TOC 0.1-1%; Unit 2: $NaSO_4$ 0-5%, NaCl 5-20%, $Na_2CO_3$ 0-5%, NaOCl.

Plant C. Volume injected: $0.6 \times 10^6\ m^3$/year

Sour water, caustic and desalter brine, ammonia, phenols, $Na_2S$, NaF, NaOH, oil and grease 1268, COD 11,378, TSS 52 (units in ppm), pH 8.3

Plant U. Volume injected: $0.9 \times 10^6$ $m^3$/year

Sour water, oily water, spent caustic, desalter brine, napthenic acids, COD 5280, oils 94, TSS 144 (units in ppm), pH 9.4

Plant E. Volume injected: 70,000 $m^3$/year

pH 2-3 in (1987/88 varied from 1.0 to 13.2), SS 100, TDS 2000, TOC 100, trace organics.

---

To finalize our comments on quantities disposed of via injection wells and to further stress the importance of this technique, it is noted that the volume of industrial wastewater surface discharged in 1986 was $1{,}313 \times 10^6$ cubic meters. This figure includes $1{,}107 \times 10^6$ cubic meters of cooling water from coal fired thermoleletric plants. In conclusion, deepwell is a disposal alternative for about $300 \times 10^6$ cubic meters of wastewater representing 50% more than the total amount of discharged to surface water bodies.

2. CHEMICAL FATE OF INJECTED WASTES

The chemical fate of wastes injected into deep formations can be determined using standard chemical engineering techniques. The concentration of hazardous components is typically reduced by reactions within the waste itself or by reactions with the injection zone material. Such reactions include: neutralization, hydrolysis, ion exchange, adsorption, oxidation/reduction, precipitation, and microbial degradation.

1. Neutralization

Various reactions neutralize alkaline or acidic wastes. The most significant ones are:

a) Carbonate dissolution

Limestones and dolomites react with acidic materials to raise the pH. The typical reaction is:

$$2H^+ + Ca\ CO_3 \rightarrow Ca^{2+} + H_2O + CO_2$$

b) Sand dissolution

Sand ($SiO_2$) dissolves in alkaline solutions to lower the pH. This reaction is slower than carbonate dissolution.

c) Clay dissolution

Clays react with alkaline or acidic wastes to bring the pH to the neutral range.

2. Hydrolysis

Many organic compounds hydrolyze in aqueous solutions. Others, like hydrocarbons and halogenated compounds resist hydrolysis. The reaction rate is very much dependent on the pH of the solution. Examples of wastes prone to hydrolysis include hydrogen cyanide, acetonitrile and acrylonitrite.

3. Precipitation

Reactions of injected and interstitial fluids with rock components produce precipitates and include:

a) Precipitation of alkaline metals as insoluble carbonates, bicarbonates, hydroxides, sulphates, orthophosphates and fluorides;

b) Co-precipitation of heavy metal ions such as lead and chromium with iron hydroxides or precipitation of heavy metal carbonates, bicarbonates, hydroxides, orthophosphates and sulfides; and

c) Precipitation of oxidation/reaction products, such as hydrogen sulphide with chromium (VI)

4. Ion exchange

The ability of subsoil to exhibit ion exchange properties depend primarily on the types and amounts of materials in the clay fraction. This is due to the substitution of sodium and calcium ions by heavy metal ions such as nickel, lead and chromium. It should be noted that since the exchange capacity of a subsoil is already saturated with common cations ($Ca^{2+}$ and $Na^{+}$), retention of wastewater chemicals or heavy metals will be accompanied by the release of these cations into solution.

5. Microbial degradation

Microbes can aerobically and anaerobically transform most of the organic compounds into first organic acids and then into compounds such as methane, water and carbon dioxide. Such microbial degradation is known to occur in disposal wells and, properly designed, is the base of some biological wastewater treatments. It should be noted that under favorable conditions microbial degradation can be many orders of magnitude faster than hydrolysis.

The above described reactions show how deepwells could be useful mostly in managing inorganic wastes which infortunately never go away. They may be rendered non-hazardous by dilution, isolation, and in some cases by changes in oxidation states. Treatment methods such as incineration are ineffective because metals do not degrade by burning. Solidification, besides being costly, adds volume and requires landfill space with the potential for long term leaching when not properly conducted.

## 3. COMPATIBILITY OF WASTEWATERS WITH FORMATION MATERIALS

In addition to the chemical processes described, particular attention has to be given to the compatibility of the injected wastes not only with the mechanical components of the well system but also with injection and confining geological formations, and the natural formation fluids.

The assessment of this compatibility requires detailed characterization of the wastewater and simulation or actual testing, in the lab or in the field to prevent corrosion of the well parts, plugging of the receiving formation or damage of the integrity of the injection zone or confining layers.

If compatibility problems are foreseen these are often addressed by proper material selection or by pretreatment of the wastewater prior to injection.

## 4. ALTERNATIVE TECHNOLOGIES

Although properly conducted underground injection is an environmentally sound method for managing liquid waste, it should not be the preferred method all the time a waste meets a quality suitability criteria. Alternative treatment and destruction methods such as neutralization, biophysical treatment, wet air oxidation and incineration, are commercially available very often at competitive cost for almost all industrial waste streams now commonly being injected.

## 5. QUALITY CRITERIA

The present government policy views the potential offered by subsurface reservoirs in Alberta as a resource to be utilized in a responsible manner for waste water disposal. However, it is also policy to retain waste water in the hydrological cycle whenever possible.

Based on these policies, Alberta Environment assesses proposals for deepwell injection within the framework of the following interim quality criteria:

1. Waste water acceptable for deepwell disposal:

   a) brine solutions produced in conjunction with oil and gas exploration activities;

   b) treated liquid waste which would require prohibitively expensive additional treatment to make it suitable for surface discharge to the surrounding watershed;

   c) liquid waste not treatable by conventional physical, chemical, or biological processes at reasonable cost; and

   d) liquid wastes, that if treated or disposed of on the surface would create evident negative environmental impacts.

2. Waste water not acceptable for deepwell injection:

   a) surface water runoff which meets criteria for surface discharge or can be treated by conventional physical, chemical or biological processes;

   b) treated or untreated municipal sewage;

   c) liquid wastes with a flash point below 61°;

   d) organic wastes which require little supplemental fuel during incineration;

   e) liquid wastes which are chemically unstable or uncompatible with formation fluids.

## 6. WASTE ASSESSMENT

When assessing characteristics of wastes one must be aware of the purpose of that assessment. Characterization for hazardous waste classification purposes is quite different from characterization for deepwell injection suitability.

Briefly, Table IV, is a simplified list of characteristics that make a liquid waste hazardous. Thus, proper classification requires measurement of the waste properties directly related with the criteria indicated in Table IV.

TABLE IV

SIMPLIFIED LIST OF CHARACTERISTICS THAT MAKE A LIQUID WASTE HAZARDOUS WASTE

| | |
|---|---|
| Class 3 | Flash point $\leq$ 61°C |
| Class 6 | LD50 $\leq$ 500 mg/kg |
| Class 8 | pH < 2 or pH > 12.5 |
| Class 9.2 | Specified substances > 100 ppm |
| Class 9.3 | Contaminants in concentrations equal or greater than the following limits:<br>$CN^-$ 20.0 As 5.0 Cr 5.0<br>Pb 5.0 Ba 100.0 Hg 0.1<br>Se 1.0 Cd 0.5 Ag 5.0 |

On the other hand, when looking at suitability for deepwell injection one has to evaluate the human health and environmental impacts that might result from injecting a certain waste stream into a receiving geologic formation and comparing those impacts with the ones expected by adopting an alternative disposal technology. Alberta Environment's present quality criteria on deepwell disposal of wastewaters goes beyond the concept of hazardous. In other words, the hazardous character of a waste should not be the limiting factor in assessing waste suitability for deepwell injection. The factors which are important in making a decision should be the safety of the operation in terms of environmental protection and human health.

These are the basis of Alberta Environment's present policy regarding the assessment of waste streams for deep subsurface injection. As an immediate consequence, situations arise where a waste is classified as hazardous waste and is perfectly suited for disposal by deepwell injection. That's often the case with aqueous waste containing heavy metals or organics in solution which make the waste stream hazardous waste but, provided that compatibility exits, the waste might be an ideal candidate for deepwell injection.

On the opposite side are wastes that, although non-hazardous, should not be allowed to be disposed into the subsurface for reasons of water resources conservation or wise use of valuable pore space within potentially suitable geologic formations. In the same class fall wastes like produced brines which would require economically unacceptable additional treatment prior to disposal to a water course with the attendant problem of disposing of highly soluble salts recovered during the treatment.

TABLE V

Examples of Waste Streams Submitted to Alberta Environment For Assessment on Deepwell Disposal Suitability (May-July, 1990)

A. HAZARDOUS

| Type | Quantity ($M^3$/mo) | Characteristics |
|---|---|---|
| 1. Tank and floor washings | 400 | Cr 4.2+ |
| 2. Barrel washing | 105 | f.p. 30°C |
| 3. Wastewater from oil refining process | 80 | Phenols 2600 |
| 4. Strip paint wastewater | 70 | Cr 27 |
| 5. Tank and floor washings | 10 | BTEX 149 |
| 6. Tank bottoms (g) | 1 | f.p. |
| 7. Tank washings | 150 | Alcohol 0.5%, NaHS 0.5% |
| 8. Steam tank washings | 150 | Phenols 2600 |
| 9. Tank and floor washings | 1 | HC, TDS, metals |
| 10. Spent sweetening | | f.p. 16°C |

+ - ppm, unless otherwise indicated

TABLE V (cont'd)

B. NON-HAZARDOUS

| Type | Quantity ($M^3$/mo) | Characteristics |
|---|---|---|
| 1. Surface water run-off | 1500 (1) | Tri-ethylene glycol 300 |
| 2. Amine soaked gravel | 2 (1) | DEA |
| 3. Flushings of pumps & lines | 30 (1) | HC, glycol |
| 4. Hydrotest fluids | 1600 (1) | Methanol, HC |
| 5. Tank bottoms (d) | 6 (1) | HC |
| 6. Tank washings | 700 | HC |
| 7. Production brine | 1500 | TDS |
| 8. Spent sweetening | 2 | Sulphur compounds |
| 9. Tank washings | 150 | Spent Caustic |
| 10. Tank bottoms | 16 | Salicilic acid and salt |
| 11. Landfill leachate | | Metals, HC |
| 12. Hydrated ammonia | 20 | pH |

(1) Denotes one time disposal

## 7. CHEMICAL AND PHYSICAL PARAMETERS

From the quality criteria, it results that in general, industrial wastes suitable for deepwell should be constituted by aqueous solutions which do not support combustion and have a flash point greater than 61°C.

Some discretion should be used in selecting the chemical parameters to be tested. These should reflect the nature of the waste and enable decision-making regarding classification, if required, designing of pre-treatment operations and assessment of disposal alternatives.

Typically, the chemical and physical characteristics to be determined may include:

1. pH
2. chemical species
3. total dissolved solids
4. major ions
5. metals
6. solvents
7. total petroleum hydrocarbons
8. phenols
9. flash point
10. density
11. physical phases
12. volume
13. compatibility

To enable proper assessment, an inorganic waste stream for instance would require testing for parameters 1 to 5, 13 and 14. An organic aqueous effluent could, eventually, require testing for most of the parameters indicated above.

DEFINITIONS

ANNULUS:

Means the space between the outside edge of the injection tube and the well casing.

COMPATIBILITY:

Means that waste constituents do not react with each other, with the materials constituting the injection well, or with fluids or solid geologic media in the injection zone or confiing zone in such a manner as to cause leaching, precipitation of solids, gas or pressure buildup, dissolution, or any other effect which will impair the effectiveness of the confining zone or the safe operation of the injection well.

CONFINING ZONE:

Means the geological formation, or part of a formation, which is intended to be a barrier to prevent the migration of waste constituents from the injection zone.

CONSTITUENT:

Means an element, chemical, compound, or mixture of compounds which is a component of a hazardous waste or leachate and which has the physical or chemical properties that cause the waste to be identified as hazardous waste by the department pursuant to this chapter.

DISCHARGE:

Means to place, inject, dispose of, or store hazardous wastes into, or in, an injection well owned or operated by the person who is conducting the placing, disposal, or storage.

GROUNDWATER:

Means water, including, but not limited to, drinking water, below the land surface in a zone of saturation.

INJECTION WELL

Means any bored, drilled, or driven shaft, dug pit, or hole in the ground whose depth is greater than 600 m and any association subsurface appurtenances, including, but not limited to, to casing.

INJECTION ZONE:

Means that portion of the receiving formation which has received, is receiving, or is expected to receive, over the lifetime of the well, waste fluid from the injection well.

OWNER:

Means a person who owns a facility or part of a facility.

PERCHED WATER:

Means a localized body of groundwater that overlies, and is hydraulically separated from, an underlying body of groundwater.

PH:

Means a measure of a sample's acidity expressed as a negative logarithm of the hydrogen ion concentration.

RECEIVING FORMATION:

Means the geologic strata which are hydraulically connected to the injection well.

STRATA:

Means a distinctive layer or series of layers of earth materials.

## RISK ASSESSMENT

*Deep Well Disposal Workshop*

*November 6,7, 1990*

**Dr. Steve E. Hrudey, P.Eng.**
**Professor**
**Environmental Health Program**
**Faculty of Medicine**
The University of Alberta

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**What is Risk?**

danger (negative)

financial (positive or negative)

many different interpretations

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**Concept of Risk**

involves

- intensity of negative
- likelihood of occurrence

cannot be a single value quantity

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**RISK:**
**a workable concept, comprised of three essential components:**

- circumstances with potential danger (a hazardous scenario)
- a probability of danger arising (always a probability distribution)
- a set of consequences arising from the occurrence of the hazardous scenario

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**What is risk assessment?**

a technical evaluation of risk that should be as objective and scientific as possible

forms the basis for:

**Risk Management** - pragmatic decisions

**Risk Communication** - interaction with affected parties

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**Risk Assessment**

emphasis on process failure

**Scenario** - industrial activity with failure modes

**Probability**- distribution of failure probabilities

**Consequence**- considers extent of failure and adverse effects

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## Risk Assessment

emphasis on health risk

Scenario - starts with failure event presumed

Probability- likelihood of adverse health effects

Consequence- nature and extent of adverse health effects

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## Requirements of assessment:

- hazard assessment
- exposure assessment
- consequence assessment

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## HAZARD ASSESSMENT

1. Determine the properties of the substance(s) which will control the nature of the hazardous scenario.
   - basic chemical / physical properties
   - fate and behaviour properties
   - functional hazard properties
   - toxicological properties
2. Characterize emissions and/or exposures from environmental monitoring

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**Basic chemical identifiers**

- synonyms, trade names
- chemical structure
- formula weight
- CAS #
- RTECS #

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**Basic physical properties**

- normal physical state
- melting point
- boiling point
- specific gravity
- vapour density

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**Fate and Behaviour Properties**

- phase properties
- distribution factors
- stability factors

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## Functional hazardous properties

- flammability (qualitative)
- flash point
- auto ignition point
- lower and upper explosive limits
- reactivity with other substances
- corrosivity

## Nuisance properties

- odour and/or taste thresholds



## Toxicological properties (includes)

- acute lethality ($LD_{50}$, $LC_{50}$) by various exposure routes (ingestion, inhalation,...)
- chronic lethality
- acute or chronic dermal irritation
- acute or chronic eye irritation



## Toxicological properties (continued)

- reproductive toxicity (*fetotoxic*)
- cell mutation (*mutagenic*)
- chromosome damage (*clastogenic*)
- developmental effects (*teratogenic*)
- tumour formation (*oncogenic*, including *carcinogenic*)

## Toxicological properties

- an open-ended list
- rely on experimental animals or in vitro cell systems in controlled laboratory exposures
- results can highlight dangers and provide evidence concerning those conditions (exposure route, etc.) associated with adverse effect
- while experiments can demonstrate harm they cannot prove *safety*

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## Exposure Assessment

Characterizing emissions and /or exposures (monitoring)

- sampling
- analysis

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## Exposure Modelling

- distribution
- dose determination
- pharmacokinetics (toxicokinetics)

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## Dose Determination Models

These models translate the concentrations of contaminant in the various environmental compartments into doses

Routes normally considered are:

- direct ingestion through drinking water
- inhalation
- skin absorption from water
- ingestion of contaminated food
- skin absorption from contaminated soil



## Ingestion through drinking - factors

- amount of water consumed per day
- fraction of contaminant absorbed through wall of gastrointestinal tract (frequently unknown and assumed to be 100%)
- average body weight of target subject



## Inhalation -factors

- air concentrations from showering, bathing and other uses of water
- fluctuation in air concentration over time
- amount of air breathed during activities leading to volatilization of contaminants
- fraction of inhaled contaminant absorbed through lungs
- average body weight of target subject

## Skin absorption from water - factors

- amount of time spent washing and bathing
- fraction of contaminant absorbed through skin
- average body weight of target subject

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## Generic Algorithm for dose determination:

$$\text{Dose (mg/kg-bw/d)} = \frac{Q \cdot C \cdot F \cdot A}{T \cdot W}$$

Q = quantity of contaminated medium exposed to
C = concentration of contaminant in medium
F = fraction of total time period exposed
A = fraction absorbed
T = total time period for evaluation
W = body weight of target consumer

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## Consequence Assessment

- translate exposure into response
- based upon toxicological principle that

  "the dose makes the poison"

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## Dose - Response Modelling

**The relationship assumed between dose and response will dictate the form and result of any health risk assessment**

**The acceptance or rejection of**

**the existence of a threshold dose below which no significant adverse response occurs**

**is a critical decision in the interpretation of any dose-response curve**

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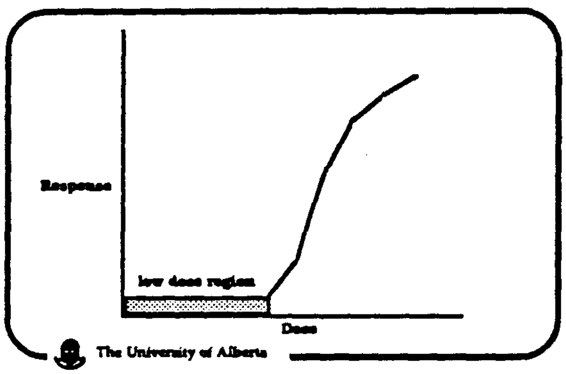


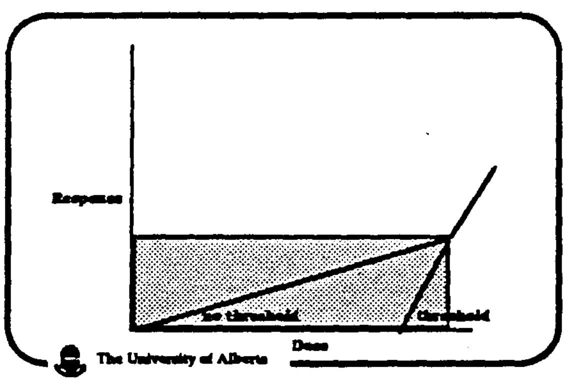

**If threshold accepted**

- highest dosage which produces no observable adverse effect is designated NOAEL
- reference dose is determined by application of safety factors to allow for confidence in the results, extrapolation from experimental animals to humans and allowance for most sensitive humans
- safety factors of 100 to 1000 below the NOAEL are common to determine a reference dose for humans (believed to pose no significant health risk)

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**Contaminants for which the threshold concept is questioned:**

- teratogens which can cause a mutation during the developmental stages of the fetus leading to incorrect proliferation of cells yielding a birth defect
- carcinogens which can cause a mutation which will initiate one of the processes leading to conversion of a normal cell into a cell which will proliferate and develop into a tumour (neoplastic conversion)

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For these contaminants

which can cause a cell mutation

which will exert the adverse effect

because of the subsequent proliferation of the damaged cell

into malfunctioning tissue (birth defect or tumour)

an argument can be made that a single mutation is capable of resulting in the final damaged condition

consequently, there may be no threshold dose below which ultimate damage will not occur.

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Generally, these models can all be fitted equally well to the data within the range of the experimental observations (i.e. high dose range)

However, they diverge dramatically when extrapolated to very low doses corresponding to low response levels ($10^{-5}$ to $10^{-6}$ lifetime risk)



## Animal - Human Extrapolation

- experimental toxicology limited to various laboratory animals
- relation of data to humans requires at least a dose conversion according to size
- mounting evidence of need for physiological corrections
- some prospects for verification with epidemiology

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## Issues in Health Risk Assessment

- recognize the enormous uncertainties associated with risk estimates
- do not use **risk assessment** as a surrogate for common sense
- use risk assessments in a preventive mode for realistic scenarios

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**Issues in Health Risk Assessment**

- seek to reconcile risk estimates with other risks in society
- recognize place of manmade risk among nature's health risks
- work towards reconciling risk estimates with epidemiological data

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**Risk Management for Deep Well Disposal**

**Focus on:**

- scenario
- probability
- consequences

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**Managing the Scenario**

some limit or ban on deep well disposal for specific waste types

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**Managing the Probability**

increased reliability of systems or monitoring capabilities



**Managing the Consequences**

- identify the most plausible consequences, and
- select management strategies which will avoid unacceptable consequences

Require some logic to guide decisions



**For Example:**

If wastes have sensory threshold above toxic threshold then tainted water could be consumed for a long time before source of problem was detected.

Severe health effects could arise.

**If wastes have sensory threshold below toxic threshold, detection should be assured**

**Health consequences should be avoided**

**Mitigation of tainted water supply involves economic loss but avoids loss of life**



**For non-threshold toxicants**

- **adopt "acceptable" risk, or**
- **ban such toxicants, provided that correct interpretation of threshold is done**

ENERGY RESOURCES CONSERVATION BOARD

# Waste and Water Disposal Application Process

- by Valerie Vogt
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# WATER DISPOSAL APPLICATION PROCESS

The Energy Resources Conservation Board's (the Board) authority to approve schemes for suburface disposal is contained within Section 26 of the Oil and Gas Conservation Act. Those parts of Section 26 that are applicable to suburface disposal are (Figure 1):

Section 26 - subsection (1), clause (c) and clause (d),
- subsection (2), and
- subsection (3).

As is noted from subsection (1) (d) and subsections (2) and (3), waste disposal shares a joint jurisdiction between the Board and Alberta Environment, and even though it is not specifically required by the Legislation, the Board also refers those applications for shallow disposal to Alberta Environment for its review. Shallow disposal is defined as disposal into a zone less than 600 metres K.B.

The information that is to be submitted in an application for subsurface disposal is outlined within section 15.070 of the Oil and Gas Conservation Regulations (Figure 2).

In addition to the Act and Regulations, the Board relies on obtaining certain information that's addressed from time to time in various Board Publications. In particular for disposal wells, we look to the Board's Information Letter, IL 84-12. That information letter, among other things, requires that an operator prove the integrity of the casing and the cement behind the casing prior to the commencement of disposal operations. As a note, Information Letter, IL 84-12, is currently under review.

In 1989, the Board registered some 257 applications requesting approval for either new disposal schemes or amendments to existing disposal schemes. Board staff completed some 273 disposal applications that same year. So far in 1990, the Board has registered some 170 applications relating to subsurface disposal and completed some 150 applications.

During the processing of the applications, the applications go through three stages (Figure 3):

- REVIEW
- RECOMMENTDATION
- APPROVAL

## I REVIEW

The review stage is by far the most labor intensive part of the process.

The Board's objectives at the review stage are (Figure 4):

- CONSERVATION OF RESOURCES
- SAFE AND EFFICIENT OPERATION OF WELLS
- CONTROL OF POLLUTION

In the review process the Board relies on its own expertise, including staff geologists, reservoir engineers, Drilling and Completion personnel, and from time to time, its other professionals such as Economics staff. The review stage enables the Application processor to gather sufficient information to meet its objectives when evaluating applications for subsurface disposal.

In addition, for those applications that are referred to Alberta Environment, the Board relies on Alberta Environment's expertise to determine matters of an environmental concern. Specifically, Alberta Environment identifies the depth of useable water acquifers and is instrumental is determining the criteria for the suitability of waste streams for subsurface disposal.

MEETING THE BOARD'S OBJECTIVES IN SUBSURFACE DISPOSAL:

### CONSERVATION OF RESOURCES

In looking at the Conservation of Resources, Board staff basically evaluate the ability of the receiving zone to accept fluids without causing any detrimental effect to hydrocarbon recovery from that zone (Figure 5).

This review would be more applicable to those applications for produced water disposal, rather than waste disposal, because waste disposal, and particularily industrial waste disposal almost always occurs into wet zones, or zones not containing hydrocarbons.

At this stage Board staff has consideration for:

a) Geology of the disposal zone - As part of the scheme approval process, Board staff perform a geological evaluation of the proposed disposal zone to determine its suitability for disposal operations. The pool into which disposal is proposed is evaluated for its extent, porosity, permeability, segregation from deeper or shallower zones, where the disposal zone may outcrop, if applicable, and whether or not hydrocarbon potential is present within the zone.

b) Hydrocarbon Conservation - the disposal interval is reviewed with the concept that the top of the injection interval occurs at a depth far enough removed from any pool hydrocarbon/water interface that disposal will not detrimentally affect hydrocarbon recovery from the pool.

c) Reservoir Voidage/Voidage Replacement - should disposal be proposed at or near a pool hydrocarbon/water interface or should the applicant propose to inject large volumes of produced water into a hydrocarbon bearing pool, the Board may limit the volume of water to be disposed. The injection volume in that case may be limited to the total volume of hydrocarbon production from the pool. This action is taken to prevent "pressuring-up" of the pool and the possibility of produced water being forced into the hydrocarbon bearing part of the pool by the possible over-pressuring of the pool in the vicinity of the disposal well.

d) Reservoir Pressure and Injection Pressure - the Board limits the maximum wellhead injection pressure for the disposal zone to below the actual or estimated formation fracture pressure. A value greater than the formation fracture pressure may be approved only after the applicant has satisfied the Board that no adverse effects to the zone or hydrocarbon recovery will result if the formation is fractured.

e) Injectivity - the Board evaluates the extent, porosity, and permeability of the pool to determine if the proposed disposal zone will have the capability to accept the disposal volumes required by the applicant. The Board may also request that the applicant run an injectivity test on the zone to show that the zone meets its disposal requirements at a wellhead injection pressure not exceeding that specified in the approval.

f) Formation Fracture Pressure - the Board will limit the injection pressure of a disposal scheme to a value below the formation fracture pressure of the zone. This would eliminate the possibility of early water breakthrough into a hyrocarbon bearing portion of the pool through fractures which could emanate from the water leg of the pool and propogate into the hydrocarbon bearing part of the pool.

SAFE AND EFFICIENT OPERATION OF WELLS

For every well being applied for use in a subsurface disposal scheme, Board staff have consideration for (Figure 6):

a) Casing and cementing of the well

b) Presence of tubing and placement of packer in the wellbore - section 6.120 of the Oil and Gas Conservation Regualtions states that the packer should be set as closely above the injection interval as is practical. As a matter of policy, the Board prefers the packer to be set no more that 20 metres above the injection perfs.

c) Presence of corrosion inhibited fluid in the annulus - has a two-fold purpose: to prevent corrosion of the production casing over time, and to provide an early warning detection for casing, tubing, or packer failure; that is, if the fluid were to suddenly disappear from the annulus, the operator could immediately suspect the failure of the casing, tubing, or packer and immediately shut in the well until the problem was found and rectified.

d) Casing integrity of the well

e) Cement integrity behind the production casing - to ensure that the injected fluid enters the targeted formation and does not migrate up or down the casing to some shallower or deeper zone.

For waste disposal wells and shallow disposal wells, Board staff, in its dealings with Alberta Environment, have come to realize that Alberta Environment is looking for two levels of protection of useable water acquifers. The two most common levels of protection are:

- Surface casing set below the deepest useable water acquifer and cemented full length, and

- Production casing cemented full length.

Board staff then, when evaluating waste disposal applications, will typically address this criteria in its own initial review of applications for waste or shallow disposal.

CONTROL OF POLLUTION

(Figure 7)

a) Surface handling facilities - enables Board staff to evaluate if the surface handling facilites are adequate to service the scheme.
   - tanks, not pits, on site to contain any fluid before it goes down hole.
   - placement of fluid meter to ensure that all disposal fluid is measured so that it can be reported by the operator in monthly reports to the Board.

b) Casing and cement integrity
   - requires the running and submission of various accepted oil industry logs to ensure that the casing is void of any holes or leaks and thus, prevent the leakage of any fluid through the wellbore to any zone but the targeted disposal zone.

   - requires the running and submission of various accepted oil industry logs to ensure that there is sufficient cement and quality of cement to ensure that the disposal fluid is entering the targeted disposal zone.

c) Wellhead Injection Pressure - Board staff using a very conservative approach, sets the injection pressure to a value below the formation fracture pressure. This ensures that the disposal fluid does not leave the targeted disposal formation through a fracture emanating in the disposal zone and propogating into a shallower or deeper zone.
   - There is opportunity for an operator to request an injection pressure above the formation fracture pressure, and provided the operator can show through technical data that the fracture will be contained to the disposal zone, then the higher pressure may be approved.

## II RECOMMENDATION

Once Board staff has completed its review, or essentially gathered information, it then makes its written recommendation on the application to Department Management, and eventually the Board, as to whether the disposal scheme should be denied or approved (Figure 8).

If the recommendation is to DENY, and the Board agrees with that recommendation, a letter will go out to the applicant relating the Board's decision to deny and the reasons for that decision.

There are very few applications that are outright denied. In the past eight years, there have been two denied: one, because the wellbore did not have mechanical integrity, and the second, because the scheme proposed produced water disposal into a extremely shallow formation (approximately 135 metres K.B.). The latter scheme, in the Board's opinion, presented too great a risk to contamination of a useable water acquifer.

For the most part, if Board staff evaluates an application that would likely be denied, it works with the applicant to devise an amended scheme that would be approved. Examples:

- If disposal at the proposed injection interval would, in the Board's opinion, harm hydrocarbon production from the pool, the applicant may agree to squeeze the shallower set of perfs and re-perf deeper into the water leg of the pool for disposal purposes.

- If there is some question of the well's integrity over time, the applicant may agree to a continuous monitoring program on the well, that would enable him to quickly detect any problems with the well that might lead to contamination of any zones other than the intended disposal zone.

If the recommendation is to APPROVE, and the Board agrees with that recommendation, an approval will be issued.

## III APPROVAL

Approval No. 6258 (Figure 9) is an example of a typical routine Board approval for subsurface disposal. A Ministerial Approval from Alberta Environment was not required before this approval could be issued.

Clause 1 - Names operator of scheme
- Names sources from which fluids are approved for disposal through the well
- Names disposal zone
- Identifies the disposal well
- Identifies the application that resulted in the issuance of the approval

Clause 2 - Identifies the top of the disposal interval in metres subsea

Clause 3 - Identifies the setting depth of the packer in metres subsea and what is to be contained in the annulus

Clause 4 - Lists the maximum wellhead injection pressure under which the scheme is allowed to operate

Approval No. 5230 (Figure 10) is an example of an approval issued by the Board and containing special conditions requested by the Board that need to be followed by the operator.

Clause 4 - special monitioring provision of the tubing/casing annulus added

Clause 6 - requires monitoring of the reservoir

Clause 8 - special clause of analysis of fluids being injected

Clause 9 - special reporting clause requirement

This scheme (Board Approval No. 5230) is for the disposal of waste; therefore, it also carries a Ministerial Approval from Alberta Environment. In this case, the Ministerial Approval carries special conditions of its own which the operator is also bound to abide by.

Condition 1 - continuous bottom hole pressure measurement

Condition 2 - bi-yearly report addressing injection well performance

## OIL AND GAS CONSERVATION ACT

## SUBSURFACE DISPOSAL

26. (1) No scheme for

(a)

(b)

(c) the disposal of produced water,

(d) the disposal of any fluid other than produced water,

(e)

shall proceed unless the Board has approved the scheme on any terms or conditions that it prescribes.

(2) An application under subsection (1) (d) also requires the consent of the Minister of the Environment in the form of a Ministerial Approval.

(3) The Ministerial Approval may contain conditions.

Figure 7

## OIL AND GAS CONSERVATION REGULATIONS

## SUBSURFACE DISPOSAL

15.070 An application for subsurface disposal shall include, when applicable,

(a) maps showing

- location of disposal well
- lessors and lessees
- adjacent well status
- disposal zone pool structure

(b) figures showing

- geological cross-sections
- completion details
- measurement and water handling facilities

(c) tabulation of

- reservoir parameters
- reservoir pressures
- material balance calculations
- pool production history

(d) discussion of equity

# APPLICATION PROCESS

- **Review**
- **Recommendation**
- **Approval**

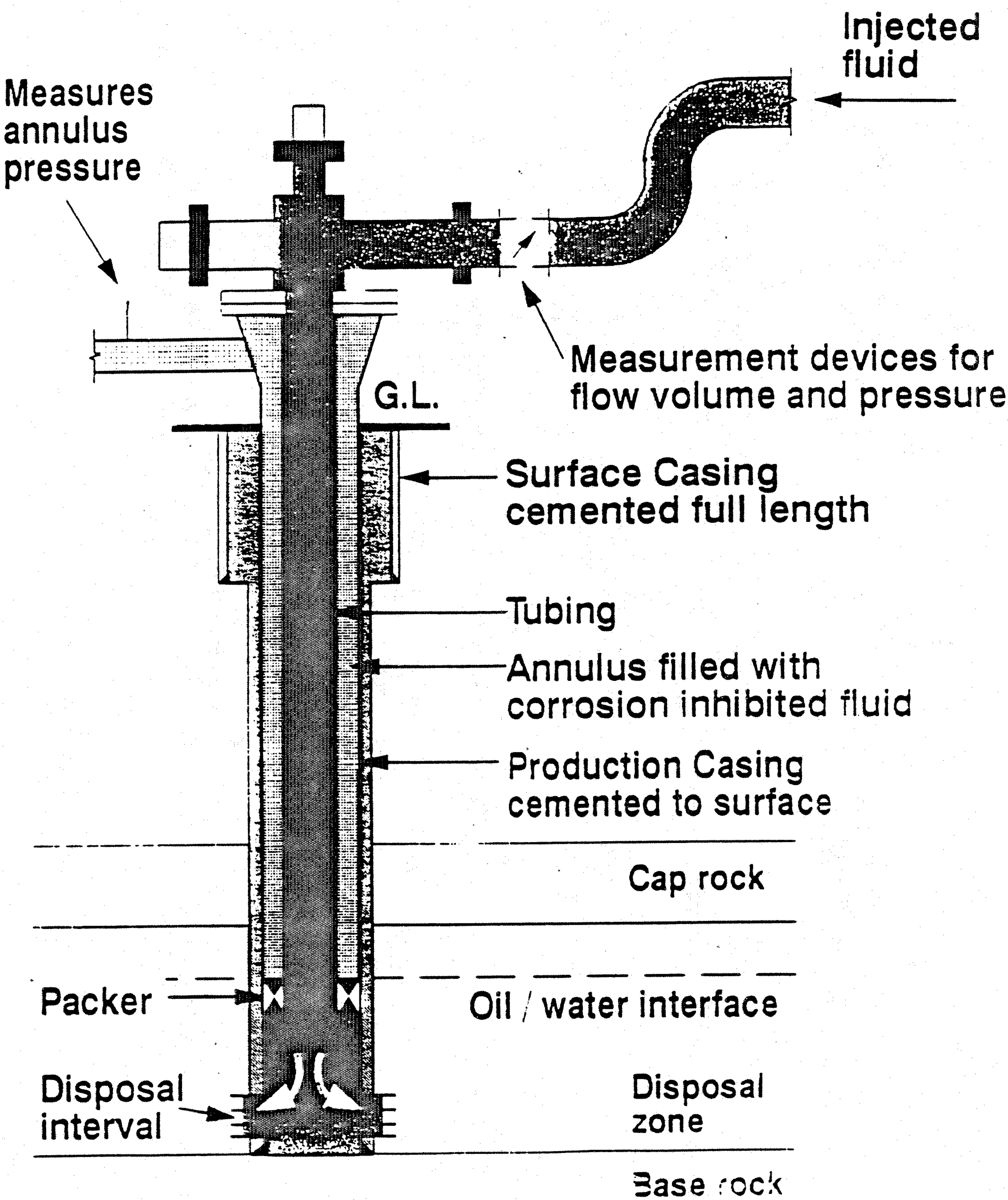
# ERCB OBJECTIVES

- Conservation of resources
- Safe and efficient operation of wells
- Control of pollution above, at, or below surface

# CONSERVATION OF RESOURCES

- Geology of disposal zone
- Hydrocarbon conservation
- Reservoir voidage / voidage replacement
- Reservoir pressure and injection pressure
- Injectivity
- Formation fracture pressure

# DISPOSAL WELL SCHEMATIC



# CONTROL OF POLLUTION

- Surface handling facilities
- Casing and cement integrity
- Wellhead injection pressure

# RECOMMENDATION

- Deny
- Approve

THE PROVINCE OF ALBERTA

OIL AND GAS CONSERVATION ACT

ENERGY RESOURCES CONSERVATION BOARD

IN THE MATTER of a scheme of Pembina Resources Limited for the disposal of water in the Hotchkiss Field

APPROVAL NO. 6258

The Energy Resources Conservation Board, pursuant to the Oil and Gas Conservation Act, being chapter 0-5 of the Revised Statutes of Alberta, 1980, hereby orders as follows:

1. The scheme of Pembina Resources Limited for the disposal of water produced in conjunction with oil or gas from the Hotchkiss Debolt A Pool by injection into the zone of origin through the well, PEMBINA ET AL HOTCHKISS 7-34-94-2, located in Legal Subdivision 7 of Section 34, Township 94, Range 2, West of the 6th Meridian, as such scheme is described in Application No. 891865 dated 29 November 1989 from Pembina Resources Limited to the Board, is approved, subject to the terms and conditions herein contained.

2. No water shall be injected into the formation above a depth of 0.6 metres subsea.

3. A production packer shall be set below 19.0 metres above sea level and the annular space above the packer shall be filled with a non-corrosive, corrosion inhibited liquid.

4. The maximum wellhead injection pressure shall not exceed 3760 kilopascals (gauge).

5. The Board may at any time vary the terms and conditions hereof or may revoke or rescind this approval if, in its opinion, circumstances so warrant.

MADE at the City of Calgary, in the Province of Alberta, this 22nd day of June, 1990.

ENERGY RESOURCES CONSERVATION BOARD

THE PROVINCE OF ALBERTA

OIL AND GAS CONSERVATION ACT

ENERGY RESOURCES CONSERVATION BOARD

IN THE MATTER of a scheme of Chem-Security Ltd. for the disposal of process waste water in the Ethel Area

APPROVAL NO. 5230

WHEREAS the Energy Resources Conservation Board is prepared to grant an application by Chem-Security Ltd., subject to the terms and conditions herein contained, and the Minister of the Environment has given his approval, hereto attached, insofar as the application affects matters of the environment.

THEREFORE, the Energy Resources Conservation Board, pursuant to the Oil and Gas Conservation Act, being chapter O-5 of the Revised Statutes of Alberta, 1980, hereby orders as follows:

1. The scheme of Chem-Security Ltd. for the disposal of process waste water produced in conjunction with the operation of the Swan Hills Special Waste Management Facility by injection into the upper and lower zones of the Blueridge Member through the well, CSL ETHEL 13-6-67-8, located in Legal Subdivision 13 of Section 6, Township 67, Range 8, West of the 5th Meridian, as such scheme is described in Application No. 861064 dated 2 September 1986 from Chem-Security Ltd. to the Board, is approved, subject to the terms and conditions herein contained.

2. No water shall be injected into the formation above a depth of 821.0 metres subsea.

3. A production packer shall be set below 801.0 metres subsea and the annular space above the packer shall be filled with a non-corrosive, corrosion inhibited liquid.

4. The pressure or fluid level of the casing-tubing annulus shall be observed daily and recorded weekly, and any liquid volumes added to the annulus shall be recorded.

5. Volumes injected shall be measured and reported monthly to the Board using ERCB form S-18.

6. Bottom-hole pressure surveys, sufficient to estimate the static bottom-hole pressure, shall be performed on the well within one year from the date that injection is commenced and on an annual basis thereafter.

7. The maximum wellhead injection pressure shall not exceed 690 kilopascals (gauge).

8. Analysis of the injected fluid shall be done on a batch basis in accordance with appropriate Provincial regulations and requirements and submitted to Alberta Environment.

9. Chem-Security Ltd. shall submit to the Board an annual report which shall include

(a) a summary of monthly injection volumes,

(b) a fluid analysis representative of the annual injection volume,

(c) discussion of wellbore integrity, including the results of annular pressure or fluid level monitoring and packer integrity tests,

(d) interpretation of the results of the bottom-hole pressure surveys with respect to injectivity and reservoir storage capacity,

(e) discussion of the overall performance of the waste water disposal scheme, including any problems or modifications with respect to wellbore completion.

10. This approval, insofar as it pertains to matters of the environment, is subject to the approval of the Minister of the Environment, hereto attached as Appendix A, and to the terms and conditions therein contained.

11. The Board may at any time vary the terms and conditions hereof or may revoke or rescind this approval if, in its opinion, circumstances so warrant.

MADE at the City of Calgary, in the Province of Alberta, this 13th day of August, 1987.

ENERGY RESOURCES CONSERVATION BOARD

F. J. Mink

APPENDIX A TO APPROVAL NO. 5230

Department of the Environment

# MINISTERIAL APPROVAL

No. 87-12 ERCB

Edmonton, Alberta
July 24, 1987

WHEREAS the Energy Resources Conservation Board has advised that it is prepared to grant an application from Chem-Security Ltd., in a matter of a scheme for the disposal of process waste water produced in conjunction with the operation of the Swan Hills Special Waste Management Facility.

THEREFORE, pursuant to section 26 of the Oil and Gas Conservation Act, I Vance A. MacNichol, Deputy Minister of the Environment, hereby approve Application No. 861064, dated 2 September 1986, from Chem-Security Ltd. to the Energy Resources Conservation Board, insofar as the said application affects matters of the environment, subject to the following conditions:

1. Chem-Security Ltd. shall provide the capability to continuously determine the bottom hole pressure in the injection well.

2. A report, by a qualified hydrogeologist, discussing injection well performance and bottom hole pressure shall be submitted every x months.

DEPUTY MINISTER OF THE ENVIRONMENT

# DISPOSAL WELL OPERATION AND MONITORING

R. Cox, Energy Resources Conservation Board

## INTRODUCTION

The production of large volumes of fluids associated with various industrial processes or oilfield operations is a fact which cannot be ignored. The management of these fluids in a safe, effective, environmentally acceptable manner is a problem both industry and government are constantly dealing with. These fluids are either stored on surface, treated and returned to the surface watershed, or in more recent times, disposed to a subsurface geological formation.

Subsurface disposal of fluids is not new to Alberta. The first disposal occurred in the 1920s with the injection of produced water. A further development occurred in 1951 with the disposal of liquid process wastes (industrial) and finally in 1957, the first water injection for the purpose of pressure maintaining an oil pool for improved hydrocarbon recovery.

In 1989, there were some 4437 injection and disposal wells operating in the province of Alberta, and these wells injected a total of 224.4 x $10^6$ cubic metres of water and waste fluids. Of the 4437 wells, 90 are classified as industrial waste wells and are responsible for injecting approximately 9 per cent or 20 x $10^6$ cubic metres of the 1989 volume. A significant number of these wells are located in the Edmonton, Fort Saskatchewan and Redwater areas and are disposing into either the Nisku or Leduc Formations of the Upper Devonian System at a depth of approximately 1000 to 1300m from surface. (3200 to 4260 ft.).

This paper is intended to discuss some of the technical areas of review by the ERCB in processing waste disposal applications to ensure approval of a reasonable and technically sound scheme. Operation and monitoring requirements to ensure on-going performance will also be discussed.

## TECHNICAL REVIEW

All applications to the ERCB for subsurface disposal of produced or waste water are reviewed by technical staff prior to approval. ERCB review is intended to ensure adequate formation selection, competent wellbore completion, and safe injection pressures. Matters of waste suitability and groundwater protection are forwarded to Alberta Environment for review. The following is a summary of the ERCB technical review.

### Geologic Considerations

The prime objective in subsurface disposal operations is to ensure that fluids are injected into a reservoir or formation that is capable of containing, both initially and for the long term, the disposal fluids. This can be evaluated from the perspective of whether or not the proposed formation exhibits stratigraphic isolation, and by ensuring the formation offers sufficient pore volume capacity to meet the disposal requirements.

Stratigraphic isolation is considered adequate when it can be determined that layers of confining formation rock are located both above and below the disposal horizon. The ERCB therefore review the application and related geology to evaluate the presence and extent of overlying shales as caprock, and underlying shales as base rock.

With respect to disposal capacity, as the total compressibility of formation rock and fluid is low (in the order of 1.5 x $10^{-6}$ vol/vol/kpa), it is obvious that a substantial pore volume must be available to store significant volumes of fluid with an acceptable pressure increase. Regional geology is reviewed to evaluate potential formation disposal capacity. Rigorous analysis is not usually conducted, rather formation performance and capacity is evaluated on an ongoing basis based on actual disposal volume and static formation pressure data. An acceptable static formation pressure should not be based on formation fracture pressure, but rather on the ability of the formation to contain fluids under that pressure. The ERCB does not impose limitations on static formation pressures.

Wellbore Completion

The wellbore must be completed in a manner that ensures the waste fluid is isolated from all other formations, both on route to the intended formation and also after its arrival. It is imperative that migration of the waste fluids along the wellbore does not occur. Failure to contain the fluids in and along the wellbore means a failure of the disposal operation. Such a failure could more importantly give rise to potential pollution problems through contamination of groundwater or hydrocarbon producing horizons.

A typical disposal well is completed with a relatively shallow (200-300m) string of surface casing cemented to surface for well control. (A secondary purpose is thought to be for the protection of potable groundwaters, however, the ERCB considers the cement, rather than the casing, as the primary line of groundwater protection). This is followed by a longer production casing string set at the total depth of the well and cemented to above the highest potential hydrocarbon bearing formation. The production casing is then perforated opposite the desired formation, or where geological conditions permit, an open-hole completion across the zone of interest may be used.

The aforementioned completion would be typical of a well drilled specifically for the purpose of waste disposal. However, disposal wells are more often proposed as conversions of existing producing wells in which production casing may be cemented to a pre-determined depth. Production casing cement requirements are specified on the well license, in accordance with ERCB Guide G-9; Casing Cementing - Minimum Requirements. In cases where less than 180 metres of surface casing has been run, or casing is not set more than 25 metres below any usable water aquifer, the production casing must be cemented full length. It should be noted that determination of these requirements has been an evolutionary process such that existing wells may or may not meet these requirement at the time of proposed conversion to disposal.

Given this general completion scenario, wellbore integrity can be achieved through the following completion practices:

1. Tubing and Packer - Sections 6.101(1) and 6.120(1a) of the Oil and Gas Conservation Regulations (OGCR) requires all wells injecting fluids other than fresh water to be completed with a tubing and packer. Injection through a tubing string with a production packer protects the production casing from exposure to the disposal fluid and any significant pressures applied to achieve the desired injection rates. Protection of the production casing from corrosion is essential as the casing and associated exterior cement serve to isolate all uphole formations and ensure stability of the wellbore. Tubing corrosion, although undesirable, can be tolerated as the tubing can be pulled and repaired while casing, on the other hand, is cemented in place and can only be repaired with some difficulty. The packer should be placed as close as

practical to the top of the perforations to minimize the length of casing exposed to disposal fluid and ensure zonal isolation below the packer in the event of casing corrosion. Generally, all casing below the packer is treated by the ERCB as perforation, although actual re-perforation still requires ERCB review and approval. In situations where corrosive fluids are being injected, fibreglass tubing is sometimes used.

2. Inhibited Annulus - As an additional measure of protection, section 6.120(1b) of the OGCR also requires the tubing/casing annulus of disposal or injection wells (except those injecting fresh water) to be filled with a non-corrosive corrosion inhibited fluid. This protects both the exterior of the tubing and the interior of the casing from deterioration by corrosion, and the fluid in the annulus also serves as a medium through which casing or tubing leaks can be detected. A short interval of the annular space at and below surface should be filled with an inert gas or non-freezing inhibited fluid to protect against freezing.

3. Casing Integrity Logs - Logging of the well casing to establish the presence and extent of corrosion gives an indication of the general casing condition, in particular the wall thickness and potential trouble spots. This operation is particularly necessary when converting an old well to injection for disposal purposes, and can also be used for detecting or locating potential leaks. ERCB Informational Letter IL 84-12 requires casing integrity logs when converting a well of age greater than 5 years to disposal or injection.

4. Cement Integrity Logs - Cement logging of the wellbore gives an indication of the quality of the cement-to-casing bond and overall effectiveness of the cement with respect to hydraulic isolation. The function of the cement with respect to a disposal operation is to provide hydraulic isolation between porous zones, particularly between the disposal zones and adjacent formations. The mere presence of cement behind the casing may not be sufficient to provide hydraulic isolation and the logs must be interpreted carefully to ensure that vertical migration of the disposal fluid will not occur. For wells disposing at depths greater than 600m, IL 84-12 requires cement bond or cement evaluation logs across the disposal zone and the surface casing shoe where production casing is cemented full length, and across the disposal zone and cement top where production casing is not cemented full length. For wells injecting at depths of less than 600m, both cement bond and evaluation logs are required from total depth to 25 metres inside the surface casing. Waste disposal at this depth would not usually be approved.

A typical wellbore completion, in compliance with current regulations, is shown in Figure 1. The aforementioned requirements, specifically as outlined in IL 84-12 regarding casing and cement integrity logs, are currently under review by the ERCB. Proposed changes are discussed later in this paper.

It is important to note that adjacent wellbores could potentially jeopardize the safe and effective operation of a subsurface disposal scheme. Improperly abandoned or poorly cemented wellbores in communication with a disposal formation can allow for vertical migration of the disposal fluid. Consideration must therefore be given to the wellbore completion and subsequent integrity of adjacent wellbores. No specific policies or requirements for review exist at present, although this matter has been addressed in specific applications where it was believed warranted.

## Formation Fracture

To some extent, increased injectivity may be achieved by initiating and propagating fractures within the designated disposal zone. However, even with limited fracturing, there may be little to be gained if the proposed injection rates exceed the flow capacity of rock pores. Depending on cap and base rock qualities, potential exists for propagation of the fracture outside the disposal zone, thereby jeopardizing stratigraphic isolation and containment. Accordingly, the ERCB normally conditions all disposal approvals limiting injection pressures to somewhat below fracture pressure. In the absence of site specific fracture data, the ERCB uses a conservative fracture gradient based on statistical analysis of province-wide fracture data. Fracture pressures are determined for a well by this composite data such that there is a 90% probability that the formation will not fracture at that pressure. A further reduction to 90% ( if friction is included) or 95% (if friction is not included) is applied to the estimated fracture pressure (90% probability), from which an equivalent wellhead injection pressure is determined and specified on the approval. If the ERCB estimated fracture pressure, and resulting maximum wellhead injection pressure, prove too restrictive to the operator, opportunity exists for the operator to justify a higher pressure. Step-rate injectivity tests are generally conducted to determine the actual fracture pressure of the disposal zone at the well, or conversely to illustrate a pressure at which disposal can occur without initiating a fracture. In some instances, fracture pressure may be exceeded where formation thicknesses are large and rock characteristics are favourable, i.e. high quality cap and base rock and some indication of effective barriers to fracture propagation. Disposal above fracture pressure must certainly be considered an exception.

## OPERATION AND MONITORING REQUIREMENTS

Given a properly completed wellbore as described in the previous section, and assuming a competent and suitable disposal formation, the disposal well should initially perform safely and efficiently. However, the components of a wellbore completion are susceptible to mechanical failure, whether through equipment design failures, manufacturing faults, or time-related aspects such as corrosion. A system of monitoring must therefore be implemented to ensure continued wellbore integrity. With respect to pollution control, failures in the subsurface environment hold the largest potential for going undetected for any appreciable length of time as surface failures should easily be detected visually. The emphasis here will therefore be placed on monitoring for subsurface system failures.

## Failure Analysis

Subsurface failure of a disposal operation may result from any one of a number of possible failure modes. The consequences of a failure in relation to environmental pollution are variable.

Assume for the time being that hydraulic isolation is provided to the wellbore by the cement outside the casing and that formation integrity exists. From the required wellbore completion as shown in Figure 1, it is apparent that the potential for a sudden or catastrophic failure of the subsurface system is low as it would require simultaneous failure of two or more components of the completion. That is, failure of a single component such as tubing, casing, or packer would not result in environmental pollution as in all cases, a second line of defense exists.

For the purpose of this discussion, this type of failure would be termed of "secondary consequence" due to the backup protection. A failure of "primary consequence", by contrast, would be one in which no backup protection exists. With respect to the required wellbore completion, the following summarizes the possible failure modes and associated consequences.

| Failure Mode | Consequence | Backup Protection |
|---|---|---|
| Surface | Primary | None |
| Tubing | Secondary | Casing/Cement |
| Packer | Secondary | Casing/Cement |
| Casing | Secondary | Requires tubing or packer failure |
| Cement | Primary | None |
| Formation (integrity) | Primary | None |
| Formation (fracture) | Primary | None |

Note that this analysis is meant to address only the consequences of a failure and does not address the effectiveness of monitoring or detection. Figure 2 illustrates the possible failure modes and backup protection.

Monitoring Parameters

Monitoring and surveillance procedures should be applied to waste disposal schemes that are consistent with both the nature and the sensitivity of the scheme in general. For instance, high pressure injection of a toxic fluid should command more attention than a well disposing of near-potable water at very low pressure or even vacuum conditions. With the aforementioned in mind, monitoring of the following parameters may be required in an ERCB approval for produced water or waste disposal.

1. Disposal Volume - Section 14.200 of the OGCR requires continuous measurement of all fluids injected through a well to an underground formation. This allows for evaluation of reservoir disposal capacity and waste front migration. When considered as an injection rate it can also be used as an indicator, in conjunction with injection pressure, of well integrity. Any changes in the injectivity may indicate wellbore or formation integrity problems.

2. Tubing Injection Pressure - The tubing pressure is a measure of the resistance of the formation and system to accept the disposal volumes. As such, it is an indicator of injectivity problems, component failure, or reservoir failure when compared to corresponding disposal rates. Generally speaking, a sudden drop in the injection pressure with all other factors being equal (particularly disposal rates) is an indication that a combined casing and packer/tubing failure, or reservoir fracture has occurred. Conversely an increase in tubing pressure at constant injection rates alludes to formation plugging or reservoir fillup, and can therefore be used as an indicator of potential problems. All new disposal wells, waste or produced water, are subject to a maximum wellhead injection pressure to avoid formation fracture. Waste disposal wells may also require some continuing monitoring of tubing injection pressure as a condition of the disposal approval.

3. <u>Casing-Tubing Annular Pressure</u> - Monitoring the pressure of the liquid in the casing-tubing annular space provides an indication of tubing, packer, or casing integrity. Changes in the annular pressure, other than those expected due to tubing expansion and contraction, are indications of possible failure of either of these components. The specific response is dependent on the nature of the fluid gradients and injection pressures and the corresponding pressure contrasts at the point of failure. Monitoring the fluid level in the annular space is a common alternative to pressure measurements. Annular pressure or fluid level monitoring is often required for waste disposal wells as a condition of the disposal approval.

   In addition to monitoring this parameter under normal operating conditions, a test of packer and tubing/casing annular integrity is required at lease annually by Section 6.120(2) of the OGCR by applying an external pressure to the annulus. A negative test does not always identify the component that has failed, but rather that one of the components (casing, tubing, packer) has failed.

4. <u>Static Formation Pressure</u> - Regular bottomhole static pressure surveys along with the pressure falloff behaviour allows for analysis of reservoir performance, particularly with respect to formation quality or damage and future reservoir disposal capacity. In large-volume schemes and those of significant sensitivity, annual bottomhole pressure surveys may be required as a condition of the ERCB approval. They are not required for all schemes.

In drawing meaningful conclusions from the results of a monitoring program, the program must be designed and information must be interpreted with due consideration of the nature of the operation. Situations such as intermittent or batch injections or disposal under vacuum conditions would require modifications to monitoring procedures and subsequent interpretation of data. For instance, batch disposal operations may negate the reliability of tubing pressure measurements as a sudden reduction in tubing pressure could signify the end of a batch injection rather than a tubing/packer/formation failure. All pertinent information must therefore be considered in both program design and data interpretation.

The frequency of monitoring should be consistent with the nature of the fluids injected or the consequences of a failure. Generally speaking the back-up feature of the required completion negates the need for state-of-the-art continuous monitoring, and indicates that frequent monitoring of these parameters would suffice. Given the fact that industrial waste disposal wells are typically located within the confines of a plant or refinery and are easily assessable to operators, daily observation and weekly recording of both tubing and annular pressures in these wells are generally considered adequate. In situations where injection near the formation fracture pressure is necessary, more frequent monitoring of tubing pressures and disposal rates would be required. In special cases of high pressure injection of toxic fluids, consideration would be given to continuous pressure monitoring with a surface high pressure alarm shutoff. Low pressure alarms may also be warranted to protect against surface leaks due to surface equipment failure.

Formation failure can be considerably more difficult to detect, and generally requires analysis of injectivity and bottomhole pressure data. Regarding formation fracturing, monitoring of tubing pressures and injectivity can be used as an indicator, as fracturing requires a steadily building pressure to initiate the fracture followed by a sudden reduction in pressure (increased injectivity) while the fracture propagates. Formation failures are often evidenced only through the presence of the disposal fluids in adjacent formations. Such failures can be avoided by injecting at a pressure well below the fracture pressure. However, if it is necessary to approach the fracture pressure then appropriate monitoring of injectivity must be performed.

The previous discussion has assumed that cement integrity is such that hydraulic isolation will not allow vertical migration of disposal fluids beyond the injection interval. In absence of hydraulic isolation and depending on the injection pressure vs. the resident wellbore gradients, vertical migration could go undetected for a significant length of time. Unfortunately, as with a suspected formation failure, monitoring of this problem is difficult and generally the failure may not be discovered until some measure of damage has already been done. Accordingly, this reinforces the need for prudent cementing practices and conscientious evaluation of hydraulic isolation.

Upon observation of a possible subsurface failure, a number of techniques can be employed to verify and locate the failures. They are summarized as follows:

| | | | |
|---|---|---|---|
| 1 | Tubing Failure | - | visual detection by pulling and inspecting the tubing string |
| | | - | tubing inspection logs |
| | | - | pressure testing for tubing integrity using wireline tubing plugs |
| 2 | Packer Failure | - | packer isolation pressure test |
| 3 | Casing Failure | - | casing inspection logs |
| | | - | pressure testing |
| | | - | leak or flow detection logs |
| 4 | Cement Integrity | - | cement logs |
| | | - | radioactive tracer logs |
| | | - | temperature surveys |

A complete summary of disposal well failure modes, consequences, and monitoring parameters is given in Table 1.

Annual Reports

To ensure on-going integrity of disposal operations, waste disposal operators may be required, as a condition of the disposal approval, to submit annual reports on the progress and efficiency of the scheme. Again, the need for and content of annual reports is consistent with the nature of the scheme. Annual reports may include the following information:

- a summary of monthly injection volumes,
- a fluid analysis representative of the annual injection volume,
- a discussion of wellbore integrity, including the results of annular pressure or fluid level monitoring and packer integrity tests,
- an interpretation of the results of the bottom-hole pressure surveys and injection pressure monitoring with respect to injectivity and formation storage capacity, and

- a discussion of the overall performance of the waste disposal scheme, including any problems or modifications with respect to wellbore completion.

## PERFORMANCE

The ERCB has in the past denied some applications for subsurface disposal based on some of the items addressed in this paper. It also has seen numerous instances in which wells have failed to maintain injectivity due to formation plugging or poor formation choice. In the Board's experience with administering subsurface disposal wells, there have been relatively few instances of formation or wellbore failure that have resulted in communication with formation other than the intended disposal zone or escape of fluids to surface. There have been no major failures in terms of large volume releases. Monitoring programs have been generally successful in detecting tubing, packer, or casing failures or corrosion in time to take remedial action before significant damage is done.

## FUTURE CONSIDERATIONS

From Table 1 it can be seen that further evaluation of some primary consequence failures may be appropriate, specifically in the areas of hydraulic isolation and formation integrity. The ERCB is satisfied with its technical review and monitoring requirements of other failure modes.

With respect to hydraulic isolation, the ERCB is in the process of revising IL 84-12 to move away from inferential techniques such as cement bond or evaluation logs towards a direct measurement of flow behind casing such as radioactive tracers and temperature surveys or suitable alternatives. Cement logs would therefore become an option rather than a requirement, although circumstances may well warrant cement logging as the preferred diagnostic tool when isolation of uphole zones behind casing are a concern.

A summary of the proposed requirements, to replace IL 84-12, are as follows:

<u>Cement and Casing</u>

- All useable water bearing zones shall be isolated with the appropriate combination of surface or intermediate casing and cement which extends from a minimum of 25 metres below the lowest useable water zone to surface.

- All potential hydrocarbon bearing zones, including the injection or disposal zone shall be isolated.

<u>Logging</u>

- If the production casing is not cemented to surface or cement returns to surface are not obtained, then the cement top locating log shall be run.

- Radioactive tracer survey or other approved method shall be utilized to confirm hydraulic isolation of the injection or disposal zone and the results of the test submitted to the ERCB for approval prior to commencement of regular injection/disposal operations.

- Full length casing inspection log shall be run on any existing well being converted to injection or disposal service and the log submitted to the ERCB for review and approval prior to commencement of regular injection/disposal operations.

Other Tests and Submission Requirements

- Initial pressure test of the casing of tubing/casing annulus shall be conducted.
- All logs will be submitted with a detailed interpretation by the service company or operator.
- Monitoring program of the tubing/casing annulus pressure, or injection pressure vs. injection flow rate in wells without a packer must be submitted with the application for injection or disposal and records retained for 1 year.
- Casing integrity program must be submitted with the application for injection or disposal.

With respect to formation integrity, the ERCB is considering the need for policy regarding maximum formation pressures as they relate to ensuring cap and base rock integrity. Potential exists for a limit to be set on static bottomhole pressure in relation to the confining threshold pressure. Note that this is a cautionary consideration, and no evidence of problems has been seen.

## CONCLUSION

The ERCB believes that subsurface waste disposal through deep wells is a safe and responsible option where wellbore and formation integrity, both initially and on an ongoing basis, can be achieved. In Alberta, this is achieved through initial technical review of the proposed disposal scheme, conditioning disposal approvals respecting specific operating parameters, and imposing requirements for ongoing monitoring consistent with the nature of the operation.

TABLE 1 - DISPOSAL WELL FAILURE MODES ; SUMMARY

| MODE | CONSEQUENCE | BACKUP PROTECTION | REVIEW PRECAUTIONS | MONITORING REQUIREMENTS | DETECTION TECHNIQUES |
|---|---|---|---|---|---|
| Surface | Primary | None | • None | • None | • Visual |
| Tubing | Secondary | Casing/Cement | • Tubing selection*<br>• Annular fluid (inhibited) for external corrosion | • Annular fluid pressure or level* | • Increase or decrease of annular fluid pressure or level<br>• Pressure tests<br>• Logs<br>• Visual inspection |
| Packer | Secondary | Casing/Cement | • Setting depth | • Annular fluid pressure or level*<br>• Packer isolation tests | • Packer isolation test |
| Casing | Secondary | Requires tubing or packer leak | • Annular fluid (inhibited) for internal corrosion<br>• Cement for external corrosion<br>• Casing integrity logs (baseline)<br>• Pressure tests | • Annular fluid pressure or level*<br>• Periodic logs*<br>• Periodic pressure tests | • Logs<br>• Pressure tests |
| Cement | Primary | None | • Cementing requirements<br>• Cement logs (initial)<br>• Tracer/temperature surveys | • Tracer/temp. surveys* | • Cement logs<br>• Tracer/temperature surveys<br>• Charging of adjacent formations<br>• Vent blows |
| Formation (integrity) | Primary | None | • Geologic selection<br>• Formation pressure limitation* | • Static formation pressure* | • Charging of adjacent zones |
| Formation (fracture) | Primary | None | • Fracture pressure analysis<br>• Injection pressure limitations<br>• Analysis of cap/base rock integrity* | • Injectivity<br>• Injection pressure | • Increased injectivity<br>• Excessive injection pressures<br>• Charging of adjacent zones |

* Indicates review items or monitoring requirements that may be applied in certain circumstances, but are not considered "typical".

# DISPOSAL WELL SCHEMATIC

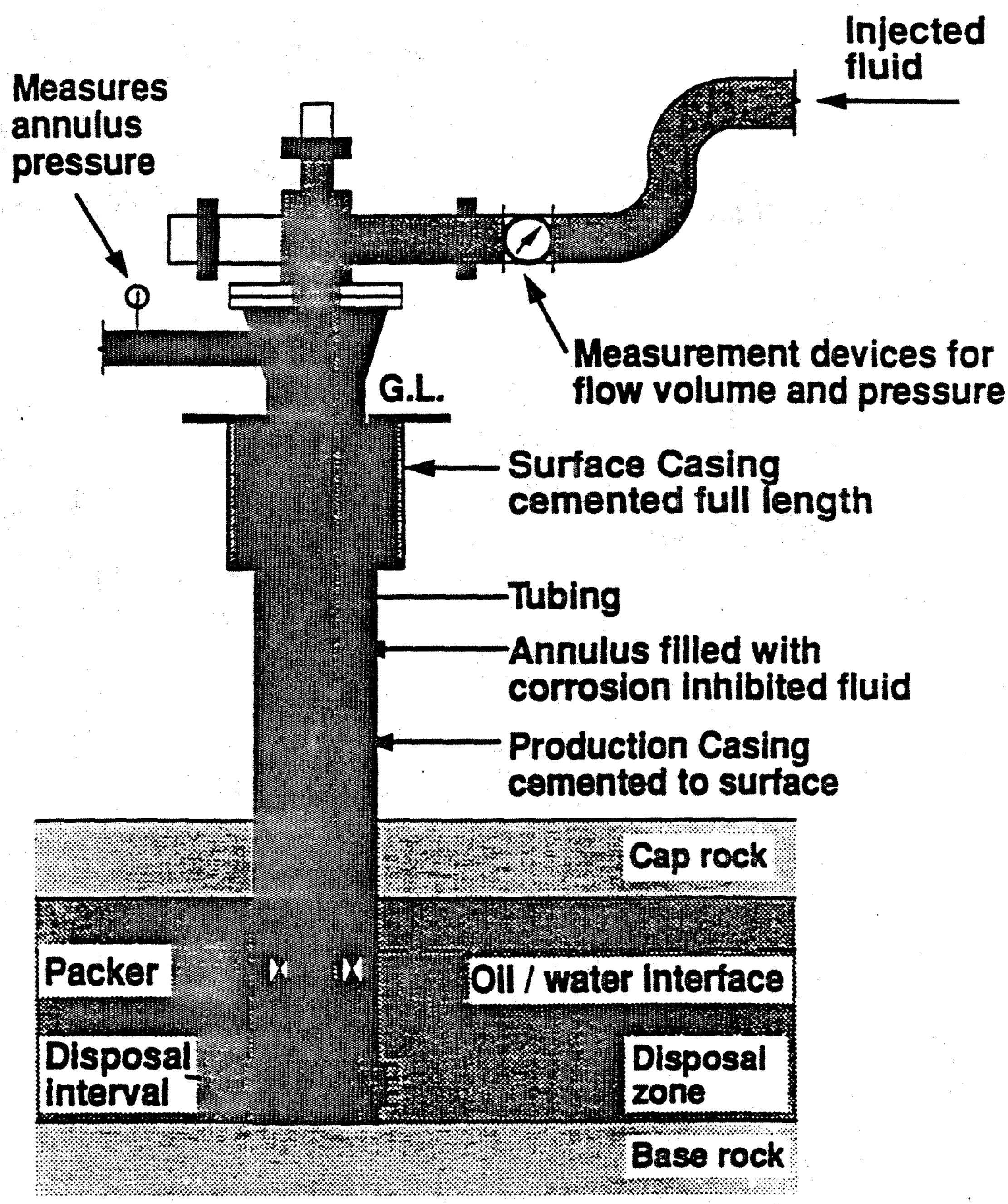



FIGURE 1

# FAILURES MODES ANALYSIS

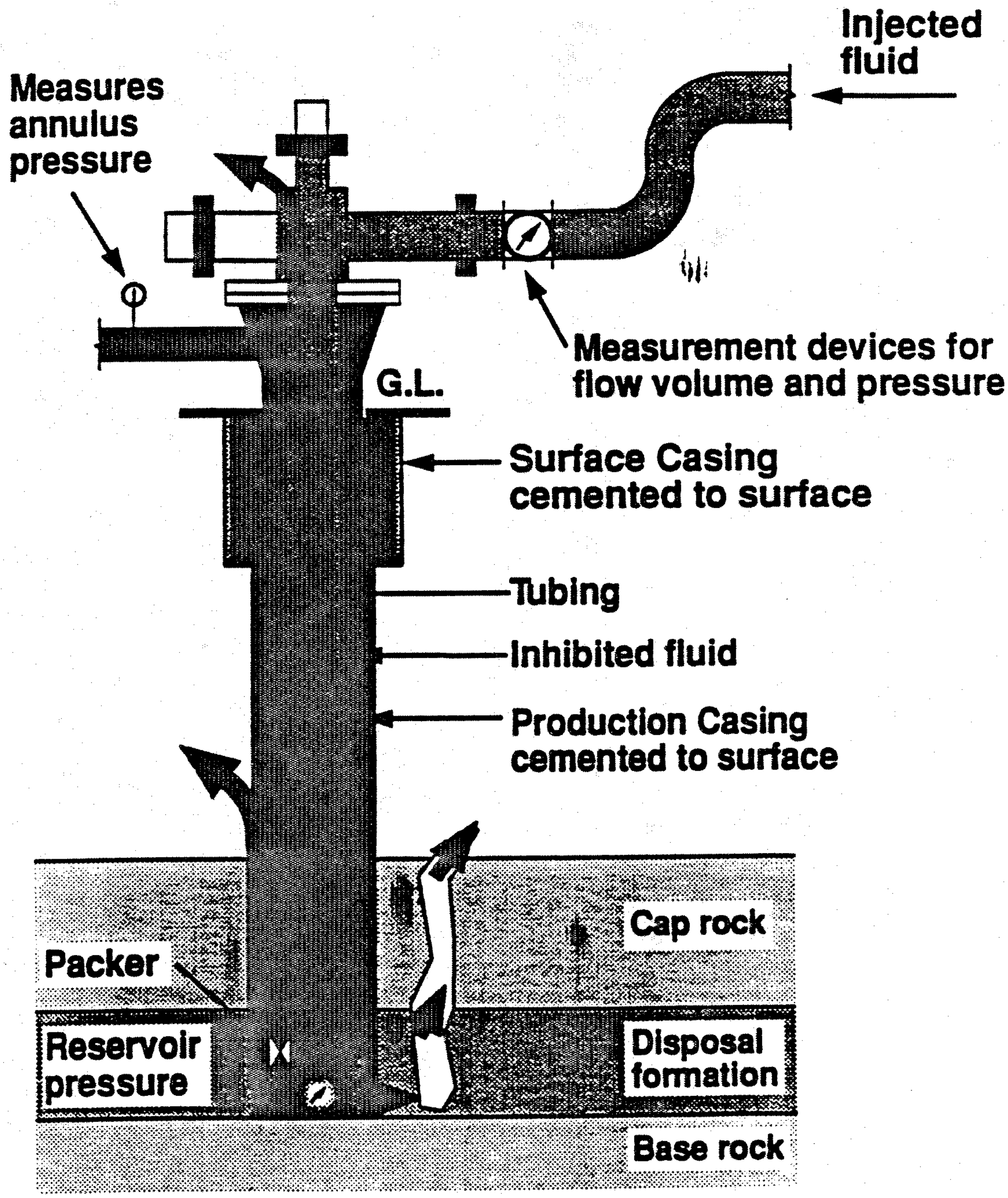



FIGURE 2

# REFINERIES - DEEP WELL DISPOSAL SYSTEMS

(BY PAUL KNETTIG, ESSO PETROLEUM CANADA)

- REFINERIES RELY ON DEEP WELL DISPOSAL (EDMONTON/FORT SASKATCHEWAN AREA)

- CONTINGENCIES IN PLACE TO MINIMIZE IMPACT IF THE D.W.D.S. WOULD BE UNAVAILABLE

- D.W.D.S. IS MONITORED 24 HR/DAY. NO CHANCE FOR UNDETECTED LEAKAGE (SURFACE OR CASING)

  A. PLANT SITE:
  - EXTREMELY HIGH SECURITY
  - CONTAINMENT/TREATMENT OF RUN OFF LIQUIDS
  - MANY WAYS TO REDUCE/MINIMIZE WATER PRODUCTION
  - USE OF SPARE/SECOND WELL
  - 24 HOUR WELL SERVICING SYSTEM AVAILABLE

  B. HARDWARE DESCRIPTION
  - COLLECTION/OIL SEPARATION TANKS
  - FLOW CONTROL
  - PRESSURE/VACUUM MEASUREMENT
  - ANNULUS FLUID MONITORING
  - BOTTOM HOLE PRESSURE TESTING

  C. REPORTING: (MONTHLY AND YEARLY)
  - TO ERCB (VOLUME & ANY OPERATING DIFFICULTIES)
  - TO ALBERTA ENVIRONMENT (VOLUME AND SOME BASIC WATER QUALITY PARAMETERS)

  D. 1987-88 ERCB - INDUSTRY TASKFORCE ACCOMPLISHED:
  - INJECTION SYSTEMS REVIEWED
  - INITIATION OF JOINT ANNUAL REPORTING (ISOLATION OF ANNULAR SPACE, BOTTOM HOLE TEST, CHANGES TO INJECTION SYSTEM, FLOW METER CALIBRATION)
  - ALL LICENCES REISSUED-UPDATED (SIGNED JOINTLY BY ERCB AND ALBERTA ENVIRONMENT)

- CURRENT REPORTING AND MONITORING SYSTEM IS SOUND AND PROVIDES EXCELLENT PROTECTION AND EARLY WARNING

MEMO01.PK

## REFINERY DEEP WELL INJECTION SYSTEM

SLIDE SEQUENCE:

#1-3 A MODERN REFINERY IS A VERY SOPHISTICATED PLANT

#4-5 ALL SURFACE WATER MUST BE TREATED PRIOR TO RELEASE

#6-9 DEEP WELL (GENERAL LAYOUT AND CLOSE UP)

#10 COLLECTION SYSTEM OF INJECTED WATER

#11 WATER SAMPLING SYSTEM

#12 A FLOWMETER

#13 FLOW CONTROL VALVE

#14-15 VACUUM/PRESSURE GAUGES

#16-19 REFINERY CONTROL ROOM IS MANED 24 HOURS/DAY

#20 ANNULAR SPACE INTEGRITY TEST

#21-22 BOTTOM HOLE TESTING RIG

DEEP WELL DISPOSAL WORKSHOP

ERCB - WELL ABANDONMENT PROCEDURES

ALBERTA RESEARCH COUNCIL - EDMONTON

NOVEMBER 5-7, 1990

Brian McFarlane

Providing a well has production casing set and cemented in place, the same abandonment considerations apply regardless of the well history. By this I mean, the well may have previously been a producer, a well that failed to produce, a waste water disposal well or whatever. In each case, the abandonment applications are reviewed on an individual basis to determine the best procedure for the particular well.

Considerations that apply are:

- Casing integrity,
- Cement top,
- Depth(s) of useable water,
- Depth of up-hole hydrocarbon bearing zones,
- Whether there is a flow of liquid or gas from the surface casing vent.

Guidelines that we follow on cased-hole abandonments are:

- Perforations or open-hole completion must be isolated. This can be accomplished with a bridge plug, packer with plug in place, cement plug, or cement squeeze.

- Bridge plugs or other mechanical isolation tools must be set within 15 metres of the perforations (or as close as is practical).

- Mechanical isolation tools (bridge plugs or packers) must be pressure tested to a minimum of 7000 kPa or a pressure sufficient to obtain a differential below the bridge plug or packer for 10 minutes and then capped with 8 linear meters of cement. A wireline dump bailer may be used to set the cement cap.

- Cement plugs across perforations or in open-hole sections must be felt with tubing or drill pipe after waiting 8 hours. The casing must then be pressure tested to minimum of 7000 kPa for 10 minutes prior to cutting and capping at surface.

- The casing must then be circulated to a corrosion-inhibited fluid. Weighted inhibitors may be used if the well does not have tubing.

- Where the intermediate or production casing is not cemented to surface the casing must be perforated at least 15 metres below the deepest useable water aquifer and re-cemented to surface or cement squeezed prior to completing the surface abandonment.

- Surface abandonment shall consist of cutting the casing strings off a minimum of 1 metre below ground level. The production or intermediate casing shall be plugged at the top with 5 sacks of cement and the surface casing shall be capped with a welded steel plate section 3.070.

- Surface casing vent flows must be shut off at their point of origin prior to the final surface abandonment. Proposed remedial programs to shut off vent flows require Board approval.

Attached are schematics showing an water disposal well Pam Am A2 Gilwood In 9-9-73-18W5 that was recently abandoned.

**Attachment I**

Shows the wellbore completion when in the disposal phase.

**Attachment II**

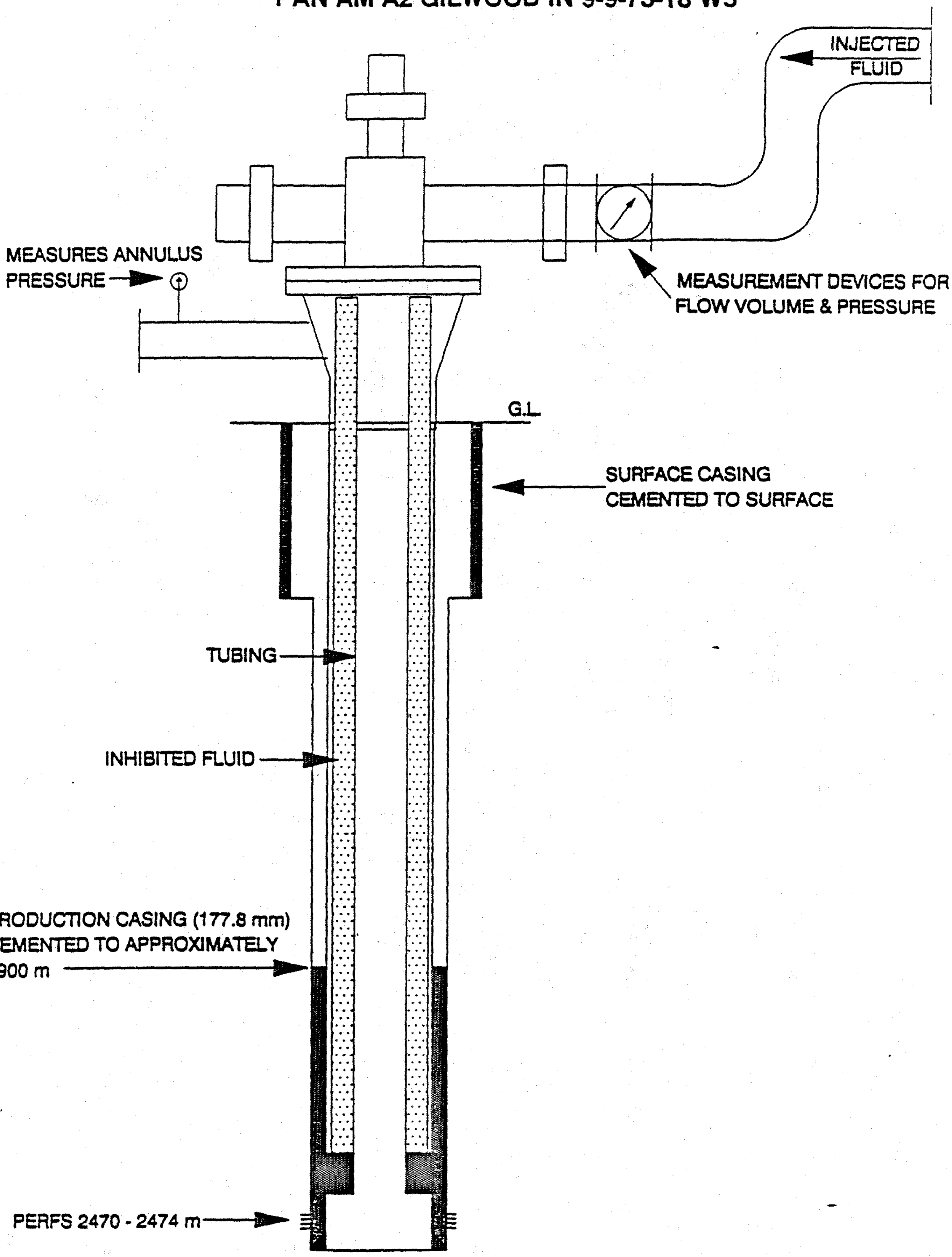
Show the abandonment application, our changes and subsequent approval.

**Attachment III**

Shows the wellbore, as abandoned.

This is the well that I discussed during my talk.

# PAN AM A2 GILWOOD IN 9-9-73-18 W5




WELLBORE COMPLETION

See Instructions on rever[se]

**ERCB** Energy Resources Conservation Board
640 Fifth Avenue SW
Calgary, Alberta T2P 3G4

☐ APPLICATION TO: ☒ APPROVAL TO: ☐ ABANDON A WELL ☐ ABANDON A ZONE ☐ PLUG BACK A WELL ☐ RE-ENTER A WELL ☐ RESUME DRILLING ☐ SUSPEND DRILLING ☐ TEMPORARILY ABANDON A ZONE ☐

| Well Name | Unique Well Identifier | Licence Number | ERCB Area Office | Company Representative | Phone |
|---|---|---|---|---|---|
| PAN AM A2 Gilwood IN 9-9-73-18 | 0[redacted] 09 [redacted] 073 18 W5 0 | [redacted] | Grande Prairie | R.R. Macpherson | 264-3635 |

| Log Markers | Depth (m) | Porous or Perf. Intervals (m) |
|---|---|---|
| ~~Lea Park~~ | ~~219.5~~ | |
| ~~Cardium~~ | ~~395.3~~ | |
| B.F.S. | 660.8 | |
| Viking | 721.8 | |
| Joli Fou | 741.3 | |
| ~~Mannville~~ | ~~781.4~~ | |
| ~~Glauconite SS~~ | ~~1053.7~~ | |
| Fernie | 1087.5 | |
| Paleozoic | 1160.7 | |
| Mississippian | 1191.2 | |
| ~~Wabamun~~ Beaver Hill | ~~1700.2~~ | |
| ~~Lake~~ | ~~2351.0~~ | |
| Slave Point | 2448.5 | |
| Gilwood | 2468.3 | 2469.8-2473.8 |
| Muskeg | 2480.8 | |

OPERATOR CONFIRMED NO USEABLE WATER AQUIFER BELOW SURFACE CASING

* DISPLACE WELL TO MINIMIZE FRESH WATER.

PRIOR TO SURFACE ABANDONMENT FILING NO VENT FLOW EXISTS

| Data | Depth (m) | Casing Size (mm) | Hole Size (mm) |
|---|---|---|---|
| KB 673.0 | | | |
| Casing SFC | 191.4 | 273.0 | 339.7 |
| Inter | | | |
| Prod | 2487.5 | 177.8 | 222 |
| Total Depth | 2487.5 | PBTD | 2475 |

**Program of Operations**

1. * Set bridge plug @ 2460 m.
2. Pressure test plug to 7000 kPa. FOR 15 MINS
3. ~~Dump 8 linear metres of~~
~~cement on plug.~~
4. ~~[illegible]~~ ~~[illegible]~~. THIS ... NOT ALLOWED
5. ~~Cut casing 1 metre below~~ ~~ground level.~~
6. ~~Plug production casing with~~ ~~1 sack of cement.~~
7. ~~Weld steel plate over surface~~ ~~casing.~~

**ERCB Authorized Abandonment Program**

Plug No. ____ May be Staged and ____ Stage Felt

| Cement Plug | Interval (m) | | Felt After 8 hours |
|---|---|---|---|
| 1 | ____ To | ____ | |
| 2 | ____ To | ____ | |
| 3 | ____ To | ____ | |
| 4 | ____ To | ____ | |
| 5 | ____ To | ____ | |
| 6 | ____ To | ____ | |
| 7 | ____ To | ____ | |
| 8 | ____ To | ____ | |

Conditions for this program as described on the reverse side are as follows:
No.(s) CONDITIONS 1,3,7,8
NOT ALLOWED

**Program Authorization**

On YR MO DY 90 02 15
By A.J. (Jim) [illegible] Name (Typed)
[signature] Signature
[illegible] Office

**Program Approval**

On YR MO DY
By ____

**Summary Report of Abandonment Program Followed**

| Volume of Cement and Additives | Bottom of Pipe Set at (m) | Plug Felt – (If logged, attach logs) Depth (m) | Mass (daN) | Date | T[ime] |
|---|---|---|---|---|---|
| | | | | | |

Was either condition 2 or 3 (described on reverse side) completed? ☐ Yes ☐ No

**Reason for Abandonment**

☐ It is no longer commercially productive of oil or gas.
☐ Testing and logging failed to disclose evidence of commercially recovera[ble] hydrocarbons.
☐ It was necessary to abandon for safety or mechanical reasons.

**Certification**

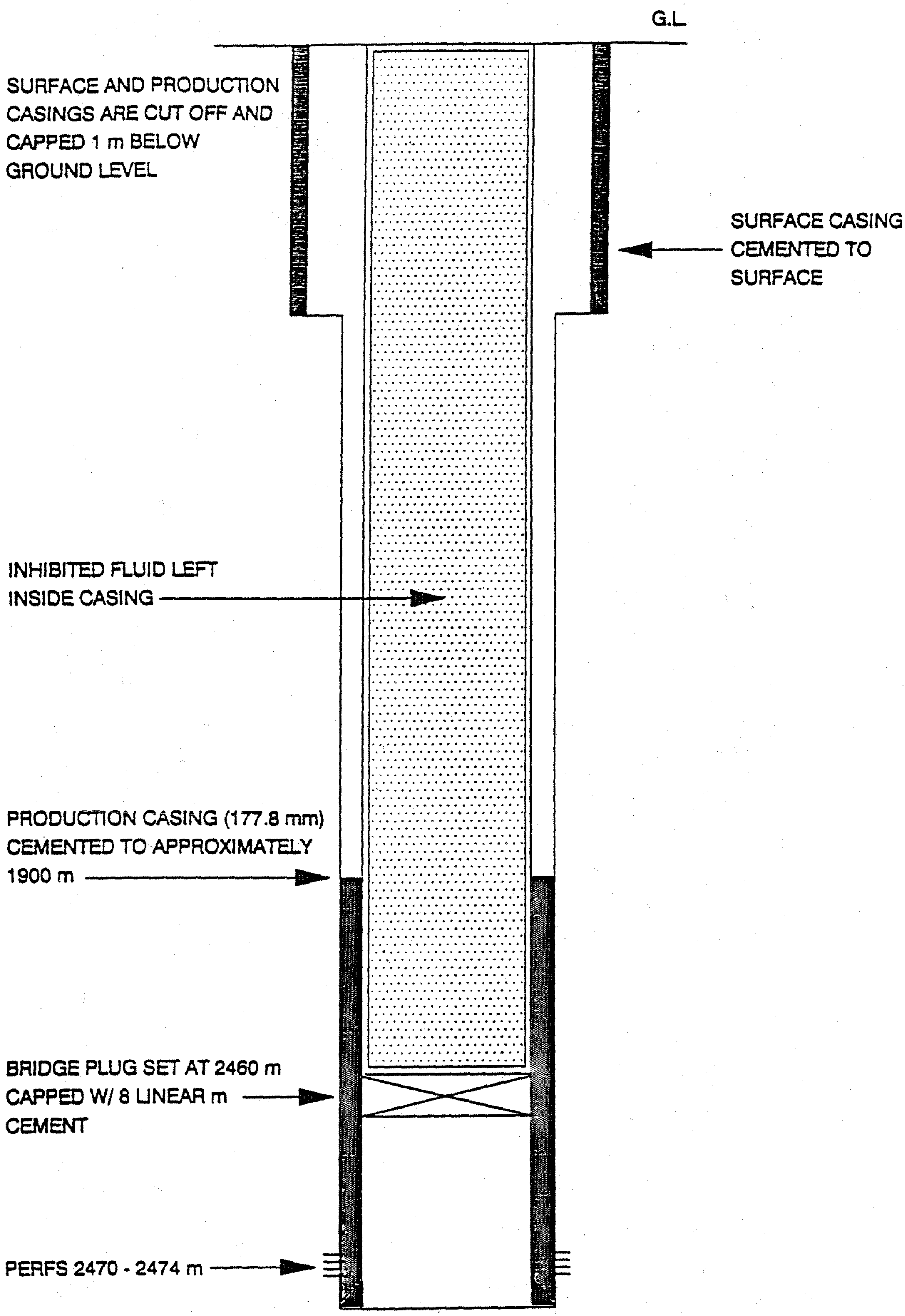
☐ The Licensee (Agent) hereby certifies that the abandonment was carried out for the reason(s) indicated and in accordance with the program authorized by the ERCB as shown in the summary report.
☒ The Licensee (Agent) hereby certifies that the program of operations wil[l be] carried out for the reason(s) indicated.

Signature [signature] Vice President
Company ~~Sargico Engineering (1977) Ltd.~~ February 12, 199[0]
630 - 6th Ave S.W.
Calgary T2P 0S8

ED 21 83 06

154

# PAN AM A2 GILWOOD IN 9-9-73-18 W5




ABANDONMENT

DEEPWELL DISPOSAL SEMINAR/WORKSHOP PARTICIPANTS

| | |
|---|---|
| **Ahlstrom**, Mr. Ralph<br>Celanese Canada Inc. | W 471-0323 |
| **Appleby**, Mr. Don<br>Community Advisory Committee | W 594-2770 |
| **Axford**, Mr. David<br>CIL Fort Saskatchewan Inc. | W 998-2225 |
| **Bachu**, Mr Stefan<br>Alberta Research Council | W 438-7601 |
| **Barker**, Mr. Bob<br>Pembina Oil Separators | W 542-4733 |
| **Barrie**, Mr. Denzil<br>Petro Canada Products | W 464-8610 |
| **Bartmann**, Mr. Gary<br>BP Resources Canada Ltd. | W 237-1234 |
| **Benoit**, Mr. Jacques<br>Mobil Oil | W 260-7910 |
| **Betts**, Mr. Wayne<br>Newalta Corporation | W 266-6556 |
| **Bietz**, Mr. Brian<br>E.R.C.B. | W 297-8311 |
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| **Cox**, Mr. Rob<br>E.R.C.B. | W 297-8311 |
| **Croft**, Mr. Brian<br>Amoco Canada Pet. Co. | W 233-1313 |
| **Crumbs**, Mr. Kevin<br>Home Oil Ltd. | W 232-7100 |
| **Cusack**, Mr. Kevin<br>Gulf Canada Resources Ltd. | W 233-4000 |
| **Dal Molin**, Mr. Louis<br>Turbo Resources Ltd. | W 294-6400 |
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| **Feick**, Mr. Bob<br>I.P.A.C. | W 290-1530 |
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| **Fernandes**, Mr. Tony<br>Alberta Environment | W 427-5855 |
| **Fletcher**, Mr. Tom<br>B.F. Goodrich Co. Inc. | W 998-8796 |
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| **Hammond**, Mr. Brian<br>Alberta Environment | W 427-6182 |
| **Heffler**, Mr. Howard<br>Norcen Energy Res. Ltd. | W 231-0111 |
| **Hittel**, Mr. Harvey<br>Alberta Energy Company Ltd. | W 266-8111 |
| **Hrudey**, Mr Steve<br>University of Alberta | W 492-6807 |
| **Hugo**, Mr. Ken<br>Esso Resources Canada Ltd. | W 237 - 3737 |
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| **Johnson**, Kim<br>Shell Canada Ltd. | W 691-3111 |
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| **Knettig**, Mr. Paul<br>Esso Petroleum Canada Ltd. | W 449-8247 |

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| **McCoy**, Mr Dave<br>Husky | W 298-6141 |
| **McFarlane**, Mr. Brian<br>E.R.C.B. | W 297-8311 |
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| **Worbets, Mr. Barry**<br>Husky Oil Ltd. | W 298-6111 |
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