A STUDY FOR THE IMPROVEMENT OF THE AUTOMATED CHEMICAL EQUIPMENT USED FOR THE QUANTITATIVE DETERMINATION OF FLUORIDE AT THE ALCAN INGOT SEBREE PLANT

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ABSTRACT

Mora, Ana E. M.S.I.M., University of Southern Indiana, May, 2002.
A study for the improvement of the automated chemical equipment used for the quantitative determination of fluoride at the Alcan Ingot Sebree plant. Major Professor: Dr. David E. Schultz.

This problem was defined starting with an evaluation of the present automated method for fluoride determinations at the Alcan Ingot Sebree plant. After evaluation, the problem was recognized as the need for process upgrade or process improvement.

Several possible alternatives were discussed and only three analyzed. An economic evaluation of the alternatives selected was performed and the decision was made based on different economic criterions. The economic criterions utilized were the cash analysis by present worth, the cash analysis by uniform annual cost, sensitivity analysis, the payback period, and incremental analysis. The final decision made was to purchase a sampler upgrade to improve the current process. The project activities were also studied using project management tools and the conclusions were that Alcan could finalize this project within this calendar year.

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1. INTRODUCTION

1.1 Purpose of the Project and Explanation of the Problem

The purpose of this project is to study different alternatives for the improvement of the current determination of fluoride by the Alcan Ingot Sebree plant.

Cassette samples are taken by the Environmental Group and analyzed by the Alcan Ingot Sebree Laboratory. A cassette is a special arrangement of plastic filter holders and filters utilized in the sampling procedure of fluorides; see Figure 1.1. A more detailed explanation of the cassettes will be covered in Section 3 of this paper.

Figure 1.1. Sample Cassettes. SKC. Coated Filters in Preloaded Cassettes. 18 February 2002 <http://www.skcinc.com /prod/Cfilters.html>. (1).

These samples are analyzed for total fluorides which is the sum of the values of gaseous and particulate fluoride. Explanation of gaseous and particulate fluorides is covered in Section 2 of this paper. The cassette method became the official sampling method for aluminum smelters in 1999 and is commonly known as the Alcan Cassette Method. This method is the United States Environmental Protection Agency (USEPA) Method 14A (40 CFR 60, Appendix A, amended October 7, 1997) Method 14A -

Determination of Total Fluoride Emissions from Selected Sources at Primary Aluminum Production Facilities.[1.1] This method can be found in Appendix A of this paper.

These samples are analyzed at the laboratory and the results are reported back to the Environmental Group who finalizes the final calculations in pounds of total fluoride per ton of aluminum produced. The Environmental Group is also responsible for reporting the final numbers to the federal and state agencies. The laboratory is only responsible for determining concentration in total micrograms of fluoride. The legal permissible limit for fluoride emissions is 1.9 pounds of fluoride per ton of aluminum produced per month per potline. Alcan Ingot Sebree has three potlines where the aluminum is produced and 8 cassettes are utilized to sample each potline. The term potline is explained in Section 2 of this paper. One of the potlines was shut down in 1994 due to a worldwide glut of aluminum inventory and was re-opened in 2001. There are 2 sampling periods per month. The total number of cassettes analyzed per sampling period is 24. The first sampling period, which requires a 48-hour sampling time, occurs the first 15 days of the month. The second sampling period, which requires a 24-hour sampling time, occurs the second half of the month and after the 15th day. The number of days between the two sampling periods cannot be less than 6 days. All of these sampling conditions have been established by the regulatory agencies.

There are several methods outlined in USEPA Method 14A for the analysis of fluoride. One of the most common is the manual fluoride electrode method, which will be explained in Section 3 of this paper. Alcan Ingot Sebree utilized this method until 1998 when a new completely automated instrument was purchased. This instrument is

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[1.1] Appendix A to Part 60 –Test Methods. Method 14A – Determination of Total Fluoride Emissions from Selected Sources at Primary Aluminum Production Facilities. 01 February 2002 <http://on-linelearning.ca/idec3307/method_14a.htm> 1-11.

capable also of analyzing in addition to Fluoride, Cyanide, pH, Total Hardness and Conductivity in aqueous solutions, and Total Acid Number (TAN) in transformer oil samples. This instrument is capable of handling 55 samples per test.

The re-opening of the idled potline in 2001 and the change of sampling and analysis to the Alcan Cassette Method caused an increase in the number of samples analyzed by the laboratory. As a result of this, sample fluoride concentrations are submitted to the Environmental Group within 48-hours of receipt of samples instead of the 24-hour time turnaround desired by the Environmental Group. A 24-hour time turnaround is preferred by the Environmental Group to allow ample time for re-sampling if necessary or if other conditions are present.

It is important to note here and as explained in detail in Section 3 of this paper, Overview of the Manual Method, that there will not be a bottleneck problem caused by the analysis of fluoride samples. The reason is because the Alcan Ingot Sebree plant has kept the manual method as the backup method, and Alcan also has personnel properly trained in this procedure for emergency situations. But Alcan considers it critical that this project is realized because it will improve productivity and will reduce the risks associated with re-sampling conditions and/or going back to the manual method for a long period of time.

1.2 Scope of the Project

The scope of this project is to study several possible alternative solutions to the problem and present the best alternative to the Management Group.

The possible alternatives for this study will include:

1. Purchase a new unit for fluoride only, with a megasampler of capacity for 179 samples per run. With this option the existing instrument would be retained and used for the other chemistries. This unit would be purchased from the same vendor as the original equipment supplier in 1998, Vendor A.

2. Replace the existing sampler with the megasampler and keep the other instrument parts. Basically this option will keep all the chemistries together with the advantage of increasing the sampler capacity. Additional equipment would likely be purchased from same vendor as in 1998, Vendor A.

3. Purchase a new unit with a megasampler for fluoride only from a different vendor and keep the current instrument for the other chemistries. New vendor to consider will be Vendor B.

4. Consideration of purchase of another sampler from a different vendor is not a feasible alternative because of vendor and customer support incompatibility and complexity of the process.

5. Doing nothing would not be a feasible alternative because Alcan Ingot Sebree plant wants to improve sample efficiency and utilizing the existing sampler process will not provide increased efficiency.

6. Consideration of third party services through sample analyses by an external laboratory is not an option that the Alcan Ingot Sebree plant was to consider due to the inability to meet the desired 24-hour cycle time turnaround.

7. Hiring another person would not be a feasible option either because automated equipment does not require more personnel; it requires larger capacity and better features.

After consideration of all seven options, only alternatives 1, 2, and 3 appear to be viable for further analysis in this project effort.

1.3 Project Outline

The remainder of this paper will have several sections consisting of the following topics:

Section 2: History of the company and the aluminum process.

Section 3: Overview of the manual method for fluoride analysis.

Section 4: Overview of the current automated method.

Section 5: Presentation of alternatives for process improvement.

Section 6: Economic analysis of the alternatives.

Section 7: Project management and implementation.

Section 8: Bibliography.

Appendices.

2. ABOUT THE COMPANY AND THE ALUMINUM PROCESS

2.1 History of the Company

With headquarters in Canada, Alcan is the parent of a worldwide group of companies involved in all stages of the aluminum industry. Alcan has approximately 48,000 employees in 38 countries. Alcan's activities around the world include bauxite mining, alumina refining, aluminum smelting, manufacturing, sales and recycling. [2.1]

Alcan Ingot Sebree Reduction Plant is a division of Alcan Aluminum Corporation located near Sebree, Kentucky and operates as a primary smelter of alumina. The Sebree plant was founded in 1972. The plant employees approximately 600 persons and occupies a 3200 acre site. The Sebree smelter produces quality primary aluminum in a variety of shapes and alloys.

The main departments of the plant are the Potlines Department where the alumina is smelted and the Casting Department where the molten aluminum is cast into ingots for further processing by other plants. Another essential department is the Electrode Department where replacement anodes and cathodes are prepared for the electrolytic cells. Another essential department of this plant is the Environmental Group who is responsible for all relations and interactions with the federal and state regulatory agencies. The plant has three potlines, containing 128 individual electrolytic cells per

[2.1] The New Alcan: Imagination Materialized. Providing Innovative Aluminum and Packaging Solutions Worldwide. 01 February 2002 <http://www.alcan.com/corporate/AlcanCom.nsf/93182f151d5e6087852569e50065ba6c/b911bc2e6d751b40852569e7005418e7?OpenDocument>. 1.

potline, for the alumina reduction process into aluminum. The Alcan Ingot Sebree smelter has a production capacity of 186,000 tonnes of aluminum per year. [2.2]

2.2 Company Vision and Mission

In their Quality Manual Alcan Ingot Sebree's states:

> The employees of Alcan Sebree will provide high quality, cost effective, value-added aluminum, services and other products that meets the needs of our customers and contribute to the success of Alcan and other stakeholders.
>
> We will achieve this by working together to create a quality workplace.
>
> We are committed to improving safety, trust and respect, training, communications and the environment.
>
> By accomplishing this mission, we will assure the long-term success of the Sebree Plant and its employees.
>
> "Working Together for a New and Better Tomorrow." [2.3]

2.3 How Aluminum is Made

The reduction of aluminum requires the use of a fluoride salt, commonly known as bath in the aluminum industry. Bath is a salt made of sodium, aluminum and fluoride, commonly known as cryolite. The following paragraphs describing technically how aluminum is produced were extracted from Chemical of the Week – Aluminum:

[2.2] Alcan primary Metal Production. Smelter Capacities. 01 February 2002. <http://www.former.alcan.com/Markets.nsf/Topics-E/Primary#tab>. 3.

[2.3] Quality Manual. Alcan Ingot, Sebree Plant. 22 Nov. 2000. 1.

The chief ore of aluminum is bauxite, a mixture of hydrated aluminum oxide ($Al_2O_3.xH_2O$) and hydrated iron oxide ($Fe_2O_3.xH_2O$). Another mineral important in the production of aluminum metal is cryolite (Na_3AlF_6). However, cryolite is not used as an ore; the aluminum is not extracted from it.

In 1886, Charles Martin Hall of Oberlin, Ohio, and Paul Heroult of France, who were both 22 years of age, independently discovered and patented the process in which aluminum oxide is dissolved in molten cryolite and decomposed electrolytically. The Hall-Heroult process remains the only method by which aluminum metal is produced commercially.

The first step in the commercial production of aluminum is the separation of aluminum oxide from the iron oxide in bauxite. This is accomplished by dissolving the aluminum oxide in a concentrated sodium hydroxide solution. Aluminum ions form a soluble complex ion with hydroxide ions, while iron ions do not.

$Al_2O_3.xH_2O(s) + 2\ OH^-(aq) \rightarrow 2\ Al(OH)_4^-(aq) + (x3)\ H_2O(l)$

After the insoluble iron oxide is filtered from the solution, $Al(OH)_3$ is precipitated from the solution by adding acid to lower the pH to about 6. Then the precipitate is heated to produce dry Al_2O_3 (alumina).

$$2\ Al(OH)_3(s) \xrightarrow{\text{heat}} Al_2O_3(s) + 3\ H_2O(g)$$

In the Hall-Heroult process, aluminum metal is obtained by electrolytic reduction of alumina. Pure alumina melts at over 2000°C. To produce an electrolyte at lower temperature, alumina is dissolved in molten cryolite (Na_3AlF_6) at 1000°C. The electrolyte is placed in an iron cell or pot lined with graphite. The pot serves as the cathode. Carbon anodes are inserted into the electrolyte from the top. The oxygen produced at the anodes reacts with them, forming carbon dioxide and carbon monoxide. Therefore, the anodes are consumed and need to be replaced periodically. Molten aluminum metal is produced at the cathode, and it sinks to the bottom of the pot. The principal cell reactions are:

Cathode: $4\ Al^{3+} + 12\ e^- \rightarrow 4\ Al\ (l)$

Anode: $6\ O^{2-} \rightarrow 3\ O_2(g) + 12\ e^-$

Net: $4\ Al^{3+} \rightarrow 4\ Al(l) + 3\ O_2(g)$ [2.4]

The heat required to keep the mixture is provided by resistive heating of the electrolyte by the current passing through the cell. Typical cells use a potential of 4 to 5 volts and a current of 50,000-280,000 amperes. [2.4]

There are two types of technology that use the Hall-Haroult process and these are the Sodeberg type and the Pre-Bake type. The main difference between the two is the type of anode used. The Sodeberg type uses a continuous anode that is delivered into the

[2.4] Shakhashiri, Bassam Z. Science is Fun in the Lab of Shakhashiri. Chemical of the Week. Aluminum. 01 February 2001 <http://scifun.chem.wisc.edu/chemweek/aluminum/aluminum.html>. 2.

pot in a form of a paste, which bakes itself in the pot. The Pre-Bake technology uses multiple anodes in each cell that are prepared in a different or same facility. [2.5]

The Alcan Ingot Sebree plant uses the Pre-Bake technology and the anodes are fabricated in the same facility. A typical representation of a Pre-Bake cell or pot is illustrated in Figure 2.1. At Alcan Ingot Sebree plant the pots use a current of approximately 175,000 amperes. The aluminum is removed from the top of the pot by utilizing a piece of equipment called a crucible. Compressed air is introduced into a venturi creating a vacuum in the tapping crucible. As a result of the vacuum, the molten aluminum flows into the crucible. The outer shell of the crucible is made of steel and it is lined with firebrick to keep the molten aluminum from coming in contact with the steel. A potline is a special arrangement of pots electrically in series. At Alcan Sebree Ingot a potline consists of two potrooms electrically connected and the potrooms are named north and south respectively for each potline. [2.6]

[2.5] World-Aluminum.Org. Home of the International Aluminum Institute. Technology Types. 20 February 2002 <http://www.world-aluminium.org/production/smelting/technology.html>. (1).

[2.6] Bosley, Philip B. Environmental Field Technician. Alcan Ingot Sebree. Personal Interview. 20 February 2002.

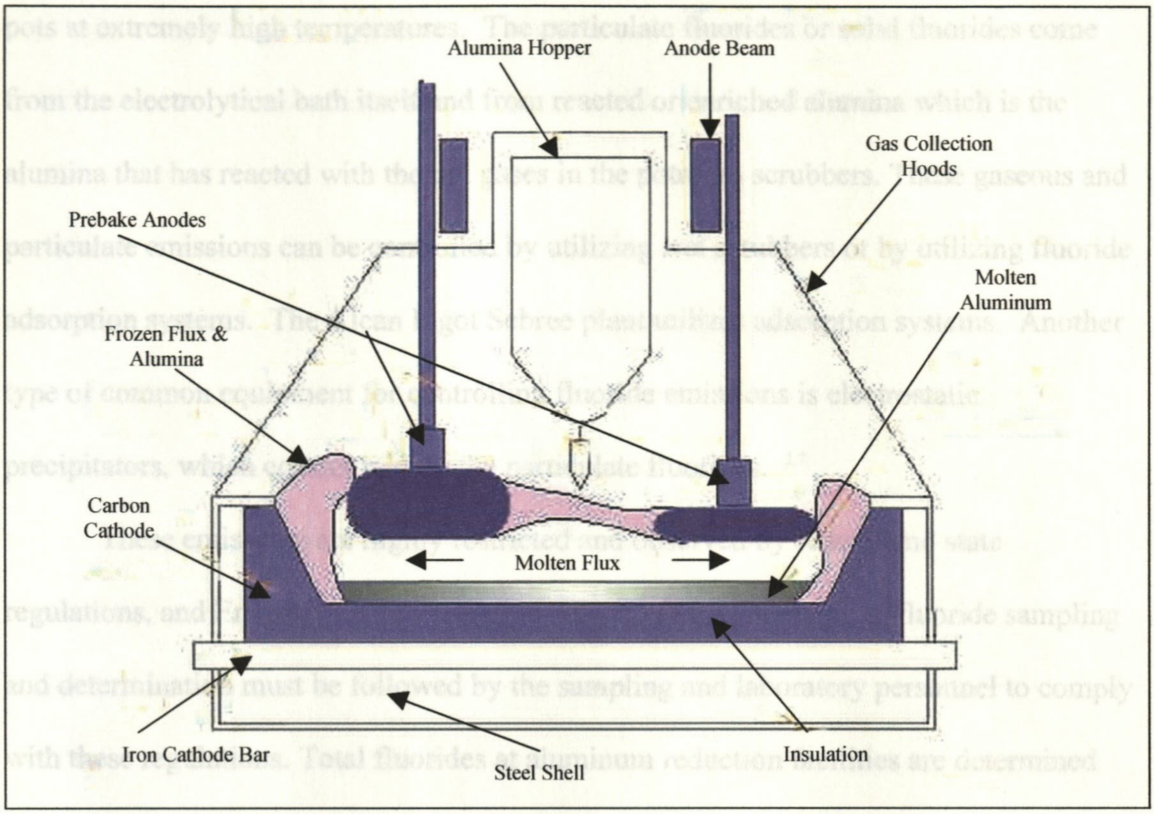

Figure 2.1. Pre-Bake Anode Reduction Pot. World-Aluminum.Org. Home of the International Aluminum Institute. Technology Types. 20 February 2002 <http://www.world-aluminium.org/production/smelting/technology.html> (1).

2.4 Emissions From Primary Aluminum Smelters

Air pollutants at primary aluminum smelters come from a variety of sources with the most common being fluorides and polycyclic organic matter. Particulate pollutants are often the result of grinding of the bauxite, calcination of the aluminum oxide, and the handling of the raw materials. [2.7]

The fluoride pollutants are considered to be the total of gaseous fluoride and particulate fluorides. Fluoride gases are produced when fluoride salts are added to the

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[2.7] Givens, Hurtis. Ingot Express. Keeping Fluorides in Check. Vol. 2 No. 2. Sebree, KY. 25 January 2002. 4-5.

pots at extremely high temperatures. The particulate fluorides or solid fluorides come from the electrolytical bath itself and from reacted or enriched alumina which is the alumina that has reacted with the pot gases in the potroom scrubbers. These gaseous and particulate emissions can be controlled by utilizing wet scrubbers or by utilizing fluoride adsorption systems. The Alcan Ingot Sebree plant utilizes adsorption systems. Another type of common equipment for controlling fluoride emissions is electrostatic precipitators, which control mainly the particulate fluorides. [2.7]

These emissions are highly restricted and observed by federal and state regulations, and Environmental Protection Agency (EPA) methods of fluoride sampling and determination must be followed by the sampling and laboratory personnel to comply with these regulations. Total fluorides at aluminum reduction facilities are determined following the guidelines of the United States Environmental Protection Agency (USEPA) Method 14A (40 CFR 60, Appendix A, amended October 7, 1997) Method 14A - Determination of Total Fluoride Emissions from Selected Sources at Primary Aluminum Production Facilities. [2.8] This method can be found in Appendix A of this paper. This method also known as the Alcan Cassette Method became effective in 1999 and the Alcan Ingot Sebree plant was required to sample all three potlines three days (2 sampling periods) per month. The old system of steel manifolds had to be abandoned to adopt the new way of sampling and determining the fluorides. [2.7]

Alcan Ingot Sebree's legal permissible limit for total fluoride is 1.90 pounds of fluoride per ton of aluminum produced per potline per month. State and federal

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[2.8] Appendix A to Part 60 –Test Methods. Method 14A – Determinations of Total Fluoride Emissions from Selected Sources at Primary Aluminum Production Facilities. 01 February 2002 < http://on-linelearning.ca/idec3307/method_14a.htm >. 1-11.

regulations require Alcan Ingot Sebree plant to maintain recordkeeping following the guidelines of the Maximum Achievable Control Technology (MACT) law. [2.7]

3. OVERVIEW OF THE ION-SELECTIVE MANUAL PROCEDURE FOR FLUORIDE DETERMINATION

3.1 History

The determination of fluoride in samples containing aluminum was a very tedious chemistry until the development of the ion selective electrode method in 1966. The fluoride was either separated by distillation (separation by heating to vapor then cooling to liquid), or by pyrohydrolysis (decomposition by the combined action of heat and water vapor). [3.1, 3.2] Some of the common and approved distillation methods are the automated Technicon technology using the Fluorine Blue Alizarine Complexone reagent, a colorimetric method following distillation. [3.2]

Another common method of distillation is the manual Willard-Winter distillation followed by the colorimetric determination using the SPADNS reagent method.

The analysis of macro amounts of fluoride in materials containing aluminum is very complicated because aluminum forms very strong complexes that can only be separated by distillation or by the addition of special buffers, or masking agents. [3.2]

Orion Research Laboratories developed a buffer named TISAB IV (Total Ionic Strength Adjustor) as a buffer to employ in fluoride determinations with the fluoride electrode method. This buffer can complex more than 100 part per millions iron or aluminum in the presence of 1 part per million fluoride. A 1 part per million (ppm) fluoride determination can be in error by 5% in the presence of 200 parts per million

[3.1] Yahoo Search. "Pyrohydrolysis." <http://composite.about.com/library/glossary/p/bldef-p4350.htm>. 16 February 2002.

(ppm) of aluminum or iron. This buffer can be prepared in-house or can be purchased commercially. [3.3]

Comparative studies performed over the years comparing the ion-selective electrode method with the traditional distillation methods haven shown that the direct determination by the ion-selective electrode method was accurate to within ± 3% of the amount present. [3.2]

The ion-selective electrode has become one of the most widely used methods of fluoride determination in the aluminum industry. This electrode method is not only utilized for the determination of fluoride in air emission samples, but it is also utilized in the determination of fluoride in drinking water, and in many other sources as well.

3.2 Principle of the Ion-Selective Electrode Method

The Ion-Selective Electrode method uses a fluoride electrode. This fluoride electrode is an ion-selective sensor. The electrode potential in fluoride solutions of various concentrations is measured across the laser-typed doped electrode lanthanum fluoride crystal. The lanthanum fluoride crystal contacts the sample test solution at one face and an internal reference solution at the other. The fluoride electrode potential reaction can be represented as:

$$Ag \mid AgCl, Cl^{-} (0.3\ M), F^{-} (0.001) \mid LaF_3 \mid \text{sample solution} \mid \text{reference electrode}$$

The fluoride electrode can be purchased commercially as a combination (fluoride and reference) electrode, or may be used with a calomel electrode as the reference

[3.2] Palmer, Thomas E. Direct Determination of Fluoride in Aluminum Reduction Materials by using an Ion-Selective Electrode. Kaiser Aluminum and Chemical Corp. 1141.

[3.3] Orion Research Inc. Fluoride/Fluoride Combination Electrode Instruction Manual. 1999. 3-17.

electrode. A standard pH tester with an extended millivolt scale may be used for the millivolt determinations. [3.4]

The specific model utilized by the Alcan Ingot Sebree plant is the ORION Model 920A and is shown in Figure 3.1 below.

Figure 3.1. Orion Fluoride Ion-Selective Electrode and pH Meter Model 920A. 27 January 2000 <http://www.thermo.com/eThermo/CDA/Products/Product_Detail/1,1075, 1000001000170-161-X-161-1000000007678,00.html>. (1).

A picture of an ORION Fluoride Ion Selective Electrode is shown in Figure 3.2 below.

[3.4] American Public Health Association, American Water Works Association, and Water Environmental Federation. Standard Methods for the Examination of Water and Wastewater. Washington, DC: American Public Health Association, 1995. 4-61- 4-62.

Figure 3.2. Fluoride Ion-Selective Electrode. Fluoride Measurement : In recent years public awareness of drinking waters quality issues has increased. 28 January 2000 < http://www.chem.ubc.ca/courseware/211/F.pdf >. (1).

3.3 Assembly of the Polystyrene Cassettes

Each cassette consists of a top cover, three central sections, and a base or bottom cover. See diagram in Figure. 3.3. The base is left empty. In the first central section, which fits onto the base so as to be airtight, a cellulose pad is placed. The cellulose pad must be impregnated in sodium formate and dried in a 50 °C oven overnight (one hour is actually sufficient). A 5.0 μm Versapor filter is impregnated by immersing it in a sodium formate solution (10% v/v in an ethyl alcohol solution). The filter is placed on the cellulose pad while wet. Two gaseous cassettes sections are required. This process is repeated to prepare the second section.

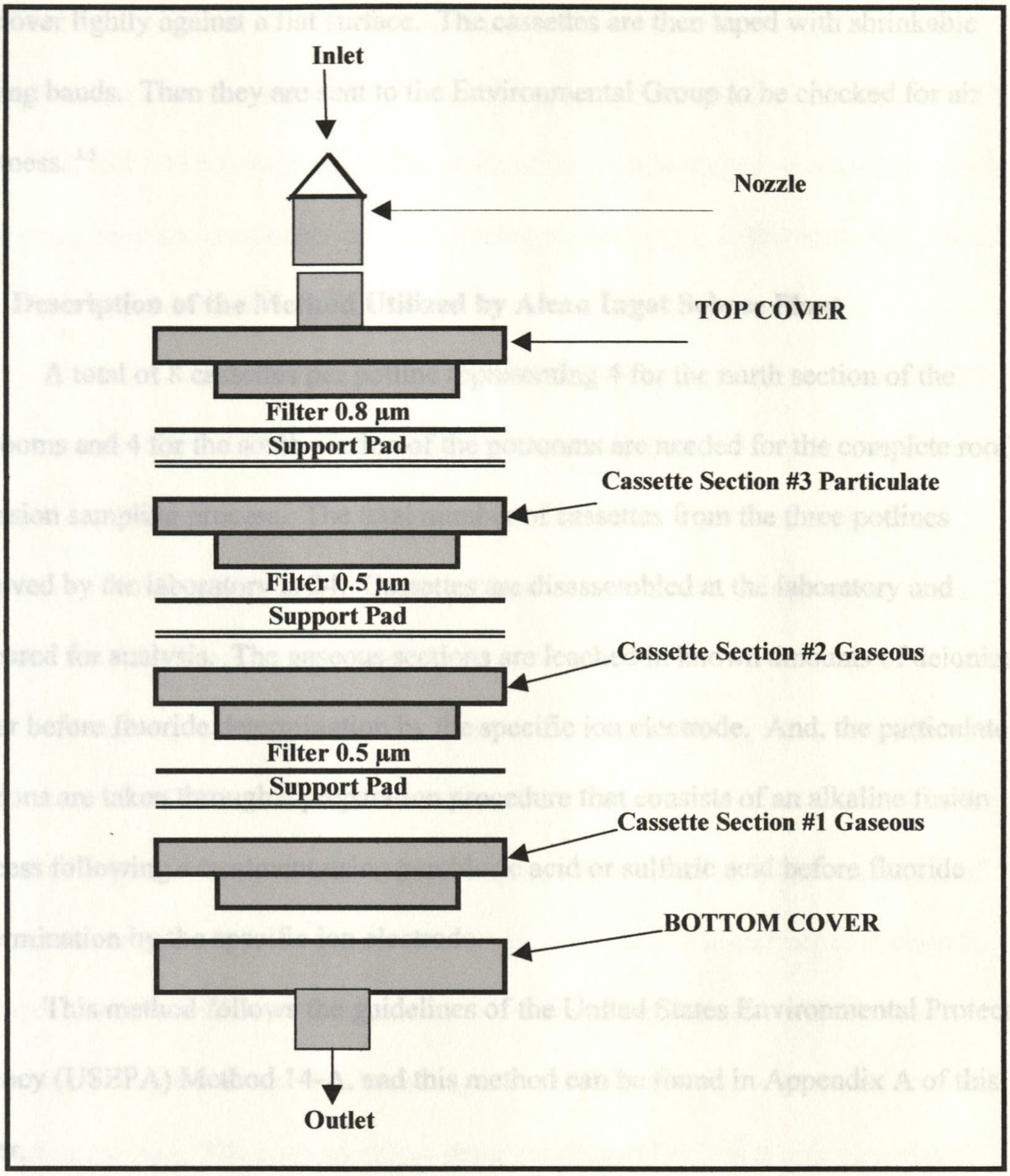


Figure 3.3. Cassette Diagram for Fluoride Emission Samples. Lajoie, Michel. Reference Procedure. Potroom Vent Sampling. 1988. (Appendix 1).

Next, another central, airtight section is added. A cellulose pad is placed in the section. On top of the pad is placed the 0.8 µm Versapor Filter. Finally, the top cover is put on. Plastic plugs are put on the cover and the base. The cassettes are closed tightly by tapping them lightly with a rubber mallet or by using a cassette press, or pressing on the cover lightly against a flat surface. The cassettes are then taped with shrinkable sealing bands. Then they are sent to the Environmental Group to be checked for air tightness. [3.5]

3.4 Description of the Method Utilized by Alcan Ingot Sebree Plant

A total of 8 cassettes per potline representing 4 for the north section of the potrooms and 4 for the south section of the potrooms are needed for the complete roof emission sampling process. The total number of cassettes from the three potlines received by the laboratory is 24. Cassettes are disassembled at the laboratory and prepared for analysis. The gaseous sections are leached in known amounts of deionized water before fluoride determination by the specific ion electrode. And, the particulate sections are taken through a preparation procedure that consists of an alkaline fusion process following a treatment using perchloric acid or sulfuric acid before fluoride determination by the specific ion electrode.

This method follows the guidelines of the United States Environmental Protection Agency (USEPA) Method 14-A, and this method can be found in Appendix A of this paper.

3.5 Standard Preparation, Electrode Calibration and Calculation of Sample Results

The fluoride electrode is filled with a filling solution according to the equipment supplier's instructions. The electrode is then connected to the Ion-Selective Meter.

[3.5] Lajoie Michel. Reference Procedure. Potroom Vent Sampling. 1988. 3.

A total of 9 fluoride standards are prepared for the calibration. The standard concentrations in parts per million of fluoride (ppm F^-) are 0.2, 0.5, 1.0, 2.0, 5.0, 10.0, 20.0, 50.0, and 100.0 respectively. The calibration for this range is plotted on semi-log scale paper with the concentration values being plotted on the logarithmic scale (x-axis or abscissa) and the millivolt readings on the linear scale (y-axes or ordinate).

Equal amounts of standard and TISAB IV are manually pipetted into centrifuge tubes. A centrifuge tube is a 50-ml cylindrical laboratory container with a conical shaped bottom. The fluoride electrode is manually immersed into each centrifuge tube containing the standard and TISAB mixture and the millivolt readings are manually recorded after each reading has stabilized.

The same process is repeated for the samples by pipetting equal amounts of sample and TISAB IV into centrifuge tubes. The electrode is manually immersed into each centrifuge tube and the millivolt readings are taken after stabilization. After all readings are taken, a linear regression analysis curve using a logarithmic function for concentration is calculated. The regression line may be calculated with Microsoft Excel Spreadsheet program or a software package named Standard Curves by the least squares regression method. The corresponding sample calculated values are compared and adjusted according to standard calibration measurements. Blank sample fluoride values are compared in the same manner and subtracted from sample values. The values are reported to the Environmental Group and the final results are input in the Laboratory Information Management System (LIMS) network.

The manual method has now become the backup method for the Alcan Ingot Sebree Plant since the purchase of the automated equipment in 1998. Alcan Ingot Sebree

Plant has two ion-selective meters and several fluoride electrodes in the laboratory as backup equipment and also trained personnel for this method are available as backup manpower. The backup test capability assures that the Environmental Group will always receive the fluoride sample test numbers on time even under conditions of automated equipment malfunction.

3.6 Example of a Fluoride Calibration Curve and Sample Results

Table 3.1 shows a typical example of the calibration and calculated results obtained for the three different sections of a sample cassette. Calibration calculations were performed using Standard Curves software package. [3.6] The regression line from Table 3.1 is expressed mathematically in the linear form of Y = m*X + b, where:

Y = millivolts

X = logarithm (concentration)

m = slope of the line

b = intercept

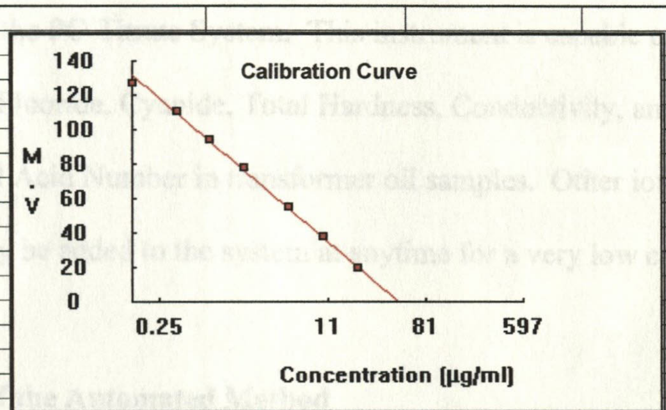
Replacing the slope and intercept with the numerical values for this particular example, the regression line is: Y = (-24.35653)*X + ((93.46643). It is important to note here that the values of the concentrations (X values) are logarithmic and they have to be converted to normal concentrations by using the anti-logarithmic function. The computer software, Standard Curves, takes care of this conversion. It is also important to note here that the slope of the line of the fluoride electrode chemistry is a negative slope, what this means is that the higher the concentration of a particular standard or sample solution is the more negative the millivolt reading will be.

The concentration results were imported into Microsoft Excel Spreadsheet in order to complete the calculations taking into consideration the dilution factors for the different solutions.

Table 3.1

Calibration and Fluoride Results of all Sections in a Typical Cassette Arrangement.

Concentration µg/ml	Intensity M.V
0.2	128.1
0.5	111.3
1.0	95.0
2.0	79.0
5.0	55.7
10.0	38.7
20.0	20.7
50.0	-3.0
100.0	-20.8



Relationship:	Logarithmic
Slope:	-24.35653
Intercept:	93.46643
Correlation Coefficient (r):	-0.99907
r²:	0.99814
Number of Entries:	9

Description	Intensity M.V	Dilution Factor	Concentration µg/ml	Final Concentration
CASSETTE 1-1	75.7	5	2.074	10
CASSETTE 1-2	96.8	5	0.872	4
CASSETTE 1-3	96.0	5	0.901	5
CASSETTE 1-4	87.8	5	1.262	6
CASSETTE 2-1	-25.8	5	133.846	669
CASSETTE 2-2	-26.9	5	140.03	700
CASSETTE 2-3	-25.2	5	130.59	653
CASSETTE 2-4	-30.0	5	159.036	795
CASSETTE 3-1	77.0	500	1.966	983
CASSETTE 3-2	76.4	500	2.015	1008
CASSETTE 3-3	88.3	500	1.236	618
CASSETTE 3-4	84.7	500	1.433	717

Source: Microsoft Excel 95 and WindowChem Standard Curves. Version 4.3. 1995.

[3.6] WindowChem Standard Curves. Version 4.3. 1995.

4. OVERVIEW OF THE ALCAN'S CURRENT AUTOMATED FLUORIDE ANALYSIS METHOD

4.1 History

Ion-selective automated electrode methods have been in the market for several decades. In 1998, after considering several vendors available at the time, Alcan purchased an automated analyzer, the PC-Titrate System. This instrument is capable of performing chemical analyses for Fluoride, Cyanide, Total Hardness, Conductivity, and pH in aqueous solutions, and Total Acid Number in transformer oil samples. Other ion-selective electrode chemistries may be added to the system at anytime for a very low cost.

4.2 Principle and Description of the Automated Method

The same chemical process principles of the manual method described in Section 3 of this paper apply to the automated electrode method. An actual photograph of the automated PC-Titrate System is shown in Figure. 4.1. The method follows the same procedures of the manual method covered in Section 3 of this paper with the change to automation. Pumping of the samples and buffer, and recording of millivolt readings are performed automatically by the computer operating the system. All equipment functions and measurements are pre-programmed using the automated instrument PC-Titrate System and computer software PC-Titration Plus. [4.1] The manual portable millivolt meter is replaced with the built-in millivolt meter of the automated PC-Titrate System. The sampler has a capacity of testing 55 samples per run.

[4.1] PC-Titration Plus Software. Windows Version 2.0. 2000.

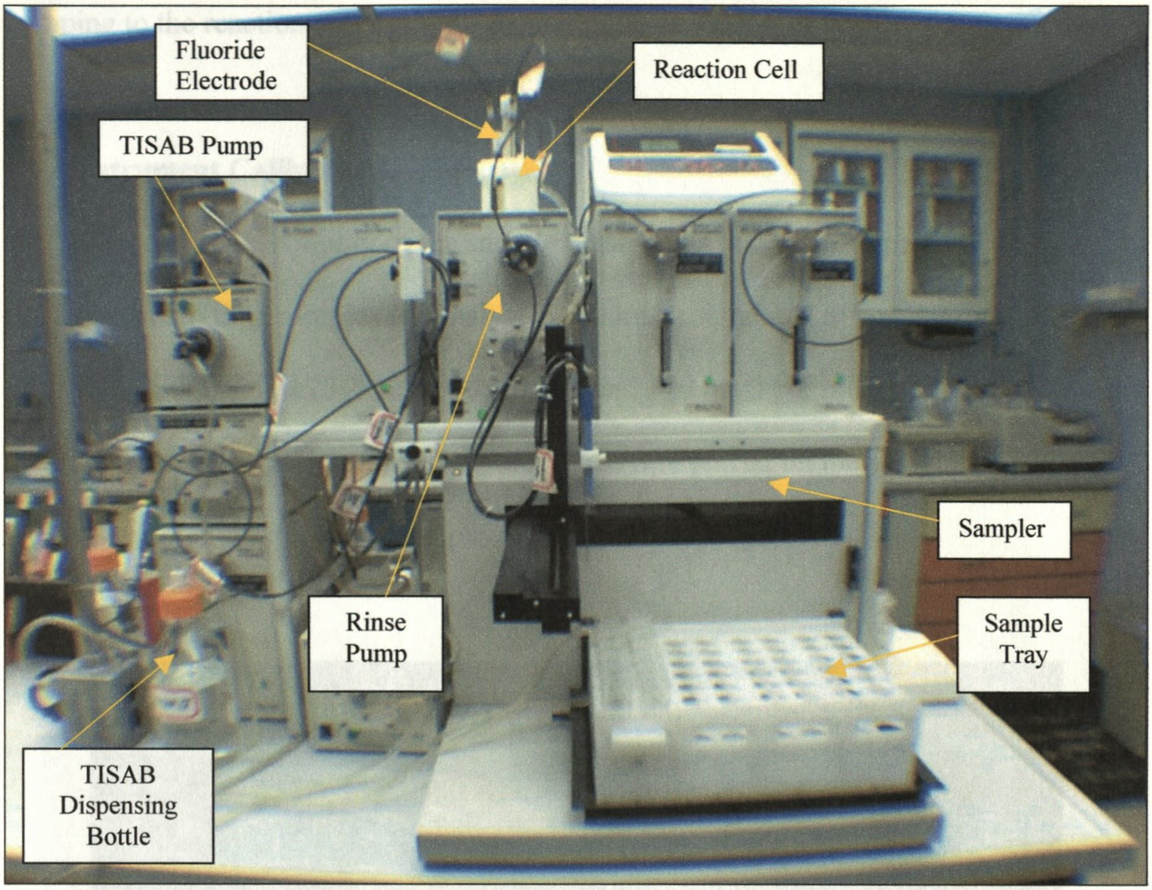


Figure 4.1. Automated PC-Titrate System. Mora, Ana E. Actual photograph taken with Kodak DC290 digital camera. Labels created with Microsoft Word 97. 30 January 2002.

4.3 Sample Preparation

Samples are prepared in the same manner as described in Section 3 of this paper. Gaseous sections of the cassettes are leached in known amounts of deionized water and particulate sections are prepared using an alkaline fusion procedure. Again, sample preparation follows the guidelines of the United States Environmental Protection Agency (USEPA) Method 14A which can be found in Appendix A of this paper. Centrifuge tubes containing the samples are placed on the instrument sampler for automated pumping to the reaction cell followed by computerized millivolt reading measurements.

4.4 Instrument Calibration

To ensure the validity of the sample results, it is necessary to perform a calibration each time samples are analyzed. Fourteen standards of concentrations of 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.75, 1, 2, 5, 10, 20, 50, and 100 parts per million fluoride (ppm F^-) are transferred to centrifuge tubes and these tubes are placed on the sampler tray for analysis. A photograph of the sampler tray is shown in Figure 4.2.

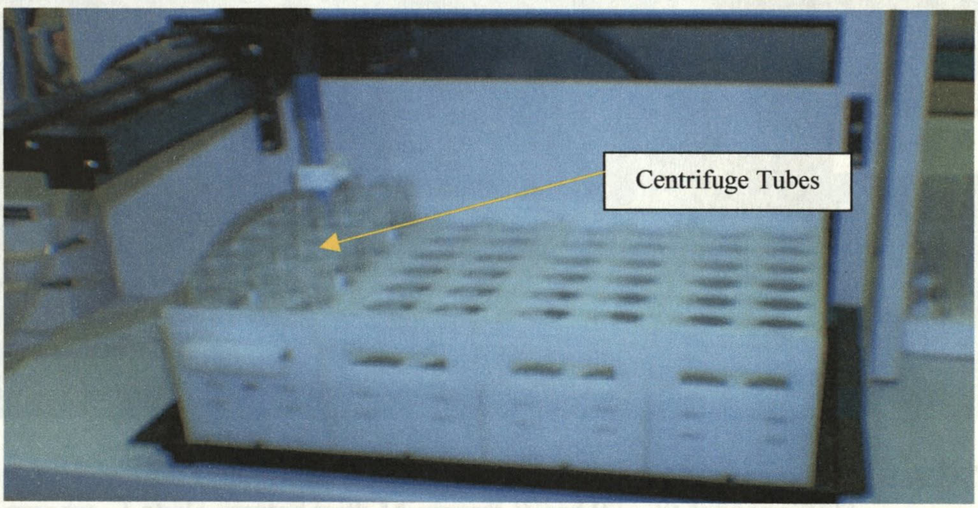


Figure. 4.2 Sampler Tray with Containers. Mora, Ana E. Actual photograph taken with Kodak DC290 digital camera. Labels created with Microsoft Word 97. 30 January 2002.

Equal amounts of standard and TISAB IV solutions are pumped into the reaction cell. The actual photograph of the reaction cell is shown in Figure 4.3.

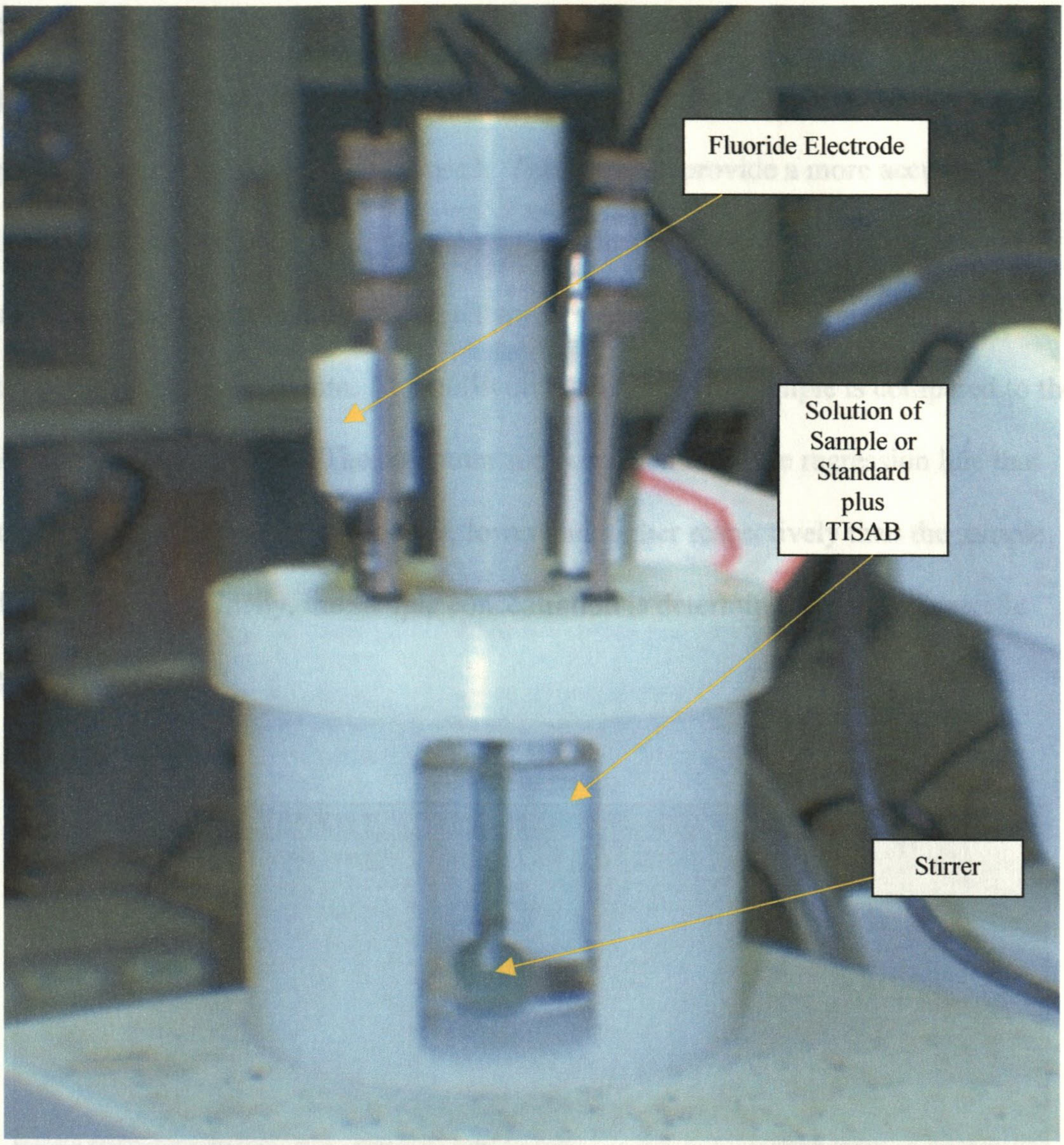


Figure 4.3. Reaction Cell. Mora, Ana E. Actual photograph taken with Kodak DC290 digital camera. Labels created with Microsoft Word 97. 30 January 2002.

The electrode reading is measured and stored electronically by the PC-Titrate software. The software calculates the regression relationship by using the least square regression analysis method. An example of the PC-Titrate Software calibration computer screen is shown in Figure. 4.4. To start the calibration, it is necessary to click on the icon indicated by the highlighted arrow. The computer prints a final calibration report. A typical calibration report is shown in Table 4.1. The computer software calculates a regression line between two consecutive standard points, resulting in 13 different regression lines for the 14 standards used. These results provide a more accurate calibration because it narrows down the range of the regression line to one line per two standard points, as opposed to the manual method that calculates a regression line for the entire range of standard points. The millivolt reading of each sample is compared to the calculated regression lines. The computer software then finds the regression line that corresponds to the two standard points, lower and higher respectively than the sample millivolt reading. Finally, the sample concentration is determined from this specific regression line.

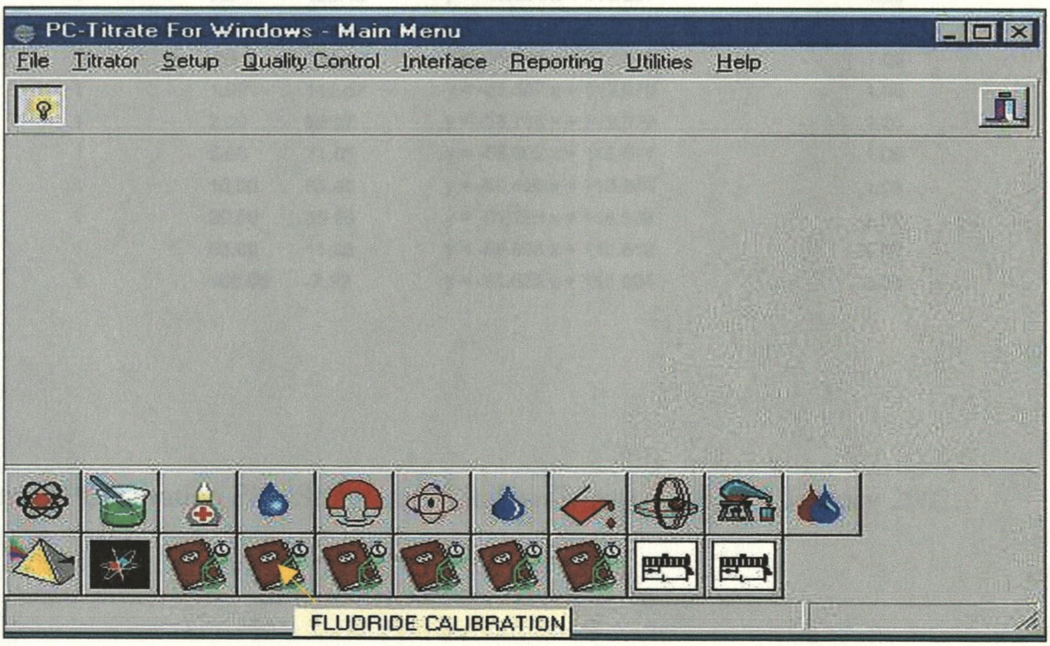


Figure. 4.4. PC-Titrate Fluoride Calibration Computer Screen. PC-Titration Plus Software. Windows Version 2.0. 04 February 2002.

Table 4.1

Typical Calibration Report

Calibration Report

Calibration Record # 532

Calibration Settings

Calibration ID	FLUORIDE CALIBRATION	Date	01/23/2002
Channel	2	Time	12:00 PM
Probe Type	ISE	Temperature	-999.00 K -1272.15 C
Probe ID	FLUORIDE	Analysis Type	Multi Line Fit

Operator A

Calibration Results

Standard	Replicate	Set	Reading	Equation	Correlation
1	1	.05	174.31		
2	1	.10	165.03	y = -30.827 x + 134.203	1.00
3	1	.20	151.48	y = -45.012 x + 120.018	1.00
4	1	.30	142.33	y = -51.962 x + 115.160	1.00
5	1	.40	136.10	y = -49.864 x + 116.257	1.00
6	1	.50	129.88	y = -64.183 x + 110.559	1.00
7	1	.75	119.62	y = -58.265 x + 112.340	1.00
8	1	1.00	112.67	y = -55.627 x + 112.670	1.00
9	1	2.00	94.97	y = -58.798 x + 112.670	1.00
10	1	5.00	71.65	y = -58.602 x + 112.611	1.00
11	1	10.00	53.46	y = -60.426 x + 113.886	1.00
12	1	20.00	35.03	y = -61.223 x + 114.683	1.00
13	1	50.00	11.23	y = -59.808 x + 112.842	1.00
14	1	100.00	-7.32	y = -61.622 x + 115.924	1.00

Source: PC-Titration Plus Software. Windows Version 2.0. 23 January 2002.

4.5 Sample Analysis and Results

After the samples are prepared in the centrifuge tubes, they are placed in the sample tray and they are ready for analysis. Equal amounts of sample and TISAB IV solutions are pumped into the reaction cell. The reaction cell is shown in Figure 4.3. The gaseous samples are loaded first and the program is started. Sample runs can be left unattended and a final sample result will print at the end of the each run. It takes about 1 hour to run 10 samples.

An example of the PC-Titrate Software fluoride analysis computer screen is shown in Figure 4.5. To start the analysis, it is necessary to click on the icon indicated by the highlighted arrow.

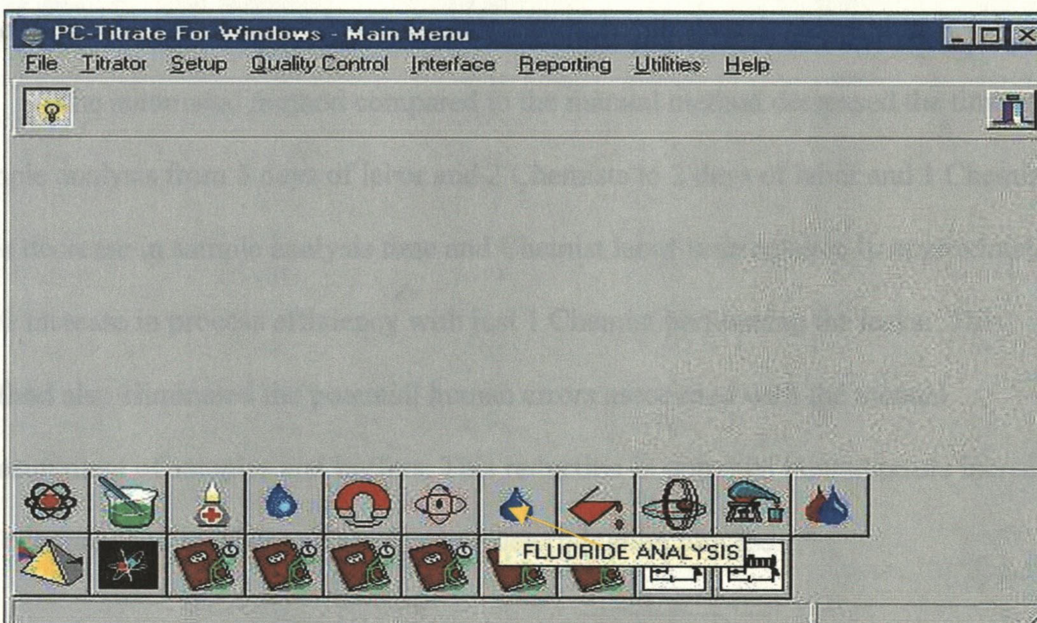


Figure 4.5. PC-Titrate Fluoride Analysis Computer Screen. PC-Titration Plus Software. Windows Version 2. 04 February 2002.

After gaseous samples are analyzed, the particulate samples are loaded on the sampler and the procedure is repeated. A sample report will print at the end of the run. A typical sample report printed by the instrument software is shown in Table 4.2.

Blank sample values (i.e. no fluoride contamination) are subtracted from sample results and final results are reported to the Environmental Group and are also entered in the Laboratory Information Management System (LIMS) network. These are not yet the final numbers reported to the regulatory agencies. The Environmental Group takes care of the final calculations of total fluoride emissions per pounds of aluminum produced. These final numbers are reported to the federal and state regulatory agencies.

A total of 106 samples are required to be analyzed. Since the sampler can only hold 55 samples per run, two sampler cycles are required to complete the analysis. Total time of sample preparation plus analysis by this automated method is 48 hours.

The automated method compared to the manual method decreased the time of sample analysis from 5 days of labor and 2 Chemists to 2 days of labor and 1 Chemist. This decrease in sample analysis time and Chemist labor time resulted in approximately a 75% increase in process efficiency with just 1 Chemist performing the tasks. This method also eliminated the potential human errors associated with the manual measurement of samples and buffers. This reduction in potential human errors increases the accuracy and precision of the fluoride determination process.

Table 4.2

Typical Sample Results Report

Sample Results Report

Print Date: 01/24/2002
Print Time: 11:06 AM

Run Number	Order Number	
1442	20020124-5	Fluoride by EPA Method

SampleID	RunDate	Intensity (mV)	Dilution Factor	Conc. (ug/mL)	Final Conc. (ug)
D WATER	01/24/2002	186.84	1.00	0.017	0.017
PART. BLANK	01/24/2002	159.66	100.00	0.132	13.161
ROOF-2N-3P-1	01/24/2002	98.87	100.00	1.725	172.481
ROOF-2N-3P-2	01/24/2002	91.06	100.00	2.343	234.315
ROOF-2N-3P-3	01/24/2002	95.82	100.00	1.935	193.452
ROOF-2N-3P-4	01/24/2002	91.91	100.00	2.256	225.552
ROOF-2S-3P-1	01/24/2002	98.51	100.00	1.733	173.294
ROOF-2S-3P-2	01/24/2002	105.95	100.00	1.307	130.716
ROOF-2S-3P-3	01/24/2002	96.19	100.00	1.907	190.669
ROOF-2S-3P-4	01/24/2002	84.35	100.00	3.051	305.121
ROOF-3N-3P-1	01/24/2002	93.50	100.00	2.119	211.892
ROOF-3N-3P-2	01/24/2002	87.28	100.00	2.706	270.554
ROOF-3N-3P-3	01/24/2002	99.85	100.00	1.652	165.209
ROOF-3N-3P-4	01/24/2002	95.82	100.00	1.925	192.545
ROOF-3S-3P-1	01/24/2002	101.44	100.00	1.552	155.236
ROOF-3S-3P-2	01/24/2002	100.46	100.00	1.613	161.309
ROOF-3S-3P-3	01/24/2002	101.56	100.00	1.545	154.508
ROOF-3S-3P-4	01/24/2002	99.48	100.00	1.676	167.620
ROOF-6N-3P-1	01/24/2002	92.28	100.00	2.223	222.297
ROOF-6N-3P-2	01/24/2002	97.29	100.00	1.836	183.562
ROOF-6N-3P-3	01/24/2002	102.41	100.00	1.494	149.450
ROOF-6N-3P-4	01/24/2002	99.36	100.00	1.684	168.410
ROOF-6S-3P-1	01/24/2002	95.70	100.00	1.944	194.363
ROOF-6S-3P-2	01/24/2002	96.31	100.00	1.898	189.776
ROOF-6S-3P-3	01/24/2002	103.14	100.00	1.452	145.238
ROOF-6S-3P-4	01/24/2002	105.34	100.00	1.332	133.249

Source: PC-Titration Plus Software. Windows Version 2.0. 24 January 2002.

4.6 Quality Control Methods

The Alcan Laboratory is responsible for reporting the official company fluoride numbers to the Environmental Group. The Alcan Laboratory has established several procedures of quality control to ensure the accuracy of the fluoride numbers reported. An analysis of audit sampling process is one such procedure as prepared by the Environmental Group. These samples are analyzed by the Chemist and reported to the Environmental Group who, in turn, evaluates the percent error based on the true prepared concentration values.

Another quality control method is the participation in inter-laboratory studies performed by a certified commercial laboratory specializing in these studies. Samples are received from the commercial laboratory monthly, and analyzed as unknowns by the Alcan Chemist. These results are reported back to the certified laboratory. The Alcan Chemist receives a statistical report of the study from the commercial laboratory at the end of the participation period. Process corrections, checks, changes, or observations are made after the Alcan Chemist reviews and interprets the statistical report.

Observation of blank sample values (i.e. no fluoride contamination) for possible contamination of fluoride is another measure of quality control. Blank sample values containing more than 20 micrograms of fluoride are an indication of fluoride contamination.

The final measure of quality control procedures is the analysis of duplicate samples of internal quality control solutions. These solutions are purchased from a commercial laboratory and they have a certified value. Quality control process charts are kept for these analyses. The duplicate analysis results measure the precision of the analysis. The comparison of obtained concentration values with the certified value range measures and determines the accuracy of the results.

5. PRESENTATION OF ALTERNATIVES FOR PROCESS IMPROVEMENT

5.1 Introduction

In Section 1 of this paper, 7 alternatives were discussed and only 3 were chosen for further analysis. These alternatives are:

1. Purchase a new unit for fluoride only, with a megasampler of capacity for 179 samples per run. With this option the existing instrument would be retained and used for the other chemistries. This unit would be purchased from the same vendor as the original equipment supplier in 1998, Vendor A.

2. Replace the existing sampler with the megasampler and keep the other instrument parts. Basically this option will keep all the chemistries together with the advantage of increasing the sampler capacity. Additional equipment would likely be purchased from same vendor as in 1998, Vendor A.

3. Purchase a new unit with a megasampler for fluoride only from a different vendor and keep the current instrument for the other chemistries. New vendor to consider will be Vendor B.

A more detailed presentation of each one of these alternatives will be explained in the remainder of this Section.

5.2 Alternative #1 : New Fluoride Unit from Vendor A

This alternative will be to purchase a new unit for fluoride only, with a megasampler with the capacity for holding 179 samples per run. This unit will be purchased from Vendor A, same vendor utilized by Alcan in 1998. A quotation from

Vendor A was obtained by e-mail on January 15, 2002. [5.1] The equipment cost of this alternative is $43,379. A photograph of the megasampler that will be the main part of this instrument is shown in Figure 5.1.

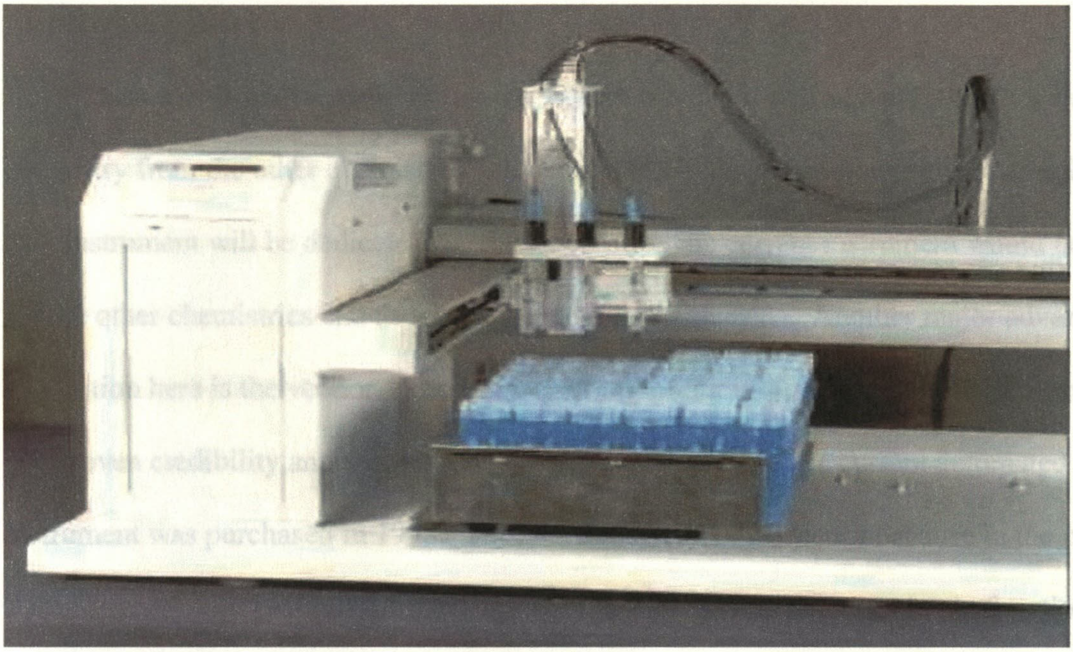


Figure 5.1. Megasampler with Centrifuge Tubes on Sample Tray. Vendor A. E-mail from the author. 15 January 2002.

The chemical process of this instrument is identical to the present automated method that Alcan now has. It is based on the automated measurement and transfer of TISAB and sample to the reaction cell where the fluoride electrode is located. It will have a more modern and larger capacity sampler that will meet the requirements of the 24-hour time turnaround of cassette sample results required by the Environmental Group.

The software is still equivalent to the present software. By being a newer software version, it will have more improvements and will be a friendlier version. Some

[5.1] Vendor A. E-mail from the author. 15 January 2002.

of the major capabilities of this software are the improved and more flexible automatic run buttons for calibration and for sample analysis. Other important features of the software are the quality control features, flexible reporting and exporting capabilities to the Laboratory Information Management System (LIMS) network system that the older versions did not have.

Some of the advantages of this alternative are that it will separate the fluoride chemistry from the other chemistries now combined in the present instrument, and the new instrument will be dedicated for fluoride only. The current instrument would be kept for the other chemistries and as a backup for fluoride analysis. Another major advantage to mention here is the vendor. Vendor A is an important issue to consider. This vendor has proven credibility and customer support at all times since the current automated instrument was purchased in 1998. This is a major issue of concern because in the past Alcan Ingot Sebree purchased laboratory equipment that was not completely functional at the time of purchase. Alcan Ingot Sebree laboratory personnel had to spend more time for research and development in order to make it functional. So Alcan does not want to invest in additional time for research and development of equipment that may not be functional at the time of purchase.

One of the disadvantages of this alternative is the higher cost than the other two alternatives. Another disadvantage of this alternative would be the additional laboratory space occupied by the new instrument. It is important to note here again that with this alternative the current instrument would be kept. Laboratory space now available at the Alcan laboratory is a concern, the laboratory is 30 years old and workbench space is now occupied with automated machinery. So, the additional equipment by choosing this alternative would require also additional studies for physical accommodations.

Another issue of concern is the shortage of manpower at the plant. The addition of a new piece of equipment will make the job for the Chemist more complex. Additional equipment will require the Chemist to run more machines simultaneously. Additional studies for manpower requirements would be needed if this alternative becomes the final decision. Alcan does not desire to add more personnel to run another instrument. Besides, automated equipment does not require more personnel; it requires larger capacity and better features.

A complete study of this and other alternatives will be presented in Section 6 of this paper.

5.3 Alternative #2: Sampler Upgrade Only from Vendor A

This alternative will be to upgrade the current equipment by replacing only the sampler of the existing unit with the megasampler with a capacity of handling 179 samples per run. Vendor A, current vendor, is the manufacturer. The vendor will offer a trade-in value at the time of upgrade. The equipment cost of this alternative will be $26,966 and it also includes upgrading to the latest version of their computer software. A quotation from the vendor was obtained by e-mail on January 15, 2002. [5.1]

This upgrade will have the same capabilities as described in Alternative #1 as far as the chemistry principles and software capabilities are concerned. The characteristics of what is expected from the vendor described in Alternative #1 apply here also.

One of the advantages of this alternative is that the chemistries will be together in the same unit making the analysis easier for the Chemist. And, of course the sampler capacity will be expanded to where the final results for the cassette samples will be finalized in 24 hours as required by the Environmental Group.

One disadvantage is that all the chemistries will remain in one unit as the present instrument causing a small problem for the analysis of Total Acid Number (TAN) in transformer oils. A different sample tray will be necessary to switch to for the analysis of TAN in transformer oils if all the chemistries are kept together. A photograph of the megasampler using the tray for Total Acid Number (TAN) analysis is shown on Figure 5.2. A more detailed analysis of this alternative will be presented in Section 6 of this paper.

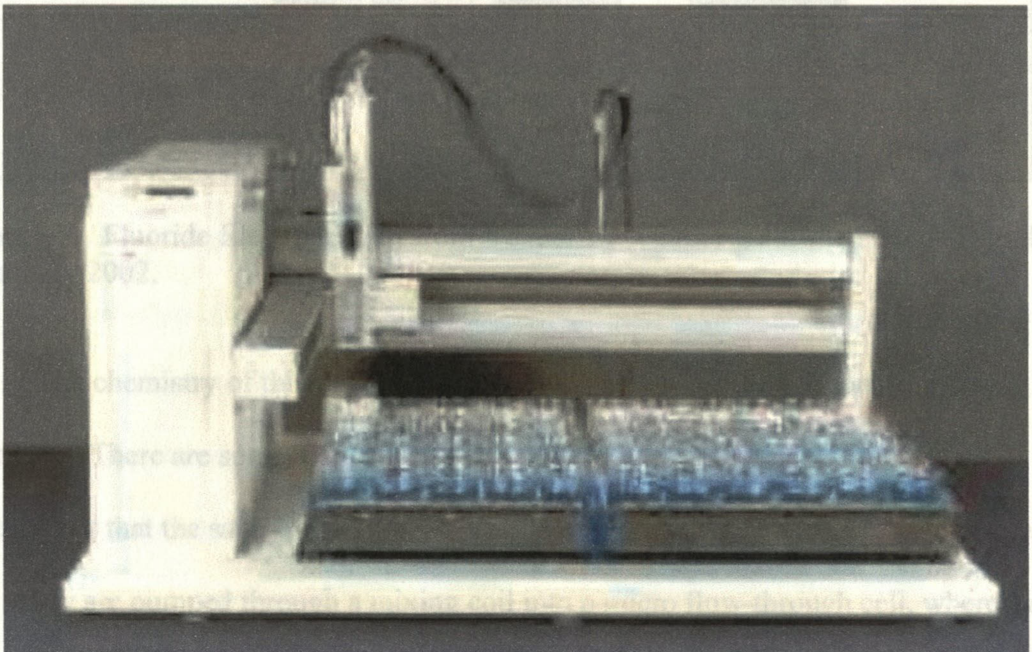


Figure 5.2. Megasampler with Beaker Tray for TAN Analysis. Vendor A. E-mail from the author. 15 January 2002.

5.4 Alternative #3: New Fluoride Unit from Vendor B

This alternative will be to purchase an equivalent unit with also a megasampler for fluoride only and keep the existing unit for the other chemistries and as a backup for fluoride analysis.

A new vendor, Vendor B, was contacted by e-mail on February 8, 2002. [5.2] A photograph of this unit is shown on Figure 5.3.

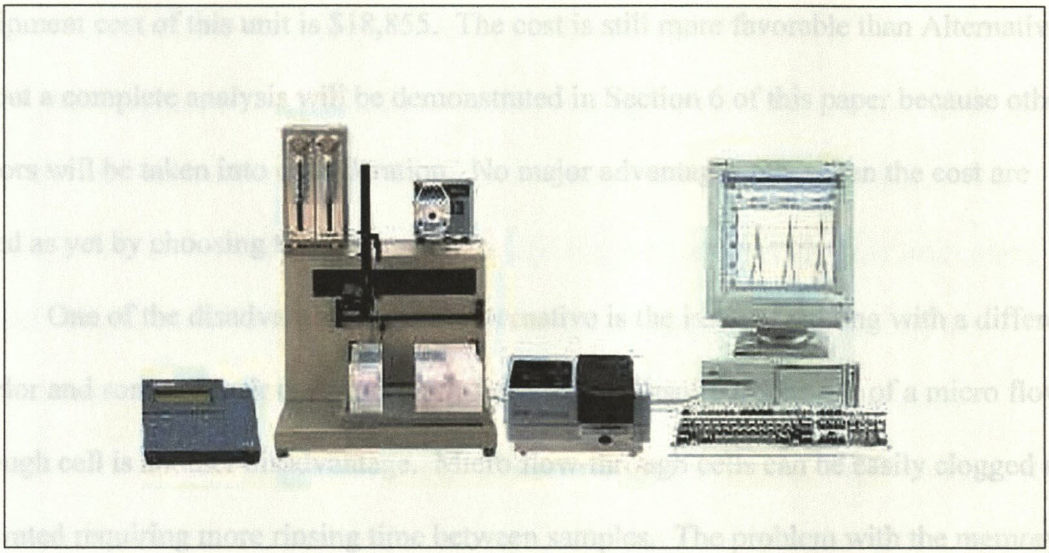


Figure 5.3. Fluoride Electrode Unit from Vendor B. Vendor B. E-mail from the author. 08 January 2002.

The chemistry of this automated equipment is also based on fluoride electrode chemistry. There are some differences when compared to the Vendor A unit. One difference is that the sample and TISAB are electronically pumped but not to a reaction cell. They are pumped through a mixing coil into a micro flow-through cell, where the fluoride is measured. Another difference is that the instrument does not have a built-in millivolt meter, it uses a regular pH/Specific Ion meter. Samples can not be left unattended because the memory of the meter becomes overloaded and must be cleared before proceeding with more samples. The sampler capabilities will be similar as Alternative #1 with the difference of using small test tubes. Small test tubes are 10-ml capacity sample tubes. The samples prepared in the centrifuge tubes will have to be transferred to the 10-ml test tubes adding additional manual labor to the process. Software capabilities are the same as Vendor A unit.

The advantage of this unit versus Alternative #1 is the equipment cost. The equipment cost of this unit is $18,855. The cost is still more favorable than Alternative #2 but a complete analysis will be demonstrated in Section 6 of this paper because other factors will be taken into consideration. No major advantages other than the cost are noted as yet by choosing this alternative.

One of the disadvantages of this alternative is the issue of dealing with a different vendor and some of their customers may have to be consulted. The use of a micro flow-through cell is another disadvantage. Micro flow-through cells can be easily clogged and saturated requiring more rinsing time between samples. The problem with the memory of the meter that has to be cleared periodically not allowing the instrument to run unattended overnight is another disadvantage. And, the additional manual transfer of samples from the centrifuge tubes to small test tubes which causes additional labor and time delay in reporting of sample results is another disadvantage. Evaluation of this alternative will be considered in Section 6 of this paper.

[5.2] Vendor B. E-mail from the author. 08 January 2002.

6. ECONOMIC ANALYSIS OF THE ALTERNATIVES

6.1 Introduction

The summary of the alternatives for this study presented in the Section 5 of this paper are:

- Alternative #1: complete new fluoride unit from Vendor A.
- Alternative #2: sampler upgrade only from Vendor A.
- Alternative #2: complete new fluoride unit from Vendor B.

All expenses throughout this economic evaluation will be estimated before taxes. The most important factors to consider here are the benefits that the equipment will provide for the laboratory at the lowest cost and the payback period of the instrument. Capital budgets are strictly monitored this year as a result of a weak economy and recession and it is very important for Alcan to choose the alternative that would maximize savings for the company. The company considers a Minimum Attractive Rate of Return (MARR) to be 11% and a very successful Payback Period to be less than 3 years. [6.1]

All alternatives will be analyzed over a five-year period. Five-year period is a good representation of what the company considers to be a successful project life for laboratory equipment before any upgrades are necessary. Laboratory equipment at Alcan is considered to have a 5-year life since it is technologically obsolete sooner than most equipment. Also Alcan considers laboratory equipment to have a trade-in value equal to

[6.1] Schneider, Pam. Controller. Alcan Ingot. “Re: Some Financial Questions.” E-mail from the author. 27 November 2000.

10% of the original cost at the end of the 5-year useful life. [6.2] This cost is credited to the cost of a new instrument by the new vendor at the time when the equipment is replaced or upgraded.

6.2 Basic Estimation of Chemicals and Operating and Maintenance Costs

The estimated typical chemical and maintenance and operating costs were estimated from past history records of the operation of the present automated method. The cost of chemicals from 1998 to 2001 is summarized in Table 6.1.

A future worth cost was calculated for the chemical expenses listed on Table 6.1. Then with this future worth cost the Equivalent Uniform Annual Cost (EUAC) for Chemicals was estimated. [6.3] The interest rate used is the Minimum Attractive Rate of Return (MARR) of 11 %. The calculations were performed with Microsoft Excel 97 and are shown in Table 6.2.

[6.2] Schneider, Pam. Controller. Alcan Ingot. "Re: Financial Question." E-mail from the author. 03 March 2002.

[6.3] Newnan Donald G., Lavelle Jerome P., Eschenbach Ted G. Engineering Economic Analysis. Engineering Press. Austin, Texas. 8th Edition. 2000. 207-223.

Table 6.1

Historical Cost of Chemicals from 1998 to 2001

	1998	1999	2000	2001
January	$379 $90 $189	$192 $24 $92	$413 $219	$610
February	$190 $52 $77	$113 $390	$172 $449	$376 $76 $450 $919
March	$906 $84	$24 $189	$190 $190	
April	$192	$156	$47 $450 $55	$228 $376
May	$734	$189 $389	$225 $467 $56	$115 $58
June	$761 $104	$375 $645	$449	$555 $190 $190
July	$374 $209 $384 $45 $91	$75		$450 $155
August	$155 $263 $91	$52	$130 $162 $27 $450 $78	$376 $232
September	$54 $560 $55 $389	$562 $376 $130 $138	$375	$228 $26
October	$119 $734	$375 $56	$78 $450 $55	$227 $171 $636 $88
November	$159		$305 $375	$109
December	$52 $54 $189	$32		
Total	**$7,735**	**$4,382**	**$5,867**	**$5,837**

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Table 6.2

Calculations of EUAC of Chemicals

i = 11%				
Period	**Year**	**Reagents**	**NPV**	**F=P*(1+i)^n**
1	1998	$7,735	$6,968	$10,579
2	1999	$4,382	$10,525	$5,399
3	2000	$5,867	$14,815	$6,512
4	2001	$5,837	$18,660	$5,837
Total				**$28,327**
EUAC of Chemicals =		F(A/F,11%,4) =	$6,015	
EUAC of Chemicals =		P(A/P,11%,4) =	$6,015	

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Other historical costs of equipment maintenance and consumable parts from 1998 to 2001 are shown in Table 6.3. No other historical data for maintenance and operating costs were available at the company for this particular instrument.

The Equivalent Uniform Annual Cost (EUAC) for Operating and Maintenance was calculated using Microsoft Excel and the calculations are shown in Table 6.4. The interest rate used here is also 11%.

Table 6.3

Operating and Maintenance Historical Costs

Year	1998	1999	2000	2001
	$889 $348	$965	$0	$858
Total	**$1,237**	**$965**	**$0**	**$858**

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Table 6.4

Calculation of EUAC for Instrument Operating and Maintenance

i = 11%				
Period	**Year**	**O&M**	**NPV**	**F=P*(1+i)^n**
1	1998	$1,237	$1,114	$1,692
2	1999	$965	$1,898	$1,189
3	2000	$0	$1,898	$0
4	2001	$858	$2,463	$858
Total				**$3,739**
EUAC of O&M =		F(A/F,11%,4) =	$794	
EUAC of O&M =		P(A/P,11%,4) =	$794	

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Another common cost for all alternatives is the replacement of electrodes. The cost of one electrode is $500 (cost obtained from recent Laboratory Equipment Catalog) and 2 electrodes are needed per year. The cost of electrodes per year is $1000.

The EUAC just calculated are summarized as:

- Chemicals: $6,015.
- Operating and Maintenance: $794.
- Fluoride electrode replacements: $1,000.

The Equivalent Uniform Annual Costs for Chemicals and Operating and Maintenance, and Fluoride Electrode replacements will be common for all three alternatives. Again it is important to note here that after tax figures, depreciation, or inflation will not be considered in this study.

6.3 Cash Flow and Net Present Worth Calculations for Alternative #1, New Unit from Vendor A

Initial equipment cost and installation for this alternative is $43,379.

The following cost estimates for benefits are made for a 5-year period if the complete fluoride unit from Vendor A is purchased:

- The ability to own a larger sampler and the capacity to analyze all samples in 24 hours will represent a benefit to the company of $17,280 per year. This figure was calculated using a labor rate of $30/hour and 2 sample periods per month ($30/hour * 24 hours *2 sample periods/ month * 12 months/year).
- Another benefit will be the ability to separate the fluoride chemistry from other chemistries allowing simultaneous analyses of fluoride and Total Acid Number (TAN) samples. This benefit was estimated at $30 per hour labor rate times 16 hours per month times 12 months per year ($30/hour * 16 hours/month * 12 months/year). And this benefit to the company is calculated as $5,760/year.
- Additional cost to the company for research and development after installation for this unit is estimated to be $0. This means no additional research and development is expected to be needed by Alcan personnel at the time of setup.
- Trade-in value at the end of five years is ($43,379)*0.10 = $4,338. [6.2]
- Chemicals: $6,015.
- Operating and Maintenance: $794.
- Fluoride electrode replacements: $1,000.

The cash flows for this alternative were entered in a Microsoft Excel spreadsheet and they are represented in Table 6.5.

Table 6.5

Cash Flows for Alternative #1

Alternative #1 from Vendor A
i = 11%
Additional Cost on Research at Time of Setup = $0

Year	Period	Initial Cost	Annual Benefits From Larger Sampler = ($30*24*2*12)	Annual Benefits Freeing up for TAN = ($30*16*12)	Expenses Electrodes	Expenses Chemicals	Maintenance and Operating Expenses
2002	0	($43,379)					
2003	1		$17,280	$5,760	($1,000)	($6,015)	($794)
2004	2		$17,280	$5,760	($1,000)	($6,015)	($794)
2005	3		$17,280	$5,760	($1,000)	($6,015)	($794)
2006	4		$17,280	$5,760	($1,000)	($6,015)	($794)
2007	5	$4,338	$17,280	$5,760	($1,000)	($6,015)	($794)

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

The benefit columns were summed together, and the expense columns were subtracted from the benefits. The trade-in cost was added to the benefits in year 5. This value yields the net benefit for each year. The net benefit column is shown in Table 6.6. The Present Worth (PW) was calculated for both the initial cost and the benefits for this alternative. The Net Present Worth (NPW) for this alternative is $15,490. Next, the Equivalent Uniform Annual Cost (EUAC) and the Equivalent Uniform Annual Benefit (EUAB) were calculated. The EUAC was subtracted from EUAB and the net value for this alternative, known as the Uniform Annual Benefit (UAB), is $4,191. The results of all of these calculations are also illustrated in Table 6.6.

Table 6.6

Net Present Worth and Uniform Annual Benefit Calculations for Alternative #1

Year	Period	Initial Cost	Net Benefits	Present Worth Net Benefits P*(1+i)^-n
2002	0	($43,379)		
2003	1		$15,232	$13,722
2004	2		$15,232	$12,362
2005	3		$15,232	$11,137
2006	4		$15,232	$10,034
2007	5		$19,569	$11,614
Total				$58,869

PW Cost (1) = Initial Cost :	$43,379	
PW Benefits (1) =	$58,869	
EUAC (1) =	**$43,379*(P/A, 11%,5) =**	$11,737
EUAB (1) =	**$58,869*(P/A, 11%, 5) =**	$15,928
Net Present Worth (1) =	**PW(Benefits) - Initial Cost =**	$15,490
EUAB (1) - EUAC (1) =	**UAB (1) = $15,490*(P/A, 11%,5) =**	$4,191

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

6.4 Cash Flow and Net Present Worth Calculations for Alternative #2, Sampler Upgrade Only from Vendor A

Initial equipment cost and installation for this alternative is $26,966.

The following cost estimates for benefits are made for a 5-year period if the sampler upgrade unit from Vendor A is purchased:

- The ability to own a larger sampler and the capacity to analyze all samples in 24 hours will represent a benefit to the company of $17,280 per year. This figure was calculated using a labor rate of $30/hour and 2 sample periods per month ($30/hour * 24 hours *2 sample periods/ month * 12 months/year). Same as Alternative #1.

- Simultaneous analyses of fluoride and TAN are not possible with this alternative. The benefit provided by this alternative would be the capacity of the larger sampler that would allow more samples per run. This benefit was estimated at $30 per hour labor rate times 8 hours per month times 12 months per year ($30/hour * 8 hours/month * 12 months/year). And this benefit to the company is calculated as $2,280 per year.
- Additional cost to the company for research and development after installation for this unit is estimated to be $0. This means no additional research and development is expected to be needed by Alcan personnel at the time of setup.
- Trade-in value at the end of five years is ($26,966)*0.10 = $2,697. [6.2]
- Chemicals: $6,015.
- Operating and Maintenance: $794.
- Fluoride electrode replacements: $1,000.

The cash flows for this alternative were entered in a Microsoft Excel spreadsheet and they are represented in Table 6.7.

Table 6.7

Cash Flows for Alternative #2

Alternative #2 from Vendor A
i = 11%
Additional Cost on Research at Time of Setup = $0

Year	Period	Initial Cost	Annual Benefits From Larger Sampler = ($30*24*2*12)	Annual Benefits Larger Sampler for TAN = ($30*8*12)	Expenses Electrodes	Expenses Chemicals	Maintenance and Operating Expenses
2002	0	($26,966)					
2003	1		$17,280	$2,880	($1,000)	($6,015)	($794)
2004	2		$17,280	$2,880	($1,000)	($6,015)	($794)
2005	3		$17,280	$2,880	($1,000)	($6,015)	($794)
2006	4		$17,280	$2,880	($1,000)	($6,015)	($794)
2007	5	$2,697	$17,280	$2,880	($1,000)	($6,015)	($794)

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

The benefit columns were summed together, and the expense columns were subtracted from the benefits. The trade-in cost was added to the benefits in year 5. This value yields the net benefit for each year. The net benefit column is shown in Table 6.8. The Present Worth (PW) was calculated for both the initial cost and the benefits for this alternative. The Net Present Worth (NPW) for this alternative is $20,284. Next, the Equivalent Uniform Annual Cost (EUAC) and the Equivalent Uniform Annual Benefit (EUAB) were calculated. The EUAC was subtracted from EUAB and the net value for this alternative, known as the Uniform Annual Benefit (UAB), is $5,488. The results of all of these calculations are also illustrated in Table 6.8.

Table 6.8

Net Present Worth and Uniform Annual Benefit Calculations for Alternative #2

Year	Period	Initial Cost	Net Benefits	Present Worth Net Benefits P*(1+i)^-n
2002	0	($26,966)		
2003	1		$12,352	$11,128
2004	2		$12,352	$10,025
2005	3		$12,352	$9,031
2006	4		$12,352	$8,136
2007	5		$15,048	$8,930
Total				$47,250

PW Cost (2) = Initial Cost =	$26,966	
PW Benefits (2) =	$47,250	
EUAC (2) =	$26,966*(P/A, 11%,5) =	$7,296
EUAB (2) =	$47,250*(P/A, 11%, 5) =	$12,785
Net Present Worth (2) =	PW(Benefits) - Initial Cost =	$20,284
EUAB (2) - EUAC (2) =	UAB (2) = $20,284*(P/A, 11%,5) =	$5,488

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

6.5 Cash Flow and Net Present Worth Calculations for Alternative #3, New Unit from Vendor B

Initial equipment cost and installation for this alternative is $18,855.

The following cost estimates for benefits are made for a 5-year period if the complete fluoride unit from Vendor B is purchased:

- This option will not allow the instrument to run unattended. The benefit to the company was estimated to be of 16 hours per sampling period. This figure was calculated using a labor rate of $30/hour times 16 hours times 2 sample periods per month times 12 months per year ($30/hour * 16 hours *2 sample periods/ month * 12 months/year). This figure was calculated as $11,520/year.

- Another benefit will be the ability to separate the fluoride chemistry from other chemistries allowing simultaneous analyses of fluoride and Total Acid Number (TAN) samples. This benefit was estimated at $30 per hour labor rate times 16 hours per month times 12 months per year ($30/hour * 16 hours/month * 12 months/year). And this benefit to the company is calculated as $5,760/year.
- Additional cost to the company for research and development after installation for this unit is estimated to be $2,400. This means that additional research and development is expected to be needed by Alcan personnel at the time of setup. This figure was calculated at $30/hour labor times 40 hours per week times 2 weeks. This cost of $2,400 will be added to the initial cost for the economic analysis.
- Trade-in value at the end of five years is ($18,855)*0.10 = $1,886. [6.2]
- Chemicals: $6,015.
- Operating and Maintenance: $794.
- Fluoride electrode replacements: $1,000.
- An additional cost of $2000 will be added to the fluoride electrode cost. This cost represents the cost of the flow-through cells. Two cells are needed per year and the cost per cell obtained from the vendor is $1000.

The cash flows for this alternative were entered in a Microsoft Excel spreadsheet and they are represented in Table 6.9.

Table 6.9

Cash Flows for Alternative #3

Alternative #3 from Vendor B
i = 11%
Additional Cost on Research at Time of Setup = = ($30*40*2) = ($2,400)

Year	Period	Initial Cost	Annual Benefits From Larger Sampler = ($30*16*2*12)	Annual Benefits Freeing up for TAN = ($30*16*12)	Expenses Electrodes plus Flow Cell	Expenses Chemicals	Maintenance and Operating Expenses
2002	0	($18,855)					
2003	1		$11,520	$5,760	($3,000)	($6,015)	($794)
2004	2		$11,520	$5,760	($3,000)	($6,015)	($794)
2005	3		$11,520	$5,760	($3,000)	($6,015)	($794)
2006	4		$11,520	$5,760	($3,000)	($6,015)	($794)
2007	5	$1,886	$11,520	$5,760	($3,000)	($6,015)	($794)

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

The benefit columns were summed together, and the expense columns were subtracted from the benefits. The trade-in cost was added to the benefits in year 5. This value yields the net benefit for each year. The net benefit column is shown in Table 6.10. The Present Worth (PW) was calculated for both the initial cost and the benefits for this alternative. The Net Present Worth (NPW) for this alternative is $7,478. Next, the Equivalent Uniform Annual Cost (EUAC) and the Equivalent Uniform Annual Benefit (EUAB) were calculated. The EUAC was subtracted from EUAB and net value for this alternative, known as the Uniform Annual Benefit (UAB), is $2,023. The results of all of these calculations are also illustrated in Table 6.10.

Table 6.10

Net Present Worth and Uniform Annual Benefit Calculations for Alternative #3

Year	Period	Initial Cost	Net Benefits	Present Worth Net Benefits P*(1+i)^-n
2002	0	($21,255)		
2003	1		$7,472	$6,731
2004	2		$7,472	$6,064
2005	3		$7,472	$5,463
2006	4		$7,472	$4,922
2007	5		$9,357	$5,553
Total				$28,733

PW Cost (3) = Initial Cost =	$21,255	
PW Benefits (3) =	$28,733	
EUAC (3) =	**$21,255*(P/A, 11%,5) =**	$5,751
EUAB (3) =	**$28,733*(P/A, 11%, 5) =**	$7,774
Net Present Worth (3) =	**PW(Benefits) - Initial Cost =**	$7,478
EUAB (3) - EUAC (3) =	**UAB (3) = $7,478*(P/A, 11%,5) =**	$2,023

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

6.6 Cash Flow Analysis by the Net Present Worth and Uniform Annual Benefit Criterions

The Net Present Worth (NPW) and the result of subtracting the Equivalent Annual Cost (EUAC) from the Equivalent Uniform Annual Benefit (EUAB), known as the Uniform Annual Benefit (UAB), calculated for all three alternatives are summarized in Table 6.11.

Table 6.11

Summary of Net Present Worth and Uniform Annual Benefit Calculations for all Alternatives

	Alternative #1 Complete Unit Vendor A	Alternative #2 Sampler Upgrade Vendor A	Alternative #3 Complete Unit Vendor B
NPW	$15,490	$20,284	$7,478
UAB	$4,191	$5,488	$2,023

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Based on the Net Present Worth criterion for economic efficiency, the criteria is to maximize the Net Present Worth (present worth of benefits minus present worth of cost). [6.4] This means that the alternative that yields the greatest Net Present Worth value will be the preferred alternative. Based on this method the best decision is Alternative #2 because it yields the largest Net Present Worth value.

Based on the Uniform Annual Benefit criterion for economic efficiency, the criteria is to maximize the difference of the Equivalent Uniform Annual Benefits minus the Equivalent Uniform Annual Cost (EUAB – EUAC). [6.5] Based on this method the final decision is Alternative #2 because it yields the largest result for UAB.

[6.4] Newnan Donald G., Lavelle Jerome P., Eschenbach Ted G. Engineering Economic Analysis. Engineering Press. Austin, Texas. 8th Edition. 2000. 169.

[6.5] Newnan Donald G., Lavelle Jerome P., Eschenbach Ted G. Engineering Economic Analysis. Engineering Press. Austin, Texas. 8th Edition. 2000. 212.

6.7 Sensitivity Analysis

This analysis was performed using Sensitivity Analysis Tools. [6.6] From the Net Present Worth analysis summarized in Table 6.11 Alternative #2 was the preferred alternative. Here it is necessary to know how sensitive the decision is to the estimate of the initial cost of Alternative #2. The sensitivity analysis will calculate what the highest value for the initial cost of Alternative #2 would be and still have Alternative #2 as the preferred alternative. The interest rate used in these calculations is 11% which is the Alcan's MARR. With neither input nor output fixed the suitable criterion is to maximize the Net Present Worth. [6.6]

<u>Alternative #1</u>:

NPW (Alt. #1) = PW (Benefits) - PW (Cost)

NPW (Alt. #1) = $15,928 * (P/A, 11%, 5) - $43,379

NPW (Alt. #1) = $15,928 * 3.6959 - $43,379

NPW (Alt. #1) = $58,869 - $43,379

NPW (Alt. #1) = $15,490

<u>Alternative #2</u>: Let x = Initial cost of Alternative #2

NPW (Alt. #2) = $12,785 * (P/A, 11%, 5) – x

NPW (Alt. #2) = $12,785 * 3.6959 – x

NPW (Alt. #2) = $47,251 – x

<u>Alternative #3</u>:

NPW (Alt. #3) = $7,774 * 3.6959 - $18,855 - $2,400

NPW (Alt. #3) = $7,478

[6.6] Newnan Donald G., Lavelle Jerome P., Eschenbach Ted G. Engineering Economic Analysis. Engineering Press. Austin, Texas. 8th Edition. 2000. 342-349.

For the three alternatives it can be noticed that Alternative #2 will only maximize Net Present Worth (NPW) as long as its NPW is greater than $15,490.

Then:

$15,490 = $47,250 – x

x = $47,250 - $15,490

x = $31,761

Therefore, Alternative #2 is the preferred alternative if its initial cost does not exceed $31,761. The breakeven chart for the alternatives is shown on Figure 6.1. [6.6]

Figure 6.1 is a breakeven chart for the three alternatives. Here the criterion is to maximize NPW; as a result, the graph shows that Alternative #2 is preferred if its initial cost is less than $31,761. At an initial cost above $31,761, Alternative #1 is preferred. The breakeven point is at $31,761. When Alternative #2 has an initial cost of $31,761, Alternative #2 and Alternative #1 are equally desirable. [6.6]

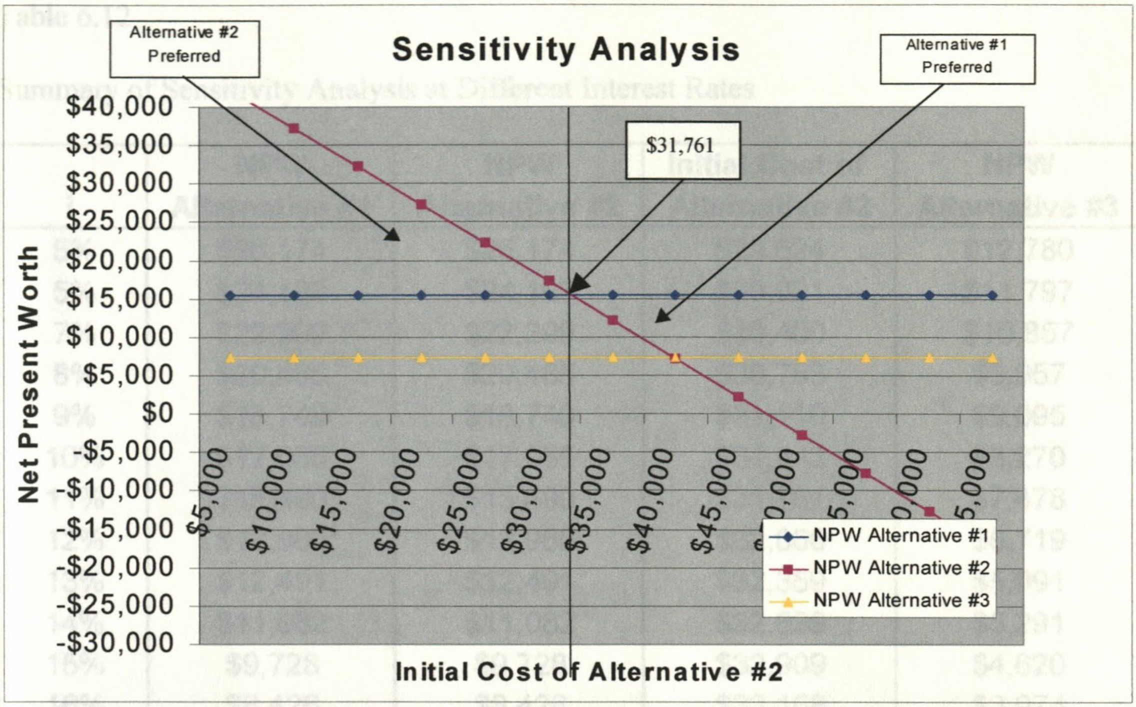


Figure 6.1. Breakeven Chart for the Three Alternatives. Mora, Ana E. Created with Microsoft Excel 97. 03 March 02.

The same calculations just explained in this sensitivity analysis were performed with the same model at different interest rates and the results are summarized in Table 6.12. The graph for these values is shown in Figure 6.2.

Table 6.12

Summary of Sensitivity Analysis at Different Interest Rates

i	NPW Alternative #1	NPW Alternative #2	Initial Cost of Alternative #2	NPW Alternative #3
5%	$26,174	$26,174	$29,624	$12,780
5%	$24,193	$24,193	$30,021	$11,797
7%	$22,299	$22,299	$30,400	$10,857
8%	$20,485	$20,485	$30,763	$9,957
9%	$18,749	$18,749	$31,110	$9,095
10%	$17,085	$17,085	$31,442	$8,270
11%	$15,490	$15,490	$31,761	$7,478
12%	$13,960	$13,960	$32,066	$6,719
13%	$12,491	$12,491	$32,359	$5,991
14%	$11,082	$11,082	$32,639	$5,291
15%	$9,728	$9,728	$32,909	$4,620
16%	$8,426	$8,426	$33,168	$3,974
17%	$7,175	$7,175	$33,416	$3,354
18%	$5,972	$5,972	$33,655	$2,757
19%	$4,813	$4,813	$33,885	$2,182
20%	$3,698	$3,698	$34,106	$1,629
21%	$2,624	$2,624	$34,319	$1,097
22%	$1,589	$1,589	$34,524	$584
23%	$591	$591	$34,722	$89
24%	($371)	($371)	$34,912	($388)
24.035%	($404)	($404)	$34,944	($404)
25%	($1,300)	($1,300)	$35,096	($848)
26%	($2,196)	($2,196)	$35,273	($1,292)
27%	($3,061)	($3,061)	$35,444	($1,721)
28%	($3,897)	($3,897)	$35,609	($2,135)
29%	($4,705)	($4,705)	$35,769	($2,535)
30%	($5,486)	($5,486)	$35,923	($2,922)

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

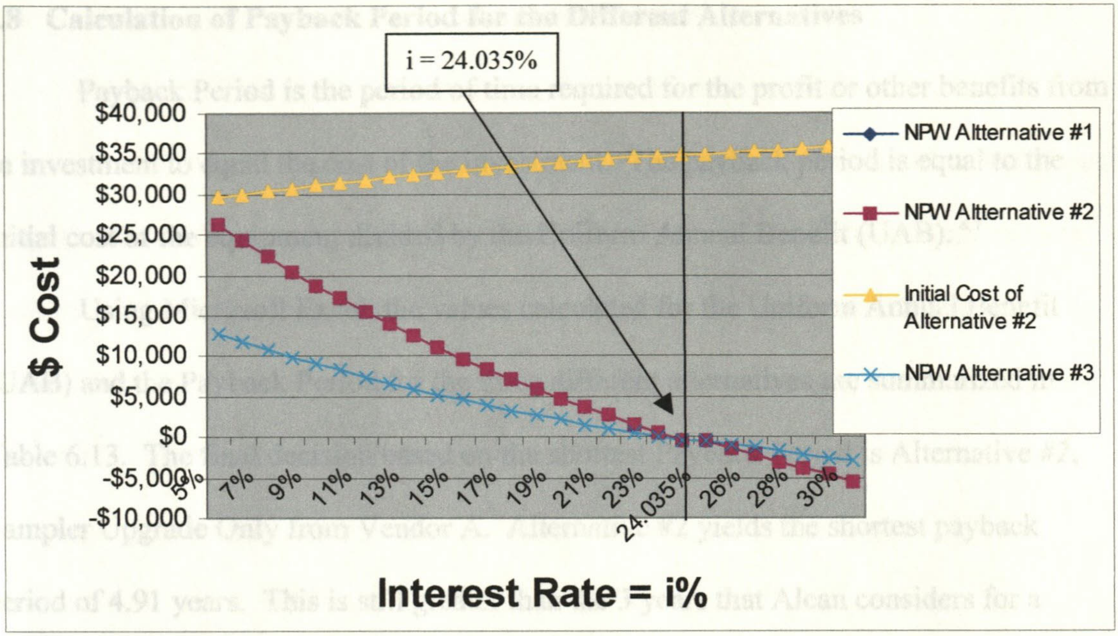


Figure 6.2. Sensitivity Analysis Values at Different Interest Rates. Mora Ana E. Created with Microsoft Excel 97. 03 March 2002.

It can be noticed from Table 6.12 and Figure 6.2 that at a rate of 24.305% is when all alternatives yield the same Net Present Worth and the cost of Alternative #2 at this point is $34,944. At interest rates higher than 24.035% the Net Present Worth of Alternative #1 is less than the Net Present Worth of Alternative #2 and the calculations explained here earlier would not work any longer. The calculation would have to be switched, stating that Alternative #2 will only maximize Net Present Worth (NPW) as long as its NPW is greater than the Net Present Worth for Alternative #3, in the equation when the variable "x" defining the cost of Alternative #2 is used. But at this point it is not necessary to continue any further with more calculations because all of the Net Present Worth values are negative and they would mean that the benefits are much less than the costs.

6.8 Calculation of Payback Period for the Different Alternatives

Payback Period is the period of time required for the profit or other benefits from an investment to equal the cost of the investment. The payback period is equal to the initial cost of the equipment divided by the Uniform Annual Benefit (UAB). [6.7]

Using Microsoft Excel, the values calculated for the Uniform Annual Benefit (UAB) and the Payback Period for the three different alternatives are summarized in Table 6.13. The final decision based on the shortest Payback Period is Alternative #2, Sampler Upgrade Only from Vendor A. Alternative #2 yields the shortest payback period of 4.91 years. This is still greater than the 3 years that Alcan considers for a project to be successful, but it is the best of the three alternatives. Payback period is considered to be only an approximation in economic analysis. [6.7]

Table 6.13

Summary of UAB and Payback Period for all Alternatives.

	Alternative #1 Complete Unit Vendor A	Alternative #2 Sampler Upgrade Vendor A	Alternative #3 Complete Unit Vendor B
Initial Cost	$43,379	$26,966	$21,255
UAB	$4,191	$5,488	$2,023
Payback Period (Years)	10.35	4.91	10.50

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

[6.7] Newnan Donald G., Lavelle Jerome P., Eschenbach Ted G. Engineering Economic Analysis. Engineering Press. Austin, Texas. 8th Edition. 2000. 337-342.

6.9 Evaluation of Alternatives by Incremental Analysis

All alternatives were analyzed using the incremental analysis tools. [6.8] The analysis started by summarizing all cash flows on one spreadsheet using Microsoft Excel. Then the alternatives were rearranged in descendent order, from the most expensive to the least expensive, and the internal rate of return (IRR) was calculated for each alternative. The calculations were performed using Microsoft Excel functions again and the results are summarized in Table 6.14

Table 6.14

Cash Flows for each Alternative and Calculation of IRR

Year	Alternative #1 Complete Unit Vendor A	Alternative #2 Sampler Upgrade Vendor A	Alternative #3 Complete Unit Vendor B
0	-$43,379	-$26,966	-$21,255
1	$15,232	$12,352	$7,472
2	$15,232	$12,352	$7,472
3	$15,232	$12,352	$7,472
4	$15,232	$12,352	$7,472
5	$19,569	$15,048	$9,357
IRR	23.911%	37.121%	23.781%

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Since all the calculated internal rates of return (IRR) are greater than the Alcan's Minimum Attractive Rate of Return (MARR) of 11%, no alternatives can be discarded at

[6.8] Newnan Donald G., Lavelle Jerome P., Eschenbach Ted G. Engineering Economic Analysis. Engineering Press. Austin, Texas. 8th Edition. 2000. 295-315.

this point. At this point Alternative #2 yielded the best internal rate of return (IRR) of 37.121%.

Then the next step is to compare Alternative #3 to Alternative #2, Alternative #3 was subtracted from Alternative #2 and the results are summarized in Table 6.15.

Table 6.15

Comparison of Alternative #3 to Alternative #2.

Year	Alternative #2 - Alternative #3
0	-$5,711
1	$4,880
2	$4,880
3	$4,880
4	$4,880
5	$5,691
IRR =	81.723%

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Since IRR (internal rate of return) is greater than 11%, Alternative #3 is discarded and Alternative #2 is kept. Next, Alternative #2 is compared to Alternative #1 by subtracting the cash flows of Alternative #2 from Alternative #1, and the results are summarized in Table 6.16.

Table 6.16

Comparison of Alternative #2 to Alternative #1

Year	Alternative #1 - Alternative #2
0	-$16,413
1	$2,880
2	$2,880
3	$2,880
4	$2,880
5	$4,521
IRR =	-0.711%

Source: Mora, Ana E. Created with Microsoft Excel 97. 03 March 2002.

Now the internal rate of return is less than 11% and it is also negative (–0.711%), so Alternative #1 is discarded and Alternative #2 is kept as the final alternative.

6.10 Conclusions

As the conclusion of this economic analysis by present worth, annual benefit cost, sensitivity analysis, payback period, and incremental analysis, Alternative #2 is the final decision to make. Alternative #2 yielded the best internal rate of return (IRR) of 37.121% when all the cash flows were from each alternative were analyzed. Alternative #2 is to purchase the upgrade sampler only from Vendor A.

Alternative #2 maximizes the Net Present Worth value when the equipment cost does not exceed $31,761. If the equipment cost exceeds $31,761, then Alternative #1 would be the preferred alternative. This is true for interest rate equal to Alcan's MARR of 11%.

The alternative that yields the best payback period is also Alternative #2 of 4.91 years. This is true for interest rate equal to Alcan's MARR of 11%.

Printouts of all the calculations obtained with the different Microsoft Excel spreadsheets at an interest rate of 11% can be found in Appendix B of this paper. Printouts for the sensitivity analysis at different interest rates can also be found in Appendix B of this paper.

7. PROJECT MANAGEMENT AND IMPLEMENTATION

7.1 Identification of the Project Task Activities

Some of the activities have already been identified and completed in this project. The rest of the activities are the remainder of the tasks that will be required for the project to be realized. The time for these remaining activities are estimated based upon past projects performed by the Laboratory Group. These activities are identified as follows:

1. Evaluation and definition of the problem. The problem has been defined as the necessity and importance to replace and/or upgrade the existing automated equipment for fluoride analysis in order to be able to fulfill the requirements of the Environmental Group. This requires a 24-hour turnaround analysis and sample reporting time. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 2 days.

2. Decision times of evaluating alternatives for consideration and selection of vendors. A number of alternatives were mentioned in Section 1 of this paper and only 3 were considered relevant for the final analysis. The 3 final different alternatives were presented in Section 5 of this paper and an economic analysis was presented in Section 6 of this paper. The vendors selected for contact were Vendor A and Vendor B. The Alcan Chemist is responsible for performing this task. An estimated optimistic time for completion is 1 day.

3. Contact Vendor A and request quotation. This vendor was contacted on January 7, 2002. The vendor was asked to supply Alcan with two quotations, one for a

new fluoride analyzer and a second one for a sampler upgrade only. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 1 day.

4. Contact Vendor B and request quotation. This vendor was contacted on January 7, 2002. The vendor was asked to supply Alcan with a quotation for a new fluoride analyzer. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 1 day.

5. Time for receipt of quotation from Vendor B. A quotation from this vendor was received on January 8, 2002. The Alcan Chemist is responsible for this task. An estimated time for completion is 1 day.

6. Time of receipt of quotations from Vendor A. Two quotations from this vendor were received on January 15, 2002. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 1 day.

7. Perform economic analysis of the 3 alternatives and make a decision based on the analysis. The economic analysis was covered in Section 6 of this paper. The final selection is Alternative #2 to purchase the sampler upgrade only from Vendor A. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 15 days.

8. Complete Request for Authorization (RFA) forms for Alcan approval of purchase. These forms will cover the presentations of alternatives and process selection that will be presented to the Management Group. These forms also include all the paperwork required to proceed with the approval for purchase of the instrument. It is assumed here that Alcan will approve the project once the decision based on the best alternative selected is proven to the Management Group. It is not part of this project to

assume that the project will not be approved, because as mention in Section 1 of this paper, the alternative of doing nothing is not a feasible alternative and is not what Alcan desires. The responsible person for this task is the Alcan Chemist. Due to workload schedule and other activities, this task has been estimated to begin in the last week of April, 2002. An estimated optimistic time for completion is 15 days.

9. Present the Request for Authorization (RFA) to the Management Group. Once the RFA is completed, it will be presented to the Alcan Management Group. The responsible person for this task is the Alcan Chemist. An estimated optimistic time for completion is 2 days.

10. Approval process time in the Management Group. Once the Management Group receives the completed RFA, they will hold meetings to discuss the request and render a decision with regard to the final approval. The Management Group is responsible for this task. An estimated optimistic time for completion is 15 days.

11. Schedule for completion of the purchase order requisition. Once the RFA is completed, the next step is to complete the purchase order requisition and to proceed with the purchase of the sampler upgrade. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 3 days.

12. Schedule for submission of requisition to the Purchasing Group. Once the purchase requisition is completed, it will be submitted to the Purchasing Group. The Alcan Chemist is responsible for this task. An estimated optimistic time for completion is 1 day.

13. Alcan processes purchase order. Once the Purchasing Group receives and approves the requisition, then the instrument will be ordered from Vendor A. The

Purchasing Group is responsible for this task. An estimated optimistic time for completion is 2 days.

14. Shipment and delivery of instrument. The instrument is transported from the Alcan's Store Facility to the laboratory. Alcan's Store personnel and the Alcan Chemist are responsible for this task. An estimated optimistic time for completion is 18 days.

15. Equipment is installed on-site by vendor. Vendor arrives at laboratory and spends 3 days installing the equipment and training the Alcan Chemist. Responsible persons are Vendor A Technicians and Alcan Chemist. An estimated optimistic time for completion is 3 days.

16. Learning and experimentation period. After the instrument is installed by the vendor, the Alcan Chemist has to spend some time becoming familiar with the new equipment and new technology. Responsible person for this task is the Alcan Chemist. An estimated optimistic time for completions is 7 days.

17. System is in full operation. After training and experimentation time by the Alcan Chemist, an estimated time of 2 additional days will be necessary in order to have the instrument ready for full and complete operation. Responsible person is the Alcan Chemist. An estimated optimistic time for completion is 2 days.

7.2 Calculation of Total Estimated Activity Times

In addition to the optimistic times for each activity mentioned above, a realistic and a pessimistic time were estimated. Using PERT Project Management Tools [7.1], the total estimated activity times were calculated using Microsoft Excel. The optimistic,

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[7.1] Meredith, Jack R., Mantel. Jr., Samuel J. Project Management. John Wiley & Sons, Inc. New York, New York. 4th Edition. 2000. 303-347.

realistic, pessimistic, and calculated total estimated times for each activity are shown in Table 7.1 and Table 7.2 respectively.

Table 7.1

Identification of Activities and Estimated Optimistic Time

Task #	Activity	Estimated time Optimistic Time
1	Evaluation and definition of the problem	7d
2	Decision times of evaluating alternatives for consideration and selection of vendors	2d
3	Contact Vendor A and request quotations	1d
4	Contact Vendor B and request quotation	1d
5	Time of receipt of quotation from Vendor B	1d
6	Time of receipt of quotations from Vendor A	1d
7	Perform Economic analysis Decision is to purchase sampler upgrade from Vendor A	15d
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	15d
9	Present RFA to the Management Group	2d
10	Approval process from Management	15d
11	Schedule for completion of the purchase order requisition	3d
12	Schedule for submission of requisition to the Purchasing Group	1d
13	Alcan processes purchase order	2d
14	Shipment and delivery of instrument	18d
15	Equipment is installed on-site by vendor	3d
16	Learning and experimentation period	7d
17	System in full operation	2d

Source: Mora, Ana E. Created with Microsoft Excel 97. 25 February 2002.

Table 7.2

Calculation of Total Estimated Times for the Activities

a =optimistic time estimate
b = pessimistic time estimate
m = typical (modal) time estimate
TE = Total estimated time to complete the task

TE = (a+4*m+b)/6
Variance = ((b-a)/6)^2
Standard Deviation = (Variance)^0.5

Task #	a	m	b	TE	Variance	Standard Deviation
1	5	7	12	7.5	1.4	1.2
2	1	2	5	2.3	0.4	0.7
3	1	1	4	1.5	0.3	0.5
4	1	1	4	1.5	0.3	0.5
5	1	1	4	1.5	0.3	0.5
6	1	1	4	1.5	0.3	0.5
7	13	15	22	15.8	2.3	1.5
8	13	15	22	15.8	2.3	1.5
9	1	2	5	2.3	0.4	0.7
10	13	15	22	15.8	2.3	1.5
11	3	3	6	3.5	0.3	0.5
12	1	1	4	1.5	0.3	0.5
13	2	2	5	2.5	0.3	0.5
14	15	18	27	19.0	4.0	2.0
15	3	3	6	3.5	0.3	0.5
16	7	7	12	7.8	0.7	0.8
17	2	2	5	2.5	0.3	0.5

Source: Mora, Ana E. Created with Microsoft Excel 97. 25 February 2002.

7.3 Estimation of Start and End Times for each Activity

Start and end times for each activity were estimated based on the Alcan Chemist's workload and other scheduled projects in the present calendar year. These times and the previously calculated total estimated times for each activity were entered in Microsoft Project Version 4.0 [7.2] and they are shown in Table 7.3. Predecessors for each activity were also determined and are shown in this table. This project is very straightforward.

[7.2] Microsoft Project. Version 4.0. 1990-1994.

One task is actually followed by the next task and none of the tasks can be completed before any of the predecessors are completed.

Table 7.3

Entry Table of Total Estimated Times and Start and Finish Times for each Activity

Task #	Task Name	Duration	Start	Finish	Predecessors
1	Evaluation and definition of the problem	7.5d	12/18/2001	12/27/2001	
2	Decision times of evaluating alternatives for consideration and selection of vendors	2.3d	1/2/2002	1/4/2002	1
3	Contact Vendor A and request quotations	1.5d	1/4/2002	1/7/2002	1,2
4	Contact Vendor B and request quotation	1.5d	1/7/2002	1/8/2002	1,2
5	Time of receipt of quotation from Vendor B	1.5d	1/8/2002	1/9/2002	4
6	Time of receipt of quotations from Vendor A	1.5d	1/15/2002	1/16/2002	3
7	Perform Economic analysis Decision is to purchase sampler upgrade from Vendor A	15.8d	2/15/2002	3/8/2002	5,6
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	15.8d	4/29/2002	5/20/2002	7
9	Present RFA to the Management Group	2.3d	5/20/2002	5/23/2002	8
10	Approval process from Management	15.8d	5/23/2002	6/13/2002	9
11	Schedule for completion of the purchase order requisition	3.5d	6/13/2002	6/19/2002	10
12	Schedule for submission of requisition to the Purchasing Group	1.5d	6/19/2002	6/20/2002	11
13	Alcan processes purchase order	2.5d	6/20/2002	6/25/2002	12
14	Shipment and delivery of instrument	19d	6/25/2002	7/22/2002	13
15	Equipment is installed on-site by vendor	3.5d	7/22/2002	7/25/2002	14
16	Learning and experimentation period	7.8d	7/25/2002	8/6/2002	15
17	System in full operation	2.5d	8/6/2002	8/9/2002	16

Source: Mora, Ana E. Created with Microsoft Project Version 4.0. 25 February 2002.

7.4 Calculation of Project Schedule and Critical Path

The project schedule and the critical path were also calculated using Microsoft Project Version 4.0 and the values are shown in Table 7.4. The tasks that are part of the critical path are activities #8 to #17 inclusively. The critical path activities are defined by activities having a total slack value equal to zero. [7.3]

Table 7.4

Project Schedule, Total Slack, and Critical Path Calculations

Task #	Task Name	Start	Finish	Late Start	Late Finish	Total Slack
1	Evaluation and definition of the problem	12/18/2001	12/27/2001	3/19/2002	3/28/2002	64.9
2	Decision times of evaluating alternatives for consideration and selection of vendors	1/2/2002	1/4/2002	3/28/2002	4/2/2002	61.9
3	Contact Vendor A and request quotations	1/4/2002	1/7/2002	4/2/2002	4/3/2002	61.9
4	Contact Vendor B and request quotation	1/7/2002	1/8/2002	4/2/2002	4/3/2002	61.2
5	Time of receipt of quotation from Vendor B	1/8/2002	1/9/2002	4/3/2002	4/5/2002	61.2
6	Time of receipt of quotations from Vendor A	1/15/2002	1/16/2002	4/3/2002	4/5/2002	56.7
7	Perform Economic analysis Decision is to purchase sampler upgrade from Vendor A	2/15/2002	3/8/2002	4/5/2002	4/26/2002	35
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	4/29/2002	5/20/2002	4/29/2002	5/20/2002	0
9	Present RFA to the Management Group	5/20/2002	5/23/2002	5/20/2002	5/23/2002	0
10	Approval process from Management	5/23/2002	6/13/2002	5/23/2002	6/13/2002	0
11	Schedule for completion of the purchase order requisition	6/13/2002	6/19/2002	6/13/2002	6/19/2002	0
12	Schedule for submission of requisition to the Purchasing Group	6/19/2002	6/20/2002	6/19/2002	6/20/2002	0
13	Alcan processes purchase order	6/20/2002	6/25/2002	6/20/2002	6/25/2002	0
14	Shipment and delivery of instrument	6/25/2002	7/22/2002	6/25/2002	7/22/2002	0
15	Equipment is installed on-site by vendor	7/22/2002	7/25/2002	7/22/2002	7/25/2002	0
16	Learning and experimentation period	7/25/2002	8/6/2002	7/25/2002	8/6/2002	0
17	System in full operation	8/6/2002	8/9/2002	8/6/2002	8/9/2002	0

Source: Mora Ana E. Created with Microsoft Project Version 4.0. 25 February 2002.

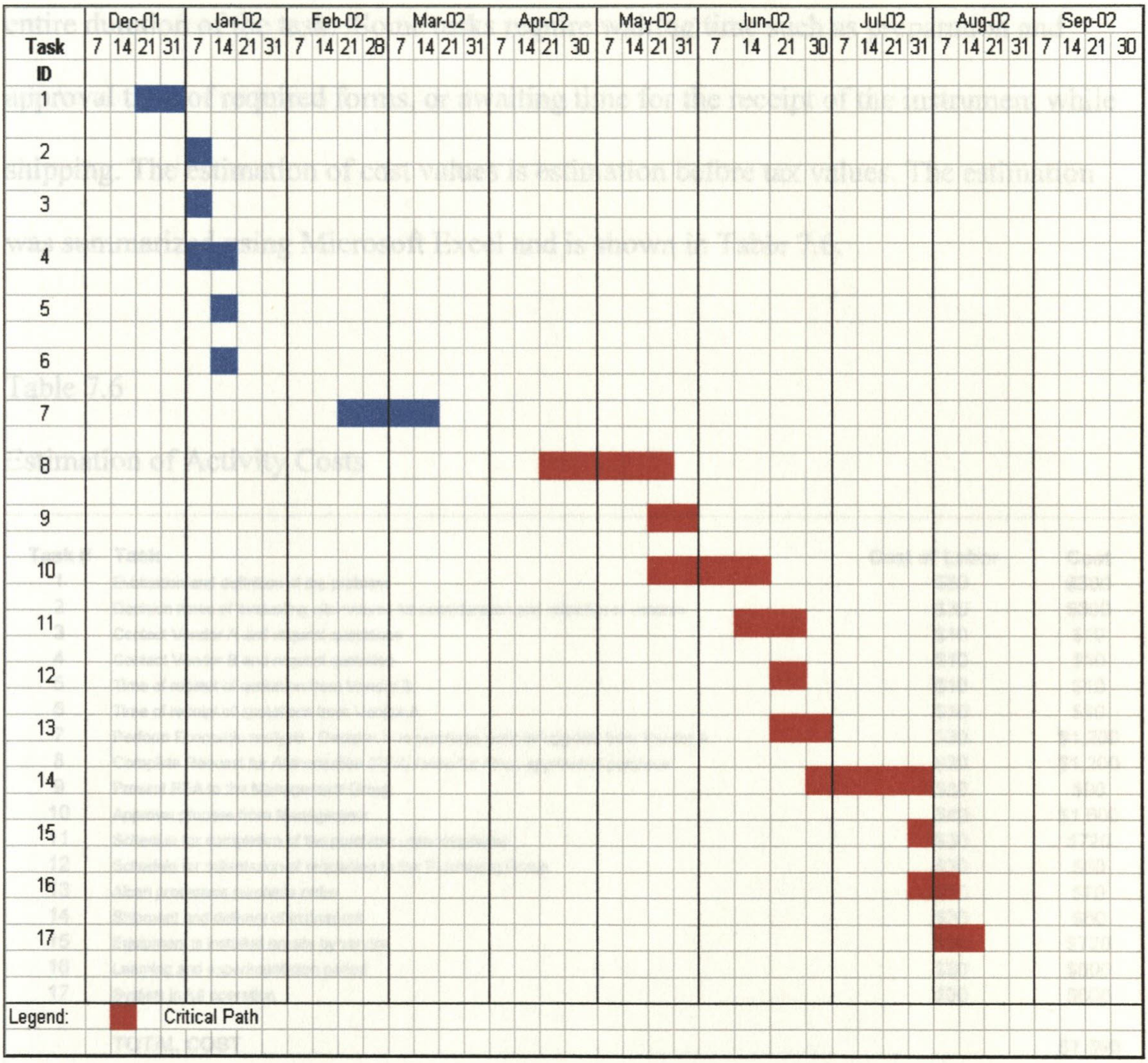
Microsoft Excel 97 was used to create a Gantt Chart of the project. The Gantt Chart is shown in Table 7.5 and the activities in red represent the activities that are part of the critical path. According to the schedule, the project can be finished by August 9,

[7.3] Meredith, Jack R., Mantel. Jr., Samuel J. Project Management. John Wiley & Sons, Inc. New York, New York. 4th Edition. 2000. 317-320.

2002. This is a very good representation of the project realization because Alcan would like to see the project finished before the end this year 2002.

Table 7.5

Project Schedule Gantt Chart



Source: Mora, Ana E. Created with Microsoft Excel 97. 26 February 2002.

7.5 Estimation of Activity Costs

Activity costs were estimated from the network database for similar activities performed by the Laboratory Group in previous years. These costs do not include the cost of the equipment; it includes total labor cost estimated for each of the activities. The cost per activity does not indicate that there is work associated with the activity for the entire duration of the task. Some tasks require waiting time such as preparation and approval time of required forms, or awaiting time for the receipt of the instrument while shipping. The estimation of cost values is estimation before tax values. The estimation was summarized using Microsoft Excel and is shown in Table 7.6.

Table 7.6

Estimation of Activity Costs

Task #	Task	Cost of Labor	Cost
1	Evaluation and definition of the problem	$30	$300
2	Decision times of evaluating alternatives for consideration and selection of vendors	$30	$300
3	Contact Vendor A and request quotations	$10	$10
4	Contact Vendor B and request quotation	$10	$10
5	Time of receipt of quotation from Vendor B	$10	$10
6	Time of receipt of quotations from Vendor A	$10	$10
7	Perform Economic analysis - Decision is to purchase sampler upgrade from Vendor A	$30	$1,200
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	$30	$1,200
9	Present RFA to the Management Group	$30	$90
10	Approval process from Management	$40	$1,600
11	Schedule for completion of the purchase order requisition	$30	$720
12	Schedule for submission of requisition to the Purchasing Group	$30	$60
13	Alcan processes purchase order	$35	$70
14	Shipment and delivery of instrument	$30	$60
15	Equipment is installed on-site by vendor	$30	$720
16	Learning and experimentation period	$30	$600
17	System in full operation	$30	$600
	TOTAL COST		**$7,560**

Source: Mora, Ana E. Created with Microsoft Excel 97. 25 February 2002.

7.6 Conclusions

This study reveals that the project can be completed within this calendar year with no problems. The total cost of the project will be the sum of the cost of the activities plus the cost of the equipment. Total cost of the activities is $7,560 and the cost of the equipment is $26,966. The total cost of the project before taxes is $34,526.

Complete Gantt and PERT graphs and reports obtained with Microsoft Project 4.0 can be found in Appendix C of this paper.

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APPENDIX A

USEPA Method 14A

Determination of Total Fluoride Emissions from Selected Sources

at Primary Aluminum Production Facilities

APPENDIX A TO PART 60--TEST METHODS

* * * * *

METHOD 14A-DETERMINATION OF TOTAL FLUORIDE EMISSIONS FROM SELECTED SOURCES AT PRIMARY ALUMINUM PRODUCTION FACILITIES

NOTE: This method does not include all the specifications (e.g., equipment and supplies) and procedures (e.g., sampling) essential to its performance. Some material is incorporated by reference from other methods in this part. Therefore, to obtain reliable results, persons using this method should have a thorough knowledge of at least the following additional test methods: Method 5, Methods 13A and 13B, and Method 14 of this appendix.

1.0 Scope and Application.

1.1 Analytes.

Analyte	CAS No.	Sensitivity
Total fluorides	None assigned	Not determined
Includes hydrogen fluoride	007664-39-3	Not determined

1.2 Applicability. This method is applicable for the determination of total fluorides (TF) emissions from sources specified in the applicable regulation. This method was developed by consensus with the Aluminum Association and the U.S. Environmental Protection Agency (EPA).

2.0 Summary of Method.

2.1 Total fluorides, in the form of solid and gaseous fluorides, are withdrawn from the ascending air stream inside of an aluminum reduction potroom and, prior to exiting the potroom roof monitor, into a specific cassette arrangement. The cassettes are connected by tubing to flowmeters and a manifold system that allows for the equal distribution of volume pulled through each cassette, and finally to a dry gas meter. The cassettes have a specific internal arrangement of one unaltered cellulose filter and support pad in the first section of the cassette for solid fluoride retention and two cellulose filters with support pads that are impregnated with sodium formate for the chemical absorption of gaseous fluorides in the following two sections of the cassette. A minimum of eight cassettes shall be used for a potline and shall be strategically located at equal intervals across the potroom roof so as to encompass a minimum of 8 percent of the total length of the potroom. A greater number of cassettes may be used should the regulated facility choose to do so. The mass flow rate of pollutants is determined with anemometers and temperature sensing devices located immediately below the opening of the roof monitor and spaced evenly within the cassette group.

3.0 Definitions.

3.1 Cassette. A segmented, styrene acrylonitrile cassette configuration with three separate segments and a base, for the purpose of this method, to capture and retain fluoride from potroom gases.

3.2 Cassette arrangement. The cassettes, tubing, manifold system, flowmeters, dry gas meter, and any other related equipment associated with the actual extraction of the sample gas stream.

3.3 Cassette group. That section of the potroom roof monitor where a distinct group of cassettes is located.

3.4 Potline. A single, discrete group of electrolytic reduction cells electrically connected in series, in which alumina is reduced to form aluminum.

3.5 Potroom. A building unit that houses a group of electrolytic reduction cells in which aluminum is produced.

3.6 Potroom group. An uncontrolled potroom, a potroom that is controlled individually, or a group of potrooms or potroom segments ducted to a common primary control system.

3.7 Primary control system. The equipment used to capture the gases and particulate matter generated during the reduction process and the emission control device(s) used to remove pollutants prior to discharge of the cleaned gas to the atmosphere.

3.8 Roof monitor. That portion of the roof of a potroom building where gases, not captured at the cell, exit from the potroom.

3.9 Total fluorides (TF). Elemental fluorine and all fluoride compounds as measured by Methods 13A or 13B of this appendix or by an approved alternative method.

4.0 Interferences and Known Limitations.

4.1 There are two principal categories of limitations that must be addressed when using this method. The first category is sampling bias and the second is analytical bias. Biases in sampling can occur when there is an insufficient number of cassettes located along the roof monitor of a potroom or if the distribution of those cassettes is spatially unequal. Known sampling biases also can occur when there are leaks within the cassette arrangement and if anemometers and temperature devices are not providing accurate data. Applicable instruments must be properly calibrated to avoid sampling bias. Analytical biases can occur when instrumentation is not calibrated or fails calibration and the instrument is used out of proper calibration. Additionally, biases can occur in the laboratory if fusion crucibles retain residual fluorides over lengthy periods of use. This condition could result in falsely elevated fluoride values. Maintaining a clean work environment in the laboratory is crucial to producing accurate values.

4.2 Biases during sampling can be avoided by properly spacing the appropriate number of cassettes along the roof monitor, conducting leak checks of the cassette arrangement, calibrating the dry gas meter every 30 days, verifying the accuracy of individual flowmeters (so that there is no more than 5 percent difference in the volume pulled between any two flowmeters), and calibrating or replacing anemometers and temperature sensing devices as necessary to maintain true data generation.

4.3 Analytical biases can be avoided by calibrating instruments according to the manufacturer's specifications prior to conducting any analyses, by performing internal and external audits of up to 10 percent of all samples analyzed, and by rotating individual crucibles as the "blank" crucible to detect any potential residual fluoride carry-over to samples. Should any contamination be discovered in the blank crucible, the crucible shall be thoroughly cleaned to remove any detected residual fluorides and a "blank" analysis conducted again to evaluate the effectiveness of the cleaning. The crucible shall remain in service as long as no detectable residual fluorides are present.

5.0 Safety.

5.1 This method may involve the handling of hazardous materials in the analytical phase. This method does not purport to address all of the potential safety hazards associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to performing this test method.

5.2 Corrosive reagents. The following reagents are hazardous. Personal protective equipment and safe procedures are useful in preventing chemical splashes. If contact occurs, immediately flush with copious amounts of water for at least 15 minutes. Remove clothing under shower and decontaminate. Treat residual chemical burn as thermal burn.

5.3 Sodium Hydroxide (NaOH). Causes severe damage to eyes and skin. Inhalation causes irritation to nose, throat, and lungs. Reacts exothermically with limited amounts of water.

5.4 Perchloric Acid ($HClO_4$). Corrosive to eyes, skin, nose, and throat. Provide ventilation to limit exposure. Very strong oxidizer. Keep separate from water and oxidizable materials to prevent vigorous evolution of heat, spontaneous combustion, or explosion. Heat solutions containing $HClO_4$ only in hoods specifically designed for $HClO_4$.

6.0 Equipment and Supplies.

6.1 Sampling.

6.1.1 Cassette arrangement. The cassette itself is a three-piece, styrene acrylonitrile cassette unit (a Gelman Sciences product), 37 millimeter (mm), with plastic connectors. In the first section (the intake section), an untreated Gelman Sciences 37 mm, 0.8 micrometer (μm) DM-800 metricel membrane filter and cellulose support pad, or equivalent, is situated. In the second and third segments of the cassette there is placed one each of Gelman Sciences 37 mm, 5 μm GLA-5000 low-ash PVC filter with a cellulose support pad or equivalent product. Each of these two filters and support pads shall have been immersed in a solution of 10 percent sodium formate (volume/volume in an ethyl alcohol solution). The impregnated pads shall be placed in the cassette segments while still wet and heated at 50°C (122°F) until the pad is completely dry. It is important to check for a proper fit of the filter and support pad to the cassette segment to ensure that there are no areas where gases could bypass the filter. Once all of the cassette segments have been prepared, the cassette shall be assembled and a plastic plug shall be inserted into the exhaust hole of the cassette. Prior to placing the cassette into service, the space between each segment shall be taped with an appropriately durable tape to prevent the infiltration of gases through the points of connection, and an aluminum nozzle shall be inserted into the intake hole of the cassette. The aluminum nozzle shall have a short section of tubing placed over the opening of the nozzle, with the tubing plugged to prevent dust from entering the nozzle and to prepare the nozzle for the cassette arrangement leak check. An alternate nozzle type can be used if historical results or scientific demonstration of applicability can be shown.

6.1.2 Anemometers and temperature sensing devices. To calculate the mass flow rate of TF from the roof monitor under standard conditions, anemometers that meet the specifications in section 2.1.1 in Method 14 of this appendix or an equivalent device yielding equivalent information shall be used. A recording mechanism capable of accurately recording the exit gas temperature at least every 2 hours shall be used.

6.1.3 Barometer. To correct the volumetric flow from the potline roof monitor to standard conditions, a mercury (Hg), aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm [0.1 inch (in)] Hg shall be used.

NOTE: The barometric reading may be obtained from a nearby National Weather Service Station. In this case, the station value (which is absolute barometric pressure) shall be requested and an adjustment for elevation differences between the weather station and the sampling point shall be made at a rate of minus 2.5 mm (0.1 in) Hg per 30 meters (m) [100 feet (ft)] elevation increase or plus 2.5 mm (0.1 in) Hg per 30 m (100 ft) elevation decrease.

6.2 Sample recovery.

6.2.1 Hot plate.

6.2.2 Muffle furnace.

6.2.3 Nickel crucible.

6.2.4 Stirring rod. Teflon®.

6.2.5 Volumetric flask. 50-milliliter (ml).

6.2.6 Plastic vial. 50-ml.

6.3 Analysis.

6.3.1 Primary analytical method. An automated analyzer having the following components or equivalent: a multichannel proportioning pump, multiposition sampler, voltage stabilizer, colorimeter, instrument recording device, microdistillation apparatus, flexible Teflon® heating bath, vacuum pump, pulse suppressers and an air flow system.

6.3.2 Secondary analytical method. Specific Ion Electrode (SIE).

7.0 Reagents and Standards.

7.1 Water. Deionized distilled to conform to ASTM Specification D 1193—77, Type 3 (incorporated by reference in § 60.17(a)(22) of this part). The $KMnO_4$ test for oxidizable organic matter may be omitted when high concentrations of organic matter are not expected to be present.

7.2 Calcium oxide.

7.3 Sodium hydroxide (NaOH). Pellets.

7.4 Perchloric acid ($HClO_4$). Mix 1:1 with water. Sulfuric acid (H_2SO_4) may be used in place of $HClO_4$.

7.5 Audit samples. The audit samples discussed in section 9.1 shall be prepared from reagent grade, water soluble stock reagents, or purchased as an aqueous solution from a commercial supplier. If the audit stock solution is purchased from a commercial supplier, the standard solution must be accompanied by a certificate of analysis or an equivalent proof of fluoride concentration.

8.0 Sample Collection and Analysis.

8.1 Preparing cassette arrangement for sampling. The cassettes are initially connected to flexible tubing. The tubing is connected to flowmeters and a manifold system. The manifold system is connected to a dry gas meter (Research Appliance Company model 201009 or equivalent). The length of tubing is managed by pneumatically or electrically operated hoists located in the roof monitor, and the travel of the tubing is controlled by encasing the tubing in aluminum conduit. The tubing is lowered for cassette insertion by operating a control box at floor level. Once the cassette has been securely inserted into the tubing and the leak check performed, the tubing and cassette are raised to the roof monitor level using the floor level control box. Arrangements similar to the one described are acceptable if the scientific sample collection principles are followed.

8.2 Test run sampling period. A test run shall comprise a minimum of a 24-hour sampling event encompassing at least eight cassettes per potline (or four cassettes per potroom group). Monthly compliance shall be based on three test runs during the month. Test runs of greater than 24 hours are allowed; however, three such runs shall be conducted during the month.

8.3 Leak-check procedures.

8.3.1 Pretest leak check. A pretest leak-check is recommended; however, it is not required. To perform a pretest leak-check after the cassettes have been inserted into the tubing, isolate the cassette to be leak-checked by turning the valves on the manifold to stop all flows to the other sampling points connected to the manifold and meter. The cassette, with the plugged tubing section securing the intake of the nozzle, is subjected to the highest vacuum expected during the run. If no leaks are detected, the tubing plug can be briefly removed as the dry gas meter is rapidly turned off.

8.3.2 Post-test leak check. A leak check is required at the conclusion of each test run for each cassette. The leak check shall be performed in accordance with the procedure outlined in section 8.3.1 of this method except that it shall be performed at a vacuum greater than the maximum vacuum reached during the test run. If the leakage rate is found to be no greater than 4 percent of the average sampling rate, the results are acceptable. If the leakage rate is greater than 4 percent of the average sampling rate, either record the leakage rate and correct the sampling volume as discussed in section 12.4 of this method or void the test run if the minimum number of cassettes were used. If the number of cassettes used was greater than the minimum required, discard the leaking cassette and use the remaining cassettes for the emission determination.

8.3.3 Anemometers and temperature sensing device placement. Install the recording mechanism to record the exit gas temperature. Anemometers shall be installed as required in section 6.1.2 of Method 14 of this appendix, except replace the word "manifold" with "cassette group" in section 6.1.2.3. These two different instruments shall be located near each other along the roof monitor. See conceptual configurations in Figures 14A-1, 14A-2, and 14A-3 of this method. Fewer temperature devices than anemometers may be used if at least one temperature device is located within the span of the cassette group. Other anemometer location siting scenarios may be acceptable as long as the exit velocity of the roof monitor gases is representative of the entire section of the potline being sampled.

8.4 Sampling. The actual sample run shall begin with the removal of the tubing and plug from the cassette nozzle. Each cassette is then raised to the roof monitor area, the dry gas meter is turned on, and the flowmeters are set to the calibration point, which allows an equal volume of sampled gas to enter each cassette. The dry gas meter shall be set to a range suitable for the specific potroom type being sampled that will yield valid data known from previous experience or a range determined by the use of the calculation in section 12 of this method. Parameters related to the test run that shall be recorded, either during the test run or after the test run if recording devices are used, include: anemometer data, roof monitor exit gas temperature, dry gas meter temperature, dry gas meter volume, and barometric pressure. At the conclusion of the test run, the cassettes shall be lowered, the dry gas meter turned off, and the volume registered on the dry gas meter recorded. The post-test leak check procedures described in section 8.3.2 of this method shall be performed. All data relevant to the test shall be recorded on a field data sheet and maintained on file.

8.5 Sample recovery.

8.5.1 The cassettes shall be brought to the laboratory with the intake nozzle contents protected with the section of plugged tubing previously described. The exterior of cassettes shall carefully be wiped free of any dust or debris, making sure that any falling dust or debris does not present a potential laboratory contamination problem.

8.5.2 Carefully remove all tape from the cassettes and remove the initial filter, support pad, and all loose solids from the first (intake) section of the cassette. Fold the filter and support pad several times and, along with all loose solids removed from the interior of the first section of the cassette, place them into a nickel crucible. Using water, wash the interior of the nozzle into the same nickel crucible. Add 0.1 gram (g) [±0.1 milligram (mg)] of calcium oxide and a sufficient amount of water to make a loose slurry. Mix the contents of the crucible thoroughly with a Teflon® stirring rod. After rinsing any adhering residue from the stirring rod back into the crucible, place the crucible on a hot plate or in a muffle furnace until all liquid is evaporated and allow the mixture to gradually char for 1 hour.

8.5.3 Transfer the crucible to a cold muffle furnace and ash at 600°C (1,112°F). Remove the crucible after the ashing phase and, after the crucible cools, add 3.0 g (±0.1 g) of NaOH pellets. Place this mixture in a muffle furnace at 600°C (1,112°F) for 3 minutes. Remove the crucible and roll the melt so as to reach all of the ash with the molten NaOH. Let the melt cool to room temperature. Add 10 to 15 ml of water to the crucible and place it on a hot plate at a low temperature setting until the melt is soft or suspended. Transfer the contents of the crucible to a 50-ml volumetric flask. Rinse the crucible with 20 ml of 1:1 perchloric acid or 20 ml of 1:1 sulfuric acid in two (2) 10 ml portions. Pour the acid rinse slowly into the volumetric flask and swirl the flask after each addition. Cool to room temperature. The product of this procedure is particulate fluorides.

8.5.4 Gaseous fluorides can be isolated for analysis by folding the gaseous fluoride filters and support pads to approximately 1/4 of their original size and placing them in a 50-ml plastic vial. To the vial add exactly 10 ml of water and leach the sample for a minimum of 1 hour. The leachate from this process yields the gaseous fluorides for analysis.

9.0 Quality Control.

9.1 Laboratory auditing. Laboratory audits of specific and known concentrations of fluoride shall be submitted to the laboratory with each group of samples submitted for analysis. An auditor shall prepare and present the audit samples as a "blind" evaluation of laboratory performance with each group of samples submitted to the laboratory. The audits shall be prepared to represent concentrations of fluoride that could be expected to be in the low, medium and high range of actual results. Average recoveries of all three audits must equal 90 to 110 percent for acceptable results; otherwise, the laboratory must investigate procedures and instruments for potential problems.

NOTE: The analytical procedure allows for the analysis of individual or combined filters and pads from the cassettes provided that equal volumes (±10 percent) are sampled through each cassette.

10.0 Calibrations.

10.1 Equipment evaluations. To ensure the integrity of this method, periodic calibrations and equipment replacements are necessary.

10.1.1 Metering system. At 30-day intervals the metering system shall be calibrated. Connect the metering system inlet to the outlet of a wet test meter that is accurate to 1 percent. Refer to Figure 5-4 of Method 5 of this appendix. The wet-test meter shall have a capacity of 30 liters/revolution [1 cubic foot (ft^3)/revolution]. A spirometer of 400 liters (14 ft^3) or more capacity, or equivalent, may be used for calibration; however, a wet-test meter is usually more practical. The wet-test meter shall be periodically tested with a spirometer or a liquid displacement meter to ensure the accuracy. Spirometers or wet-test meters of other sizes may be used, provided that the specified accuracies of the procedure are maintained. Run the metering system pump for about 15 min. with the orifice manometer indicating a median reading as expected in field use to allow the pump to warm up and to thoroughly wet the interior of the wet-test meter. Then, at each of a minimum of three orifice manometer settings, pass an exact quantity of gas through the wet-test meter and record the volume indicated by the dry gas meter. Also record the barometric pressure, the temperatures of the wet test meter, the inlet temperatures of the dry gas meter, and the temperatures of the outlet of the dry gas meter. Record all calibration data on a form similar to the one shown in Figure 5-5 of Method 5 of this appendix and calculate Y, the dry gas meter calibration factor, and $\Delta H_{@}$, the orifice calibration factor at each orifice setting. Allowable tolerances for Y and $\Delta H_{@}$ are given in Figure 5-6 of Method 5 of this appendix.

10.1.2 Estimating volumes for initial test runs. For a facility's initial test runs, the regulated facility must have a target or desired volume of gases to be sampled and a target range of volumes to use during the calibration of the dry gas meter. Use Equations 14A-1 and 14A-2 in section 12 of this method to derive the target dry gas meter volume (F_v) for these purposes.

10.1.3 Calibration of anemometers and temperature sensing devices. If the standard anemometers in Method 14 of this appendix are used, the calibration and integrity evaluations in sections 10.3.1.1 through 10.3.1.3 of Method 14 of this appendix shall be used as well as the recording device described in section 2.1.3 of Method 14. The calibrations or complete change-outs of anemometers shall take place at a minimum of once per year. The temperature sensing and recording devices shall be calibrated according to the manufacturer's specifications.

10.1.4 Calibration of flowmeters. The calibration of flowmeters is necessary to ensure that an equal volume of sampled gas is entering each of the individual cassettes and that no large differences, which could possibly bias the sample, exist between the cassettes.

10.1.4.1 Variable area, 65 mm flowmeters or equivalent shall be used. These flowmeters can be mounted on a common base for convenience. These flowmeters shall be calibrated by attaching a prepared cassette, complete with filters and pads, to the flowmeter and then to the system manifold. This manifold is an aluminum cylinder with valved inlets for connections to the flowmeters/cassettes and one outlet to a dry gas meter. The connection is then made to the wet-test meter and finally to a dry gas meter. All connections are made with tubing.

10.1.4.2 Turn the dry gas meter on for 15 min. in preparation for the calibration. Turn the dry gas meter off and plug the intake hole of the cassette. Turn the dry gas meter back on to evaluate the entire system for leaks. If the dry gas meter shows a leakage rate of less than 0.02 ft^3/min at 10 in. of Hg vacuum as noted on the dry gas meter, the system is acceptable to further calibration.

10.1.4.3 With the dry gas meter turned on and the flow indicator ball at a selected flow rate, record the exact amount of gas pulled through the flowmeter by taking measurements from the wet test meter after exactly 10 min. Record the room temperature and barometric pressure. Conduct this test for all flowmeters in the system with all flowmeters set at the same indicator ball reading. When all flowmeters have gone through the procedure above, correct the volume pulled through each flowmeter to standard conditions. The acceptable difference between the highest and lowest flowmeter rate is 5 percent. Should one or more flowmeters be outside of the acceptable limit of 5 percent, repeat the calibration procedure at a lower or higher indicator ball reading until all flowmeters show no more than 5 percent difference among them.

10.1.4.4 This flowmeter calibration shall be conducted at least once per year.

10.1.5 Miscellaneous equipment calibrations. Miscellaneous equipment used such as an automatic recorder/ printer used to measure dry gas meter temperatures shall be calibrated according to the manufacturer's specifications in order to maintain the accuracy of the equipment.

11.0 Analytical Procedure.

11.1 The preferred primary analytical determination of the individual isolated samples or the combined particulate and gaseous samples shall be performed by an automated methodology. The analytical method for this technology shall be based on the manufacturer's instructions for equipment operation and shall also include the analysis of five standards with concentrations in the expected range of the actual samples. The results of the analysis of the five standards shall have a coefficient of correlation of at least 0.99. A check standard shall be analyzed as the last sample of the group to determine if instrument drift has occurred. The acceptable result for the check standard is 95 to 105 percent of the standard's true value.

11.2 The secondary analytical method shall be by specific ion electrode if the samples are distilled or if a TISAB IV buffer is used to eliminate aluminum interferences. Five standards with concentrations in the expected range of the actual samples shall be analyzed, and a coefficient of correlation of at least 0.99 is the minimum acceptable limit for linearity. An exception for this limit for linearity is a condition when low-level standards in the range of 0.01 to 0.48 μg fluoride/ml are analyzed. In this situation, a minimum coefficient of correlation of 0.97 is required. TISAB II shall be used for low-level analyses.

12.0 Data Analysis and Calculations.

12.1 Carry out calculations, retaining at least one extra decimal point beyond that of the acquired data. Round off values after the final calculation. Other forms of calculations may be used as long as they give equivalent results.

12.2 Estimating volumes for initial test runs.

$$F_v = \frac{(F_d)(X)}{F_e} \qquad \text{Eq. 14A-1}$$

where

F_v = Desired volume of dry gas to be sampled, ft^3.

F_d = Desired or analytically optimum mass of TF per cassette, micrograms of TF per cassette (μg/cassette).

X = Number of cassettes used.

F_e = Typical concentration of TF in emissions to be sampled, $\mu g/ft^3$, calculated from Equation 14A-2.

$$F_e = \frac{(R_e)(R_p)(4.536 \times 10^8\ ug/lb)}{(A_r)(V_r)} \qquad \text{Eq. 14A-2}$$

where

R_e = Typical emission rate from the facility, pounds of TF per ton (lb/ton) of aluminum.

R_p = Typical production rate of the facility, tons of aluminum per minute (ton/min).

V_r = Typical exit velocity of the roof monitor gases, feet per minute (ft/min).

A_r = Open area of the roof monitor, square feet (ft^2).

12.2.1 Example calculation. Assume that the typical emission rate (R_e) is 1.0 lb TF/ton of aluminum, the typical roof vent gas exit velocity (V_r) is 250 ft/min, the typical production rate (R_p) is 0.10 ton/min, the known open area for the roof monitor (A_r) is 8,700 ft^2, and the desired (analytically optimum) mass of TF per cassette is 1,500 μg. First calculate the concentration of TF per cassette (F_e) in $\mu g/ft^3$ using Equation 14A-2. Then calculate the desired volume of gas to be sampled (F_v) using Equation 14A-1.

Eq. 14A-3

$$F_e = 20.855 = \frac{(1.0\ lb/ton)(0.1\ tons/\text{min})(4.536\ x10^8\ ug/lb)}{(8{,}700\ ft^2)(250\ ft/\text{min})}$$

Eq. 14A-4

$$F_v = 575.40\ ft^3 = \frac{(1{,}500\ ug)(8\ cassettes)}{(20.855\ ug/ft^3)}$$

This is a total of 575.40 ft^3 for eight cassettes or 71.925 ft^3/cassette.

12.3 Calculations of TF emissions from field and laboratory data that would yield a production related emission rate can be calculated as follows:

12.3.1 Obtain a standard cubic feet (scf) value for the volume pulled through the dry gas meter for all cassettes by using the field and calibration data and Equation 5-1 of Method 5 of this appendix.

12.3.2 Derive the average quantity of TF per cassette (in μg TF/cassette) by adding all laboratory data for all cassettes and dividing this value by the total number of cassettes used. Divide this average TF value by the corrected dry gas meter volume for each cassette; this value then becomes TF_{std} ($\mu g/ft^3$).

12.3.3 Calculate the production-based emission rate (R_e) in lb/ton using Equation 14A-5.

$$R_e = \frac{(TF_{std})(V_r)(A_r)(2.2 \times 10^{-9}\ lb/\mu g)}{(R_p)}$$ Eq. 14A-5

12.3.4 As an example calculation, assume eight cassettes located in a potline were used to sample for 72 hours during the run. The analysis of all eight cassettes yielded a total of 3,000 μg of TF. The dry gas meter volume was corrected to yield a total of 75 scf per cassette, which yields a value for TF_{std} of 3,000/75 = 5 $\mu g/ft^3$. The open area of the roof monitor for the potline (A_r) is 17,400 ft^2. The exit velocity of the roof monitor gases (V_r) is 250 ft/min. The production rate of aluminum over the previous 720 hours was 5,000 tons, which is 6.94 tons/hr or 0.116 ton/min (R_p). Substituting these values into Equation 14A-5 yields:

Eq. 14A-6

$$R_e = \frac{(5\ \mu g/ft^3)(250\ ft/min)(17{,}400\ ft^2)(2.2 \times 10^{-9}\ lb/\mu g)}{(0.116\ ton/min)}$$

Eq. 14A-7

$$R_e = 0.41\ lb/ton\ of\ aluminum\ produced.$$

12.4 Corrections to volumes due to leakage. Should the post-test leak check leakage rate exceed 4 percent as described in section 8.3.2 of this method, correct the volume as detailed in Case I in section 6.3 of Method 5 of this appendix.

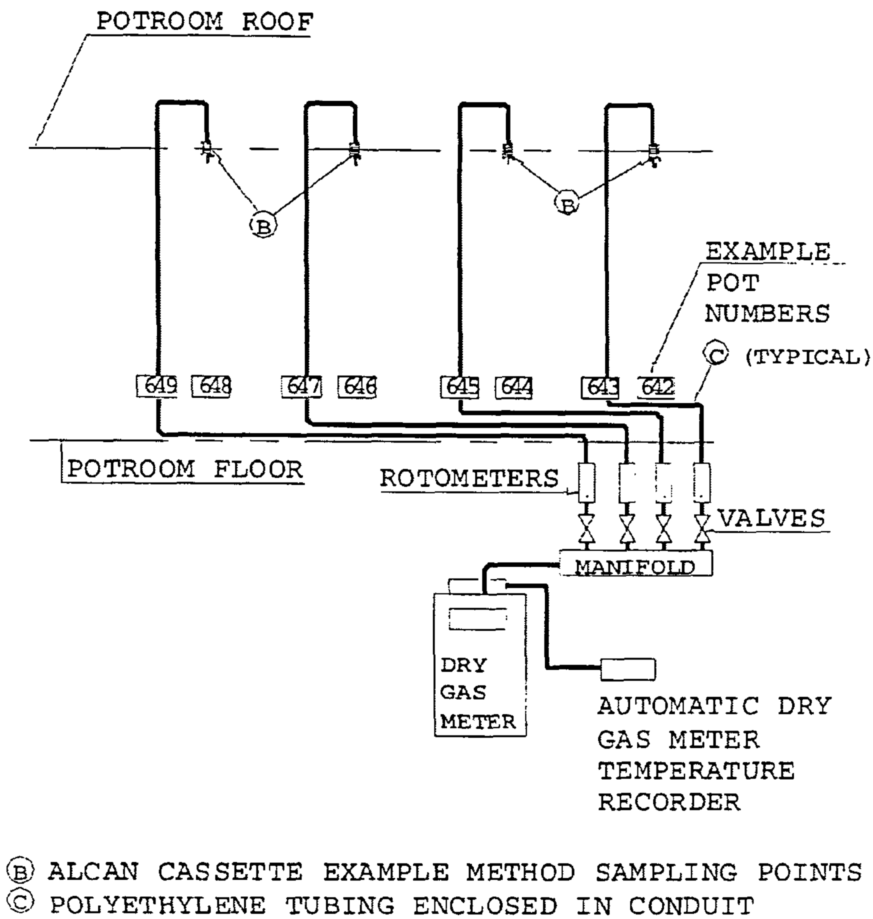


Figure 14A-1. Conceptual side view of arrangement of 4 cassettes for one-half of a potroom.
Note: This drawing does not reflect an equally acceptable arrangement of 8 cassettes in a cassette group located along at least 8 percent of the potroom roof.

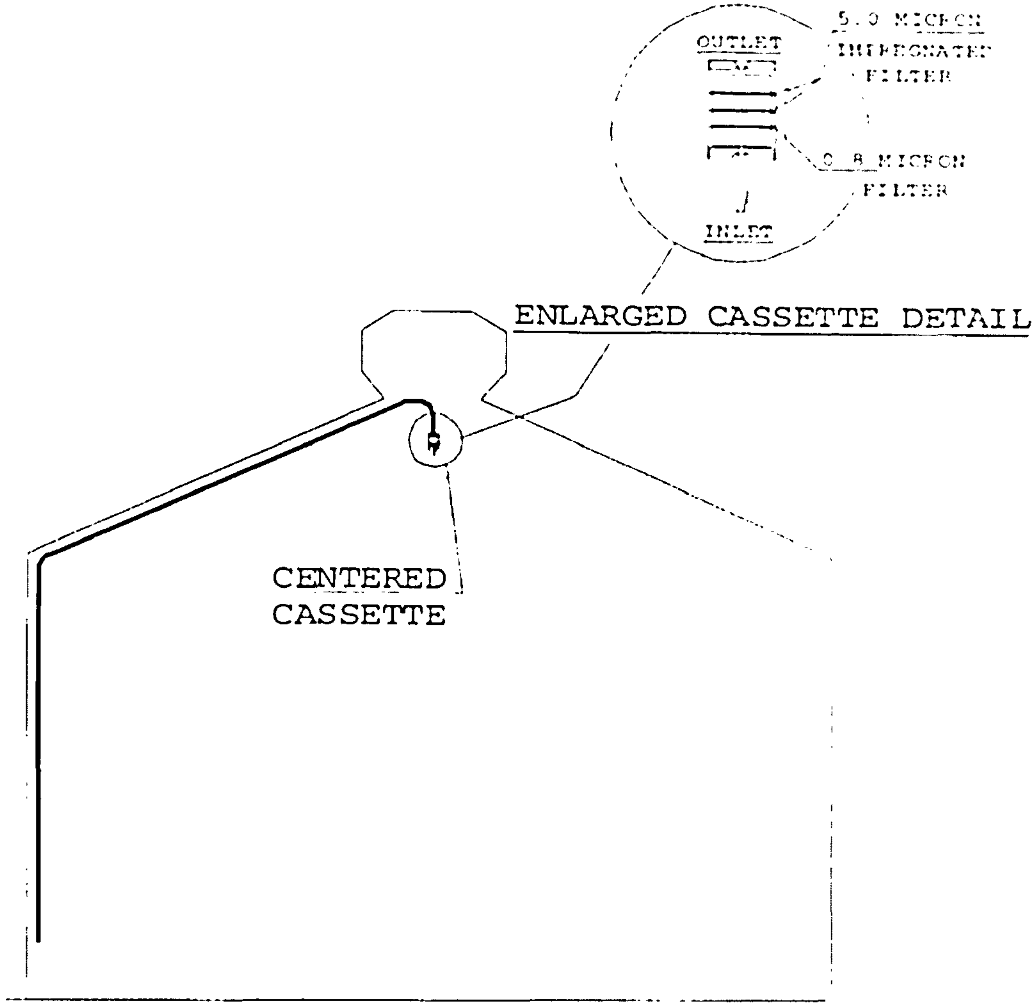


Figure 14A-2. Conceptual end view of cassette placement in a potroom roof.

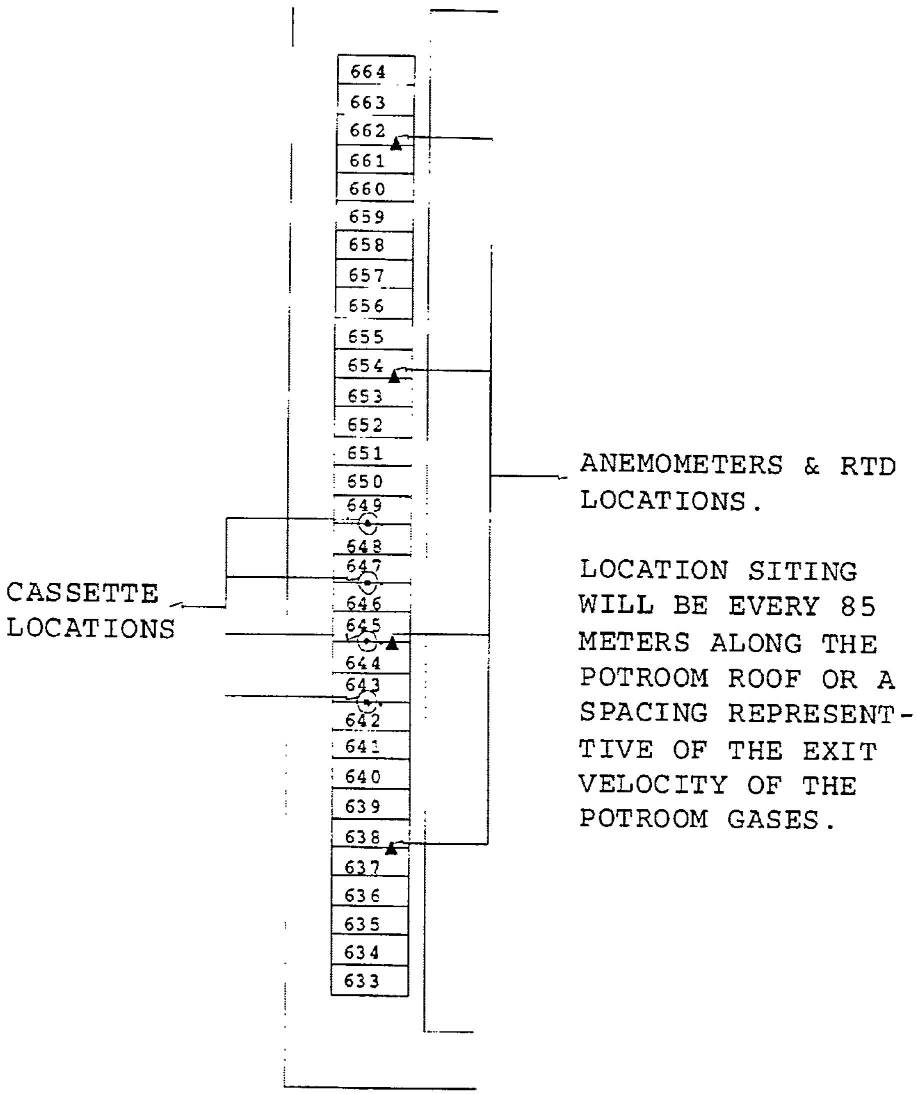


Figure 14A-3. Conceptual side view of positions of cassettes, anemometers, and RTDs in a typical half of a potroom.

Note: This drawing does not reflect other potentially acceptable arrangements.

* * * * *

APPENDIX B

Economic Analysis

Spreadsheet Printouts Created with Microsoft Excel 97

Chemicals

i =	11%			
	1998	1999	2000	2001
January	$379 $90 $189	$192 $24 $92	$413 $219	$610
February	$190 $52 $77	$113 $390	$172 $449	$376 $76 $450 $919
March	$906 $84	$24 $189	$190 $190	
April	$192	$156	$47 $450 $55	$228 $376
May	$734	$189 $389	$225 $467 $56	$115 $58
June	$761 $104	$375 $645	$449	$555 $190 $190
July	$374 $209 $384 $45 $91	$75		$450 $155
August	$155 $263 $91	$52	$130 $162 $27 $450 $78	$376 $232
September	$54 $560 $55 $389	$562 $376 $130 $138	$375	$228 $26
October	$119 $734	$375 $56	$78 $450 $55	$227 $171 $636 $88
November	$159		$305 $375	$109
December	$52 $54 $189	$32		
Total	$7,735	$4,382	$5,867	$5,837

i = 11%

Period	Year	Reagents	NPV	F=P*(1+i)^n
1	1998	$7,735	$6,968	$10,579
2	1999	$4,382	$10,525	$5,399
3	2000	$5,867	$14,815	$6,512
4	2001	$5,837	$18,660	$5,837
Total				**$28,327**

EUAC of Chemicals =	F(A/F,11%,4) =	$6,015
EUAC of Chemicals =	P(A/P,11%,4) =	$6,015

O&M

i = 11%

Year	1998	1999	2000	2001
	$889 $348	$965	$0	$858
Total	**$1,237**	**$965**	**$0**	**$858**

Total	$1,237	$965	$0	$858

i = 11%

Period	Year	O&M	NPV	F=P*(1+i)^n
1	1998	$1,237	$1,114	$1,692
2	1999	$965	$1,898	$1,189
3	2000	$0	$1,898	$0
4	2001	$858	$2,463	$858
Total				**$3,739**

EUAC of O&M =	F(A/F,11%,4) =	$794
EUAC of O&M =	P(A/P,11%,4) =	$794

Alternative #1

Alternative #1 from Vendor A

i = 11%

Additional Cost on Research at Time of Setup = $0

Year	Period	Initial Cost	Annual Benefits From Larger Sampler = ($30*24*2*12)	Annual Benefits Freeing up for TAN = ($30*16*12)	Expenses Electrodes	Expenses Chemicals	Maintenance and Operating Expenses
2002	0	($43,379)					
2003	1		$17,280	$5,760	($1,000)	($6,015)	($794)
2004	2		$17,280	$5,760	($1,000)	($6,015)	($794)
2005	3		$17,280	$5,760	($1,000)	($6,015)	($794)
2006	4		$17,280	$5,760	($1,000)	($6,015)	($794)
2007	5	$4,338	$17,280	$5,760	($1,000)	($6,015)	($794)

Year	Period	Initial Cost	Net Benefits	Present Worth Net Benefits P*(1+i)^-n
2002	0	($43,379)		
2003	1		$15,232	$13,722
2004	2		$15,232	$12,362
2005	3		$15,232	$11,137
2006	4		$15,232	$10,034
2007	5		$19,569	$11,614
Total				$58,869

PW Cost (1) = Initial Cost =	$43,379	
PW Benefits (1) =	$58,869	
EUAC (1) =	**$43,379*(P/A, 11%,5) =**	$11,737
EUAB (1) =	**$58,869*(P/A, 11%, 5) =**	$15,928
Net Present Worth (1) =	**PW(Benefits) - Initial Cost =**	$15,490
EUAB (1) - EUAC (1) =	**UAB (1) = $15,490*(P/A, 11%,5) =**	$4,191

Alternative 2

Alternative #2 from Vendor A

i = 11%

Additional Cost on Research at Time of Setup = $0

Year	Period	Initial Cost	Annual Benefits From Larger Sampler = ($30*24*2*12)	Annual Benefits Larger Sampler for TAN = ($30*8*12)	Expenses Electrodes	Expenses Chemicals	Maintenance and Operating Expenses
2002	0	($26,966)					
2003	1		$17,280	$2,880	($1,000)	($6,015)	($794)
2004	2		$17,280	$2,880	($1,000)	($6,015)	($794)
2005	3		$17,280	$2,880	($1,000)	($6,015)	($794)
2006	4		$17,280	$2,880	($1,000)	($6,015)	($794)
2007	5	$2,697	$17,280	$2,880	($1,000)	($6,015)	($794)

Year	Period	Initial Cost	Net Benefits	Present Worth Net Benefits P*(1+i)^-n
2002	0	($26,966)		
2003	1		$12,352	$11,128
2004	2		$12,352	$10,025
2005	3		$12,352	$9,031
2006	4		$12,352	$8,136
2007	5		$15,048	$8,930
Total				$47,250

PW Cost (2) = Initial Cost =	$26,966	
PW Benefits (2) =	$47,250	
EUAC (2) =	$26,966*(P/A, 11%,5) =	$7,296
EUAB (2) =	$47,250*(P/A, 11%, 5) =	$12,785
Net Present Worth (2) =	PW(Benefits) - Initial Cost =	$20,284
EUAB (2) - EUAC (2) =	UAB (2) = $20,284*(P/A, 11%,5) =	$5,488

Alternative 3

Alternative #3 from Vendor B

i = 11%

Additional Cost on Research at Time of Setup = = ($30*40*2) = ($2,400)

Year	Period	Initial Cost	Annual Benefits From Larger Sampler = ($30*16*2*12)	Annual Benefits Freeing up for TAN = ($30*16*12)	Expenses Electrodes plus Flow Cell	Expenses Chemicals	Maintenance and Operating Expenses
2002	0	($18,855)					
2003	1		$11,520	$5,760	($3,000)	($6,015)	($794)
2004	2		$11,520	$5,760	($3,000)	($6,015)	($794)
2005	3		$11,520	$5,760	($3,000)	($6,015)	($794)
2006	4		$11,520	$5,760	($3,000)	($6,015)	($794)
2007	5	$1,886	$11,520	$5,760	($3,000)	($6,015)	($794)

Year	Period	Initial Cost	Net Benefits	Present Worth Net Benefits P*(1+i)^-n
2002	0	($21,255)		
2003	1		$7,472	$6,731
2004	2		$7,472	$6,064
2005	3		$7,472	$5,463
2006	4		$7,472	$4,922
2007	5		$9,357	$5,553
Total				$28,733

PW Cost (3) = Initial Cost =	$21,255	
PW Benefits (3) =	$28,733	
EUAC (3) =	$21,255*(P/A, 11%,5) =	$5,751
EUAB (3) =	$28,733*(P/A, 11%, 5) =	$7,774
Net Present Worth (3) =	PW(Benefits) - Initial Cost =	$7,478
EUAB (3) - EUAC (3) =	UAB (3) = $7,478*(P/A, 11%,5) =	$2,023

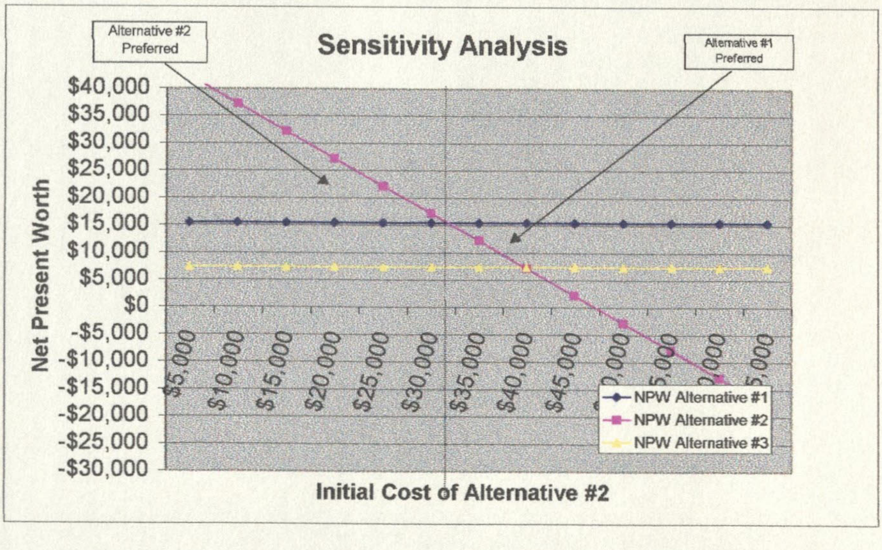
Sensitivity Analysis, 11%

i =	11%				n = 5	P/A	i
NPW (Alt. #1) =		$15,490				4.3295	5.00%
NPW (Alt #2) =		$20,284				4.2124	6.00%
NPW (Alt. #3) =		$7,478				4.1002	7.00%
EUAB (1) =		$15,928				3.9927	8.00%
EUAB (2) =		$12,785				3.8897	9.00%
EUAB (3) =		$7,774				3.7908	10.00%
						3.6959	11.00%
Let x = Initial cost of Alt. #2			$26,966			3.6048	12.00%
						3.5172	13.00%
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =		$47,250	-x		3.4331	14.00%
						2.9906	20.00%
						2.4356	30.00%

x = $47,250 - $15,490 = $31,761

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$31,079	$15,490	$5,000	$42,250	$7,478
$31,079	$15,490	$10,000	$37,250	$7,478
$31,079	$15,490	$15,000	$32,250	$7,478
$31,079	$15,490	$20,000	$27,250	$7,478
$31,079	$15,490	$25,000	$22,250	$7,478
$31,079	$15,490	$30,000	$17,250	$7,478
$31,079	$15,490	$35,000	$12,250	$7,478
$31,079	$15,490	$40,000	$7,250	$7,478
$31,079	$15,490	$45,000	$2,250	$7,478
$31,079	$15,490	$50,000	-$2,750	$7,478
$31,079	$15,490	$55,000	-$7,750	$7,478
$31,079	$15,490	$60,000	-$12,750	$7,478
$31,079	$15,490	$65,000	-$17,750	$7,478

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $31,761
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $31,761



NPW and UAB Cost Summary

	Alternative #1 Complete Unit Vendor A	Alternative #2 Sampler Upgrade Vendor A	Alternative #3 Complete Unit Vendor B
NPW	$15,490	$20,284	$7,478
UAB	$4,191	$5,488	$2,023

Payback Period

	Alternative #1 Complete Unit Vendor A	Alternative #2 Sampler Upgrade Vendor A	Alternative #3 Complete Unit Vendor B
Initial Cost	$43,379	$26,966	$21,255
UAB	$4,191	$5,488	$2,023
Payback Period (Years)	10.35	4.91	10.50

Differences in Alternatives

DIFFERENCES IN ALTERNATIVES

Year	Alternative #1 Complete Unit Vendor A	Alternative #2 Sampler Upgrade Vendor A	Alternative #3 Complete Unit Vendor B
0	-$43,379	-$26,966	-$21,255
1	$15,232	$12,352	$7,472
2	$15,232	$12,352	$7,472
3	$15,232	$12,352	$7,472
4	$15,232	$12,352	$7,472
5	$19,569	$15,048	$9,357
IRR	23.911%	37.121%	23.781%

Year	Alternative #2 - Alternative #3		
0	-$5,711		
1	$4,880		
2	$4,880		
3	$4,880		
4	$4,880		
5	$5,691		
IRR =	81.723%	> 11%	Keep Alt. 2, discard Alt. 3

Year	Alternative #1 - Alternative #2		
0	-$16,413		
1	$2,880		
2	$2,880		
3	$2,880		
4	$2,880		
5	$4,521		
IRR =	-0.711%	< 11%	Discard Alt. 1, keep Alt. 2

ANSWER: Alternative 2

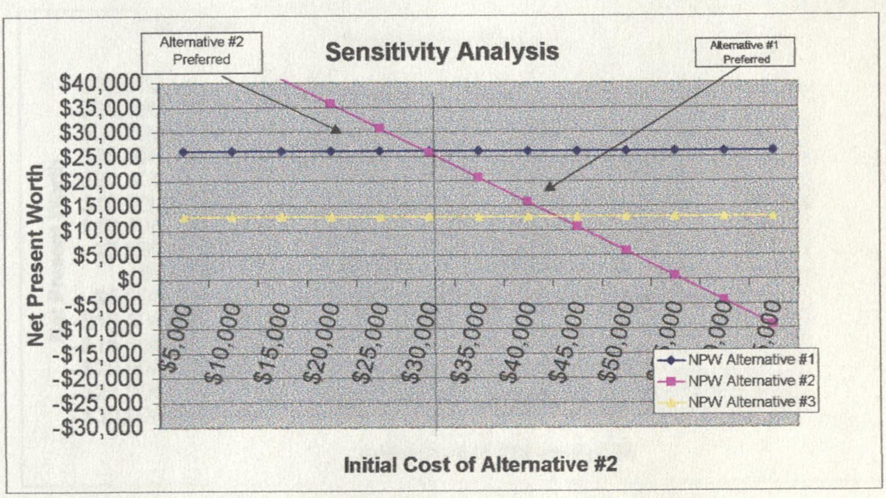
Sensitivity Analysis, 5%

i =	5%			n = 5	P/A	i
					4.3295	5.00%
NPW (Alt. #1) =	$26,174				4.2124	6.00%
NPW (Alt #2) =	$28,832				4.1002	7.00%
NPW (Alt. #3) =	$12,780				3.9927	8.00%
EUAB (1) =	$16,065				3.8897	9.00%
EUAB (2) =	$12,888				3.7908	10.00%
EUAB (3) =	$7,861				3.6959	11.00%
					3.6048	12.00%
Let x = Initial cost of Alt. #2		$26,966			3.5172	13.00%
					3.4331	14.00%
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =	$55,798	-x		2.9906	20.00%
					2.4356	30.00%

x = $55,798 - $26,174 = $29,624

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$20,395	$26,174	$5,000	$50,798	$12,780
$20,395	$26,174	$10,000	$45,798	$12,780
$20,395	$26,174	$15,000	$40,798	$12,780
$20,395	$26,174	$20,000	$35,798	$12,780
$20,395	$26,174	$25,000	$30,798	$12,780
$20,395	$26,174	$30,000	$25,798	$12,780
$20,395	$26,174	$35,000	$20,798	$12,780
$20,395	$26,174	$40,000	$15,798	$12,780
$20,395	$26,174	$45,000	$10,798	$12,780
$20,395	$26,174	$50,000	$5,798	$12,780
$20,395	$26,174	$55,000	$798	$12,780
$20,395	$26,174	$60,000	-$4,202	$12,780
$20,395	$26,174	$65,000	-$9,202	$12,780

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $29,624
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $29,624



Sensitivity Analysis, 6%

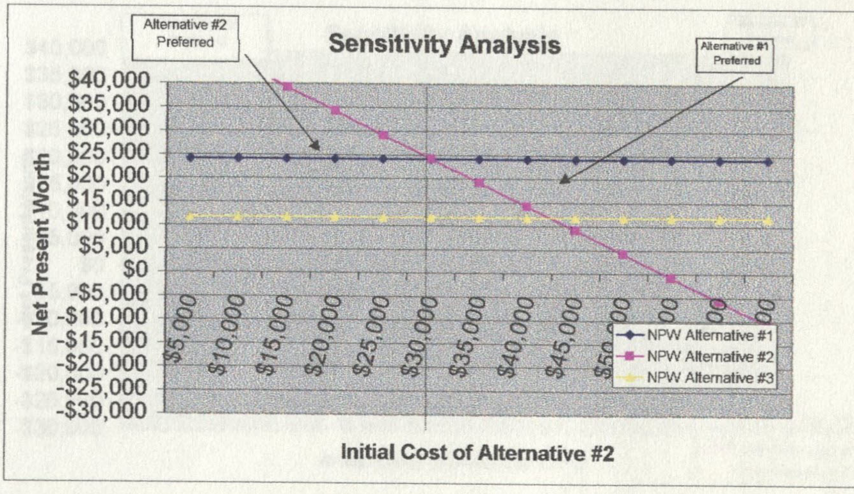
i = 6%

NPW (Alt. #1) =	$24,193		n = 5	P/A	i
NPW (Alt. #2) =	$27,248			4.3295	5.00%
NPW (Alt. #3) =	$11,797			4.2124	6.00%
EUAB (1) =	$16,041			4.1002	7.00%
EUAB (2) =	$12,870			3.9927	8.00%
EUAB (3) =	$7,846			3.8897	9.00%
				3.7908	10.00%
				3.6959	11.00%
Let x = Initial cost of Alt. #2		$26,966		3.6048	12.00%
				3.5172	13.00%
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x =		$54,214 -x		3.4331	14.00%
				2.9906	20.00%
				2.4356	30.00%

x = $54,214 - $24,193 = $30,021

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$22,376	$24,193	$5,000	$49,214	$11,797
$22,376	$24,193	$10,000	$44,214	$11,797
$22,376	$24,193	$15,000	$39,214	$11,797
$22,376	$24,193	$20,000	$34,214	$11,797
$22,376	$24,193	$25,000	$29,214	$11,797
$22,376	$24,193	$30,000	$24,214	$11,797
$22,376	$24,193	$35,000	$19,214	$11,797
$22,376	$24,193	$40,000	$14,214	$11,797
$22,376	$24,193	$45,000	$9,214	$11,797
$22,376	$24,193	$50,000	$4,214	$11,797
$22,376	$24,193	$55,000	-$786	$11,797
$22,376	$24,193	$60,000	-$5,786	$11,797
$22,376	$24,193	$65,000	-$10,786	$11,797

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $30,021
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $30,021



Sensitivity Analysis, 7%

i = 7%

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
2.9906	20.00%
2.4356	30.00%

NPW (Alt. #1) = $22,299
NPW (Alt. #2) = $25,733
NPW (Alt. #3) = $10,857
EUAB (1) = $16,018
EUAB (2) = $12,853
EUAB (3) = $7,832

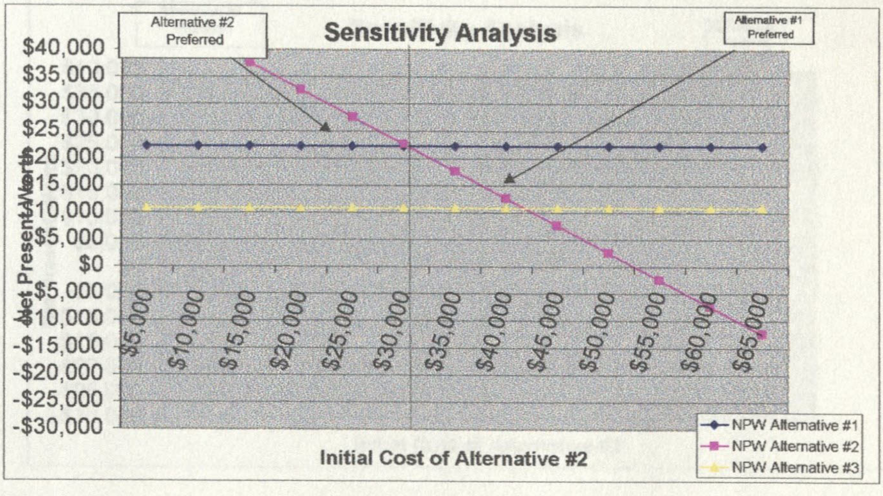
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $52,699 -x

x = $52,699 - $22,299 = $30,400

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$24,270	$22,299	$5,000	$47,699	$10,857
$24,270	$22,299	$10,000	$42,699	$10,857
$24,270	$22,299	$15,000	$37,699	$10,857
$24,270	$22,299	$20,000	$32,699	$10,857
$24,270	$22,299	$25,000	$27,699	$10,857
$24,270	$22,299	$30,000	$22,699	$10,857
$24,270	$22,299	$35,000	$17,699	$10,857
$24,270	$22,299	$40,000	$12,699	$10,857
$24,270	$22,299	$45,000	$7,699	$10,857
$24,270	$22,299	$50,000	$2,699	$10,857
$24,270	$22,299	$55,000	-$2,301	$10,857
$24,270	$22,299	$60,000	-$7,301	$10,857
$24,270	$22,299	$65,000	-$12,301	$10,857

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $30,400
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $30,400



i = 8%

n = 5	P/A	i
	4.3295	5.00%
	4.2124	6.00%
	4.1002	7.00%
	3.9927	8.00%
	3.8897	9.00%
	3.7908	10.00%
	3.6959	11.00%
	3.6048	12.00%
	3.5172	13.00%
	3.4331	14.00%
	2.9906	20.00%
	2.4356	30.00%

NPW (Alt. #1) = $20,485
NPW (Alt #2) = $24,282
NPW (Alt. #3) = $9,957
EUAB (1) = $15,995
EUAB (2) = $12,835
EUAB (3) = $7,817

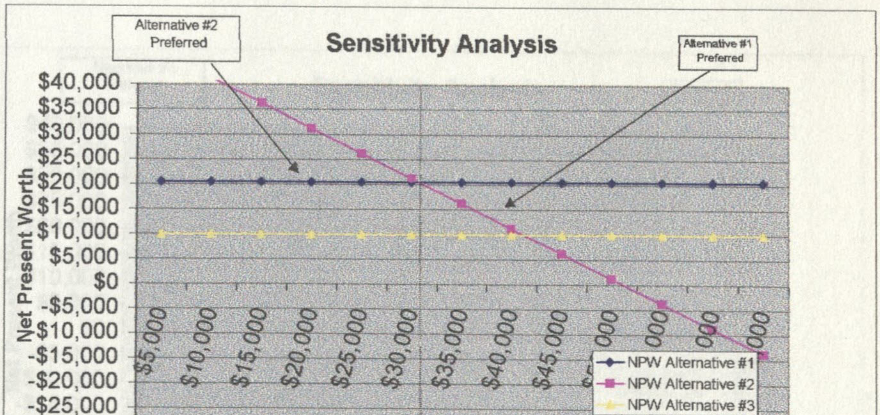
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $51,248 -x

x = $51,248 - $20,485 = $30,763

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$26,084	$20,485	$5,000	$46,248	$9,957
$26,084	$20,485	$10,000	$41,248	$9,957
$26,084	$20,485	$15,000	$36,248	$9,957
$26,084	$20,485	$20,000	$31,248	$9,957
$26,084	$20,485	$25,000	$26,248	$9,957
$26,084	$20,485	$30,000	$21,248	$9,957
$26,084	$20,485	$35,000	$16,248	$9,957
$26,084	$20,485	$40,000	$11,248	$9,957
$26,084	$20,485	$45,000	$6,248	$9,957
$26,084	$20,485	$50,000	$1,248	$9,957
$26,084	$20,485	$55,000	-$3,752	$9,957
$26,084	$20,485	$60,000	-$8,752	$9,957
$26,084	$20,485	$65,000	-$13,752	$9,957

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $30,763
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $30,763



Sensitivity Analysis, 9%

i = 9%

NPW (Alt. #1) =	$18,749
NPW (Alt #2) =	$22,893
NPW (Alt. #3) =	$9,095
EUAB (1) =	$15,973
EUAB (2) =	$12,818
EUAB (3) =	$7,803

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
2.9906	20.00%
2.4356	30.00%

Let x = Initial cost of Alt. #2 $26,966

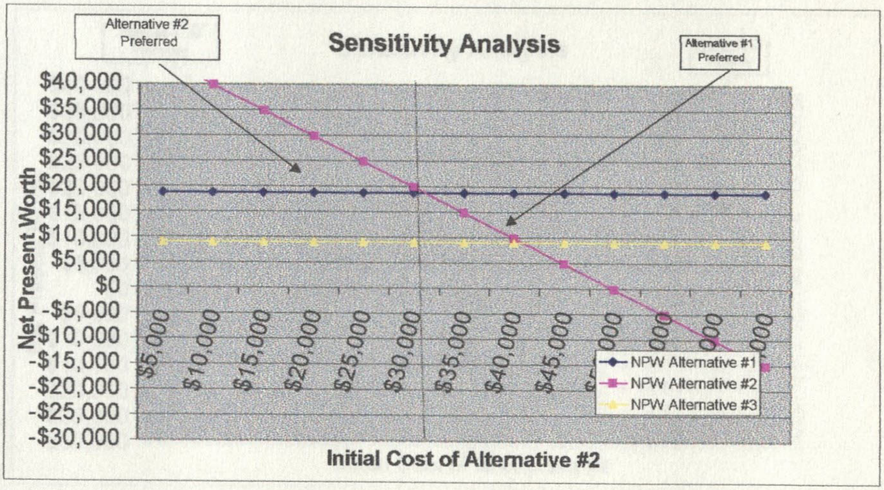
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $49,859 -x

x = $49,859 - $18,749 = $31,110

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$27,820	$18,749	$5,000	$44,859	$9,095
$27,820	$18,749	$10,000	$39,859	$9,095
$27,820	$18,749	$15,000	$34,859	$9,095
$27,820	$18,749	$20,000	$29,859	$9,095
$27,820	$18,749	$25,000	$24,859	$9,095
$27,820	$18,749	$30,000	$19,859	$9,095
$27,820	$18,749	$35,000	$14,859	$9,095
$27,820	$18,749	$40,000	$9,859	$9,095
$27,820	$18,749	$45,000	$4,859	$9,095
$27,820	$18,749	$50,000	-$141	$9,095
$27,820	$18,749	$55,000	-$5,141	$9,095
$27,820	$18,749	$60,000	-$10,141	$9,095
$27,820	$18,749	$65,000	-$15,141	$9,095

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $31,110

Alternative #1 is preferred if initial cost of Alternative #2 exceeds $31,110



Sensitivity Analysis, 10%

i = 10%

NPW (Alt. #1) =	$17,085
NPW (Alt. #2) =	$21,561
NPW (Alt. #3) =	$8,270
EUAB (1) =	$15,950
EUAB (2) =	$12,801
EUAB (3) =	$7,789

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
2.9906	20.00%
2.4356	30.00%

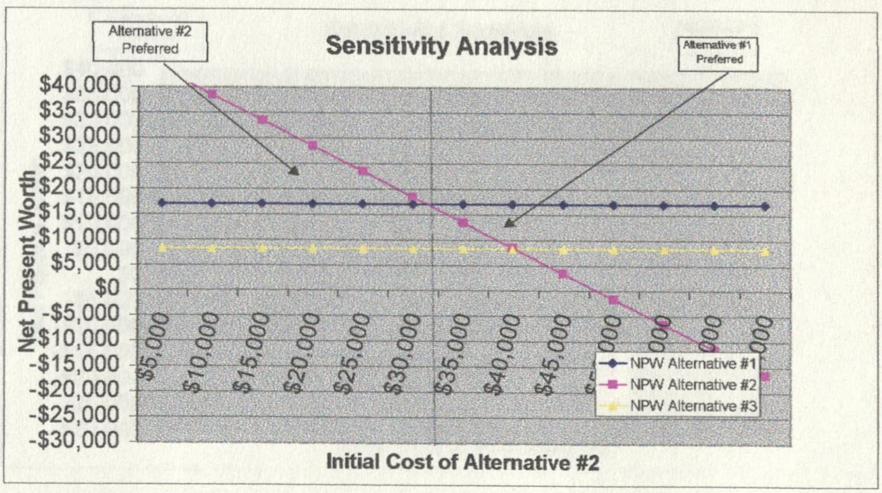
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $48,527 -x

x = $48,527 - $17,085 = $31,442

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$29,484	$17,085	$5,000	$43,527	$8,270
$29,484	$17,085	$10,000	$38,527	$8,270
$29,484	$17,085	$15,000	$33,527	$8,270
$29,484	$17,085	$20,000	$28,527	$8,270
$29,484	$17,085	$25,000	$23,527	$8,270
$29,484	$17,085	$30,000	$18,527	$8,270
$29,484	$17,085	$35,000	$13,527	$8,270
$29,484	$17,085	$40,000	$8,527	$8,270
$29,484	$17,085	$45,000	$3,527	$8,270
$29,484	$17,085	$50,000	-$1,473	$8,270
$29,484	$17,085	$55,000	-$6,473	$8,270
$29,484	$17,085	$60,000	-$11,473	$8,270
$29,484	$17,085	$65,000	-$16,473	$8,270

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $31,442
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $31,442



Sensitivity Analysis, 11%

i =	11%		n = 5	P/A	i
NPW (Alt. #1) =	$15,490			4.3295	5.00%
NPW (Alt. #2) =	$20,284			4.2124	6.00%
NPW (Alt. #3) =	$7,478			4.1002	7.00%
EUAB (1) =	$15,928			3.9927	8.00%
EUAB (2) =	$12,785			3.8897	9.00%
EUAB (3) =	$7,774			3.7908	10.00%
				3.6959	11.00%
				3.6048	12.00%
				3.5172	13.00%
				3.4331	14.00%
				2.9906	20.00%
				2.4356	30.00%

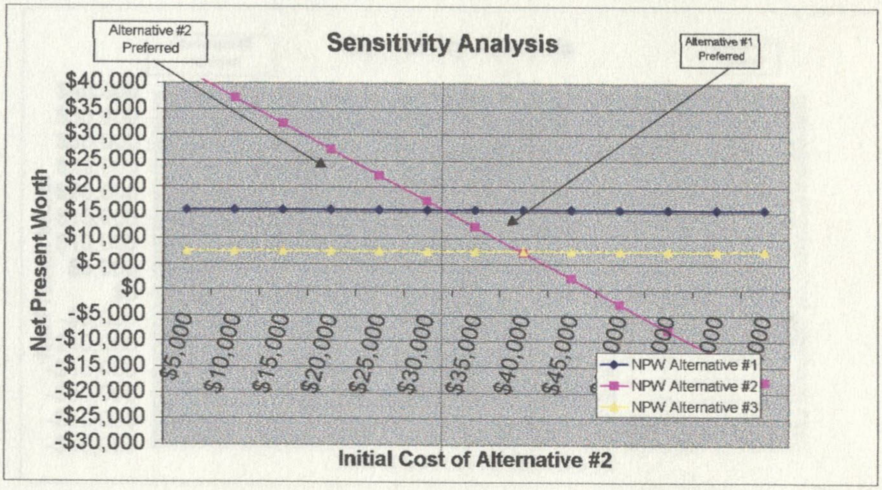
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $47,250 -x

x = $47,250 - $15,490 = $31,761

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$31,079	$15,490	$5,000	$42,250	$7,478
$31,079	$15,490	$10,000	$37,250	$7,478
$31,079	$15,490	$15,000	$32,250	$7,478
$31,079	$15,490	$20,000	$27,250	$7,478
$31,079	$15,490	$25,000	$22,250	$7,478
$31,079	$15,490	$30,000	$17,250	$7,478
$31,079	$15,490	$35,000	$12,250	$7,478
$31,079	$15,490	$40,000	$7,250	$7,478
$31,079	$15,490	$45,000	$2,250	$7,478
$31,079	$15,490	$50,000	-$2,750	$7,478
$31,079	$15,490	$55,000	-$7,750	$7,478
$31,079	$15,490	$60,000	-$12,750	$7,478
$31,079	$15,490	$65,000	-$17,750	$7,478

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $31,761
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $31,761



Sensitivity Analysis, 12%

i = 12%

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
2.9906	20.00%
2.4356	30.00%

NPW (Alt. #1) = $13,960
NPW (Alt. #2) = $19,060
NPW (Alt. #3) = $6,719
EUAB (1) = $15,906
EUAB (2) = $12,768
EUAB (3) = $7,760

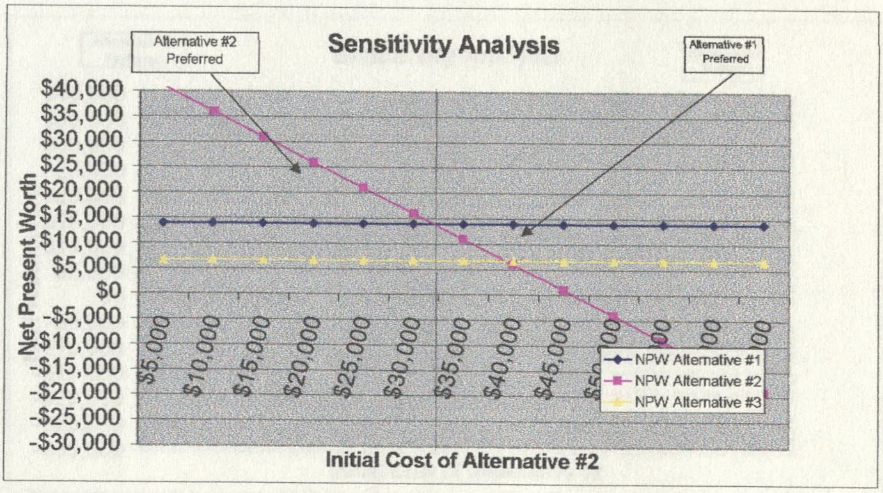
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $46,026 -x

x = $46,026 - $13,960 = $32,066

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$32,609	$13,960	$5,000	$41,026	$6,719
$32,609	$13,960	$10,000	$36,026	$6,719
$32,609	$13,960	$15,000	$31,026	$6,719
$32,609	$13,960	$20,000	$26,026	$6,719
$32,609	$13,960	$25,000	$21,026	$6,719
$32,609	$13,960	$30,000	$16,026	$6,719
$32,609	$13,960	$35,000	$11,026	$6,719
$32,609	$13,960	$40,000	$6,026	$6,719
$32,609	$13,960	$45,000	$1,026	$6,719
$32,609	$13,960	$50,000	-$3,974	$6,719
$32,609	$13,960	$55,000	-$8,974	$6,719
$32,609	$13,960	$60,000	-$13,974	$6,719
$32,609	$13,960	$65,000	-$18,974	$6,719

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $32,066
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $32,066



Sensitivity Analysis, 13%

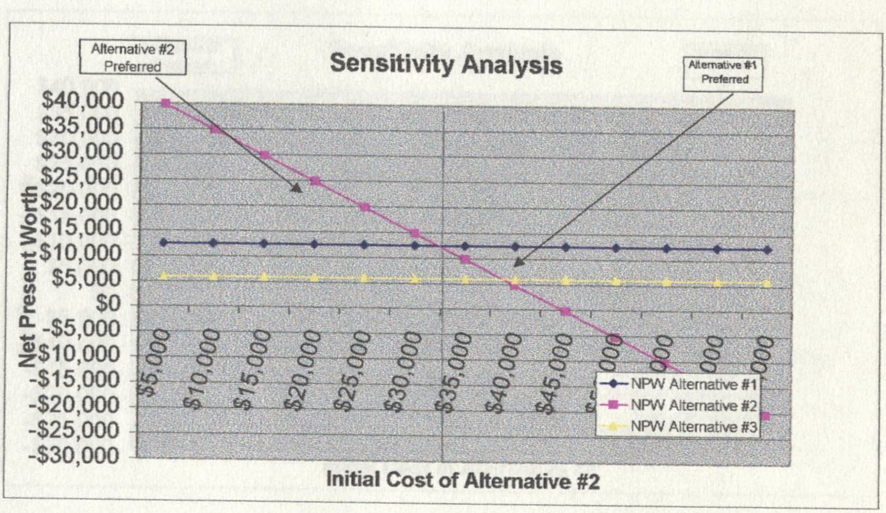
i = 13%

				n = 5	P/A	i
NPW (Alt. #1) =		$12,491			4.3295	5.00%
NPW (Alt #2) =		$17,884			4.2124	6.00%
NPW (Alt. #3) =		$5,991			4.1002	7.00%
EUAB (1) =		$15,885			3.9927	8.00%
EUAB (2) =		$12,752			3.8897	9.00%
EUAB (3) =		$7,746			3.7908	10.00%
					3.6959	11.00%
Let x = Initial cost of Alt. #2		$26,966			3.6048	12.00%
					3.5172	13.00%
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =	$44,850	-x		3.4331	14.00%
					2.9906	20.00%
					2.4356	30.00%

x = $44,850 - $12,491 = $32,359

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$34,078	$12,491	$5,000	$39,850	$5,991
$34,078	$12,491	$10,000	$34,850	$5,991
$34,078	$12,491	$15,000	$29,850	$5,991
$34,078	$12,491	$20,000	$24,850	$5,991
$34,078	$12,491	$25,000	$19,850	$5,991
$34,078	$12,491	$30,000	$14,850	$5,991
$34,078	$12,491	$35,000	$9,850	$5,991
$34,078	$12,491	$40,000	$4,850	$5,991
$34,078	$12,491	$45,000	-$150	$5,991
$34,078	$12,491	$50,000	-$5,150	$5,991
$34,078	$12,491	$55,000	-$10,150	$5,991
$34,078	$12,491	$60,000	-$15,150	$5,991
$34,078	$12,491	$65,000	-$20,150	$5,991

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $32,359
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $32,359

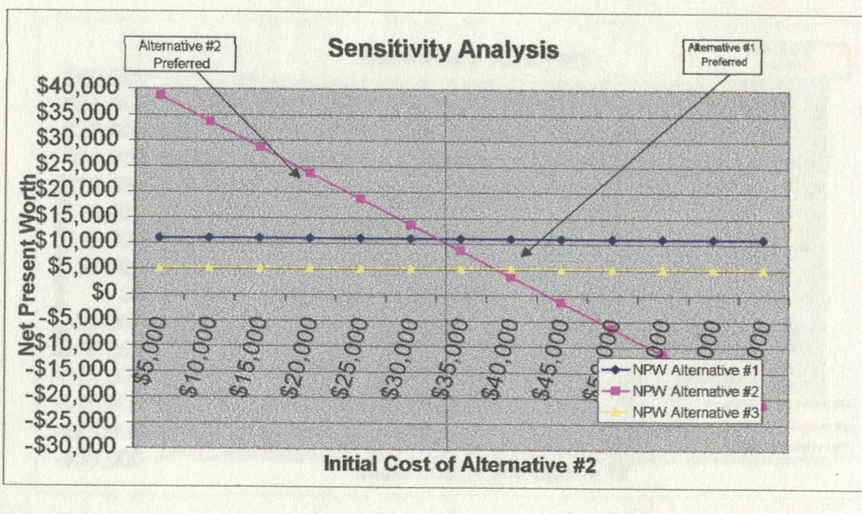


Sensitivity Analysis, 14%

i =	14%					n = 5	P/A	i
NPW (Alt. #1) =		$11,082					4.3295	5.00%
NPW (Alt. #2) =		$16,755					4.2124	6.00%
NPW (Alt. #3) =		$5,291					4.1002	7.00%
EUAB (1) =		$15,864					3.9927	8.00%
EUAB (2) =		$12,735					3.8897	9.00%
EUAB (3) =		$7,733					3.7908	10.00%
							3.6959	11.00%
Let x = Initial cost of Alt. #2			$26,966				3.6048	12.00%
							3.5172	13.00%
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =		$43,721	-x			3.4331	14.00%
							2.9906	20.00%
							2.4356	30.00%
x =	$43,721	-		$11,082	=	$32,639		

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$35,487	$11,082	$5,000	$38,721	$5,291
$35,487	$11,082	$10,000	$33,721	$5,291
$35,487	$11,082	$15,000	$28,721	$5,291
$35,487	$11,082	$20,000	$23,721	$5,291
$35,487	$11,082	$25,000	$18,721	$5,291
$35,487	$11,082	$30,000	$13,721	$5,291
$35,487	$11,082	$35,000	$8,721	$5,291
$35,487	$11,082	$40,000	$3,721	$5,291
$35,487	$11,082	$45,000	-$1,279	$5,291
$35,487	$11,082	$50,000	-$6,279	$5,291
$35,487	$11,082	$55,000	-$11,279	$5,291
$35,487	$11,082	$60,000	-$16,279	$5,291
$35,487	$11,082	$65,000	-$21,279	$5,291

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $32,639
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $32,639



Sensitivity Analysis, 15%

i = 15%

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.6893	25.00%
2.4356	30.00%

NPW (Alt. #1) = $9,728
NPW (Alt. #2) = $15,671
NPW (Alt. #3) = $4,620
EUAB (1) = $15,843
EUAB (2) = $12,719
EUAB (3) = $7,719

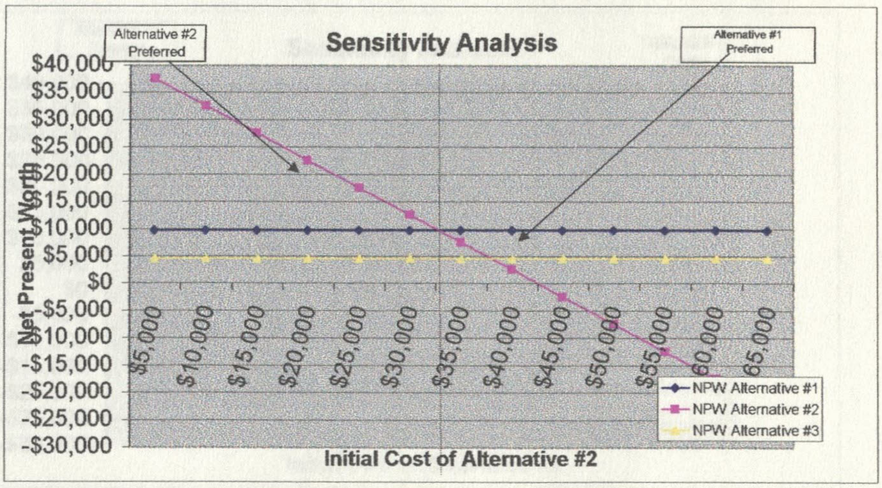
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $42,637 -x

x = $42,637 - $9,728 = $32,909

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$36,841	$9,728	$5,000	$37,637	$4,620
$36,841	$9,728	$10,000	$32,637	$4,620
$36,841	$9,728	$15,000	$27,637	$4,620
$36,841	$9,728	$20,000	$22,637	$4,620
$36,841	$9,728	$25,000	$17,637	$4,620
$36,841	$9,728	$30,000	$12,637	$4,620
$36,841	$9,728	$35,000	$7,637	$4,620
$36,841	$9,728	$40,000	$2,637	$4,620
$36,841	$9,728	$45,000	-$2,363	$4,620
$36,841	$9,728	$50,000	-$7,363	$4,620
$36,841	$9,728	$55,000	-$12,363	$4,620
$36,841	$9,728	$60,000	-$17,363	$4,620
$36,841	$9,728	$65,000	-$22,363	$4,620

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $32,909
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $32,909



Sensitivity Analysis, 16%

i = 16%

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.6893	25.00%
2.4356	30.00%

NPW (Alt. #1) =	$8,426
NPW (Alt #2) =	$14,628
NPW (Alt. #3) =	$3,974
EUAB (1) =	$15,822
EUAB (2) =	$12,703
EUAB (3) =	$7,705

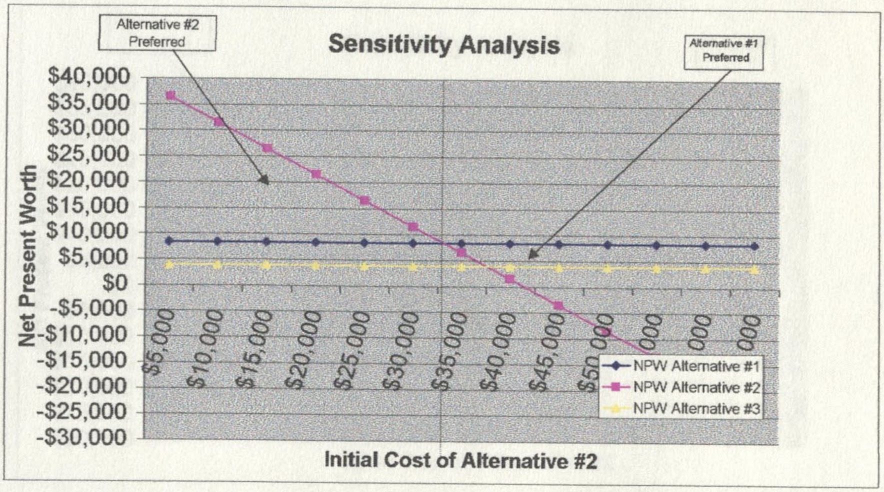
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $41,594 -x

x = $41,594 - $8,426 = $33,168

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$38,143	$8,426	$5,000	$36,594	$3,974
$38,143	$8,426	$10,000	$31,594	$3,974
$38,143	$8,426	$15,000	$26,594	$3,974
$38,143	$8,426	$20,000	$21,594	$3,974
$38,143	$8,426	$25,000	$16,594	$3,974
$38,143	$8,426	$30,000	$11,594	$3,974
$38,143	$8,426	$35,000	$6,594	$3,974
$38,143	$8,426	$40,000	$1,594	$3,974
$38,143	$8,426	$45,000	-$3,406	$3,974
$38,143	$8,426	$50,000	-$8,406	$3,974
$38,143	$8,426	$55,000	-$13,406	$3,974
$38,143	$8,426	$60,000	-$18,406	$3,974
$38,143	$8,426	$65,000	-$23,406	$3,974

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $33,168
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $33,168



Sensitivity Analysis, 17%

i = 17%

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.6893	25.00%
2.4356	30.00%

NPW (Alt. #1) =	$7,175
NPW (Alt #2) =	$13,625
NPW (Alt. #3) =	$3,354
EUAB (1) =	$15,801
EUAB (2) =	$12,687
EUAB (3) =	$7,692

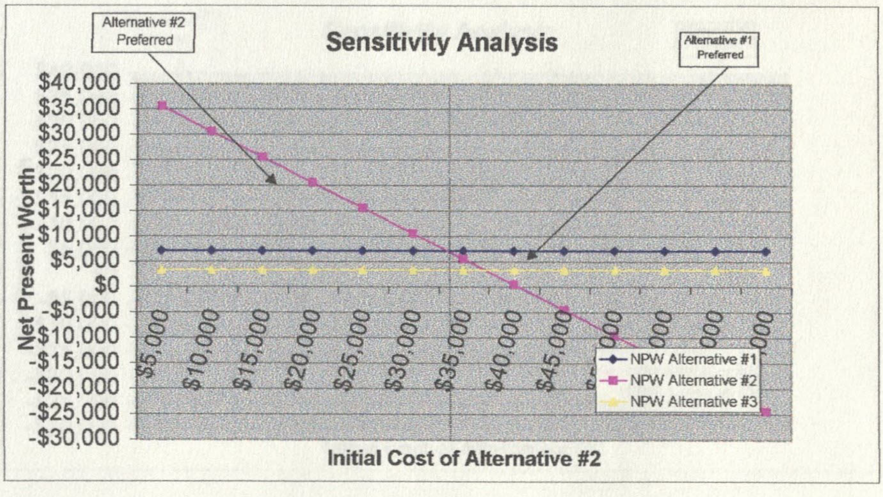
Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $40,591 -x

x = $40,591 - $7,175 = $33,416

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$39,394	$7,175	$5,000	$35,591	$3,354
$39,394	$7,175	$10,000	$30,591	$3,354
$39,394	$7,175	$15,000	$25,591	$3,354
$39,394	$7,175	$20,000	$20,591	$3,354
$39,394	$7,175	$25,000	$15,591	$3,354
$39,394	$7,175	$30,000	$10,591	$3,354
$39,394	$7,175	$35,000	$5,591	$3,354
$39,394	$7,175	$40,000	$591	$3,354
$39,394	$7,175	$45,000	-$4,409	$3,354
$39,394	$7,175	$50,000	-$9,409	$3,354
$39,394	$7,175	$55,000	-$14,409	$3,354
$39,394	$7,175	$60,000	-$19,409	$3,354
$39,394	$7,175	$65,000	-$24,409	$3,354

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $33,416
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $33,416



Sensitivity Analysis, 18%

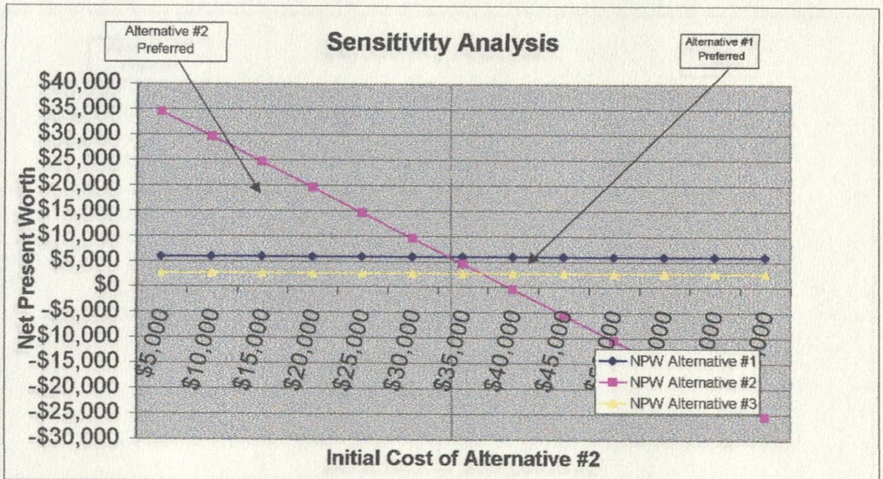
i =	18%						
NPW (Alt. #1) =		$5,972					
NPW (Alt. #2) =		$12,661					
NPW (Alt. #3) =		$2,757					
EUAB (1) =		$15,781					
EUAB (2) =		$12,672					
EUAB (3) =		$7,678					
Let x = Initial cost of Alt. #2			$26,966				
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =		$39,627	-x			
	x =	$39,627	-	$5,972	=	$33,655	

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.6893	25.00%
2.4356	30.00%

	NPW Alternative #1	**Initial Cost Alternative #2**	**NPW Alternative #2**	**NPW Alternative #3**
$40,597	$5,972	$5,000	$34,627	$2,757
$40,597	$5,972	$10,000	$29,627	$2,757
$40,597	$5,972	$15,000	$24,627	$2,757
$40,597	$5,972	$20,000	$19,627	$2,757
$40,597	$5,972	$25,000	$14,627	$2,757
$40,597	$5,972	$30,000	$9,627	$2,757
$40,597	$5,972	$35,000	$4,627	$2,757
$40,597	$5,972	$40,000	-$373	$2,757
$40,597	$5,972	$45,000	-$5,373	$2,757
$40,597	$5,972	$50,000	-$10,373	$2,757
$40,597	$5,972	$55,000	-$15,373	$2,757
$40,597	$5,972	$60,000	-$20,373	$2,757
$40,597	$5,972	$65,000	-$25,373	$2,757

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $33,655
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $33,655



Sensitivity Analysis, 19%

i = 19%

NPW (Alt. #1) = $4,813
NPW (Alt #2) = $11,733
NPW (Alt. #3) = $2,182
EUAB (1) = $15,761
EUAB (2) = $12,656
EUAB (3) = $7,665

Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $38,699 -x

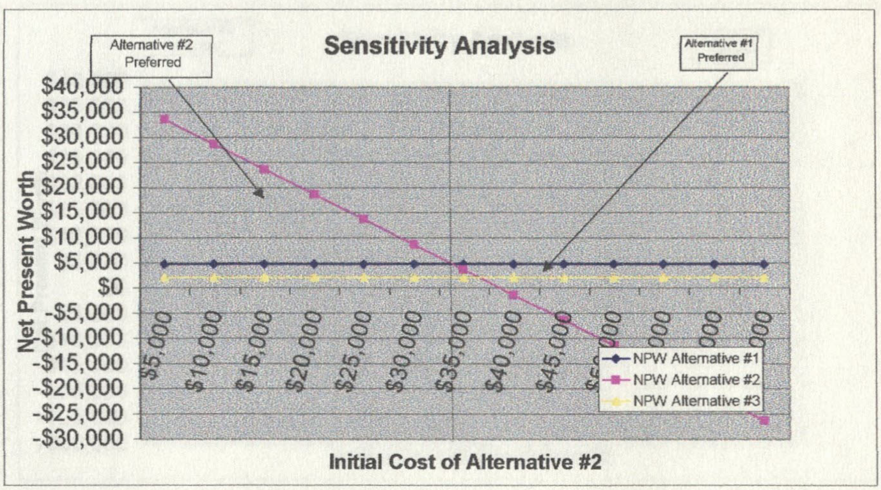
x = $38,699 - $4,813 = $33,885

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.6893	25.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$41,756	$4,813	$5,000	$33,699	$2,182
$41,756	$4,813	$10,000	$28,699	$2,182
$41,756	$4,813	$15,000	$23,699	$2,182
$41,756	$4,813	$20,000	$18,699	$2,182
$41,756	$4,813	$25,000	$13,699	$2,182
$41,756	$4,813	$30,000	$8,699	$2,182
$41,756	$4,813	$35,000	$3,699	$2,182
$41,756	$4,813	$40,000	-$1,301	$2,182
$41,756	$4,813	$45,000	-$6,301	$2,182
$41,756	$4,813	$50,000	-$11,301	$2,182
$41,756	$4,813	$55,000	-$16,301	$2,182
$41,756	$4,813	$60,000	-$21,301	$2,182
$41,756	$4,813	$65,000	-$26,301	$2,182

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $33,885
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $33,885



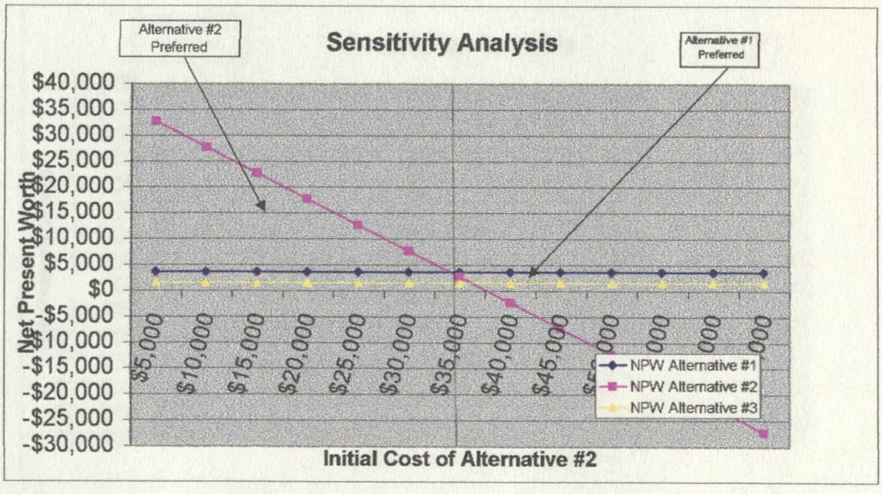
Sensitivity Analysis, 20%

i =	20%					n = 5	P/A	i
							4.3295	5.00%
NPW (Alt. #1) =		$3,698					4.2124	6.00%
NPW (Alt. #2) =		$10,839					4.1002	7.00%
NPW (Alt. #3) =		$1,629					3.9927	8.00%
EUAB (1) =		$15,742					3.8897	9.00%
EUAB (2) =		$12,641					3.7908	10.00%
EUAB (3) =		$7,652					3.6959	11.00%
							3.6048	12.00%
Let x = Initial cost of Alt. #2			$26,966				3.5172	13.00%
							3.4331	14.00%
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =		$37,805	-x			3.3522	15.00%
							3.2743	16.00%
							3.1993	17.00%
x =	$37,805		-	$3,698	=	$34,106	3.1272	18.00%
							3.0576	19.00%
							2.9906	20.00%
							2.9260	21.00%
							2.8636	22.00%
							2.8035	23.00%
							2.7454	24.00%
							2.6893	25.00%
							2.6351	26.00%
							2.5827	27.00%
							2.5320	28.00%
							2.4830	29.00%
							2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$42,871	$3,698	$5,000	$32,805	$1,629
$42,871	$3,698	$10,000	$27,805	$1,629
$42,871	$3,698	$15,000	$22,805	$1,629
$42,871	$3,698	$20,000	$17,805	$1,629
$42,871	$3,698	$25,000	$12,805	$1,629
$42,871	$3,698	$30,000	$7,805	$1,629
$42,871	$3,698	$35,000	$2,805	$1,629
$42,871	$3,698	$40,000	-$2,195	$1,629
$42,871	$3,698	$45,000	-$7,195	$1,629
$42,871	$3,698	$50,000	-$12,195	$1,629
$42,871	$3,698	$55,000	-$17,195	$1,629
$42,871	$3,698	$60,000	-$22,195	$1,629
$42,871	$3,698	$65,000	-$27,195	$1,629

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $34,106

Alternative #1 is preferred if initial cost of Alternative #2 exceeds $34,106



Sensitivity Analysis, 21%

i = 21%

n = 5

NPW (Alt. #1) =	$2,624
NPW (Alt #2) =	$9,977
NPW (Alt. #3) =	$1,097
EUAB (1) =	$15,722
EUAB (2) =	$12,626
EUAB (3) =	$7,639

Let x = Initial cost of Alt. #2 $26,966

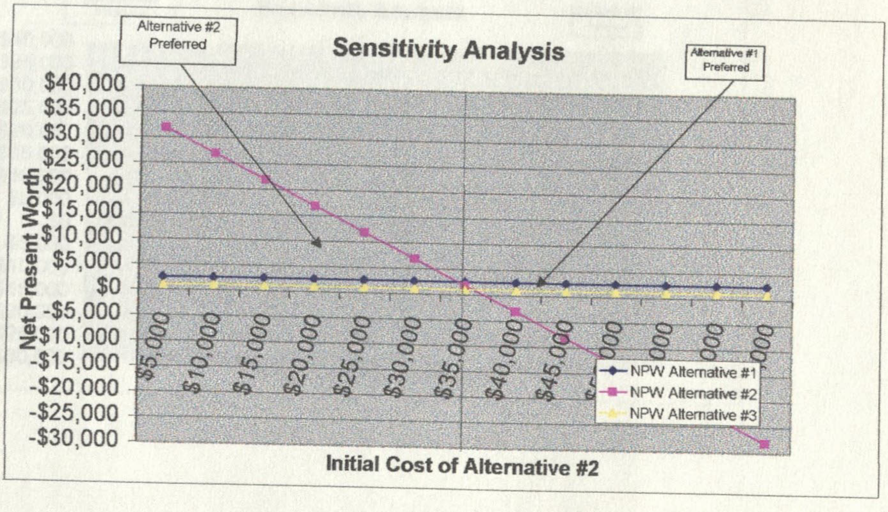
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $36,943 -x

x = $36,943 - $2,624 = $34,319

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$43,945	$2,624	$5,000	$31,943	$1,097
$43,945	$2,624	$10,000	$26,943	$1,097
$43,945	$2,624	$15,000	$21,943	$1,097
$43,945	$2,624	$20,000	$16,943	$1,097
$43,945	$2,624	$25,000	$11,943	$1,097
$43,945	$2,624	$30,000	$6,943	$1,097
$43,945	$2,624	$35,000	$1,943	$1,097
$43,945	$2,624	$40,000	-$3,057	$1,097
$43,945	$2,624	$45,000	-$8,057	$1,097
$43,945	$2,624	$50,000	-$13,057	$1,097
$43,945	$2,624	$55,000	-$18,057	$1,097
$43,945	$2,624	$60,000	-$23,057	$1,097
$43,945	$2,624	$65,000	-$28,057	$1,097

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $34,319
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $34,319



Sensitivity Analysis, 22%

i = 22%

NPW (Alt. #1) =	$1,589	
NPW (Alt. #2) =	$9,147	
NPW (Alt. #3) =	$584	
EUAB (1) =	$15,703	
EUAB (2) =	$12,611	
EUAB (3) =	$7,626	

Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $36,113 -x

x = $36,113 - $1,589 = $34,524

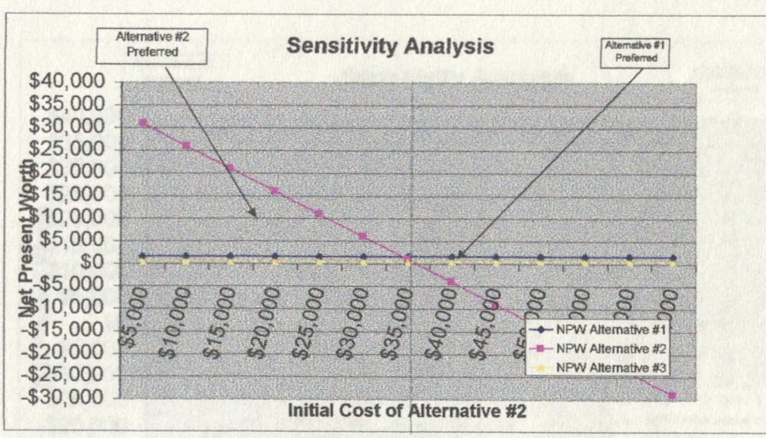
n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$44,980	$1,589	$5,000	$31,113	$584
$44,980	$1,589	$10,000	$26,113	$584
$44,980	$1,589	$15,000	$21,113	$584
$44,980	$1,589	$20,000	$16,113	$584
$44,980	$1,589	$25,000	$11,113	$584
$44,980	$1,589	$30,000	$6,113	$584
$44,980	$1,589	$35,000	$1,113	$584
$44,980	$1,589	$40,000	-$3,887	$584
$44,980	$1,589	$45,000	-$8,887	$584
$44,980	$1,589	$50,000	-$13,887	$584
$44,980	$1,589	$55,000	-$18,887	$584
$44,980	$1,589	$60,000	-$23,887	$584
$44,980	$1,589	$65,000	-$28,887	$584

4498005.72% $44,980 $44,980

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $34,524
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $34,524

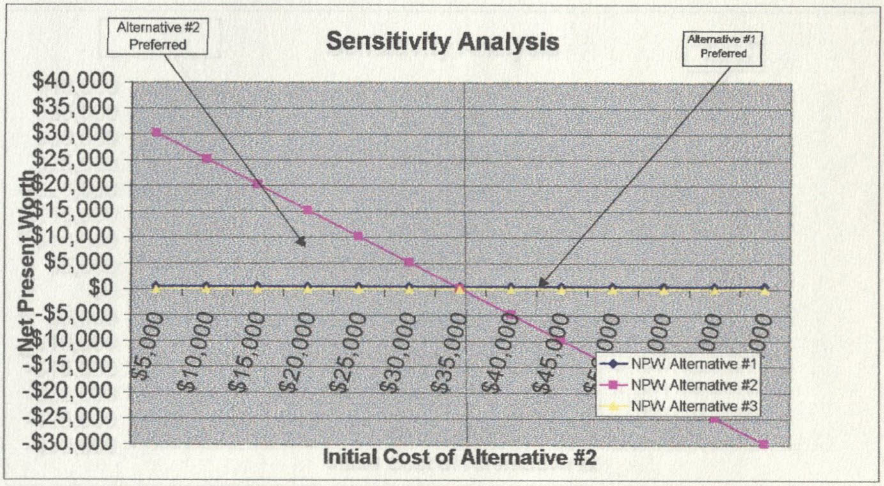


Sensitivity Analysis, 23%

i =	23%		n = 5	P/A	i
				4.3295	5.00%
NPW (Alt. #1) =	$591			4.2124	6.00%
NPW (Alt. #2) =	$8,347			4.1002	7.00%
NPW (Alt. #3) =	$89			3.9927	8.00%
EUAB (1) =	$15,684			3.8897	9.00%
EUAB (2) =	$12,596			3.7908	10.00%
EUAB (3) =	$7,613			3.6959	11.00%
				3.6048	12.00%
Let x = Initial cost of Alt. #2		$26,966		3.5172	13.00%
				3.4331	14.00%
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x =		$35,313 -x		3.3522	15.00%
				3.2743	16.00%
				3.1993	17.00%
x = $35,313 - $591 =		$34,722		3.1272	18.00%
				3.0576	19.00%
				2.9906	20.00%
				2.9260	21.00%
				2.8636	22.00%
				2.8035	23.00%
				2.7454	24.00%
				2.6893	25.00%
				2.6351	26.00%
				2.5827	27.00%
				2.5320	28.00%
				2.4830	29.00%
				2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$45,978	$591	$5,000	$30,313	$89
$45,978	$591	$10,000	$25,313	$89
$45,978	$591	$15,000	$20,313	$89
$45,978	$591	$20,000	$15,313	$89
$45,978	$591	$25,000	$10,313	$89
$45,978	$591	$30,000	$5,313	$89
$45,978	$591	$35,000	$313	$89
$45,978	$591	$40,000	-$4,687	$89
$45,978	$591	$45,000	-$9,687	$89
$45,978	$591	$50,000	-$14,687	$89
$45,978	$591	$55,000	-$19,687	$89
$45,978	$591	$60,000	-$24,687	$89
$45,978	$591	$65,000	-$29,687	$89

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $34,722
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $34,722



Sensitivity Analysis, 24%

i = 24%

NPW (Alt. #1) = -$371
NPW (Alt #2) = $7,575
NPW (Alt. #3) = -$388
EUAB (1) = $15,665
EUAB (2) = $12,582
EUAB (3) = $7,601

Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $34,541 -x

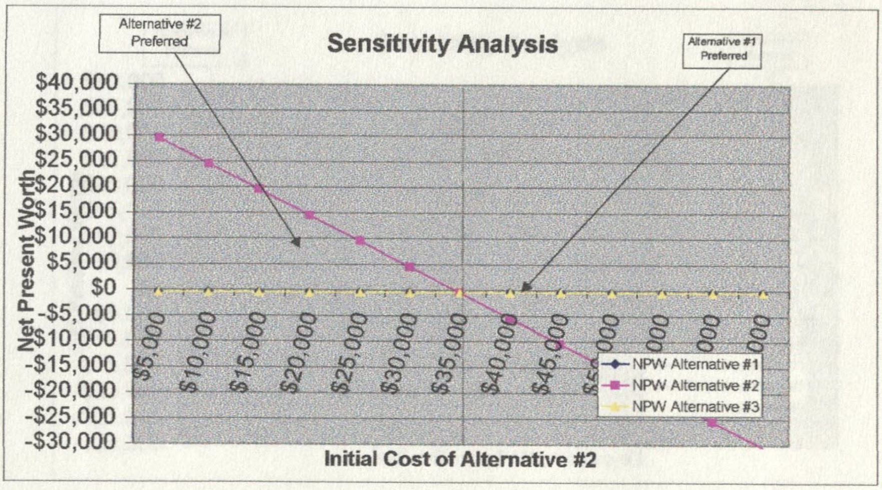
x = $34,541 - -$371 = $34,912

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	**Initial Cost Alternative #2**	**NPW Alternative #2**	**NPW Alternative #3**
$46,940	-$371	$5,000	$29,541	-$388
$46,940	-$371	$10,000	$24,541	-$388
$46,940	-$371	$15,000	$19,541	-$388
$46,940	-$371	$20,000	$14,541	-$388
$46,940	-$371	$25,000	$9,541	-$388
$46,940	-$371	$30,000	$4,541	-$388
$46,940	-$371	$35,000	-$459	-$388
$46,940	-$371	$40,000	-$5,459	-$388
$46,940	-$371	$45,000	-$10,459	-$388
$46,940	-$371	$50,000	-$15,459	-$388
$46,940	-$371	$55,000	-$20,459	-$388
$46,940	-$371	$60,000	-$25,459	-$388
$46,940	-$371	$65,000	-$30,459	-$388

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $34,912
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $34,912



Sensitivity Analysis, 24.035%

i =	24.035%			
NPW (Alt. #1) =	-$404			
NPW (Alt. #2) =	$7,549		-$16,069	
NPW (Alt. #3) =	-$404			
EUAB (1) =	$15,665			
EUAB (2) =	$12,581			
EUAB (3) =	$7,600			

Let x = Initial cost of Alt. #2 $26,966

NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $34,540 -x

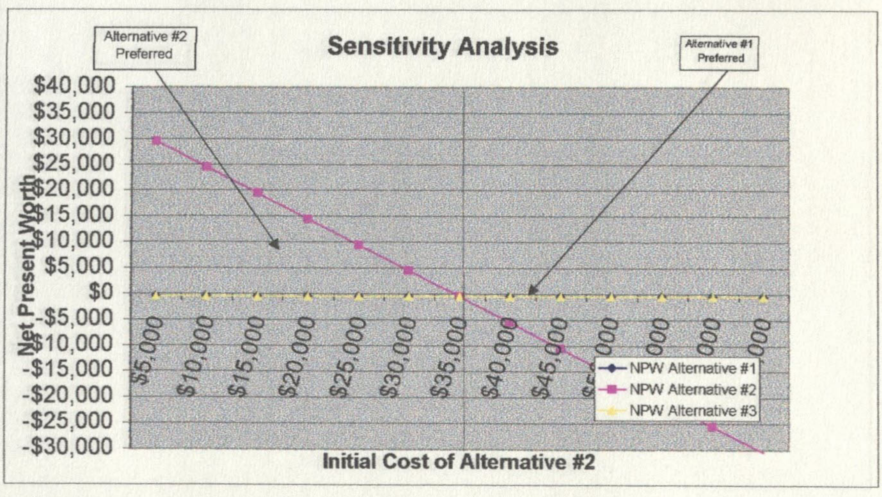
x = $34,540 - -$404 = $34,944

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$46,973	-$404	$5,000	$29,540	-$404
$46,973	-$404	$10,000	$24,540	-$404
$46,973	-$404	$15,000	$19,540	-$404
$46,973	-$404	$20,000	$14,540	-$404
$46,973	-$404	$25,000	$9,540	-$404
$46,973	-$404	$30,000	$4,540	-$404
$46,973	-$404	$35,000	-$460	-$404
$46,973	-$404	$40,000	-$5,460	-$404
$46,973	-$404	$45,000	-$10,460	-$404
$46,973	-$404	$50,000	-$15,460	-$404
$46,973	-$404	$55,000	-$20,460	-$404
$46,973	-$404	$60,000	-$25,460	-$404
$46,973	-$404	$65,000	-$30,460	-$404

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

Alternative # 2 is preferred if initial cost of Alternative #2 does not exceed $34,944
Alternative #1 is preferred if initial cost of Alternative #2 exceeds $34,944



Sensitivity Analysis, 25%

i = 25%

NPW (Alt. #1) =	-$1,300
NPW (Alt. #2) =	$6,830
NPW (Alt. #3) =	-$848
EUAB (1) =	$15,647
EUAB (2) =	$12,567
EUAB (3) =	$7,588

Let x = Initial cost of Alt. #2 $26,966

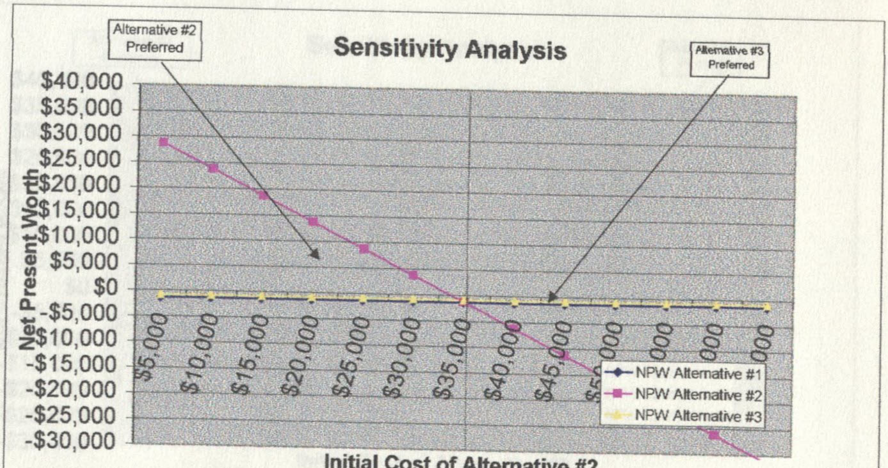
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $33,796 -x

x = $33,796 - -$1,300 = $35,096

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$47,869	-$1,300	$5,000	$28,796	-$848
$47,869	-$1,300	$10,000	$23,796	-$848
$47,869	-$1,300	$15,000	$18,796	-$848
$47,869	-$1,300	$20,000	$13,796	-$848
$47,869	-$1,300	$25,000	$8,796	-$848
$47,869	-$1,300	$30,000	$3,796	-$848
$47,869	-$1,300	$35,000	-$1,204	-$848
$47,869	-$1,300	$40,000	-$6,204	-$848
$47,869	-$1,300	$45,000	-$11,204	-$848
$47,869	-$1,300	$50,000	-$16,204	-$848
$47,869	-$1,300	$55,000	-$21,204	-$848
$47,869	-$1,300	$60,000	-$26,204	-$848
$47,869	-$1,300	$65,000	-$31,204	-$848



Sensitivity Analysis, 26%

i = 26%

NPW (Alt. #1) = -$2,196
NPW (Alt. #2) = $6,111
NPW (Alt. #3) = -$1,292
EUAB (1) = $15,629
EUAB (2) = $12,553
EUAB (3) = $7,576

Let x = Initial cost of Alt. #2 $26,966

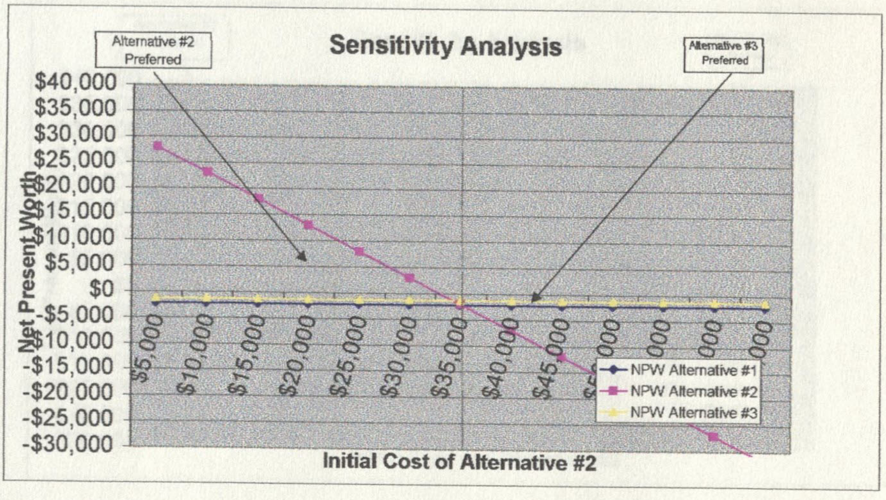
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $33,077 -x

x = $33,077 - -$2,196 = $35,273

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$48,765	-$2,196	$5,000	$28,077	-$1,292
$48,765	-$2,196	$10,000	$23,077	-$1,292
$48,765	-$2,196	$15,000	$18,077	-$1,292
$48,765	-$2,196	$20,000	$13,077	-$1,292
$48,765	-$2,196	$25,000	$8,077	-$1,292
$48,765	-$2,196	$30,000	$3,077	-$1,292
$48,765	-$2,196	$35,000	-$1,923	-$1,292
$48,765	-$2,196	$40,000	-$6,923	-$1,292
$48,765	-$2,196	$45,000	-$11,923	-$1,292
$48,765	-$2,196	$50,000	-$16,923	-$1,292
$48,765	-$2,196	$55,000	-$21,923	-$1,292
$48,765	-$2,196	$60,000	-$26,923	-$1,292
$48,765	-$2,196	$65,000	-$31,923	-$1,292



Sensitivity Analysis, 27%

i = 27%

NPW (Alt. #1) =	-$3,061	
NPW (Alt. #2) =	$5,417	
NPW (Alt. #3) =	-$1,721	
EUAB (1) =	$15,611	
EUAB (2) =	$12,539	
EUAB (3) =	$7,563	

Let x = Initial cost of Alt. #2 $26,966

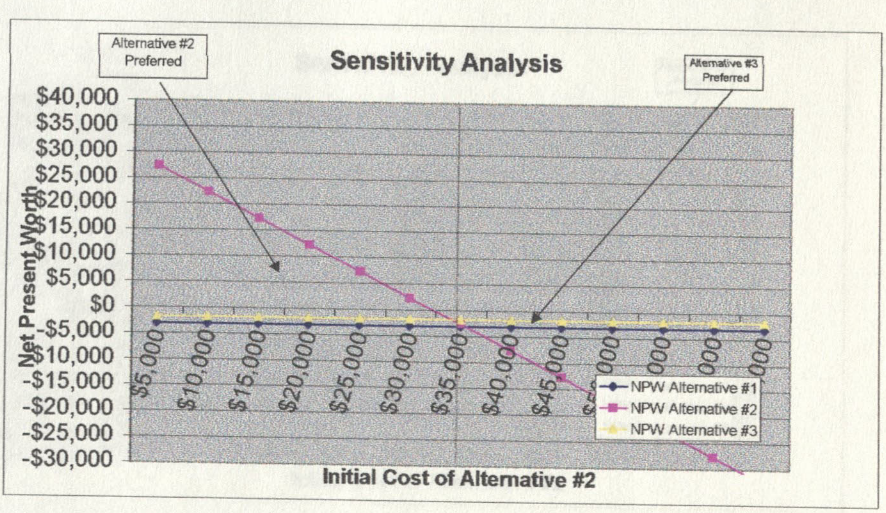
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $32,383 -x

x = $32,383 - -$3,061 = $35,444

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$49,630	-$3,061	$5,000	$27,383	-$1,721
$49,630	-$3,061	$10,000	$22,383	-$1,721
$49,630	-$3,061	$15,000	$17,383	-$1,721
$49,630	-$3,061	$20,000	$12,383	-$1,721
$49,630	-$3,061	$25,000	$7,383	-$1,721
$49,630	-$3,061	$30,000	$2,383	-$1,721
$49,630	-$3,061	$35,000	-$2,617	-$1,721
$49,630	-$3,061	$40,000	-$7,617	-$1,721
$49,630	-$3,061	$45,000	-$12,617	-$1,721
$49,630	-$3,061	$50,000	-$17,617	-$1,721
$49,630	-$3,061	$55,000	-$22,617	-$1,721
$49,630	-$3,061	$60,000	-$27,617	-$1,721
$49,630	-$3,061	$65,000	-$32,617	-$1,721



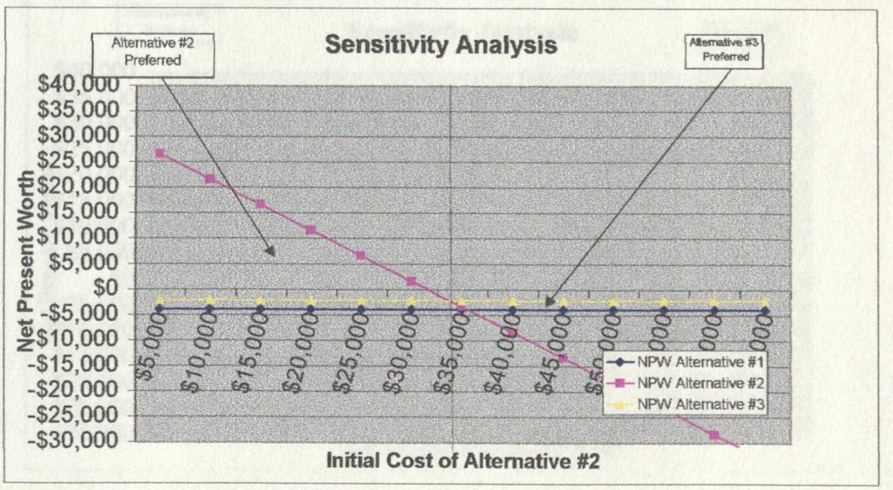
Sensitivity Analysis, 28%

i =	28%					
NPW (Alt. #1) =		-$3,897				
NPW (Alt. #2) =		$4,746				
NPW (Alt. #3) =		-$2,135				
EUAB (1) =		$15,593				
EUAB (2) =		$12,524				
EUAB (3) =		$7,551				
Let x = Initial cost of Alt. #2			$26,966			
NPW (Alt. #2) =	EUAB (2) * (P/A, i%, 5) - x =		$31,712	-x		
x =	$31,712		-	-$3,897	=	$35,609

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$50,466	-$3,897	$5,000	$26,712	-$2,135
$50,466	-$3,897	$10,000	$21,712	-$2,135
$50,466	-$3,897	$15,000	$16,712	-$2,135
$50,466	-$3,897	$20,000	$11,712	-$2,135
$50,466	-$3,897	$25,000	$6,712	-$2,135
$50,466	-$3,897	$30,000	$1,712	-$2,135
$50,466	-$3,897	$35,000	-$3,288	-$2,135
$50,466	-$3,897	$40,000	-$8,288	-$2,135
$50,466	-$3,897	$45,000	-$13,288	-$2,135
$50,466	-$3,897	$50,000	-$18,288	-$2,135
$50,466	-$3,897	$55,000	-$23,288	-$2,135
$50,466	-$3,897	$60,000	-$28,288	-$2,135
$50,466	-$3,897	$65,000	-$33,288	-$2,135



Sensitivity Analysis, 29%

i = 29%

NPW (Alt. #1) =	-$4,705
NPW (Alt. #2) =	$4,098
NPW (Alt. #3) =	-$2,535
EUAB (1) =	$15,576
EUAB (2) =	$12,511
EUAB (3) =	$7,539

Let x = Initial cost of Alt. #2 $26,966

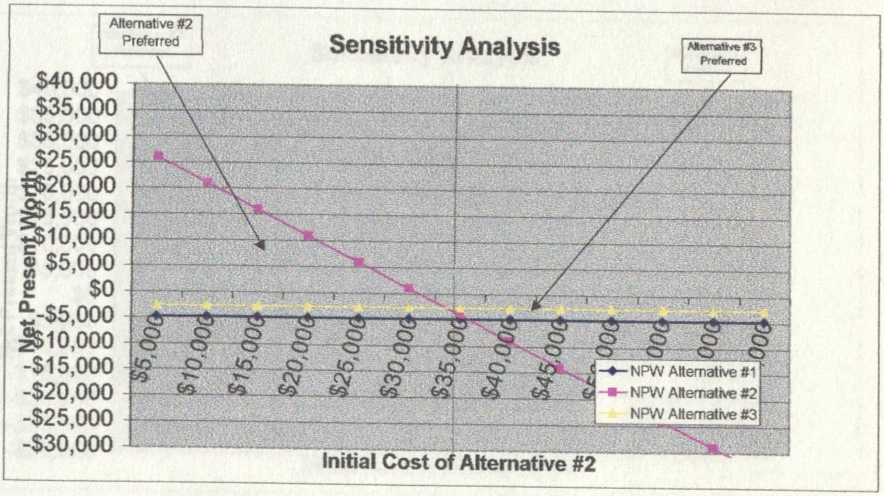
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $31,064 -x

x = $31,064 - -$4,705 = $35,769

n = 5

P/A	*i*
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$51,274	-$4,705	$5,000	$26,064	-$2,535
$51,274	-$4,705	$10,000	$21,064	-$2,535
$51,274	-$4,705	$15,000	$16,064	-$2,535
$51,274	-$4,705	$20,000	$11,064	-$2,535
$51,274	-$4,705	$25,000	$6,064	-$2,535
$51,274	-$4,705	$30,000	$1,064	-$2,535
$51,274	-$4,705	$35,000	-$3,936	-$2,535
$51,274	-$4,705	$40,000	-$8,936	-$2,535
$51,274	-$4,705	$45,000	-$13,936	-$2,535
$51,274	-$4,705	$50,000	-$18,936	-$2,535
$51,274	-$4,705	$55,000	-$23,936	-$2,535
$51,274	-$4,705	$60,000	-$28,936	-$2,535
$51,274	-$4,705	$65,000	-$33,936	-$2,535



Sensitivity Analysis, 30%

i = 30%

NPW (Alt. #1) = -$5,486
NPW (Alt #2) = $3,471
NPW (Alt. #3) = -$2,922
EUAB (1) = $15,558
EUAB (2) = $12,497
EUAB (3) = $7,527

Let x = Initial cost of Alt. #2 $26,966

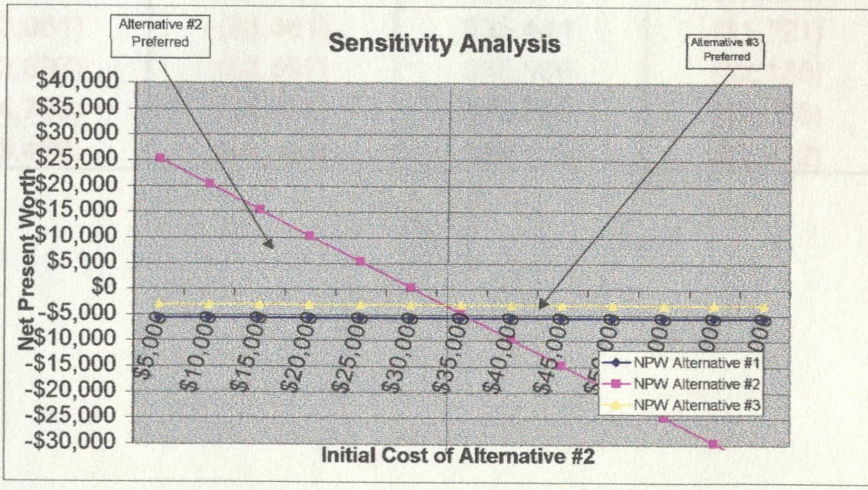
NPW (Alt. #2) = EUAB (2) * (P/A, i%, 5) - x = $30,437 -x

x = $30,437 - -$5,486 = $35,923

n = 5

P/A	i
4.3295	5.00%
4.2124	6.00%
4.1002	7.00%
3.9927	8.00%
3.8897	9.00%
3.7908	10.00%
3.6959	11.00%
3.6048	12.00%
3.5172	13.00%
3.4331	14.00%
3.3522	15.00%
3.2743	16.00%
3.1993	17.00%
3.1272	18.00%
3.0576	19.00%
2.9906	20.00%
2.9260	21.00%
2.8636	22.00%
2.8035	23.00%
2.7454	24.00%
2.6893	25.00%
2.6351	26.00%
2.5827	27.00%
2.5320	28.00%
2.4830	29.00%
2.4356	30.00%

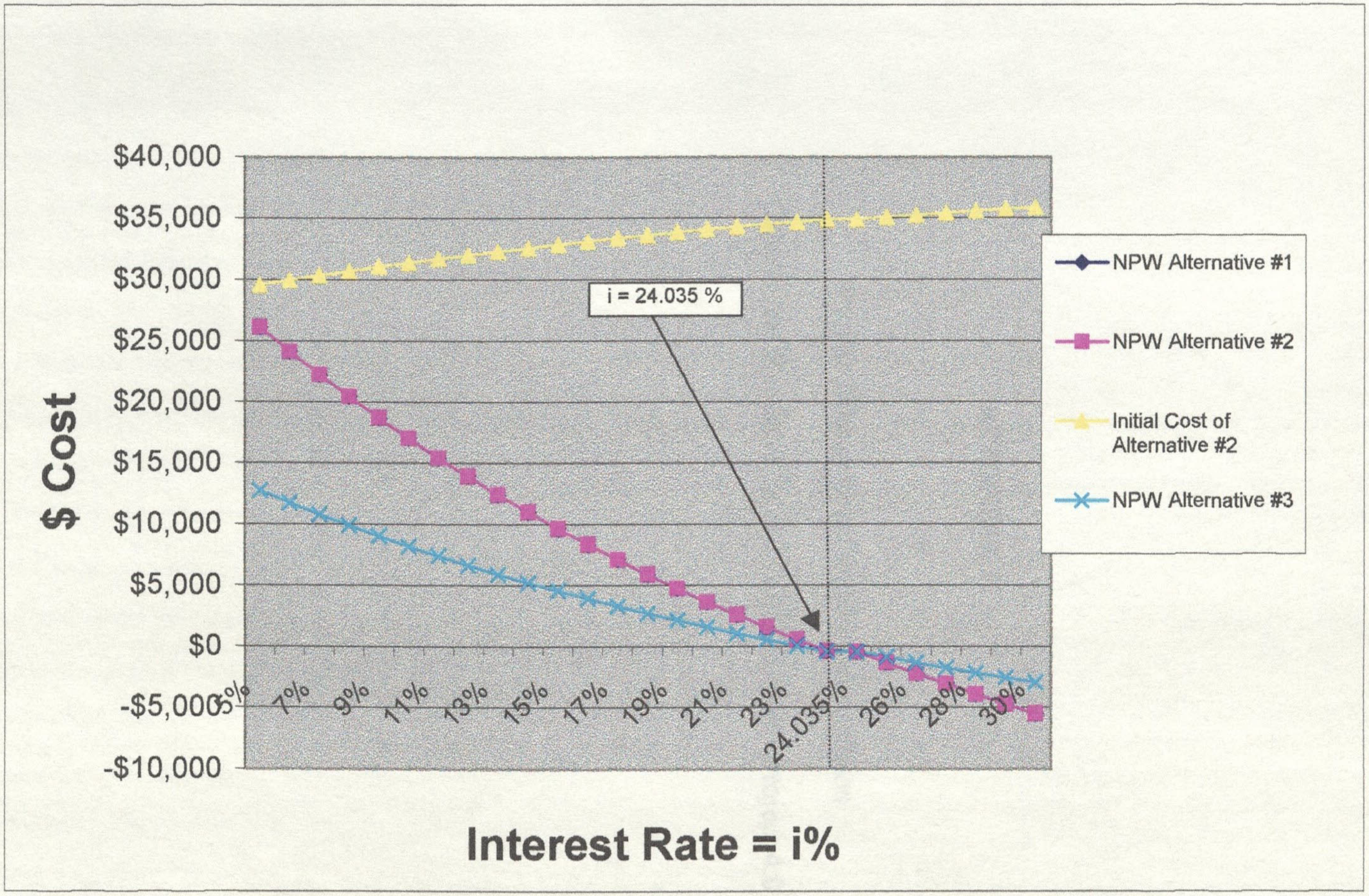
	NPW Alternative #1	Initial Cost Alternative #2	NPW Alternative #2	NPW Alternative #3
$52,055	-$5,486	$5,000	$25,437	-$2,922
$52,055	-$5,486	$10,000	$20,437	-$2,922
$52,055	-$5,486	$15,000	$15,437	-$2,922
$52,055	-$5,486	$20,000	$10,437	-$2,922
$52,055	-$5,486	$25,000	$5,437	-$2,922
$52,055	-$5,486	$30,000	$437	-$2,922
$52,055	-$5,486	$35,000	-$4,563	-$2,922
$52,055	-$5,486	$40,000	-$9,563	-$2,922
$52,055	-$5,486	$45,000	-$14,563	-$2,922
$52,055	-$5,486	$50,000	-$19,563	-$2,922
$52,055	-$5,486	$55,000	-$24,563	-$2,922
$52,055	-$5,486	$60,000	-$29,563	-$2,922
$52,055	-$5,486	$65,000	-$34,563	-$2,922



Summary of Sensitivity at Different Interest Rates

i	NPW Alternative #1	NPW Alternative #2	Initial Cost of Alternative #2	NPW Alternative #3
5%	$26,174	$26,174	$29,624	$12,780
5%	$24,193	$24,193	$30,021	$11,797
7%	$22,299	$22,299	$30,400	$10,857
8%	$20,485	$20,485	$30,763	$9,957
9%	$18,749	$18,749	$31,110	$9,095
10%	$17,085	$17,085	$31,442	$8,270
11%	$15,490	$15,490	$31,761	$7,478
12%	$13,960	$13,960	$32,066	$6,719
13%	$12,491	$12,491	$32,359	$5,991
14%	$11,082	$11,082	$32,639	$5,291
15%	$9,728	$9,728	$32,909	$4,620
16%	$8,426	$8,426	$33,168	$3,974
17%	$7,175	$7,175	$33,416	$3,354
18%	$5,972	$5,972	$33,655	$2,757
19%	$4,813	$4,813	$33,885	$2,182
20%	$3,698	$3,698	$34,106	$1,629
21%	$2,624	$2,624	$34,319	$1,097
22%	$1,589	$1,589	$34,524	$584
23%	$591	$591	$34,722	$89
24%	($371)	($371)	$34,912	($388)
24.035%	($404)	($404)	$34,944	($404)
25%	($1,300)	($1,300)	$35,096	($848)
26%	($2,196)	($2,196)	$35,273	($1,292)
27%	($3,061)	($3,061)	$35,444	($1,721)
28%	($3,897)	($3,897)	$35,609	($2,135)
29%	($4,705)	($4,705)	$35,769	($2,535)
30%	($5,486)	($5,486)	$35,923	($2,922)

Summary of Sensitivity at Different Interest Rates



APPENDIX C

Project Management and Implementation

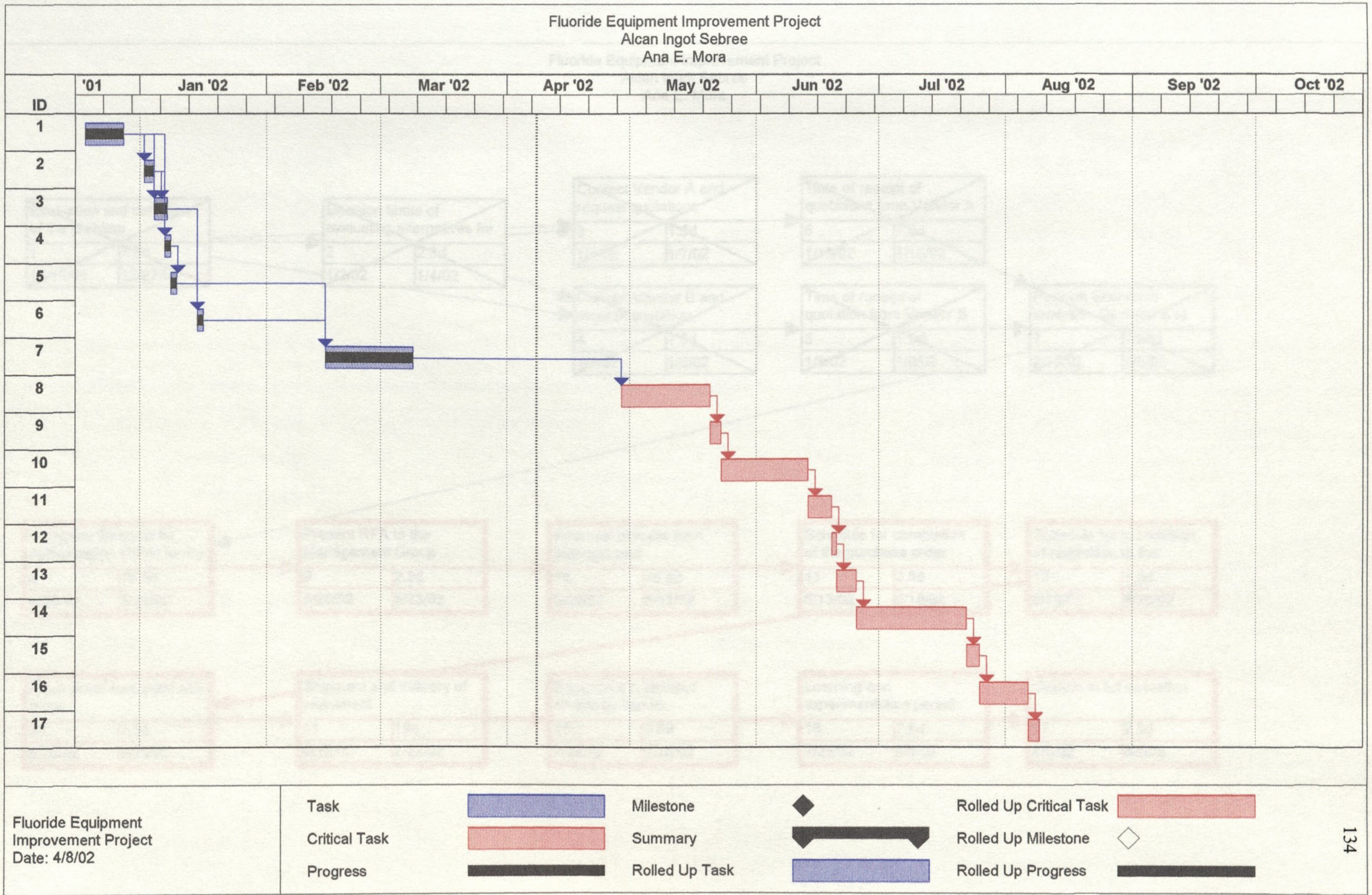
Graphs and Reports Created with Microsoft Project 4.0

Fluoride Equipment Improvement Project
Alcan Ingot Sebree
Ana E. Mora

ID	ID	Task Name	Duration	Predecessors
1	1	Evaluation and definition of the problem	7.5d	
2	2	Decision times of evaluating alternatives for consideration and selection of vendors	2.3d	1
3	3	Contact Vendor A and request quotations	1.5d	1,2
4	4	Contact Vendor B and request quotation	1.5d	1,2
5	5	Time of receipt of quotation from Vendor B	1.5d	4
6	6	Time of receipt of quotations from Vendor A	1.5d	3
7	7	Perform Economic analysis - Decision is to purchase sampler upgrade from Vendor A	15.8d	5,6
8	8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	15.8d	7
9	9	Present RFA to the Management Group	2.3d	8
10	10	Approval process from Management	15.8d	9
11	11	Schedule for completion of the purchase order requisition	3.5d	10
12	12	Schedule for submission of requisition to the Purchasing Group	1.5d	11
13	13	Alcan processes purchase order	2.5d	12
14	14	Shipment and delivery of instrument	19d	13
15	15	Equipment is installed on-site by vendor	3.5d	14
16	16	Learning and experimentation period	7.8d	15
17	17	System in full operation	2.5d	16

Fluoride Equipment Improvement Project
Alcan Ingot Sebree
Ana E. Mora

ID	Task Name	Start	Finish	Late Start	Late Finish	Free Slack	Total Slack
1	Evaluation and definition of the problem	12/18/01	12/27/01	3/19/02	3/28/02	3d	64.9d
2	Decision times of evaluating alternatives for consideration and selection of vendors	1/2/02	1/4/02	3/28/02	4/2/02	0d	61.9d
3	Contact Vendor A and request quotations	1/4/02	1/7/02	4/2/02	4/3/02	5.2d	61.9d
4	Contact Vendor B and request quotation	1/7/02	1/8/02	4/2/02	4/3/02	0d	61.2d
5	Time of receipt of quotation from Vendor B	1/8/02	1/9/02	4/3/02	4/5/02	26.2d	61.2d
6	Time of receipt of quotations from Vendor A	1/15/02	1/16/02	4/3/02	4/5/02	21.7d	56.7d
7	Perform Economic analysis - Decision is to purchase sampler upgrade from Vendor A	2/15/02	3/8/02	4/5/02	4/26/02	35d	35d
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	4/29/02	5/20/02	4/29/02	5/20/02	0d	0d
9	Present RFA to the Management Group	5/20/02	5/23/02	5/20/02	5/23/02	0d	0d
10	Approval process from Management	5/23/02	6/13/02	5/23/02	6/13/02	0d	0d
11	Schedule for completion of the purchase order requisition	6/13/02	6/19/02	6/13/02	6/19/02	0d	0d
12	Schedule for submission of requisition to the Purchasing Group	6/19/02	6/20/02	6/19/02	6/20/02	0d	0d
13	Alcan processes purchase order	6/20/02	6/25/02	6/20/02	6/25/02	0d	0d
14	Shipment and delivery of instrument	6/25/02	7/22/02	6/25/02	7/22/02	0d	0d
15	Equipment is installed on-site by vendor	7/22/02	7/25/02	7/22/02	7/25/02	0d	0d
16	Learning and experimentation period	7/25/02	8/6/02	7/25/02	8/6/02	0d	0d
17	System in full operation	8/6/02	8/9/02	8/6/02	8/9/02	0d	0d



Fluoride Equipment Improvement Project
Alcan Ingot Sebree
Ana E. Mora
ID
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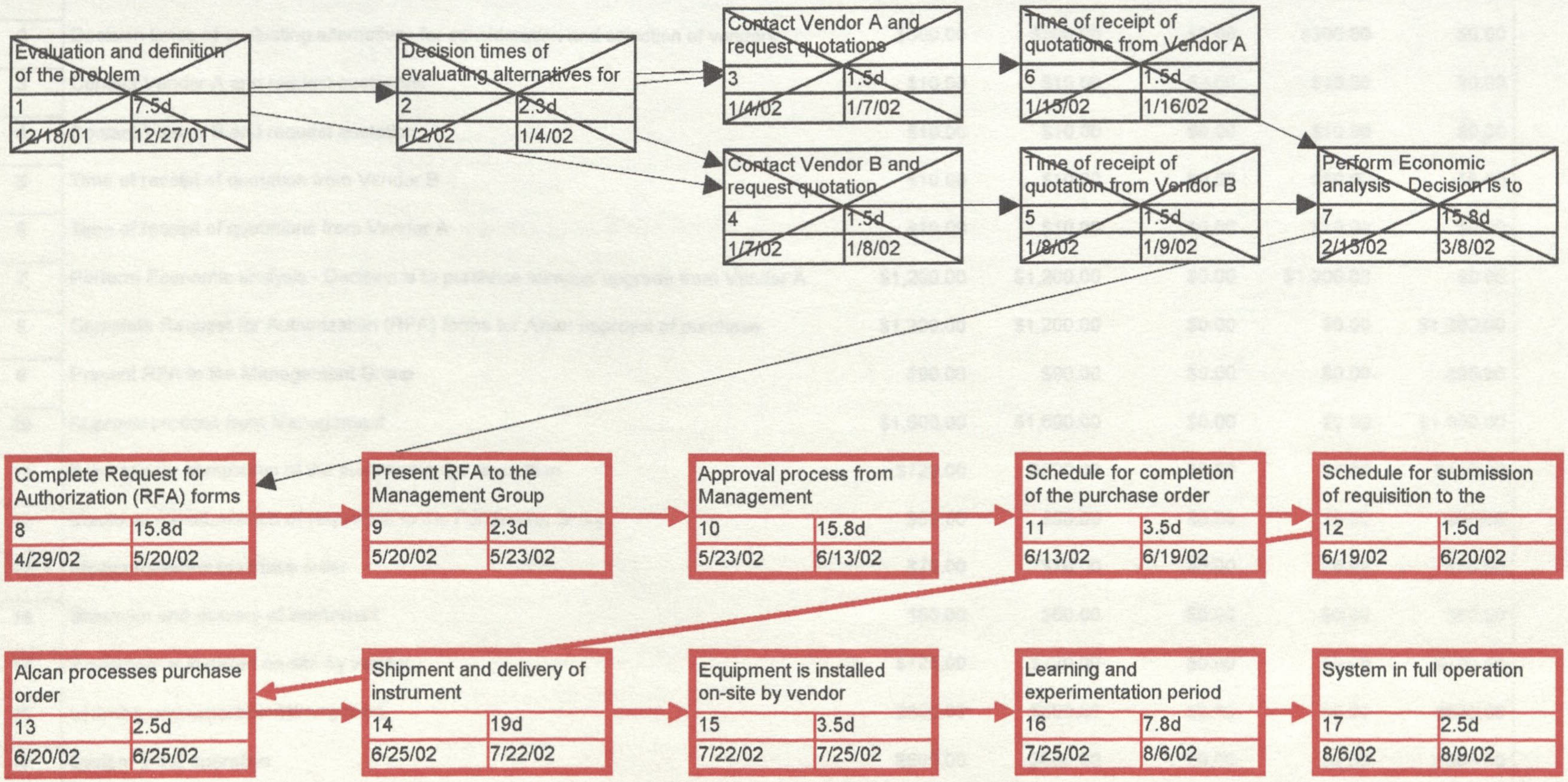
Mar '02
Apr '02
May '02
Jun '02
Jul '02
Aug '02
Sep '02
Oct '02
Fluoride Equipment
Improvement Project
Date: 4/8/02
Task
Critical Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Critical Task
Rolled Up Milestone
Rolled Up Progress

GANTT CHART

Fluoride Equipment Improvement Project
Alcan Ingot Sebree
Ana E. Mora



PERT CHART

Fluoride Equipment Improvement Project
Alcan Ingot Sebree
Ana E. Mora

ID	Task Name	Fixed Cost	Total Cost	Variance	Actual	Remaining
1	Evaluation and definition of the problem	$300.00	$300.00	$0.00	$300.00	$0.00
2	Decision times of evaluating alternatives for consideration and selection of vendors	$300.00	$300.00	$0.00	$300.00	$0.00
3	Contact Vendor A and request quotations	$10.00	$10.00	$0.00	$10.00	$0.00
4	Contact Vendor B and request quotation	$10.00	$10.00	$0.00	$10.00	$0.00
5	Time of receipt of quotation from Vendor B	$10.00	$10.00	$0.00	$10.00	$0.00
6	Time of receipt of quotations from Vendor A	$10.00	$10.00	$0.00	$10.00	$0.00
7	Perform Economic analysis - Decision is to purchase sampler upgrade from Vendor A	$1,200.00	$1,200.00	$0.00	$1,200.00	$0.00
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	$1,200.00	$1,200.00	$0.00	$0.00	$1,200.00
9	Present RFA to the Management Group	$90.00	$90.00	$0.00	$0.00	$90.00
10	Approval process from Management	$1,600.00	$1,600.00	$0.00	$0.00	$1,600.00
11	Schedule for completion of the purchase order requisition	$720.00	$720.00	$0.00	$0.00	$720.00
12	Schedule for submission of requisition to the Purchasing Group	$60.00	$60.00	$0.00	$0.00	$60.00
13	Alcan processes purchase order	$70.00	$70.00	$0.00	$0.00	$70.00
14	Shipment and delivery of instrument	$60.00	$60.00	$0.00	$0.00	$60.00
15	Equipment is installed on-site by vendor	$720.00	$720.00	$0.00	$0.00	$720.00
16	Learning and experimentation period	$600.00	$600.00	$0.00	$0.00	$600.00
17	System in full operation	$600.00	$600.00	$0.00	$0.00	$600.00

Budget Report as of 4/8/02
Fluoride Equipment Improvement Project
Ana E. Mora

ID	Task Name	Fixed Cost	Total Cost
10	Approval process from Management	$1,600.00	$1,600.00
7	Perform Economic analysis - Decision is to purchase sampler upgrade from Vendor A	$1,200.00	$1,200.00
8	Complete Request for Authorization (RFA) forms for Alcan approval of purchase	$1,200.00	$1,200.00
11	Schedule for completion of the purchase order requisition	$720.00	$720.00
15	Equipment is installed on-site by vendor	$720.00	$720.00
16	Learning and experimentation period	$600.00	$600.00
17	System in full operation	$600.00	$600.00
1	Evaluation and definition of the problem	$300.00	$300.00
2	Decision times of evaluating alternatives for consideration and selection of vendors	$300.00	$300.00
9	Present RFA to the Management Group	$90.00	$90.00
13	Alcan processes purchase order	$70.00	$70.00
12	Schedule for submission of requisition to the Purchasing Group	$60.00	$60.00
14	Shipment and delivery of instrument	$60.00	$60.00
3	Contact Vendor A and request quotations	$10.00	$10.00
4	Contact Vendor B and request quotation	$10.00	$10.00
5	Time of receipt of quotation from Vendor B	$10.00	$10.00
6	Time of receipt of quotations from Vendor A	$10.00	$10.00
		$7,560.00	**$7,560.00**

Budget Report as of 4/8/02
Fluoride Equipment Improvement Project
Ana E. Mora

Variance	Actual	Remaining
$0.00	$0.00	$1,600.00
$0.00	$1,200.00	$0.00
$0.00	$0.00	$1,200.00
$0.00	$0.00	$720.00
$0.00	$0.00	$720.00
$0.00	$0.00	$600.00
$0.00	$0.00	$600.00
$0.00	$300.00	$0.00
$0.00	$300.00	$0.00
$0.00	$0.00	$90.00
$0.00	$0.00	$70.00
$0.00	$0.00	$60.00
$0.00	$0.00	$60.00
$0.00	$10.00	$0.00
$0.00	$10.00	$0.00
$0.00	$10.00	$0.00
$0.00	$10.00	$0.00
$0.00	**$1,840.00**	**$5,720.00**