INVESTIGATION INTO THE CORRELATION BETWEEN PAPER INSULATION THERMAL AGEING ESTIMATION USING THE ARRHENIUS EQUATION AND OTHER METHODS FOR GENERATOR TRANSFORMERS

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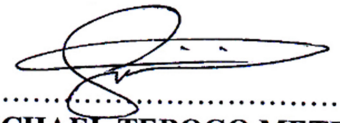
Declaration

This research has not been previously accepted for any degree or submitted for assessment purposes and is not being currently considered for any other degree or qualification at any other university.

I hereby declare that this Dissertation contains my own original work except where specifically acknowledged.



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Abstract

Many generator transformers were installed many years ago during the initial commissioning of Eskom's power stations. Many of these transformers have started showing signs of significant ageing of the paper insulation and hence require regular monitoring. There are two methods that are currently being employed to assess the degree of ageing of the paper insulation in a generator transformer, which are paper sampling and furan level measurement.

This dissertation investigates an alternative method of predicting the degree of ageing of the paper insulation instead of what is used currently. This method uses the Arrhenius equation that relates time and temperature to determine the degree of degradation of organic materials. The reliability of the Arrhenius estimation method is assessed by comparing the predicted DP (Degree of polymerisation) values with the measured DP values of the same transformer paper insulation.

The results obtained showed that there is reasonable correlation between the DP values estimated from the Arrhenius equation and the DP values estimated from the measured furan levels. The accuracy of the prediction method is reduced when the oil temperature greatly differs from the paper insulation temperature.

The application of the Arrhenius equation to estimate the ageing of paper insulation is a great milestone in the quest to predict the remaining life of a transformer. It is the only method available to do this prediction and using online temperature measurement on transformers makes the method more reliable.

Acknowledgements

Praise and worship to our heavenly father, Jesus Christ because it is not by power or might that I managed to complete this project, but is His grace and mercy on me. Thanks a million to Dr. John van Coller (my academic supervisor), who was the engine of this project. He was patient with me, supportive and motivating every step of this project.

I would like to gratefully acknowledge the contribution of Eskom Free State Business Unit for the opportunity to participate in the EPPEI (Eskom Power Plant Engineering Institute) programme. Thank you very much to the EPPEI management, who entrusted me to research on this topic and opening channels for me to use the Eskom database. Many thanks to my colleagues Roger Cormack (my industrial (Eskom) mentor), Sidwell Mtetwa, Matlali Makhetha, Tshilidzi Mashau, Yvonne Lekalakala, Fulufhelo Netshiongolwe and many others.

Most importantly, thanks to Kgaogelo (my wife), Mohlomphegi (my son) and other family members for emotional support and giving courage to carry on during challenging times. To you all *Motho ke motho ka batho* (Pedi idiom meaning '*a person is a person (achiever) because of others*').

Abbreviations and Acronyms

2FAL	2-Furaldehyde
°C	Degree Celcius
ASTM	American Society for Testing and Materials
DGA	Dissolved Gas Analysis
DP	Degree of Polymerization
DP_o	Initial Degree of Polymerization
DP_t	Final Degree of Polymerization
GIC	Geomagnetically Induced Currents
h^{-1}	Per hour
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
kJ/mole	Kilo joules per mole
kV	Kilovolts
MVA	Megavolt-amps
OLTC	On-Load Tap-Changer
PPM	Parts Per Million
PPB	Parts Per Billion
T or Temp	Temperature in ^oC

Chapter 1: Introduction

1.1 Background

Many of the generator transformers now used by utilities were installed many years ago during the initial commissioning stages of the respective power station. Therefore due to the many years that these generator transformers have spent in operation at raised temperatures, these transformers have started showing signs of significant paper insulation ageing. As a result, these transformers require regular monitoring. Figure 1 below summarises the ageing process of the paper insulation and of the oil inside a transformer at operating temperature [16].

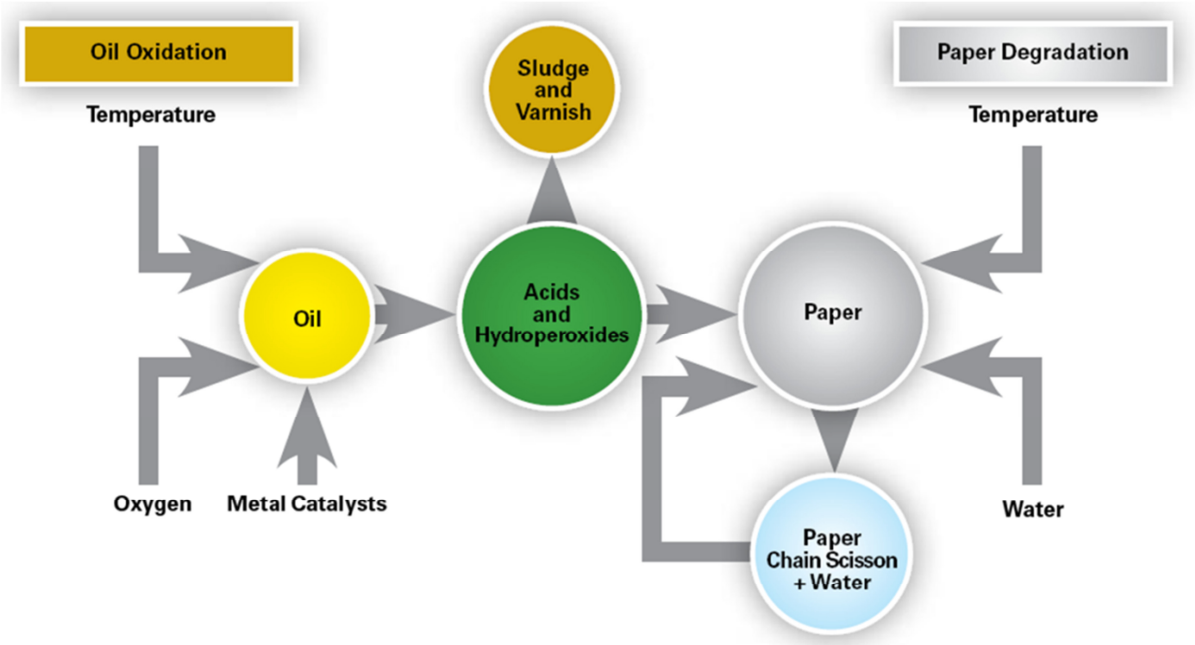


Figure 1: Paper insulation and oil ageing process [16]

There are two methods that are currently being employed to assess the condition of the paper insulation:

- Paper sampling

  This is a direct way of obtaining the Degree of Polymerisation (DP) by actually measuring the length of the polymer chains. Ageing of the paper insulation occurs through scission (breaking) of the molecular chains which are the building blocks of the paper insulation. To perform paper sampling the transformer has to be opened, which is very expensive and requires that the transformer has to be out of service for a significant time.

- Furan level measurement

  Furan level measurement is an indirect method whereby an oil sample from the transformer is taken to a laboratory to test for impurities in the oil that are released when the polymer chains of the paper insulation break. This method is less expensive but it may also take weeks or months to obtain results, depending on the laboratory. It is also susceptible to oil contamination during its handling which leads to incorrect diagnosis.

A need was identified for an alternative method for monitoring the ageing of paper insulation. The alternative method would have to be at least as reliable as the existing methods and have low cost. Prediction of ageing using the Arrhenius equation was the alternative method proposed for in-depth investigation. The application of the Arrhenius equation to estimate the ageing of paper insulation is a great milestone in the quest to predict the remaining life of a transformer. It is the only method available to do this prediction without having to do much laboratory testing. It can be done using information from online temperature measurement on transformers, which provide reliable information.

The reliability of the Arrhenius prediction method was assessed by comparison with estimations using furan level measurements.

The research will address the questions below

- Is there a correlation between the DP estimated from furan level measurements and the DP predictions using the Arrhenius equation that uses the transformer thermal loading history?

- How does the Arrhenius equation prediction method compare with other methods for estimating transformer paper insulation aging?

- Can other information obtained during typical transformer online monitoring assist when applying the Arrhenius equation prediction method?

- Can the use of the Arrhenius equation prediction method improve the management of generator transformers?

The Eskom transformer database was used to get the required data on the respective generator transformer histories.

1.2 Brief dissertation overview

a) Chapter 2 is the literature review focusing on the operation and failure of transformers, looking specifically at paper insulation failure. Transformer maintenance methods are discussed in terms of their advantages and disadvantages. The chapter is concluded with a discussion of DP measurement and DP prediction.

b) Chapter 3 describes the methodologies that were used in this dissertation to collect and manipulate the data.

c) Chapter 4 presents the DP of a particular generator transformer paper insulation calculated using the Arrhenius equation prediction method based on the online and offline measured temperature.

d) Chapter 5 compares the DP values obtained using the Arrhenius equation prediction method with the DP estimated from the measured furan levels.

e) Chapter 6 conclusions are drawn based on the findings of this research and recommendations are made on improving the usability of the Arrhenius equation prediction method.

Chapter 2: Literature review

2.1 Transformer operational life

The part played by power transformers in the power system can never be underestimated. It will be difficult or impossible to do the generation, transmission and distribution of electric power over a long distance without the use of power transformers. Power transformers can be considered to be strategic equipment in a utility. The main function of power transformers is to transform the input voltage to another voltage. It takes numerous generator transformers, transmission transformers and distribution transformers to deliver power from utility generators to consumers that may be hundreds of kilometres away. These transformers are connected between the power station and consumers. In some cases transformers can be connected in parallel for redundancy or load capacity. The core, windings, insulation, tap-changer, tank, radiators and bushings are the main parts of a transformer. Figure 2 below by Kruger [7], labels the equipment that forms part of a transformer.

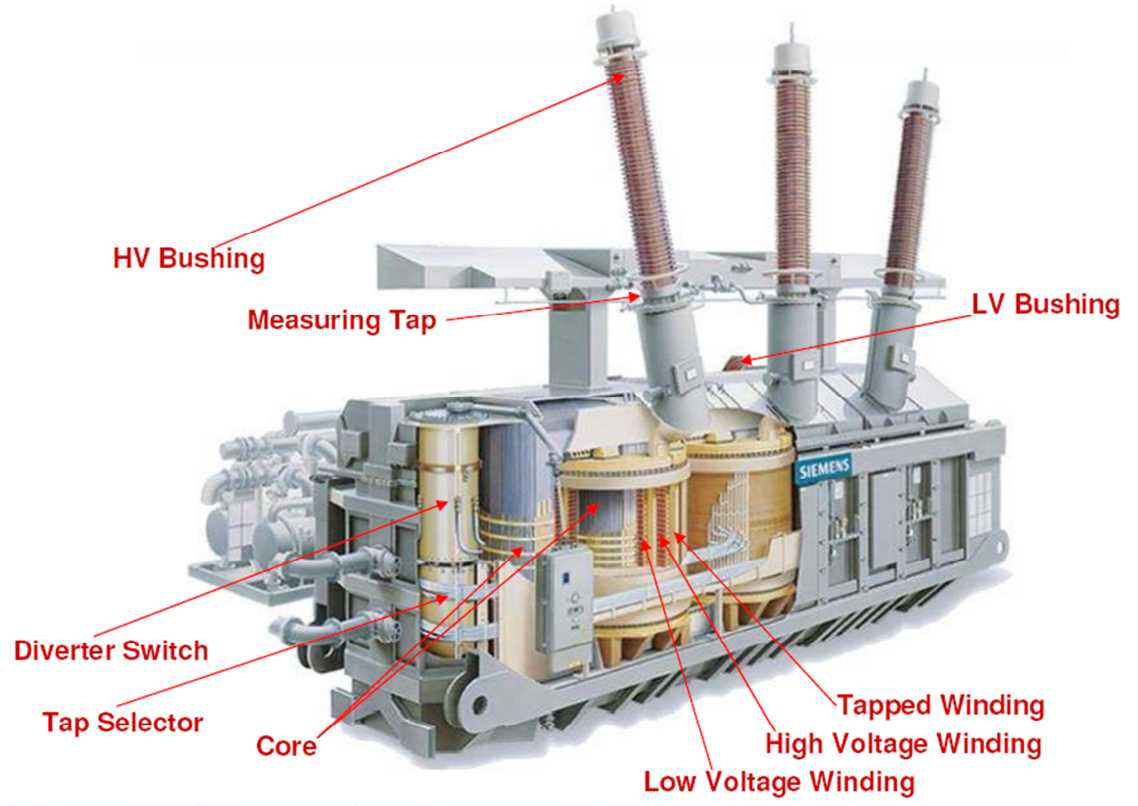


Figure 2: Generator transformer 27kV/400kV [7]

Each power station has a number of power transformers depending on the number of generators. It is difficult for utilities to have spares for their power transformer fleet, due to high cost, logistical reasons and special storage requirements. Also large power

transformers are custom designed and spare transformers should technically correspond to the transformer that they will be replacing.

Distribution transformers, often pole-mounted, are run to failure with a fuse as the main protection. This is not the case with large power transformers, due to their high purchase price and the failure impact on the network. Even though the purchase price may differ from one transformer to another, this may run from thousands to millions of rands depending on the design, rating and components. The high purchase price is offset by the envisioned operational returns for at least the pay-back period (which is between 20 to 25 years). Ideally utilities will prefer for their power transformers to last much longer than the pay-back period and also have a low maintenance cost. With the current financial situation that utilities find themselves in, more transformers are likely to have faults due to cuts in maintenance and increasing power demand. William [17] suggests an action or strategic plan which is a life-cycle management program, that sets loading priorities and provides direction to identify:

- transformer defects that can be corrected
- transformers that can be modified or refurbished
- transformers that should be re-located
- transformers that should be retired

2.2 Transformer failure timescales

According to Mirzai [9], transformer failures over their expected lifetime can in general be represented by a bathtub curve as shown below. The bathtub curve can be divided into three failure periods which are early failures, random failures and wear out failures. Figure 3 below shows the bathtub curve for transformers failure rate versus their age, were failure rate is the average number of failures in per unit of transformer at different age stages.

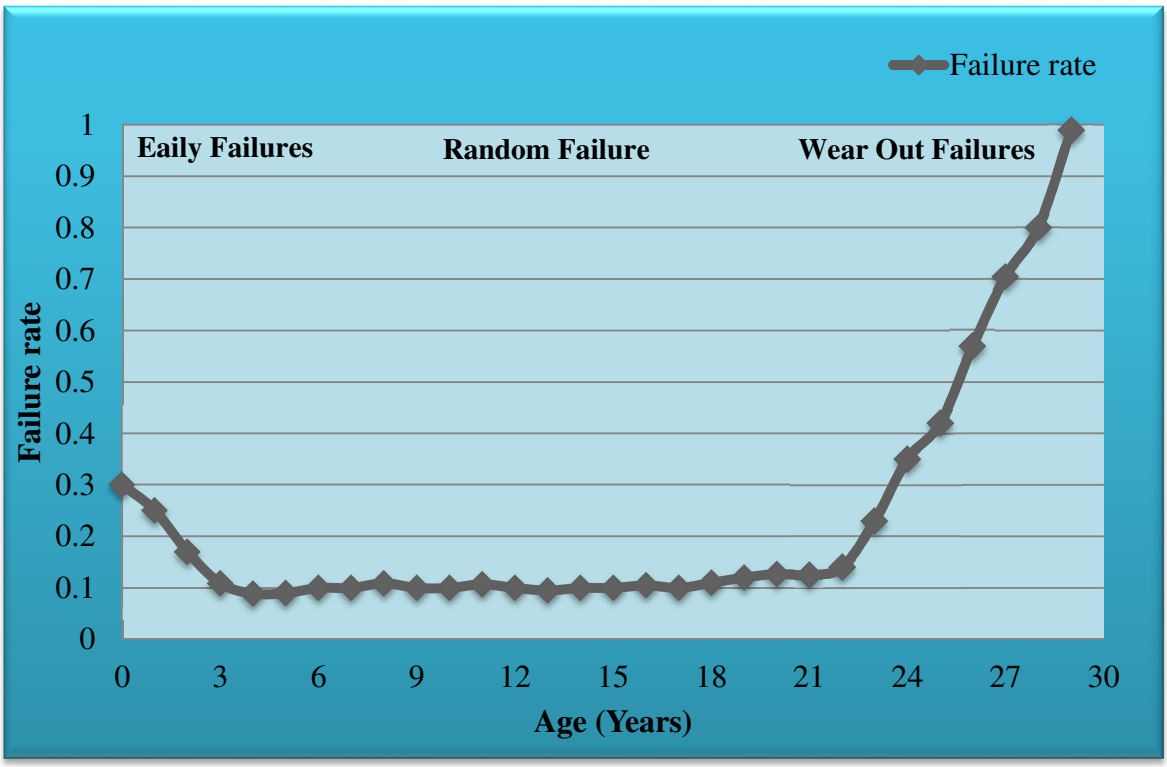


Figure 3: General bathtub curve representing transformer failures

Early failures: This period can also be called the high failure rate period. These failures may occur from installation until approximately two or three years of being energised. The cause of failure for this mode may be one or a combination of the following:

- Defective components
- Poor materials
- Poor workmanship
- Transportation damage
- Manufacturer's quality control
- Processing procedures

Random failures: This period can also be referred to as a steady-state or constant failure rate period. At this stage, the transformer failure rate has decreased substantially as compared to the early failures period. In most cases during this period the transformer failures are mainly externally induced. For instance, failures may occur as a result of operational activities like switching surges, operator error and overloading, or failures may be due to natural phenomenon such as lightning and geomagnetically induced currents (GIC). It is also important to mention that maintenance procedures done incorrectly such as oil reclamation or rewind can substantially increase the failure rate. This part of the curve is called the useful life-cycle period and is where the transformer is highly reliable.

Wear out failures: This can also be identified as the very high failure rate period. The paper insulation which is the main insulation for large transformers has seriously deteriorated at this stage. This marks the end of life of the insulation which is then the transformer end of useful life. The ageing of insulation and other materials causes random failures at small scale but this has a large impact. The transformer is very vulnerable at this stage and has a very low reliability. Normally, the wear out period becomes predominant only after 20 years of operation. This normal wear out period is followed by an increasing failure rate. At this stage it is important to know the value of the Degree of Polymerisation (DP) of the paper insulation, in order to order a spare transformer if necessary.

2.2.1 Transformer failure statistics

Minhas [10] conducted an investigation which was started in 1994. The purpose of the research was to collect data for evaluating the behaviour of large in-service transformers in the Eskom network. The main aim of this work was to produce an on-line monitoring system that could be used to provide early warning signs and to reduce the disruption of supply. The investigation focused on failure modes affecting transformer performance. These failure modes were as follows:

- General ageing
- Lightning / switching surge related failure
- Short circuit or through-fault events
- Core problems
- On-Load Tap-Changer (OLTC) initiated failures
- Others (bushing, unknown operational errors etc.)

General ageing is the only failure mode that is time dependent, since it takes time for thermally upgraded paper used in transformers to age under normal operating conditions.

Figure 4 below is Minhas' research results, showing how the failure modes are distributed over a period of approximately five years for a fleet of 20 – 100 MVA transformers.

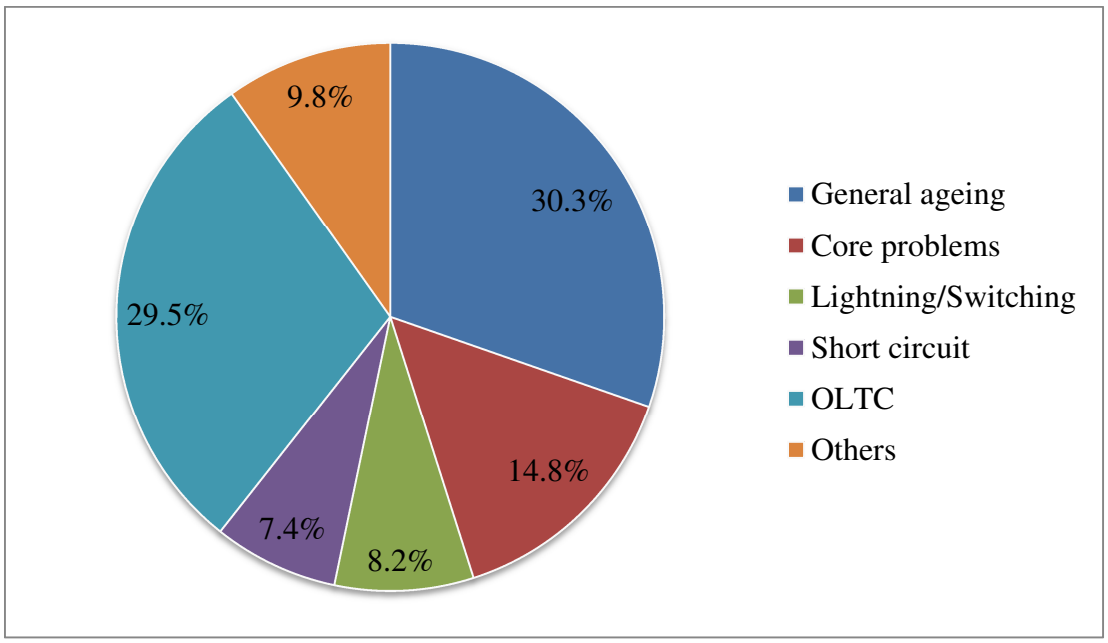


Figure 4: Failure modes for 20 – 100MVA transformers

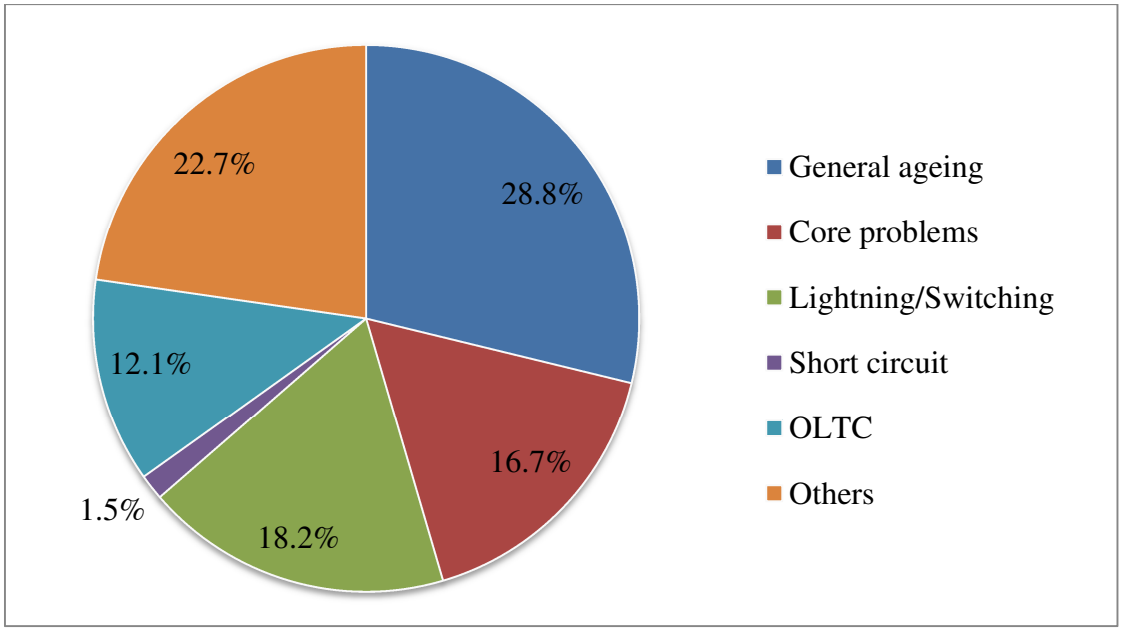


Figure 5: Failure modes for >100MVA transformers

Figure 5 above shows findings for a fleet of large transformers rated above 100MVA.

In both categories as indicated by the two figures, the most dominant failure mode is general ageing (paper insulation deterioration), which shows that the transformer fleet is much older than 11 to 15 years. The second dominant failure mode is the OLTC for transformers of 100MVA and below (Figure 4). For transformers above 100MVA the dominant failure modes are 'others' (bushing, unknown operational errors etc.). Due to the large transformer's high cost, position in the network and failure impact, any failure has to be investigated and be known. Therefore failure mode "others" can be assumed to be operational and external failure modes other than the ones mentioned.

It can also be shown in financial terms how each failure mode contributes to the total cost that transformer owners incur. Transformers have to be insured, but the insurer and owners of the transformers have to identify the financial risk and contributing factors. William [17] performed transformer failure analysis from 1997 to 2001 on 25 MVA transformers and above. The results of the study are shown in Figure 6. In Figure 4 and Figure 5, the general ageing mode as a proportion is closely related to the OLTC failure mode and the 'other' failure mode respectively. But in financial terms as shown by Figure 6 general ageing contributes more than 50%.

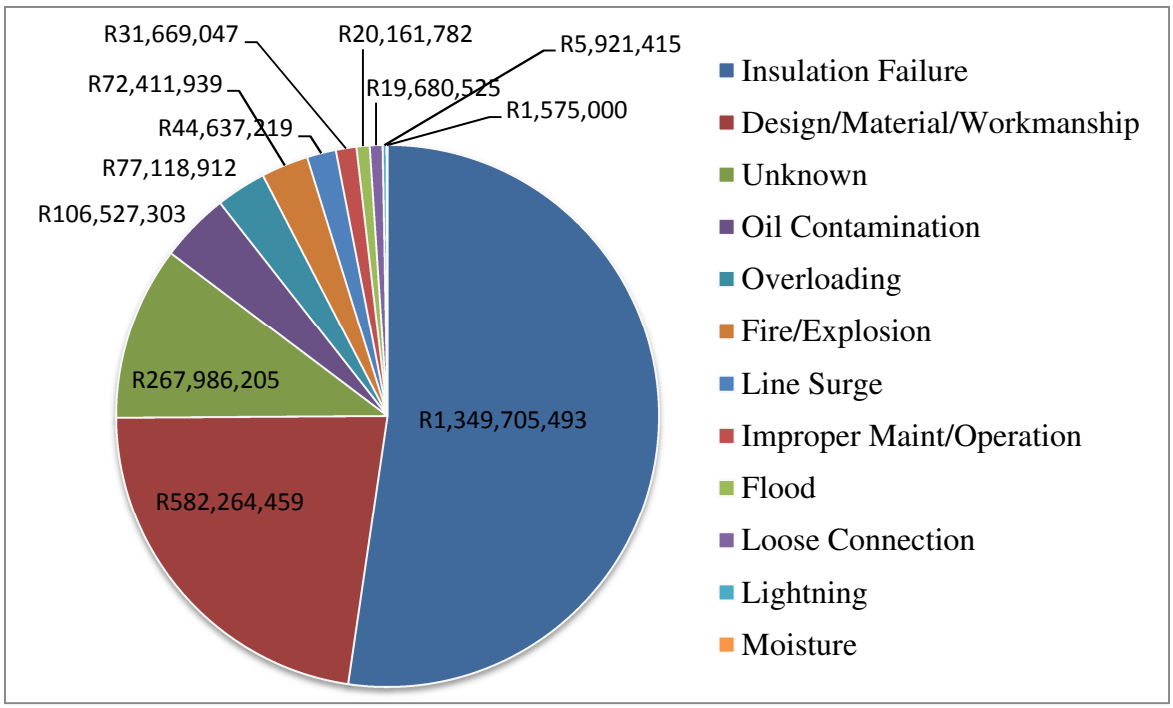


Figure 6: Financial impact of different failure modes for a transformer over a 5 year period

2.2.2 Transformer maintenance

Utilities in general are facing many challenges. Some of these challenges filter down to become transformer maintenance challenges. These challenges can be directly or indirectly transformer issues, and also can originate internally or externally. Currently the world is facing an economic crisis. Even though this maybe an external factor, it may affect the utility directly in the form of a reduction in allowed tariff increase, increase in transformer price, oil and copper price and transportation cost. Some of these challenges have led to a reduction in transformer maintenance. For instance, an increase in the cost of laboratory oil testing may cause a reduction of the oil sampling of a fleet of transformers.

Without transformer condition monitoring or reduced monitoring it will be difficult to estimate the remaining life of a transformer. Different strategies are employed by utilities or other industries in the maintenance of transformers. A paper by Abu-Elanien [1] on transformer maintenance methods analysed each type of maintenance method and also investigated their advantages and disadvantages. Figure 7 below, from the paper, shows the hierarchy of the maintenance methods.

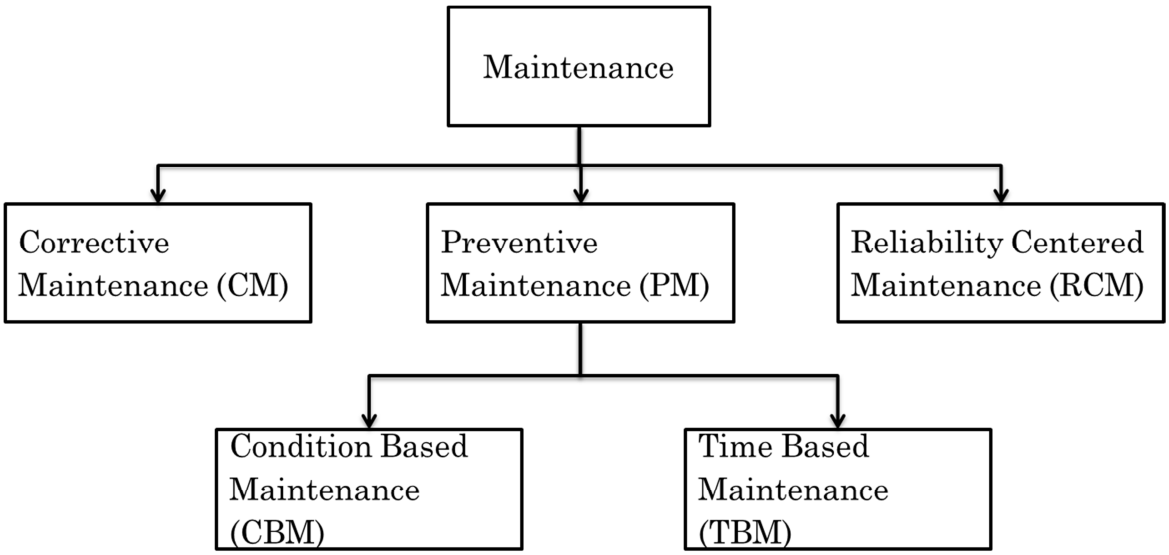


Figure 7: Classification of maintenance activities

a. Corrective Maintenance (CM)

This type of maintenance is not done or performed until failure has occurred. In short it can be described as run-to-failure maintenance. Below is the list of advantages and disadvantages of this maintenance method.

Advantages:

- It is the least expensive type of maintenance.
- It saves manpower.
- It spares the system from unnecessary shutdowns.
- The maintenance is performed only when it is needed, saving unnecessary inspections.
- It is widely understood by the maintenance personnel.

Disadvantages:

- Transformer failure becomes costly to repair and may need expensive spare parts.
- Some transformer failures may be unrepairable if not detected early.
- Some transformer failures may cause complete shutdown of the production line or the power system for a long time. This means losing revenue which in some cases exceeds the cost of the regular inspection.

b. Preventive Maintenance (PM)

The purpose of this maintenance is to prevent failure of the transformer. This is done by on-going monitoring of the equipment and by observing the condition of the equipment in operation. There are two types of preventive maintenance which are time-based maintenance and condition-based maintenance. Based on the preventive maintenance approach, transformer oil samples are taken to perform the following diagnostic tests:

- IEC 60599 method
- California State University Sacramento method
- Duval Triangle analysis
- IEEE: Guide for interpretation of gas generation in oil immersed transformers
- Rogers Ratios
- Doernenburg Ratios
- Furan compound analysis: ASTM D 5837 or IEC 61198 method.

Time-based maintenance and condition-based maintenance and their advantages and disadvantages are discussed below.

c. Time-Based Maintenance (TBM)

TBM is a well-defined consistently periodic assessment followed by maintenance. In the case of a transformer it can be the regular sampling of the transformer oil. Transformer manufacturers sometimes perform their own time-based maintenance, as shown by Rao [14] in Table 1below.

Advantages:

- It is understood by maintenance engineers and technicians.
- It can detect the inception of faults to some extent if the inspection interval is reduced.
- It increases the lifetime of the transformer due to regular inspections and maintenance.

Disadvantages:

- It is expensive due to regular, perhaps unnecessary, inspections and the large number of needed maintenance staff.
- In some cases, TBM is unable to detect faults especially when the inspection interval is large.
- It needs unnecessary shutdowns which add extra cost to the maintenance activity.

d. Condition-Based Maintenance (CBM)

This maintenance is done using systems that inspect the condition or status of the transformer. If an abnormal condition arises then corrective measures are taken. Some of the condition-based maintenance methods are developed by changing time-based maintenance methods to online monitoring.

Advantages:

- Maintenance is done when it is necessary.
- Saves costly unnecessary inspections.
- Saves manpower.
- Reduces unnecessary shutdowns of the system.
- Low possibility of complete failure.

Disadvantages:

- Continuous condition monitoring for many parameters is expensive.
- It is less understood by maintenance engineers and technicians.
- It needs fast data communication and data configuration facilities for successful online monitoring.
- It needs experienced persons to design the monitoring system, select the suitable parameters to be monitored, and select the suitable frequency of data collection.

Table 1: Typical maintenance schedule for transformers (Rao [14])

Frequency of inspection	Inspection	Inspection details	Action required if condition is unsatisfactory
Hourly	Load (amperes) Temperature, voltage	Check against rated values	Start fans if necessary
Daily	Dehydrating breather	Check that air passages are clear. Check colour of active agent.	If silica gel is yellow, change, may be reactivated for use again
Monthly	Oil level in transformer	Check transformer oil level	If low, top up with oil. Examine transformer for leaks.
Quarterly	Bushings	Examine for cracks and dirt deposits	Clean or replace
Half-yearly	No conservator	Check for moisture cover	Improve ventilation, check oil
Yearly	Oil in transformer	Check for dielectric strength and water content. Check for acidity and sludge	Take suitable action to restore quality of oil
**	Earth resistance	_	Take suitable action if earth resistance is high
**	Relays, alarms, their circuits, etc.	Examine relay and alarm contacts, their operation, fuses etc. Check relay accuracy etc.	Clean the components and replace contacts and fuses if necessary. Change the settings if necessary.
2 yearly	Non-conservator transformers	Internal inspection above core	Filter oil regardless of its condition
5 yearly or after internal fault	_	Overall inspection, lifting of core and coils	Wash by hosing with clean dry oil.

e. Reliability-Centered Maintenance (RCM)

RCM takes into consideration the holistic view of the transformer, including its functions, functional failures, interconnected or affected components, operational procedure, and staff. Its purpose is to eliminate failure before it can occur. In RCM, failure will occur but the number of failures will be reduced and the effect of failure will be minimised. The advantages and disadvantages of RCM are listed below:

Advantages:

- The cost of the maintenance operation is optimized based on risk.
- It reduces unnecessary shutdowns for low risk failures.
- It saves money paid for unnecessary timed inspections in case of TBM.
- It guarantees low possibility of occurrence of high risk failures.

Disadvantages:

- Less understood by maintenance engineers and technicians.
- Complexity of building the maintenance model.

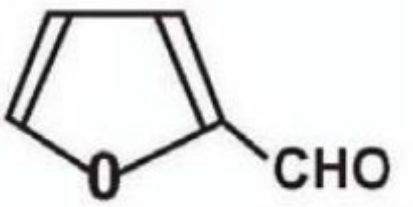
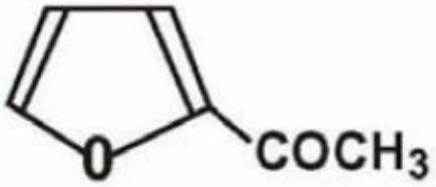
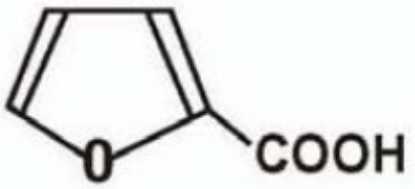
There is a need for a large amount of data about failure rates, failure modes, and failure consequences.

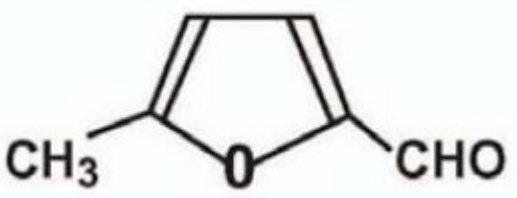
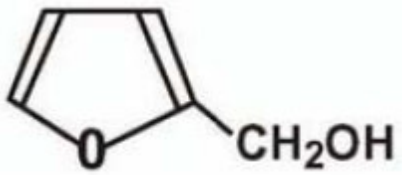
2.3 DP Measurement

Measurement of the Degree of Polymerisation (DP) is used to determine the extent of paper ageing within a transformer. Lelekakis [8] states that the degree of polymerization is the average number of glucose monomers per chain and can be used to monitor aging of the paper. Emsley [5] states that the DP is however only an average measure of the molecular weight distribution (distribution of the length of the chains (molecular weight) of molecules) and does not give detailed information about molecular weight changes occurring during degradation. Ideally the measurement of DP should be done directly from a paper sample, which requires that the transformer tank be opened and hence be exposed to additional risks. Paper degradation occurs primarily by chain scission, which leads to a large number of different chemical by-products formed according to the temperature and local conditions also indicated by Emsley [5]. The analysis of these by-products creates an indirect measurement of DP, which is the generally accepted method for determining the DP of the transformer paper. Some of these by-products are furanic compounds, gases, sludge and water. In a transformer where both paper and oil degrade simultaneously, it is important to distinguish between the by-products produced by paper degradation and the by-products produced by oil degradation. Thus is achieved for paper degradation if furanic compounds are monitored.

According to the Cigre technical brochure TB494 [3] the dominant paper degradation compounds are as listed in the Table 2 below:

Table 2: Chemical structure of furanic compounds

Name	Structure
2-furfural (2-FAL)	
2-acetylfuran (2-ACF)	
2-furoic acid	

5-methyl-2-furfural (5-MEF)	
2-furfurylalcohol (2-FOL)	
5-hydroxymethyl-2-furfural (5-HMF)	

The concentration levels of these by-products can be used to assess the condition of the paper insulation in transformers, as stated by Koreh [6]. The Cigre Technical Brochure TB494 [3] indicates that for a normal degradation process the 2-FAL compound is produced the most and hence is usually used for the paper assessment. The brochure also explains that the 2-FAL compounds may primarily originate from the degradation of the hemicellulose rather than of the cellulose. But at high temperatures between 100^{o}C and 200°C the degradation mechanisms proposed show that 2-FAL should also be generated through the 5-HMF resulting from the degradation of the cellulose.

There are a number of factors that will affect the production of furanic compounds in the transformer. Some of these factors include the paper moisture level, the oil acidity and the paper temperature. The amount of paper used in a transformer will also have a significant impact on the furan levels and this must be appreciated when interpreting furan level results.

Another factor that has a significant impact on the furan levels is the type of paper that is used in the transformer. Papers by Schaunt [15], Emsley [5] and Cigre Technical Brochure TB494 [3] have shown different proportions of cellulose, lignin and pentosans in paper insulation. Table 3 below demonstrates the range of paper composition as measured by these authors.

Table 3: Paper composition as measured by different authors

Authors	Cellulose	Lignin	Pentosans
Schaunt [15]	80%	8%	12%
Cigre Technical Brochure TB494 [3]	78-80%	2-6 %	10-20%
Emsley [5]	90%	3-7%	3-7%

Various equations have been proposed in the literature for converting measured furan levels to estimated DP levels. These equations should be used with caution because their accuracy will vary depending on the type and size of transformer. Models (equations) proposed by Cheim-Dupont, Chendong, Stebbins and De Pablo are listed below from the thesis by Mtetwa [11].

The **Cheim-Dupont model**:

$$DP = \left(\frac{2FAL}{\lambda}\right)^{\frac{1}{\Psi d}} \quad (1)$$

- where: 2FAL is the furfural concentration, in ppm
$\boldsymbol{\lambda}$ is the insulation thermal conductivity, in W mm/K
$\boldsymbol{d}$ is related to the type of paper (thermally upgraded or Kraft paper), in per Kelvin (K)
$\boldsymbol{\Psi}$ is the hot spot gradient temperature, in Kelvin (K)

This model relates paper ageing to both hot-spot gradient temperature and paper type.

The **Chendong model**:

$$DP = \frac{\log(2FAL) - 1.51}{-0.0035} \quad (2)$$

- where the 2FAL concentration is in ppm.

The Chendong model was developed using data collected from transformers insulated with Kraft paper and having free breathing conservators.

The **Stebbins model**:

$$DP = \frac{\log(2FAL \times 0.88) - 4.51}{-0.0035} \quad (3)$$

- where the 2FAL concentration is in ppb.

The Stebbins model is a modification of the Chendong model, to allow it to be used with thermally upgraded paper.

The **De Pablo model**:

$$DP = \frac{7100}{8.8 \times 2FAL} \quad (4)$$

- where the 2FAL concentration is in ppm.

The **Modified De Pablo model**:

$$DP = \frac{800}{[0.186 \times 2FAL] + 1} \quad (5)$$

- where the 2FAL concentration is in ppm.

Mtetwa [11] showed that models that only use the 2FAL concentration to determine the DP are better than the model by Cheim-Dupont, which also uses the hot-spot gradient temperature. The models that only use the 2FAL concentration do not consider what causes the degradation of the paper or the process that the paper goes through for ageing to occur. These models assume that the 2FAL, a by-product of ageing, can be directly used to find the DP of the aged paper. Paper aging depends on temperature, the moisture concentration in the paper and the concentrations of oxygen and acid in the transformer oil. The three main processes for cellulose degradation are hydrolysis, oxidation and pyrolysis as discussed by Lelekakis [8].

- Hydrolysis involves water and acids breaking the cellulose polymer chain. The water dissociates a hydrogen ion (H+) from the acid and this ion then combines with an oxygen atom to break the polymer chain. The remaining anion (RCOO−) from the acid joins with the cation (+CH2R) in the cellulose.

- Oxygen dissolved in the oil accelerates the rate of aging of paper. Several different oxidation reactions can take place on primary and secondary alcohol groups (−OH), forming aldehydes, ketones, and carboxylic acids, and thus opening the glucose ring and disrupting the cellulose chain.

- Pyrolysis is decomposition occurring at temperatures above 140°C. Transformer paper operating under normal or overload conditions does not reach this temperature unless a fault develops.

2.4 DP Prediction

Unlike indirect measurement, where physically measured furans are used as an input to determine the DP of insulation, in DP prediction methods, calculation methods are used. Furan compounds are the by-product of a degradation process, but temperature is the initiator of the ageing process. Therefore this shows the difference between measurement and prediction, where DP prediction is used to forecast the DP at a future date and DP measurement is used to determine the current paper degradation status. They are equally important in estimating the health of a transformer.

A number of factors will affect the accuracy of a model that predicts the DP of the paper insulation inside a closed transformer. The prediction model should apply for any transformer irrespective of size, design or operating conditions. Bondaskỳ [2] showed that transformer ageing can be due to thermal ageing, electrical ageing and mechanical ageing. It is important to understand that the prediction model has to focus on paper insulation ageing instead of the entire transformer ageing. Paper insulation ageing is mostly effected through thermal ageing but electrical and mechanical ageing will have an indirect effect. Lelekakis [8] discusses the links between paper insulation degradation and the building blocks of paper insulation. The building block of paper insulation is cellulose, which is a polymer chain with repeated glucose rings joined together by covalent bonds. The degradation or ageing of paper insulation is when this polymer chain is broken down giving by-products that are used in transformer ageing diagnostics. Some of the by-products are water, carbon dioxide, carbon monoxide and most importantly, furan compounds. The other by-products can also be found in oil degradation, but recent developments suggest menthol (MeOH) can be useful for ageing assessment as shown by Schaut [15].

As mentioned before, the DP indicates the average number of glucose monomers per chain. For a new unused paper, the DP is assumed to be 1200. After the transformer manufacturing process, the paper in a new transformer is left with a DP of about 950 to 1000. At a DP value of about 200 the transformer is declared to have a very high risk of failure.

Paper degradation is a chemical reaction process which occurs when the paper is exposed to high temperature, moisture and oxygen causing the chain of glucose monomers to break. It is important to also note that when this chain breakdown occurs it is an irreversible process, which makes the DP value of a transformer paper a decreasing value with time. In a 1947/8 publication Dakin premised that insulation aging was a chemical rate phenomenon and that deterioration of insulation strength could be modelled by the Arrhenius reaction rate theory (Prevost [13], Cigre TB494 [3]). This was a major breakthrough in finding a model or equation that can be used to estimate chain scission within the paper insulation.

The general Arrhenius equation is as follows:

$$Per\_Unit\_Life = A \cdot e^{\left(\frac{B}{\Theta}\right)} \tag{6}$$

where: Θ is the winding hot-spot temperature, in Kelvin (K)
A and B are constants

Lelekakis [8] modified the Arrhenius equation to describe ageing of the paper insulation in an oil-filled transformer, were the environment has constant temperature, constant moisture, and constant oxygen concentration. The Arrhenius equation is modified as follows: Emsley [4] shows the step by step derivation of the Arrhenius equation. This derivation of the model equation is shown below:

For a first-order reaction of the form:

$$A \rightarrow B + C \tag{7}$$

the rate might be described by the equation:

$$\frac{dA}{dt} = kx[A] \tag{8}$$

from which

$$[A] = [A_0]e^{-kt} \tag{9}$$

where: k = the reaction rate constant,
$[A]$ = concentration of reactant chains at time t, and
$[A_0]$ = initial concentration of reactant chains.

For a simple first-order reaction a plot of $\log_e[A]$ (or a parameter proportional to it such as sample weight) against time will yield a straight line of slope $-k$. In the case of a linear polymer undergoing random degradation, $[A]$ can be replaced by the total number of unbroken inter-monomer bonds remaining (number of chains times the number of monomer units in the chain - 1). If the initial number of molecules of polymer is M_0 and the initial, total number of monomer units is N_0, then the total number of bonds initially is l_0, where

$$l_0 = N_0 - M_0 = N_0\left(1 - \frac{1}{DP_0}\right) \tag{10}$$

where DP_0 = initial degree of polymerization= N_0/M_0.

Similarly, the number of unbroken bonds remaining at time t is:

$$l_t = N_0 - M_t = N_0\left(1 - \frac{1}{DP_t}\right) \tag{11}$$

where: M_t = the number of polymer molecules at time t,
DP_t = the degree of polymerization at time $t = N_t/M_t$, and
l_t = the number of inter-monomer bonds per molecule at time t.

For first-order kinetics of scission, the rate is proportional to the number of unbroken bonds remaining.

$$-\frac{dl}{dt} = kxl_t \tag{12}$$

So

$$l_t = l_0 e^{-kt} \tag{13}$$

Substituting for l_t and l_0

$$\log\left(1 - \frac{1}{DP_t}\right) - \log\left(1 - \frac{1}{DP_0}\right) = -kt \tag{14}$$

If DP_t are DP_0 are large this simplifies to:

$$\frac{1}{DP_t} - \frac{1}{PD_0} = kt \tag{15}$$

This approach is strictly applicable only in the following circumstances:

a) the polymer chain is linear and of high molecular weight
b) the polymer is monodisperse and the products of scission are themselves long chain molecules
c) there is a low degree of chain end-chopping

d) there is no loss of monomer units during scission

$$\frac{1}{ageing} = A \cdot e^{\left(\frac{-E}{RT}\right)} \cdot t \tag{16}$$

$$\frac{1}{DP_t} - \frac{1}{DP_o} = A \cdot e^{\left(\frac{-E}{RT}\right)} \cdot t \tag{17}$$

where: ***A*** is the chemical environment constant (pre-exponential constant)

E is the activation energy, in kJ/mole

R is the molar gas constant 8,314 J/mole/K

T is the absolute temperature, in Kelvin (K)

t is the ageing period, in hours

The Arrhenius equation assumes a constant temperature, thus it is necessary to use average temperature values calculated from the actual sampled values. Time duration (**t**) is the period between the initial DP and the final DP values. The chemical environment constant (**A**) values together with the 95% confidence limits given in per hour are shown in Table 4 from Emsley [4]. They are dependent on the type of paper used and the moisture level in the paper

Table 4: Chemical environment constant (A) of paper in oil

Data set	Average value (h^{-1})	95% confidence limit (h^{-1})	
Thermally upgraded paper	3.65×10^{7}	7.93×10^{6}	1.68×10^{8}
Dry Kraft paper	1.07×10^{8}	2.41×10^{7}	4.71×10^{8}
Kraft paper + 1% H_2O	3.50×10^{8}	8.41×10^{7}	1.46×10^{9}
Kraft paper + 2% H_2O	7.78×10^{8}	1.83×10^{8}	3.30×10^{9}
Kraft paper + 4% H_2O	3.47×10^{9}	7.66×10^{8}	1.57 10^{10}

The activation energy (**E**) for the thermal degradation of cellulose in oil, is quoted in the literature to be about 85 - 128 kJ/mole [Emsley [5], Lelekakis [8]]. Through experimental work Lelekakis [8] achieved a mean activation energy of 111 kJ/mole, with 95% confidence limits of 105 kJ/mole and 117 kJ/mole. It should be noted that cutting, shredding, sieving and the volume of the paper will have an influence on the activation energy. The activation enthalpy reportedly decreases and the activation entropy increases with increasing crystallinity of the paper.

The application of the Arrhenius equation to estimate the ageing of paper insulation is a great milestone in the quest to predict the remaining life of a transformer. It is the only method available to do this prediction without having to do much laboratory testing. It can be done using information from online temperature measurement on transformers. The aim of this dissertation is to test the accuracy of this equation compared to the other methods.

Chapter 3: Data Analysis Methodology

3.1 Research methodology adopted

The focus of this dissertation is on the ageing of the paper insulation of a power transformer. It requires many years to generate data that can be used to monitor or trend the gradual degradation of paper insulation. Therefore power transformers that had been in operation for many years and had records of relevant measurements needed to be identified. A transformer database was found that provided the results of the laboratory tests that had been performed for a particular transformer. Ideally an oil sample should be taken on a regular basis from an operational power transformer. Standards are available that recommend how often the test should be done, but currently this is at the discretion of the engineer. Generally tests are done when transformers show signs of failure or when an investigation is being performed. Online testing, using online gas analysers, is a new technology that is available for large transformers. The results from the tests should be loaded in the database, so that engineers can analyse the information before making decisions.

For this investigation the following information was required:

- Two or more furan level measurements (status of the paper insulation ageing at different times)
- Online or offline daily measurement of oil temperature (for estimation of the rate of paper insulation ageing)

The aim of this investigation was to determine if there was any correlation between the measured DP (using measured furan levels or actual paper samples) and the DP estimated using the Arrhenius equation.

3.1.1 Alternative methods for measuring the DP

The DP of transformer paper insulation can be directly measured by taking paper samples from the transformer or indirectly measured by taking oil samples from the transformer and testing the furan levels. Taking paper samples is the most reliable way as the sampled paper is part of the paper insulation of the transformer and has experienced the same ageing processes as the other paper insulation inside the transformer. But taking paper samples is an intrusive method which requires that the transformer be out of service and can be very costly. The other measurement method is through the detection of ageing by-products in the oil, whereby an oil sample is taken to the laboratory to detect the presence of furan compounds formed by the cellulose chain breaking. The furan level measurement method is much cheaper than the paper sampling method, but it is susceptible to human errors and has long turnaround time. For this investigation either measurement method was considered acceptable.

3.1.2 DP estimation using the Arrhenius equation

The use of Arrhenius equation to estimate the degree of ageing of the transformer insulation paper, offers a method that is less costly and most importantly future insulation paper DP can be predicted. The online measured temperature can be used to in the Arrhenius equation, which is more reliable because the online gas analyser measures the winding temperature. The more regularly and consistently the temperature of the transformer is recorded the more reliable will be the Arrhenius equation prediction results.

3.2 Correlation between the DP measured using alternative methods and the DP estimated using the Arrhenius equation

Figure 8 below shows the method that was used to determine if there was any correlation between the two methods for obtaining the DP.

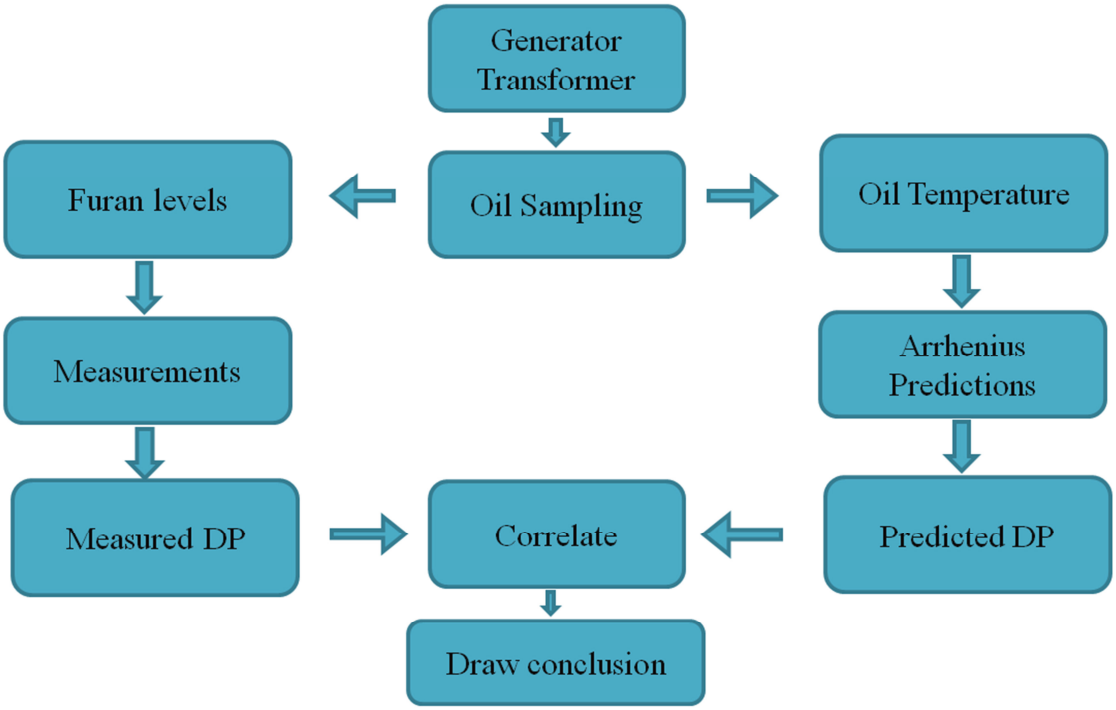


Figure 8: Research methodology

A generator transformer was identified where the required information was available.

3.3 Data Configuration

Most of the generator transformers at the power stations in South Africa were installed about 20 to 30 years ago when the power stations were initially commissioned. However power utilities are only starting to create a database of measurements that have been performed on their transformers. In some cases online monitoring is used, mainly for dissolved gas analysis and temperature measurements. These databases do not yet have enough data for this type of investigation. In some cases the data is not continuous.

For the data that was available, recording was done only many years after the transformer was placed in service. Also the sampling was not consistent. Figure 9 below shows the data configuration that was necessary to create data that was consistent and started from the time when the transformer was installed.

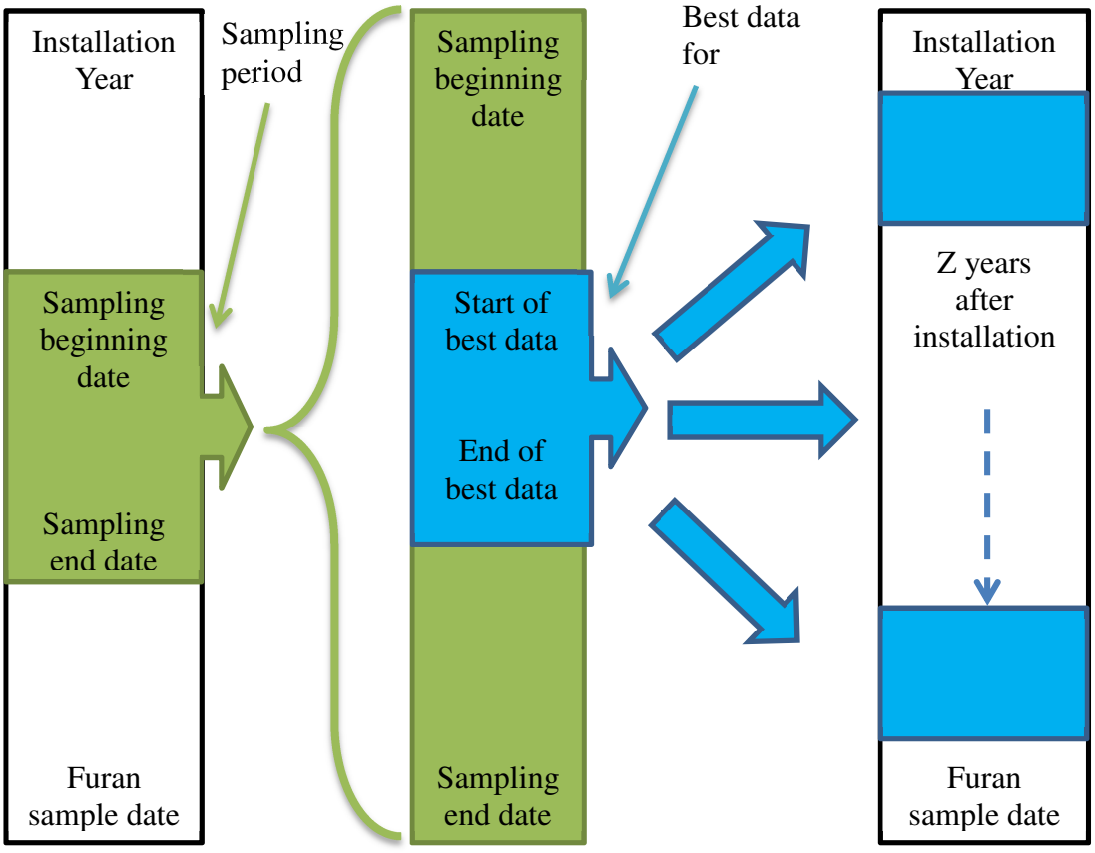


Figure 9: Data configuration

Within the available data, the best data that is reliable and consistent for Z number of years is projected from the time the transformer was installed until the time when furan level measurement was performed. The generated data is then used to predict the DP on the date that furan level measurement was performed. The projection starts from the date of transformer installation. It is assumed that the transformer initially has new paper insulation with a typical DP value associated with new paper insulation. Also since the transformer is located at a base-load station it is assumed that the load on the transformer is fairly constant. Therefore the new paper insulation will deteriorate in accordance with the base-load temperature until it reaches the date when the furan level is measured. Appendix C shows how the sampled data was manipulated so that it could be used to estimate the DP using the Arrhenius equation.

Chapter 4: Oil Sampling Data Analysis

4.1 Generator transformer data background

Transformer data has been acquired from the oil sampling laboratory database and the power station's online measuring equipment. It is clear that to monitor a transformer its historic performance data record should be continuous over time in order to do analysis and make critical decisions concerning the transformer.

The generator transformer with available data that could be rearranged to be useful for this research was a generator transformer that was manufactured in 1985 and was installed at a power station in 1986. Online data and offline oil sampling data was obtained for this unit. According to the data, sampling was performed using the online gas analyser from 3rdAugust 1992 to 6th July 2000, and offline oil sampling was performed from 30th December 1991 to 25th April 2012. The temperature range for the online gas analyser data was between 31˚C and 70˚C, while for manual oil sampling data it was between 24˚C and 87˚C. The major concern with this data was that according to the history report of this transformer the unit was shut down on the 7th July 2000, but on the manual oil sampling data there are records after this date. It could be assumed that the samples where taken when the unit was being inspected.

Both sets of data are reliable and good for analysis, thus they are systematically analysed in the sections below.

4.2 Data results

4.2.1 Online data

Online data recording is performed by an online gas analyser which is placed next to the generator transformer. The online gas analyser is used to record data at any time and can also be used to send alarms for any pre-set levels for gases or temperature that may become abnormal. Appendix A show the online data recorded for the generator transformer used for this research. Gases that are released from the oil due to transformer operation or oil ageing are detected by the online gas analyser. Transformer temperature is also recorded by the online gas analyser. Figure 10 shows the plot of the temperature data recorded by the online gas analyser of the particular generator transformer.

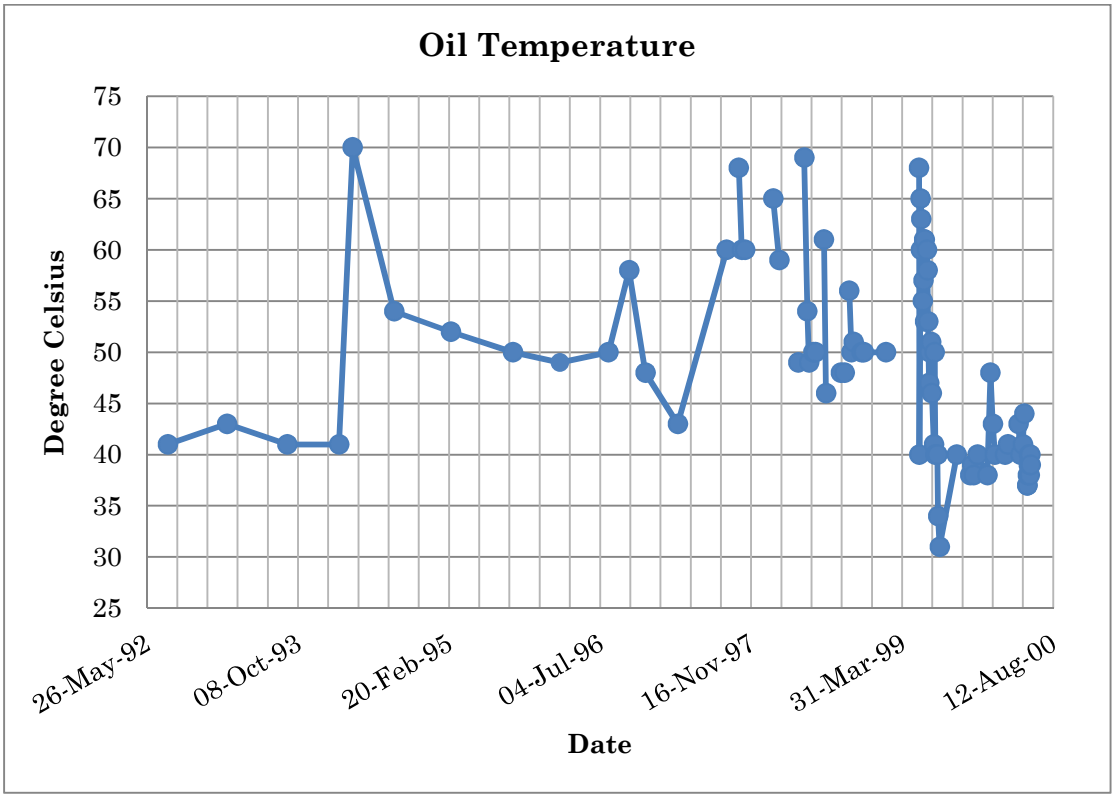


Figure 10: Online gas analyser temperature data

The points on the graph show the measured temperature on particular days, so it should be noted that the recorded temperature is not as continuous as indicated by this graph. The connection between the points is for trending purposes. Initially the online gas analyser temperature points were infrequent, but from the 27th May 1999 the data was

recorded more regularly. For better results in predicting the paper DP using the Arrhenius equation, the temperature data required must be recorded daily. Figure 11 below shows a plot of the estimated DP using the Arrhenius equation and the online temperature data.

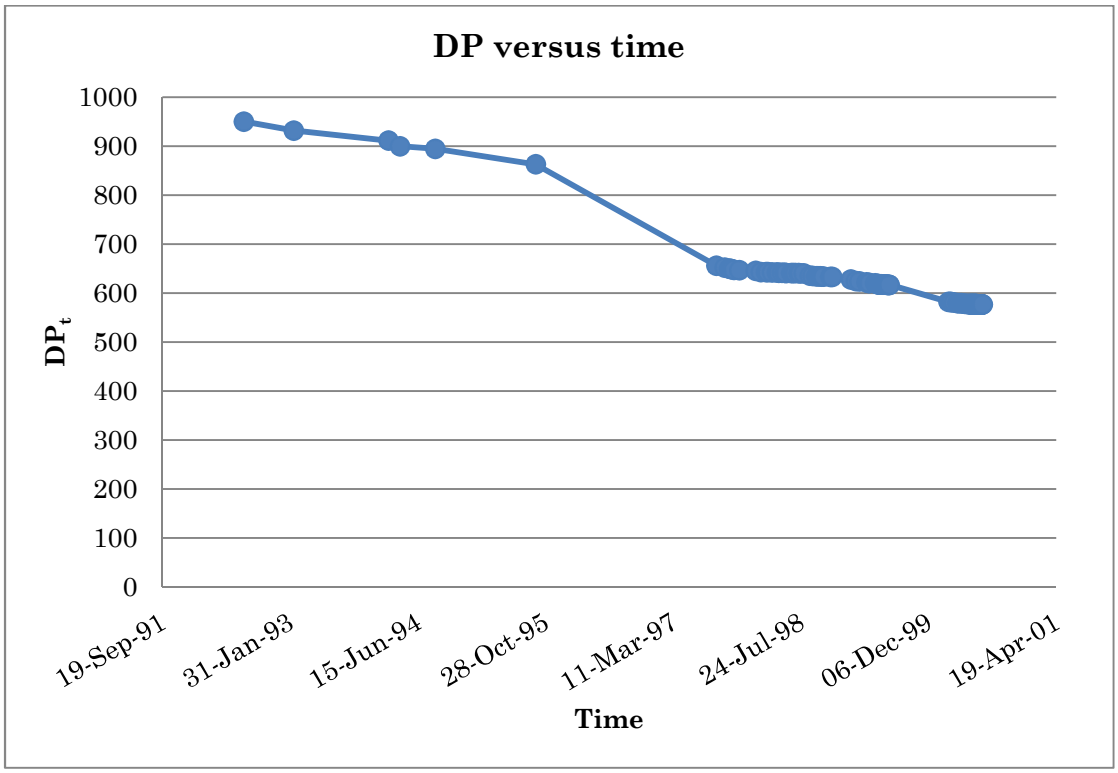


Figure 11: DP estimation using the Arrhenius equation and the online temperature data

This plot shows the estimated DP decrease as the transformer continues to operate. A DP of 950 was assumed at the beginning of data recording.

The DP at each point in Figure 11 was calculated using the temperature in Figure 10, the time from the previous point and the Arrhenius equation, as shown below:

$$\frac{1}{DP_t} - \frac{1}{DP_o} = k \cdot t \tag{18}$$

$$DP_t = \frac{DP_o}{1 + k \cdot t \cdot DP_o} \tag{19}$$

where: DP_t = is the calculated DP in Figure 11

$DP_0 =$ is the assumed DP of 950 (assume a new transformer at the start of the curve)
$k =$ is given by the equation below

$$k = A \cdot e^{\left(\frac{-E}{RT}\right)} \tag{20}$$

Figure 11 was calculated as shown in Table 5 (first seven years of the calculations, the complete calculations are in Appendix D), using equation (19) and (20) above, and the initial conditions were set to be:

$DP_o = 950$, for a new transformer
$A = 3.65 \times 10^7$ h^{-1}, the chemical environment constant for thermally upgraded paper.
$E = 100$ kJ/mole, the activation energy for the thermal degradation of cellulose in oil.
$R = 8.314$ J/mole/K, the molar gas constant.
$T =$ online temperature measured on the transformer, in ^{o}C.

Table 5: The partial Arrhenius equation calculations for DP plot in Figure 11

Date	Days	t (hours)	T (^{o}C)	k	DP_t
03-Aug-92	0	0	49	2.1866E-09	950
15-Feb-93	196	4704	55	4.3303E-09	931.9651
21-Feb-94	371	8904	51	2.7536E-09	911.1451
07-Apr-94	45	1080	65	1.2814E-08	899.7988
22-Aug-94	137	3288	48	1.9464E-09	894.647
20-Sep-95	394	9456	55	4.3303E-09	863.0309
27-Aug-97	707	16968	70	2.1527E-08	656.1773
29-Sep-97	33	792	65	1.2814E-08	651.8364
16-Oct-97	17	408	63	1.0368E-08	650.0439
21-Oct-97	5	120	67	1.5798E-08	649.2438
27-Oct-97	6	144	64	1.153E-08	648.5447
04-Nov-97	8	192	66	1.4233E-08	647.3973
25-Nov-97	21	504	53	3.4579E-09	646.6677
28-Jan-98	64	1536	47	1.7313E-09	645.5576
17-Feb-98	20	480	65	1.2814E-08	643.0043
10-Mar-98	21	504	30	2.1014E-10	642.9605
17-Mar-98	7	168	48	1.9464E-09	642.8254
02-Apr-98	16	384	49	2.1866E-09	642.4786
21-Apr-98	19	456	50	2.4547E-09	642.0169
29-Apr-98	8	192	54	3.871E-09	641.7107
11-May-98	12	288	48	1.9464E-09	641.48
21-May-98	10	240	49	2.1866E-09	641.2641
27-May-98	6	144	48	1.9464E-09	641.1488
17-Jun-98	21	504	44	1.2131E-09	640.8976
24-Jun-98	7	168	43	1.0758E-09	640.8234
03-Jul-98	9	216	41	8.4422E-10	640.7485
15-Jul-98	12	288	43	1.0758E-09	640.6213
22-Jul-98	7	168	41	8.4422E-10	640.5631

4.2.2 Manual oil sampling data

Manual oil sampling is where oil is collected from the transformer and taken to a laboratory for testing. As the oil is collected, its temperature is recorded which is used when interpreting the laboratory test results. Appendix B shows the manual sampling data collected for the generator transformer used for this research. Figure 12 below shows the oil temperature data recorded when manual oil sampling was performed.

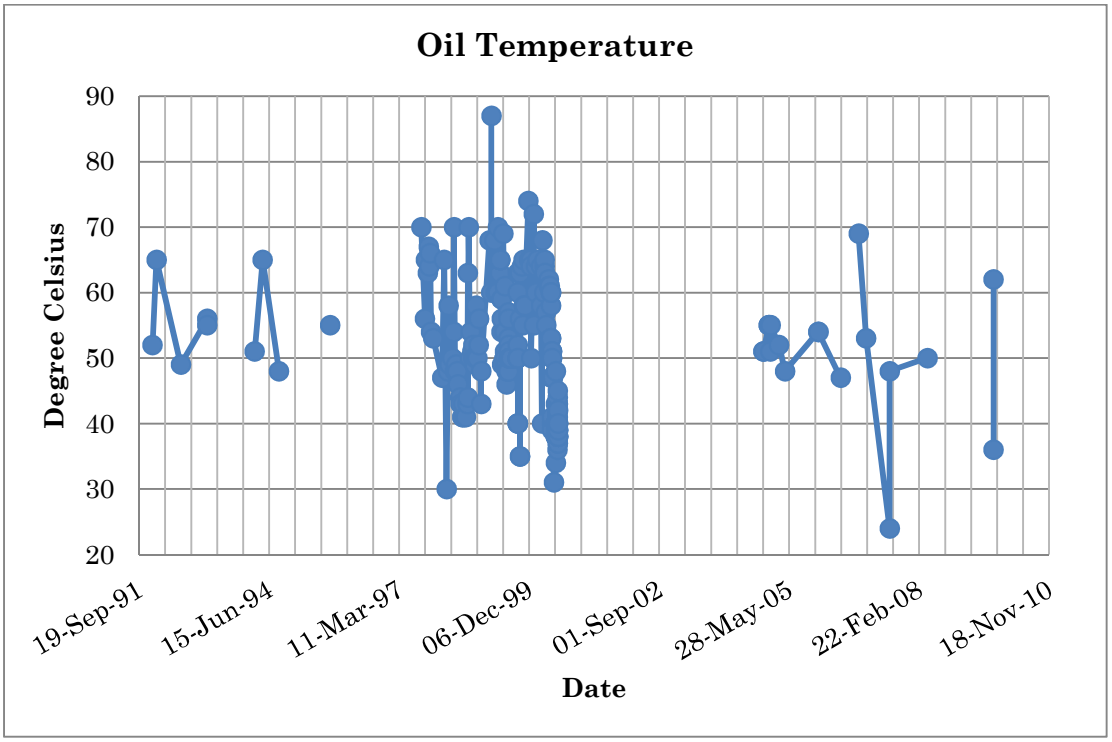


Figure 12: Manual oil sampling temperature data

During the period from 28th August 1997 to 15th July 2000 the data shows that oil sampling was performed on a regular basis. This is because the transformer condition was of concern and an instruction was issued to perform regular manual oil sampling to monitor the transformer. This part of the data is crucial in the next chapter when estimating the DP. Figure 13 below shows a plot of the DP estimated using the Arrhenius equation and the temperature data recorded during manual oil sampling.

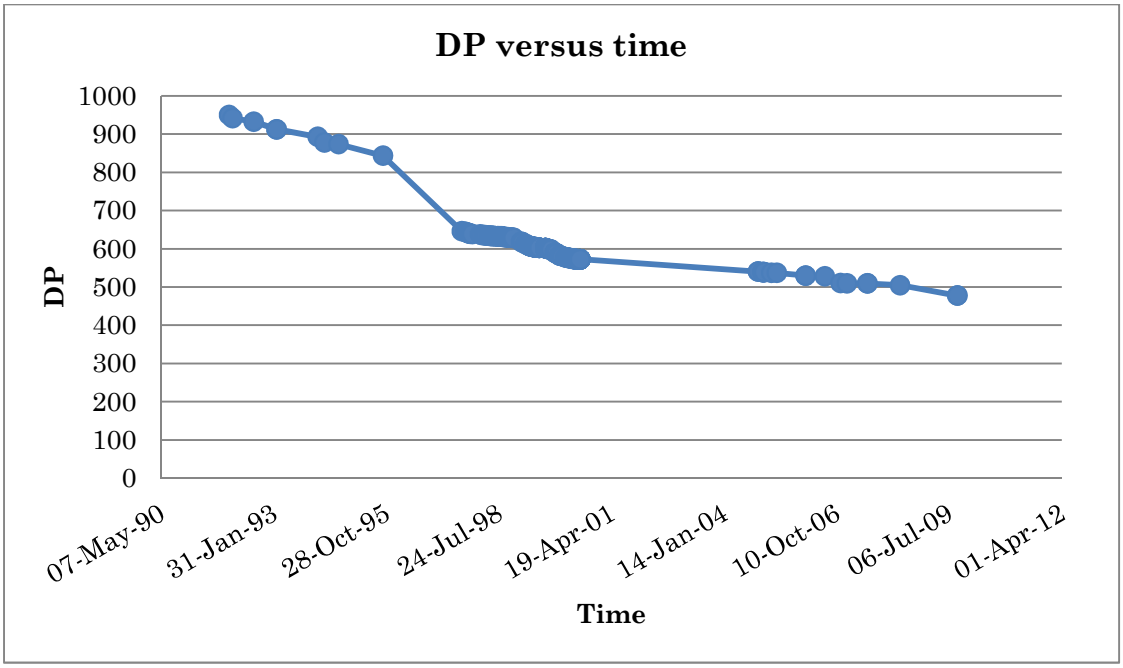


Figure 13: DP estimated using the Arrhenius equation and manual oil sampling temperature

The temperature in Figure 12 and equations (18), (19) and (20) in section 4.2.2 were used to calculate the DP estimate in Figure 13.

Figure 13 was calculated as shown in Table 6 (first seven years of the calculations, the complete calculations are in Appendix D), using equation (19) and (20) above, and the initial conditions were set to be:

$DP_o = 950$, for new transformer
$A = 3.65 \times 10^7$ h^{-1}, the chemical environment constant for thermally upgraded paper.
$E = 100$k J/mole, the activation energy for the thermal degradation of cellulose in oil.
$R = 8.314$ J/mole/K, the molar gas constant.
$T =$ online temperature measured on the transformer, in ^oC.

Table 6: The partial Arrhenius equation calculations for DP plot in Figure 13

DATE	DAYS	t (hours)	T (°C)	k	DP_t
30-Dec-91	0	0	52	3.08685E-09	950
30-Jan-92	31	744	65	1.28144E-08	941.4729
04-Aug-92	187	4488	49	2.1866E-09	932.8541
23-Feb-93	203.4167	4882	56	4.84093E-09	912.7315
23-Feb-93	0.166667	4	55	4.33035E-09	912.7171
23-Feb-94	364.4167	8746	51	2.75365E-09	893.0859
25-Apr-94	61	1464	65	1.28144E-08	878.3692
29-Aug-94	126	3024	48	1.9464E-09	873.8514

26-Sep-95	393	9432	55	4.33035E-09	843.7372
28-Aug-97	702	16848	70	2.15271E-08	646.0403
25-Sep-97	28	672	56	4.84093E-09	644.6854
03-Oct-97	8	192	65	1.28144E-08	643.6644
17-Oct-97	14	336	63	1.03683E-08	642.2243
23-Oct-97	6	144	67	1.57982E-08	641.2874
28-Oct-97	5	120	64	1.15303E-08	640.7188
04-Nov-97	7	168	66	1.42327E-08	639.7388
11-Nov-97	7	168	54	3.87097E-09	639.4727
28-Nov-97	17	408	53	3.45795E-09	638.8963
04-Feb-98	68	1632	47	1.73132E-09	637.745
20-Feb-98	16	384	65	1.28144E-08	635.7499
11-Mar-98	19	456	30	2.10143E-10	635.7112
20-Mar-98	9	216	48	1.9464E-09	635.5414
25-Mar-98	5	120	58	6.03761E-09	635.2488
02-Apr-98	8	192	49	2.1866E-09	635.0795
24-Apr-98	22	528	50	2.45467E-09	634.5572
04-May-98	10	240	54	3.87097E-09	634.1833
06-May-98	2	48	70	2.15271E-08	633.768
15-May-98	9	216	48	1.9464E-09	633.5992
25-May-98	10	240	49	2.1866E-09	633.3886
01-Jun-98	7	168	48	1.9464E-09	633.2574
05-Jun-98	4	96	46	1.53888E-09	633.1982
22-Jun-98	17	408	44	1.21309E-09	632.9998
25-Jun-98	3	72	43	1.07584E-09	632.9688
11-Jul-98	16.41667	394	41	8.44221E-10	632.8355
11-Jul-98	0.166667	4	41	8.44221E-10	632.8342
17-Jul-98	5.416667	130	43	1.07584E-09	632.7782
27-Jul-98	10	240	41	8.44221E-10	632.697
06-Aug-98	10	240	41	8.44221E-10	632.6159
18-Aug-98	12	288	43	1.07584E-09	632.492
21-Aug-98	3.416667	82	63	1.03683E-08	632.152
21-Aug-98	0.166667	4	44	1.21309E-09	632.1501
27-Aug-98	5.416667	130	70	2.15271E-08	631.0337
08-Sep-98	12	288	50	2.45467E-09	630.7524
11-Sep-98	3	72	54	3.87097E-09	630.6415
23-Sep-98	12	288	51	2.75365E-09	630.3263
01-Oct-98	8	192	52	3.08685E-09	630.0909
02-Oct-98	1	24	50	2.45467E-09	630.0675
13-Oct-98	11	264	49	2.1866E-09	629.8384
20-Oct-98	7	168	50	2.45467E-09	629.6748
23-Oct-98	3	72	58	6.03761E-09	629.5025
03-Nov-98	11	264	50	2.45467E-09	629.2458
12-Nov-98	9	216	52	3.08685E-09	628.9819

Chapter 5: Oil Sampling Data Configuration

5.1 Comparison of outcomes

Data capturing was not performed when the particular generator transformer was initially installed. The recorded data indicates that oil manual sampling was started five years after installation (31st December 1991) and oil online sampling started six years after the transformer was installed (3rd August 1992). The two sampling methods were compared for a three year period. The period analysed is towards the time when the transformer was about to shut down on the 7th July 2000, because during this time the sampling rate was increased due to the high risk of failure of the transformer. Table 5 below shows the comparison between manual sampling and online sampling.

Table 7: Manual sampling and online sampling comparison

	Manual sampling	**Online sampling**
Exact period	25th September 1997 – 3rd June 2000	29th September 1997 – 5th June 2000
Number of samples	158	101
Minimum period between samples	86 minutes	24 hours
Maximum period between samples	68 days	230 days
Average sampling rate	7 days	10 days

This above table shows that manual sampling was more frequent than online sampling in the surveyed period. This can also be confirmed by Figure 10 and Figure 12 in Chapter 4, which show the temperature graphs of online sampling and manual sampling respectively.

5.2 Data Configuration

The available data has shown that the manual sampling data is more useable than the online sampling data. The data was analysed to check for a period were manual sampling was increased sufficiently to track the performance of the transformer. A one year period and a three year period were identified as two periods that were long enough to represent the performance through the use of temperature recordings. Because the analysed transformer was from a base-load station, loading on the transformer was kept approximately constant. The two best data periods were then repeated over the duration of the transformer life. Figure 14 shows how the best three year data is obtained and used to trend data for the transformer life span.

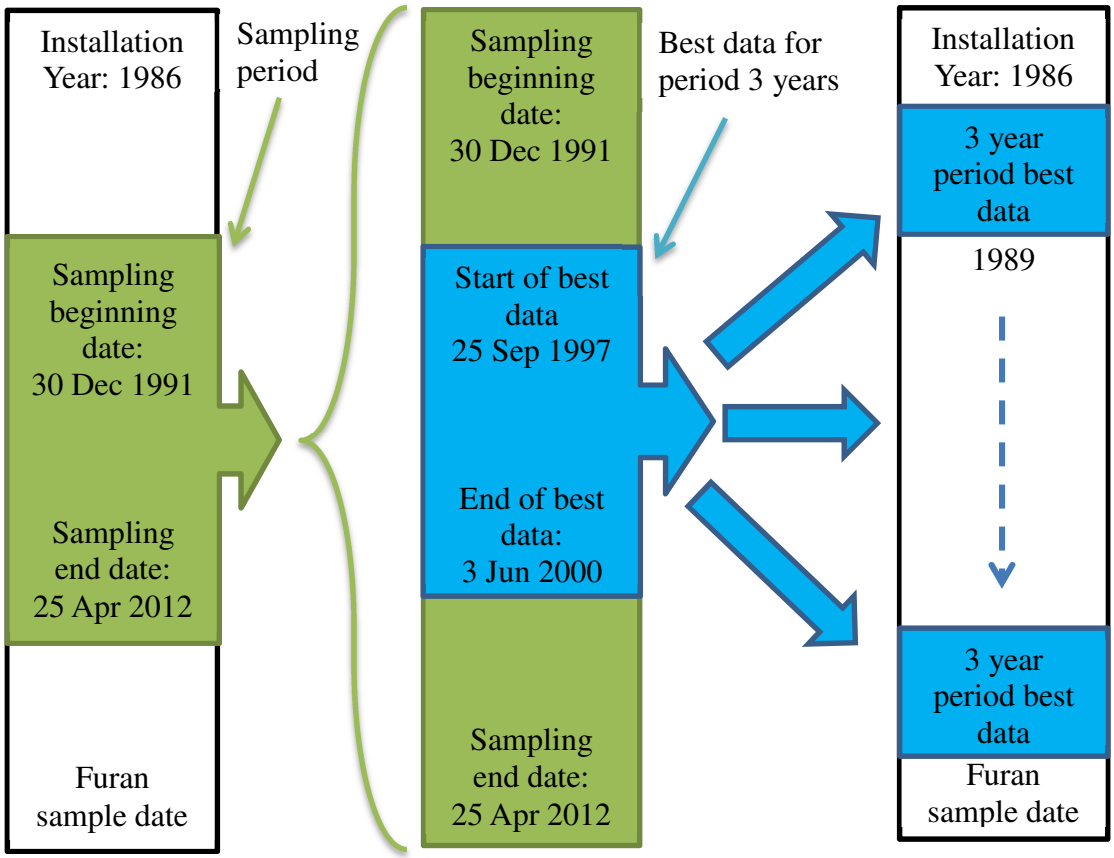


Figure 14: Three year data projection

The DP values obtained using the two data projection methods were compared with the measured DP values. Three DP values have been measured since the transformer was commissioned, the first measurement was by taking furan samples in October 1997, the second was by taking DP values from actual paper samples in October 1999 and the third was by taking furan samples in September 2000.

The DP calculations using the Arrhenius equation were made assuming that the paper insulation used in the transformer was thermally upgraded with an initial DP (DP_o) of 950, assuming a chemical environment constant (**A**) value of 3.65 x 10^7 h^{-1}, and assuming an activation energy constant (**E**) of 100kJ/mole. Table 6 shows the comparison of the measured DP values with the calculated DP values. Figure 15 and Figure 16 show the plot of the results of the predicted DP for a one year projection and a three year projection respectively.

Table 8: Comparison of measured DP and DP estimated using the Arrhenius equation

Date	Measured DP (paper sample or DP estimated from furan levels)	DP estimated using the Arrhenius equation	
		1 year projection	3 years projection
Oct 1997 Furan samples	680	494, 27% error	545, 20% error
Oct 1999 Paper samples	R: 607	456, 25% error	521, 14% error
	Y: 683	456, 33% error	521, 24% error
	B: 533	456, 14% error	521, 2% error
	Average: 608	456, 25% error	521, 14% error
Sep 2000 Furan samples	484	438, 10% error	488, 3% error

The measured DP was obtained directly from the transformer through furan level and paper insulation sampling. The DP estimated using the Arrhenius equation was obtained the same as the DP estimate in Figure 11 and Figure 13, in section 4.2.1 and 4.2.2 respectively. Appendix C has the rest of the estimated data.

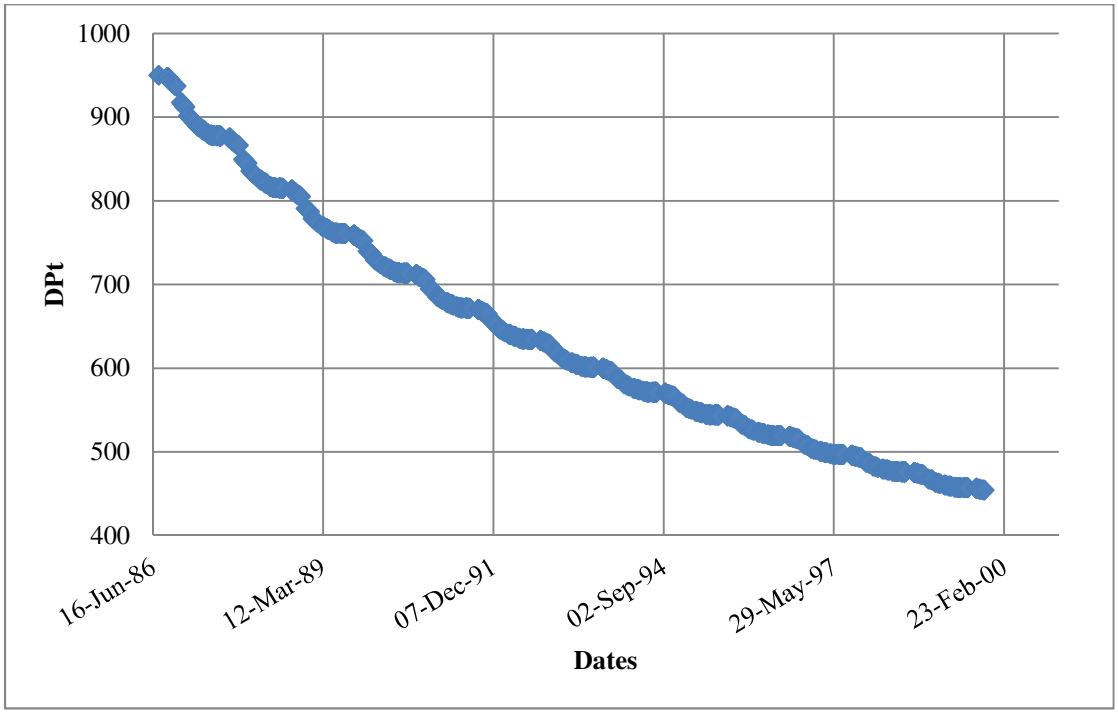


Figure 15: Plot for one year data projection

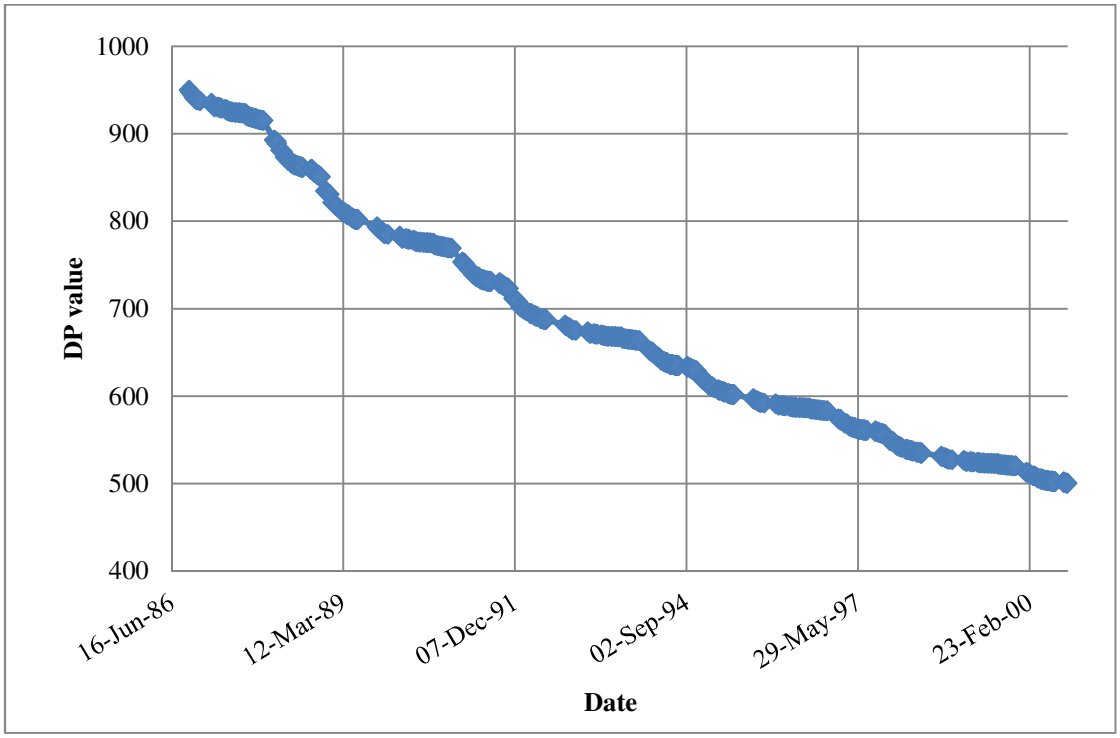


Figure 16: Plot for three year data projection

Table 8 above shows the error between the DP values obtained from actual paper measurements or DP values obtained from measured furan levels and the DP values estimated using the Arrhenius equation. The error between the measured DP and the DP estimated using the Arrhenius equation is less than 35% in all compared values. The highest error of 33% is found between the DP estimated using the Arrhenius equation and the measured DP from a paper sample. It should be noted that three measurements were taken for each paper sample, one from each phase. The DP was calculated from the average value of the three DP measurements or the lowest DP measurement (blue phase). When using this approach the error between the measured DP and the DP estimated using the Arrhenius equation was less than 30% in all compared values. For both the one year projection and the three year projection the error decreases to values much lower than 30%.

Normally the paper insulation is expected to degrade gradually with time as the transformer continues to operate. The degradation of paper insulation occurs as a chemical process which will cause the DP to drop. Figure 15 and Figure 16 above indicate that the DP is decreasing at a decelerating rate with increasing time. Thus both graphs conform to the normal expected pattern of paper insulation degradation due to transformer operations and bio-degradation activities.

From the time it was installed in 1986 until it was decommissioned in 2000, more furan level measurements could have been taken. Annual furan level sampling would have been ideal. The incident-based furan level sampling gives fewer samples and therefore it was more difficult to develop a trend. Annual DP sampling would have resulted in 14 furan level samples during the life span of this transformer, and if the sampling had been performed at roughly equal intervals this would have produced better trending.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

DP estimation using the Arrhenius equation has a number of advantages. This method can be executed at almost negligible cost since laboratory tests are not necessary and the method is non-intrusive. The main challenge with DP estimation using the Arrhenius equation which this research addresses is the accuracy of DP estimation using the Arrhenius equation compared with DP estimation using furan level measurement which is used by many power utilities. DP estimation using the Arrhenius equation and DP estimation using furan level measurements are both indirect methods for measurement of the ageing of transformer paper insulation.

Similar to DP estimation using furan level measurements, DP estimation using the Arrhenius equation is dependent on other factors for it to be accurate. Knowledge of the history of the transformer is crucial in estimating the remaining life of the paper insulation using the Arrhenius equation. From the analysis in Chapter 5, it has been established that regular measurement of temperature and moisture could have a significant impact on the accuracy of DP estimation. Thus it can be concluded that if the inputs to the Arrhenius equation are measured regularly and accurately enough, this will have a significant impact on the predicted DP.

Most utilities have systems, plans and procedures setup for executing furan analysis or have assigned laboratories to do this analysis. This will be advantageous if the utilities start analysing DP using the Arrhenius equation method, because the utilities will use furan analysis method to further check for correlation. Utilities can also vigorously test the Arrhenius equation method and determine if the method cannot be improved any further to produce required accuracy.

This project has also most importantly illustrated from the results obtained, that DP estimation results obtained using the Arrhenius equation correlates with the results estimates using furan level measurements. The electricity industry has for a long time relied on the furan level approach as one of the major tools in diagnosing the state of the paper insulation. The proposed DP estimation method has potential because it has a low cost and a quick turnaround compared with both the furan level method and the direct paper sampling method.

6.2 Recommendations

Further work is required to get more accurate values for the variables in the Arrhenius equation applicable to operational transformers. Measurements on paper insulation such as DP estimation should not be done only when faults occur, but should be assessed on a regular basis. Transformer paper insulation assessment should be part of the Key Performance Indicator (KPI) of a power station. The Arrhenius estimation method is recommended for monthly or twice a month paper insulation assessment and then DP estimation using furan level measurement and DP measurement using actual paper sampling can be used as verification methods.

The use of a generic value for the initial DP value of paper insulation in a new or refurbished transformer should be avoided. An actual measured value should be used for estimation purposes.

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Appendix

A: Online data

Table 9: Online sampling data for generator transformer for a period of eight years

Date	H_2	CH_4	C_2H_2	C_2H_4	C_2H_6	O_2	CO	CO_2	N_2	kV	H_2O	Oil Temp	Days
03-Aug-92	12	37	0	23	33	2901	448	1356	57103	79	6	49	
15-Feb-93	14	49	0	27	30	6010	474	1888	58004	79	11	55	196
02-Sep-93	8	27	0	22	18	4204	523	1300	55164	75	12		199
21-Feb-94	9	20	0	21	14	4752	441	2017	44320	61	24	51	172
07-Apr-94	7	18	0	25	15	7753	162	236	69295	50	12	65	45
22-Aug-94	10	28	0	26	18	7482	634	3055	60558	68	12	48	137
26-Feb-95	15	45	0	58	24	6826	617	2973	58501	63	16		188
20-Sep-95	14	44	0	58	23	3324	631	3553	49009	80	11	55	206
22-Feb-96	0	3	0	46	18	8911	200	3175	47048	71	14		155
01-Aug-96	20	64	0	95	31	4299	455	3055	58917	82	12		161
08-Oct-96	0	74	0	105	35	5890	416	3224	58734	78	11		68
01-Dec-96	15	72	0	106	34	6457	556	3339	54236				54
18-Mar-97	30	113	0	178	57	5621	558	4137	51954	71	14		107
27-Aug-97	31	116	0	361	110	6582	545	4664	54288	89	12	70	162
23-Sep-97	42	148	1	376	120	6352	645	3053	57800				27
29-Sep-97	38	145	0	416	171	6192	650	3525	56740	75	15	65	6
06-Oct-97	28	110	1	347	108	4754	480	4200	43364	73	15		7

16-Oct-97	23	105	1	322	94	4829	437	4129	44712	72	15	63	10
21-Oct-97	28	123	2	365	107	7513	564	3130	53628			67	5
27-Oct-97	24	87	0	256	75	5104	422	3179	39089	75	13	64	6
04-Nov-97	33	141	1	402	119	7513	564	3130	53628	74	15	66	8
25-Nov-97	16	82	0	248	47	8341	410	3595	47808	74	12	53	21
28-Jan-98	8	46	0	151	40	9808	313	2146	47992	41	49	47	64
17-Feb-98	19	109	0	356	104	6043	809	3005	55918	71	16	65	20
10-Mar-98	0	5	0	20	8	9814	18	299	3196	75	8	30	21
17-Mar-98	0	6	0	17	6	7569	46	508	26101	78	11	48	7
02-Apr-98	5	10	0	20	1	4461	51	589	14904	42	16	49	16
21-Apr-98	10	71	0	99	33	4994	542	2472	47558	76	10	50	19
29-Apr-98	11	66	0	118	43	5932	469	2196	4748	75	11	54	8
11-May-98	10	89	0	150	49	6654	675	2107	56821	71	9	48	12
21-May-98	15	30	0	42	11	9743	85	1038	29258	82	7	49	10
27-May-98	11	24	0	36	10	8583	62	868	26472	75	8	48	6
10-Jun-98	14	22	0	43	13	3570	64	722	13077			45	14
17-Jun-98	27	42	0	58	16	3992	115	643	16690	71	9	44	7
24-Jun-98	11	17	0	20	5	2344	48	414	9286	75	8	43	7
03-Jul-98	26	38	0	46	12	2767	107	539	12240	79	9	41	9
15-Jul-98	13	19	0	21	5	2407	51	293	9442	86	7	43	12
22-Jul-98	21	39	0	51	14	6478	94	675	23778	80	10	41	7
04-Aug-98	30	43	0	94	91	3409	99	629	13155	73	17	41	13

28-Aug-98	34	59	0	70	17	4192	124	749	15608	79	8	70	24
09-Sep-98	32	54	0	75	27	5950	105	595	22187	73	10	54	12
22-Sep-98	42	59	0	57	15	2814	109	470	12270	84	10	52	13
29-Sep-98	83	124	0	129	34	12339	221	1338	47611	85	13	50	7
07-Oct-98	34	48	0	43	11	3371	89	440	13394	90	12	49	8
14-Oct-98	20	47	0	72	29	10987	76	824	38485	80	16	50	7
21-Oct-98	12	87	0	136	43	6759	688	1793	66205	78	9	58	7
17-Nov-98	42	56	0	52	13	3029	76	399	12648	83	39	48	27
24-Nov-98	55	80	0	80	21	3403	101	511	14232	84	10	43	7
05-Feb-99	45	76	0	56	16	3304	87	1297	12793	70	15	60	73
13-Feb-99	60	109	0	109	31	7282	111	2304	26950				8
19-Feb-99	45	80	0	83	24	4860	73	484	17510				6
25-Feb-99	48	77	0	82	30	3397	73	419	13600	73	20	68	6
10-Mar-99	130	222	0	187	50	3630	190	769	15837	81	14	60	13
31-Mar-99	66	75	0	70	21	3569	70	1324	14335				21
07-Apr-99	168	196	0	166	47	1922	164	770	11037	87	8	60	7
12-Apr-99	185	243	0	193	55	3146	192	910	15385	73	12		5
14-Apr-99	195	237	0	195	57	2072	182	837	12266				2
15-Apr-99	43	60	0	48	14	2407	54	929	9565	74	9	65	1
20-Apr-99	16	28	0	111	32	3078	28	1453	11875	83	11	59	5
28-Apr-99	71	99	0	91	27	3945	92	1607	16048				8
04-May-99	185	256	0	214	61	3280	203	949	16532				6

07-May-99	136	196	0	164	47	3265	162	822	14745				3
11-May-99	77	104	0	85	24	2032	75	395	9343	78	7	49	4
18-May-99	114	145	0	117	34	3977	134	1870	17089				7
20-May-99	112	189	0	178	55	5887	164	916	20207	76	9	69	2
21-May-99	179	225	0	215	71	2058	196	655	11850	36	54	54	1
24-May-99	67	87	0	79	24	3827	78	1802	14446	68	9	49	3
26-May-99	37	52	0	83	26	4024	46	1621	15501	71	9	50	2
27-May-99	88	133	0	121	37	5155	117	2720	18585	67	9	50	1
31-May-99	76	95	0	82	25	2024	67	362	9563				4
01-Jun-99	68	86	0	73	22	1848	60	313	8302				1
02-Jun-99	63	89	0	87	27	5567	80	1970	21261	72	10	61	1
07-Jun-99	92	128	0	121	38	4533	102	676	18911	73	7	46	5
09-Jun-99	1	4	0	58	17	4647	4	1318	17179				2
11-Jun-99	64	73	0	65	20	3118	70	1528	12843				2
14-Jun-99	76	101	0	98	31	6207	92	2211	24102			48	3
15-Jun-99	202	269	0	209	63	1856	172	615	11948			48	1
21-Jun-99	74	82	1	68	19	7406	79	1531	28245				6
23-Jun-99	52	76	0	79	24	3227	69	1418	13070			56	2
25-Jun-99	184	240	0	193	55	1484	147	601	10496	84	10	50	2
28-Jun-99	176	230	0	185	54	2011	138	598	11597			51	3
30-Jun-99	89	111	0	130	38	3359	99	1855	14407			50	2
05-Jul-99	178	258	0	232	68	5670	190	1060	24504			50	5

07-Jul-99	118	144	0	129	38	3582	144	129	15776	89	8	50	2
14-Jul-99	51	62	0	51	15	2284	59	1208	9331				7
16-Jul-99	68	82	0	68	20	2462	81	1618	2462				2
19-Jul-99	139	184	0	154	47	4047	177	3595	17832				3
26-Jul-99	103	133	0	112	32	3979	122	2551	16833				7
28-Jul-99	84	113	0	95	9	2952	100	1586	13293				2
02-Aug-99	67	84	0	56	16	1546	85	1571	7447				5
28-Sep-99	0	3	0	6	1	3592	21	285	3592	84	11		57
19-Oct-99	11	25	0	22	7	6302	138	591	27085				21
28-Oct-99	9	22	0	17	5	3886	125	447	20279	85	10		9
11-Nov-99	15	33	0	29	9	4940	192	818	28492	34	17		14
17-Nov-99	14	36	0	33	10	6077	203	1105	32364	26	62		6
23-Nov-99	17	45	0	37	11	5827	244	1043	33521	76	14		6
06-Dec-99	18	57	0	52	16	6116	285	1331	36258	74	15		13
07-Jan-00	16	54	0	54	18	7249	269	1245	37670	42	12		32
17-Jan-00	37	100	0	74	24	1654	536	2142	36590				10
25-Jan-00	17	56	0	47	15	13817	285	1276	67780				8
01-Feb-00	22	71	0	65	20	8266	351	1595	49884				7
16-Feb-00	38	110	0	93	29	5970	483	2121	47102				15
22-Feb-00	44	109	2	94	31	4072	490	2183	40955	80	17	68	6
29-Feb-00	39	94	0	79	26	6368	420	1902	45680	76	8	40	7
06-Mar-00	33	87	2	86	30	5759	360	1698	40503	66	13	65	6

15-Mar-00	54	135	0	124	41	7031	502	2266	54693	64	10	60	9
28-Mar-00	56	180	0	146	49	2904	632	2686	43515	74	14	63	13
03-Apr-00	16	97	2	112	44	2956	683	4841	44045	79	12	55	6
12-Apr-00	44	157	0	76	76	4388	498	2609	44267	76	10	57	9
19-Apr-00	58	196	0	200	75	4396	609	2337	42340	79	10	61	7
26-Apr-00	85	293	0	272	93	5001	525	2420	43352	74	11	61	7
04-May-00	200	699	1	622	221	4168	614	2553	44165	70	12	53	8
08-May-00	185	657	1	637	233	4872	448	2125	38853	79	9	60	4
15-May-00	351	1172	1	1108	421	3058	573	2715	41639	73	8	58	7
16-May-00	367	1367	1	1237	461	2466	642	2991	42411	64	8	53	1
17-May-00	371	1371	2	1271	472	2888	626	2919	41248	76	7	47	1
18-May-00	362	1395	2	1309	486	2762	627	2872	40740	77	7	50	1
19-May-00	349	1342	2	1263	463	3140	611	2871	40518	70	7	51	1
20-May-00	419	1610	2	1427	502	2995	736	3312	47118			46	1
23-May-00	323	1237	1	1153	421	4943	594	2634	44801	73	6	41	3
24-May-00	361	1513	2	1411	525	2853	677	3066	42111	75	4	50	1
25-May-00	325	1462	2	1381	496	3300	631	2934	41815	79	4	40	1
26-May-00	343	1367	2	1318	484	2978	601	2860	41799	72	4	40	1
27-May-00	384	1478	2	1363	490	2912	662	3097	45048			34	1
28-May-00	370	1401	2	1249	432	2147	638	2788	41735			31	1
29-May-00	334	1239	2	1226	451	2825	565	2646	40467	74	4	40	1
31-May-00	353	1315	2	1270	466	2222	601	2725	40409	71	4		2

01-Jun-00	323	1213	1	1185	434	2620	556	2586	39874	72	7		1
02-Jun-00	317	1220	2	1282	478	3359	555	2724	41777	71	5	38	1
03-Jun-00	357	1355	2	1277	457	3081	627	2811	42789			39	1
04-Jun-00	287	1010	1	941	336	2738	474	2084	36302			38	1
05-Jun-00	342	1294	1	1248	454	2331	590	2730	40302	70	6	40	1
06-Jun-00	361	1312	2	1242	451	2445	603	2698	42084	77	6	38	1
07-Jun-00	362	1374	1	1283	462	2706	635	2807	43434	74	5	48	1
08-Jun-00	320	1207	1	1234	454	2687	553	2585	41102	76	8	43	1
09-Jun-00	361	1396	1	1302	476	2349	641	2868	43383	73	7	40	1
10-Jun-00	323	1268	1	1175	424	3132	578	2609	42972				1
11-Jun-00	282	1092	1	1024	364	3197	502	2186	39914				1
13-Jun-00	346	1341	1	1272	470	2000	633	2816	41997	73	6		2
14-Jun-00	322	1331	1	1258	462	2632	618	2768	42353	70	6	40	1
15-Jun-00	304	1247	1	1214	449	2642	576	2596	40661	72	5	41	1
16-Jun-00	342	1430	1	1335	471	2553	664	2875	45040				1
17-Jun-00	339	1545	1	1413	504	2648	722	3097	45368				1
18-Jun-00	367	1564	1	1427	503	2061	745	3124	45659				1
19-Jun-00	316	1205	1	1227	457	3112	554	2507	40869			43	1
20-Jun-00	328	1254	1	1175	423	1848	590	2486	37988			40	1
21-Jun-00	356	1297	1	1222	439	1776	617	2635	39566	71	7	41	1
22-Jun-00	341	1314	1	1271	460	2180	614	2638	40066			44	1
23-Jun-00	352	1332	1	1283	471	2199	623	2750	41125				1

24-Jun-00	363	1416	1	1325	464	2377	658	2798	42553				1
25-Jun-00	287	1124	1	1041	363	2279	528	2110	35728				1
26-Jun-00	325	1248	1	1198	427	2105	585	2479	38666			37	1
27-Jun-00	332	1277	1	1221	433	1904	601	2533	38716			37	1
28-Jun-00	355	1410	1	1335	471	2241	665	2796	43032	71	6	38	1
29-Jun-00	365	1349	1	1311	471	1741	664	2758	42089			39	1
30-Jun-00	341	1350	1	1335	488	2479	626	2715	41421			40	1
01-Jul-00	406	1561	1	1486	524	2345	715	3055	47414			39	1
02-Jul-00	430	1638	1	1547	546	1695	755	3168	47520			38	1
03-Jul-00	413	1567	1	1500	544	2148	720	3000	47635			39	1
04-Jul-00	379	1458	1	1429	516	3525	653	2881	48470			40	1
05-Jul-00	331	1219	1	1248	463	2587	544	2451	41059	77	4	39	1
06-Jul-00	361	1233	1	1248	449	2203	551	2474	41548				1

B: Manually captured data

Below is data from the database, manual oil samplings was performed and send to the laboratory for analyses. The laboratory results were record and stored on the data base in this form.

Table 10: Manual sampling data for generator transformer for a period of twenty one years

Date	Days to next sample	DP / Furan	Temp °C	Moisture	Acidity	H_2	O_2	N_2	CH_4	CO	CO_2	C_2H_4	C_2H_2
30-Dec-91			52	7		0	3540	57280	52	499	846	21	0
30-Jan-92	31.00		65			23	3469	69609	73	475	665	50	2
04-Aug-92	187.00		49	6	0.01	12	2901	57103	37	488	1356	23	0
23-Feb-93	203.00		56	14	0.02	14.4	6010.38	58003.63	48.89	473.94	1887.55	27.06	0
23-Feb-93	0.00		55	11									
17-Sep-93	206.00			12	0.03	8	4204	55164	27	> 500	1300	22	0
23-Feb-94	159.00		51	24	0.06	9	4752	44320	20	441	2017	21	0
25-Apr-94	61.00		65	12	0.03	7	7753	69295	18	162	236	25	0
29-Aug-94	126.00		48	12	0.04	10	7482	60558	28	>500	3055	26	0
27-Feb-95	182.00			16		15	6826	58501	45	617	2973	58	0
26-Sep-95	211.00		55	11	0.11	14	3324	49009	44	631	3553	58	0
27-Feb-96	154.00			14	0.05	0	8911	47048	3	200	3175	46	0
06-Jun-96	100.50			13		0.1	11424	50625	2	243	586	0.5	0.5
07-Jun-96	1.00					10	8753	64124	48	383	1229	6	0
07-Jun-96	0.00					0.1	5230	54920	34	126	312	2	0.1
07-Jun-96	0.00			14		10	1876	57010	69	256	556	4	0

02-Aug-96	55.50			12	0.05	20	4299	58917	64	445	3305	95	0
09-Oct-96	68.53			11	0.06	20	10701	72301	63	371	2223	81	0
14-Oct-96	4.47			16	0.07	0	5890	58734	74	416	3224	105	0
18-Dec-96	65.00					15	6457	54236	72	556	3339	106	0
19-Mar-97	91.00			14	0.07	30	5621	51954	113	588	4137	178	0
28-Aug-97	162.52		70	12	0.07	31	6582	54288	116	545	4664	361	1
25-Sep-97	27.48		56	12		42	6353	57800	148	645	3053	376	1
03-Oct-97	8.00		65	15	0.07	38	6197	56740	145	650	3525	415	0
09-Oct-97	6.00			15	0.06	28	4754	43364	110	480	4200	347	1
17-Oct-97	8.00		63	15	0.08	23	6959	44712	105	437	4129	322	1
23-Oct-97	6.00		67			28	7513	53629	123	564	3130	365	2
28-Oct-97	5.00		64	13	0.08	24	5104	39089	87	422	3179	256	0
04-Nov-97	7.00		66	15	0.09	33	5929	56595	141	667	3131	402	1
11-Nov-97	7.00		54	30	0.06	19	7220	44583	96	463	2455	285	0
28-Nov-97	17.00		53	12	0.07	16	8341	47808	82	410	3595	248	0
04-Feb-98	68.00		47	49	0.1	8	9808	46992	46	313	2146	151	0
20-Feb-98	16.00		65	16	0.09	19	6043	55917	108	809	3005	356	0
11-Mar-98	19.00		30	8	0.08	0	9814	31696	5	18	299	20	0
20-Mar-98	9.00		48	11	0.07	0	7569	26101	6	46	508	17	0
25-Mar-98	5.46		58	14	0.08	3	5581	21167	6	47	522	13	0
02-Apr-98	7.54		49	16	0.07	5	4461	14904	10	51	589	20	0
24-Apr-98	22.00		50	10	0.07	10	4994	47558	71	542	2472	99	0

04-May-98	10.00		54	11	0.07	0	0	0	0	0	0	0	0
06-May-98	2.72		70	14	0.06	10	10017	31722	23	68	984	40	0
15-May-98	8.28		48	9	0.08	0	0	0	0	0	0	0	0
25-May-98	10.00		49	7	0.04	15	9743	29258	30	85	1038	42	0
01-Jun-98	7.00		48	8		11	8583	26472	24	62	869	36	0
05-Jun-98	4.00		46	9	0.06	0	0	0	0	0	0	0	0
22-Jun-98	17.00		44	9	0.07	26	3992	16690	42	115	643	58	0
25-Jun-98	3.00		43	8	0.04	11	2344	9286	17	48	414	20	0
11-Jul-98	16.00		41	9	0.04	0	0	0	0	0	0	0	0
11-Jul-98	0.00		41	9	0.04	26	2767	12240	38	107	539	46	0
17-Jul-98	6.00		43	7	0.08	13	2407	9442	19	51	293	21	0
27-Jul-98	10.00		41	10	0.07	21	6478	23778	39	94	675	51	0
06-Aug-98	10.00		41	17	0.13	30	3409	13155	43	99	629	94	0
18-Aug-98	12.00		43	8	0.06	0	0	0	0	0	0	0	0
21-Aug-98	3.00		63	11	0.08	32	12304	46358	59	125	1228	93	0
21-Aug-98	0.00		44	12	0.07	0	0	0	0	0	0	0	0
27-Aug-98	6.00		70	8	0.05	34	4192	15608	59	124	749	70	0
08-Sep-98	12.00		50	10	0.09	0	0	0	0	0	0	0	0
11-Sep-98	3.00		54	10	0.05	32	5950	22187	54	105	595	75	0
23-Sep-98	12.00		51	10	0.09	0	0	0	0	0	0	0	0

01-Oct-98	8.00		52	10	0.05	42	2814	12270	59	109	470	57	0
02-Oct-98	1.00		50	13	0.08	83	12339	47611	124	221	1338	129	0
13-Oct-98	11.00		49	12	0.06	34	3371	13394	48	89	441	44	0
20-Oct-98	7.00		50	16	0.06	20	10987	38485	47	76	824	72	0
23-Oct-98	3.00		58	9	0.04	12	6759	66205	87	688	1793	136	0
03-Nov-98	11.00		50	12	0.07	76	3484	15456	106	162	566	97	0
12-Nov-98	9.00		52	16	0.08	0	0	0	0	0	0	0	0
16-Nov-98	4.00		56	16	0.08	69	5947	22401	104	138	720	105	0
01-Dec-98	15.00		43	10	0.07	55	3403	14232	80	101	511	80	0
01-Dec-98	0.00		48	39	0.05	42	3029	12648	56	76	399	52	0
04-Feb-99	65.00		68	19	0.04	96	3803	16757	164	160	708	168	2
17-Feb-99	13.00		60	15	0.01	45	3304	12793	76	87	1297	56	0
18-Feb-99	1.00		87	15	0.15	60	7282	26950	109	111	2304	109	0
02-Mar-99	12.00			17	0.04	45	4860	17510	80	73	484	83	0
14-Mar-99	12.00		68	20	0.13	48	3397	13600	77	73	419	82	0
24-Mar-99	10.00		60	14	0.06	130	3630	15837	222	190	769	187	0
10-Apr-99	17.00		70	12	0.06	66	3559	14335	75	70	1324	70	0
10-Apr-99	0.00		60	8	0.05	168	1922	11037	196	164	770	166	0
21-Apr-99	11.00			10	0.07	122	10211	37073	204	155	1434	220	0
26-Apr-99	5.00			11	0.06	195	2072	12266	237	182	837	195	0
26-Apr-99	0.00		63			88	1960	10307	86	116	567	83	0
26-Apr-99	0.00		65	9	0.04	43	2407	9565	60	54	929	48	0

26-Apr-99	0.00		65	13	0.05	185	3146	15385	243	192	910	193	0
26-Apr-99	0.00		65	13	0.05	30	1757	7280	29	39	257	29	0
26-Apr-99	0.00			12	0.05	91	2093	10774	91	116	566	90	0
06-May-99	10.00		59	11	0.24	16	3078	11875	28	28	1453	111	0
06-May-99	0.00		54	13	0.05	71	3945	16048	99	92	1607	91	0
08-May-99	2.00		56	12	0.06	185	3280	16532	256	203	949	214	0
08-May-99	0.00		59			136	3265	14745	196	162	822	164	0
12-May-99	4.00		49	7	0.06	77	2032	9343	104	75	395	85	0
20-May-99	8.00		69	9	0.04	114	3977	17089	145	134	1870	117	0
31-May-99	11.00		54	11	0.05	112	5887	20207	189	164	916	178	0
31-May-99	0.00		54	54	0.05	179	2058	11850	225	196	655	214	0
31-May-99	0.00		49	9	0.04	67	3827	14446	87	77	1802	79	0
31-May-99	0.00		50	9	0.1	37	4024	15501	52	47	1621	83	0
31-May-99	0.00		50	9	0.06	88	5155	18585	133	117	2720	121	0
03-Jun-99	3.00		61	10	0.05	63	5567	21261	89	80	1970	87	0
03-Jun-99	0.00		51	10	0.07	76	2024	9563	95	67	362	82	0
03-Jun-99	0.00		50	18	0.08	68	1848	8302	86	60	313	73	0
04-Jun-99	1.00		50	9	0.05	0	0	0	0	0	0	0	0

14-Jun-99	10.00		49			1	4647	17179	4	4	1319	58	0
14-Jun-99	0.00		46	7	0.05	92	4533	18911	128	102	676	121	0
15-Jun-99	1.00		48			64	3118	12843	73	70	1528	65	0
29-Jun-99	14.00		57			0	0	0	0	0	0	0	0
29-Jun-99	0.00		48			76	6207	24102	101	92	2211	98	0
29-Jun-99	0.00		53			74	7406	28245	82	79	1531	68	1
30-Jun-99	1.00		48			202	1856	11948	269	172	615	209	0
30-Jun-99	0.00		56			52	3227	13070	76	69	1418	80	0
02-Jul-99	2.00		52	10	0.07	184	1484	10496	240	147	601	193	0
02-Jul-99	0.00		50	10	0.07	176	2011	11597	231	138	598	185	0
05-Jul-99	3.00		51			89	3359	14407	111	99	1855	130	0
07-Jul-99	2.00		50			178	5670	24504	258	190	1060	232	0
07-Jul-99	0.00		50			0	0	0	0	0	0	0	0
13-Jul-99	6.00		50	8	0.06	118	3582	15776	144	129	2013	129	0
13-Jul-99	0.00		50	9	0.06	0	0	0	0	0	0	0	0
15-Jul-99	2.00		50	8	0.05	0	0	0	0	0	0	0	0
15-Jul-99	0.00		50			51	2284	9331	62	59	1208	51	0
20-Jul-99	5.00		50			68	2462	10199	82	81	1618	68	0
08-Sep-99	50.00		50			139	4047	17832	184	177	3595	154	0
08-Sep-99	0.00		50			0	0	0	0	0	0	0	0
08-Sep-99	0.00		60			0	0	0	0	0	0	0	0
08-Sep-99	0.00		52			85	2952	13293	113	100	1586	95	0

08-Sep-99	0.00		63			77	2735	10964	96	89	1844	79	0
09-Sep-99	1.00		50			103	3980	16833	133	122	2551	112	0
09-Sep-99	0.00		40	3									
09-Sep-99	0.00		40			67	1546	7447	84	85	1571	56	0
09-Sep-99	0.00		40	6	0.06	170	1603	10740	220	530	3720	153	0
27-Sep-99	18.00		63	9	0.05	0	3037	10356	2	37	191	1	0
27-Sep-99	0.00		35	6									
27-Sep-99	0.00		56	6	0.1	0	0	0	0	0	0	0	0
27-Sep-99	0.00		35	2									
27-Sep-99	0.00												
11-Oct-99	14.00		64	11	0.05	4	4212	16536	10	52	232	8	0
14-Oct-99	3.61	533											
14-Oct-99	0.00	607											
14-Oct-99	0.00	683											
18-Oct-99	3.39		55	11	0.06	0	3592	13362	2	21	285	6	0
23-Oct-99	5.00		65	13	0.03	8	5826	24376	20	123	556	18	0
25-Oct-99	2.00		58	11	0.12	11	6302	27085	25	138	591	22	0
01-Nov-99	7.00		58	10	0.05	9	3886	20279	22	125	447	17	0
30-Nov-99	29.00		74	15	0.01	13	6499	31050	39	205	844	33	0
06-Dec-99	6.00		65	17	0.06	15	4940	28492	33	192	818	29	0
20-Dec-99	14.00		65	14	0.03	17	5827	33521	45	244	1043	37	0
20-Dec-99	0.00		64	62	0.08	14	6077	32364	36	203	1105	33	0

21-Dec-99	1.00		50	10	0.04	22	1236	20761	53	185	339	47	0
11-Jan-00	21.00		72	15	0.04	18	6116	36258	57	285	1331	52	0
12-Jan-00	1.00		55	12	0.02	16	7249	37670	54	269	1245	54	0
27-Jan-00	15.00		64	10	0.06	37	1654	36590	100	536	2142	74	0
27-Jan-00	0.00		60	11	0.05	17	13817	67780	56	285	1276	47	0
09-Feb-00	13.00		65	15	0.05	22	8266	49884	71	351	1595	65	0
06-Mar-00	26.00		64	14	0.06	20	12942	57763	87	339	2154	91	0
06-Mar-00	0.00		58	15	0.06	37	5970	47102	109	483	2121	93	0
13-Mar-00	7.00		40	8	0.01	39	6369	45680	94	420	1902	79	0
16-Mar-00	3.00		68	16	0.04	44	4072	40955	109	490	2183	94	2
31-Mar-00	15.00		60	10	0.05	54	7031	54693	135	502	2266	124	0
04-Apr-00	4.00		64	13	0.06	63	3776	42133	161	523	2368	147	0
04-Apr-00	0.00		65	13	0.06	33	5759	40503	87	360	1698	86	2
06-Apr-00	2.00		63	14	0.03	56	2904	43515	180	632	2686	146	0
13-Apr-00	7.00		57	10	0.1	44	4388	44267	157	498	2609	182	0
14-Apr-00	1.00		55	12	0.1	16	2956	44045	97	683	4841	112	2
04-May-00	20.00		62	10	0.07	39	10161	52730	185	436	2332	184	0
04-May-00	0.00		61	10	0.05	58	4396	42340	196	609	2337	200	0
11-May-00	7.00		61	11	0.07	85	5001	43352	293	525	2420	272	0
23-May-00	12.00		53	8	0.06	367	2466	42411	1367	642	2991	1237	1

23-May-00	0.00		58	8	0.06	351	3058	41639	1172	573	2715	1108	1
23-May-00	0.00		47	7	0.06	371	2888	41248	1371	626	2919	1271	2
23-May-00	0.00		53	12	0.07	200	4168	44165	699	614	2553	622	1
23-May-00	0.00		60	11	0.06	185	4872	38853	657	448	2125	637	1
23-May-00	0.00		60	9	0.06	184	2847	31725	636	442	2014	584	1
30-May-00	7.00		50	7	0.05	362	2762	40740	1395	627	2872	1309	2
30-May-00	0.00		40	2	0.05	407	2993	45685	1549	744	4450	1789	1
30-May-00	0.00		41	6	0.07	323	4943	44801	1237	595	2634	1153	1
30-May-00	0.00		39			440	2143	44951	1624	758	4561	1815	1
30-May-00	0.00		51	7	0.08	296	5333	43747	1133	574	2257	1073	1
30-May-00	0.00		51	7	0.06	349	3140	40518	1342	611	2871	1263	2
30-May-00	0.00		50	4	0.06	361	2853	42111	1513	677	3066	1411	2
05-Jun-00	6.00		47			419	2995	47118	1610	736	3312	1427	2
13-Jun-00	8.00		31			370	2147	41735	1401	638	2788	1249	2
27-Jun-00	14.00		39	3	0.07	442	2342	48556	1674	739	3275	1600	1
27-Jun-00	0.00		40	4	0.06	325	3300	41815	1462	631	2934	1381	2
27-Jun-00	0.00		34			384	2912	45048	1478	662	3097	1363	2
27-Jun-00	0.00			4	0.06	353	2222	40709	1315	601	2725	1270	2

28-Jun-00	1.00		40	4	0.06	343	2978	41799	1376	601	2860	1318	2
28-Jun-00	0.00		40	4	0.05	334	2825	40467	1239	565	2646	1226	2
28-Jun-00	0.00		43	8	0.06	320	2687	41102	1207	553	2586	1234	1
29-Jun-00	1.00		38	5	0.06	356	3040	43199	1281	589	2745	1267	2
29-Jun-00	0.00		38	6	0.06	361	2445	42084	1312	603	2698	1242	2
29-Jun-00	0.00		48	5	0.05	362	2106	42433	1374	635	2807	1283	1
29-Jun-00	0.00		38	5	0.04	317	3359	41777	1220	555	2724	1282	2
03-Jul-00	4.00		40	6	0.06	342	2331	40302	1294	590	2730	1248	1
03-Jul-00	0.00		39			357	3081	42798	1355	627	2811	1277	2
03-Jul-00	0.00		38			288	2738	36302	1010	474	2084	941	1
10-Jul-00	7.00					282	3197	39914	1092	502	2186	1024	1
10-Jul-00	0.00					323	3172	42972	1268	578	2609	1175	1
10-Jul-00	0.00		36	7	0.06	323	2620	39874	1213	556	2586	1185	1
11-Jul-00	1.00		42	6	0.04	346	2000	41997	1341	633	2816	1277	1
11-Jul-00	0.00		41	5	0.06	304	2642	40661	1247	576	2596	1214	1
11-Jul-00	0.00		40	6	0.06	322	2632	42353	1331	618	2768	1258	1
13-Jul-00	2.00		43			352	2199	41125	1332	623	2750	1283	1
13-Jul-00	0.00		43			316	3112	40869	1205	554	2507	1227	1
13-Jul-00	0.00		38	6	0.06	355	2241	43032	1410	665	2796	1335	1
13-Jul-00	0.00		40			367	2061	45659	1564	745	3124	1426	1
13-Jul-00	0.00		41	7	0.06	356	1776	39566	1297	617	2635	1222	1
13-Jul-00	0.00		44			341	2180	40066	1314	614	2638	1271	1

14-Jul-00	1.00					362	2377	42552	1416	658	2798	1325	1
14-Jul-00	0.00		45			339	2648	45368	1545	722	3097	1413	1
14-Jul-00	0.00		37			325	2105	38666	1248	585	2479	1198	1
14-Jul-00	0.00		37			332	1904	38716	1277	601	2533	1221	1
14-Jul-00	0.00		39			287	2279	35728	1124	528	2110	1041	1
14-Jul-00	0.00		40			342	2553	45040	1430	664	2875	1335	1
14-Jul-00	0.00		40			327	1848	37988	1254	590	2486	1175	1
14-Jul-00	0.00		39			406	2344	47414	1561	715	3055	1486	1
14-Jul-00	0.00		40	7	0.04	361	2349	43383	1396	641	2868	1302	1
15-Jul-00	1.00		40			380	2471	43809	1340	601	2632	1335	1
15-Jul-00	0.00		39			365	1741	42089	1349	634	2758	1311	1
15-Jul-00	0.00			7	0.07	308	3450	43050	1177	537	2446	1190	1
15-Jul-00	0.00					413	2148	47635	1567	720	3000	1500	1
15-Jul-00	0.00		38			368	3036	47060	1516	702	3042	1466	1
15-Jul-00	0.00		38			430	1695	47520	1638	755	3169	1547	1
15-Jul-00	0.00		42			341	2479	41421	1350	625	2715	1335	1
15-Jul-00	0.00		38			361	2204	41548	1234	552	2474	1248	1
15-Jul-00	0.00		39	4	0.04	331	2587	41059	1219	544	2451	1248	1
15-Jul-00	0.00		40			379	3525	48470	1458	653	2881	1429	1
27-Sep-00	74.38	484											
10-Nov-04	1505.13		51	5		16	1625	34323	54	138	420	12	0
11-Nov-04	0.93		51	4	0.01	8	2342	22830	28	80	309	4	0

22-Dec-04	41.16		55	10	0.01	11	6871	26499	22	63	463	4	2
22-Dec-04	0.00		55	9	0.01								
24-Dec-04	1.73		55			18	807	42598	70	189	584	13	0
03-Jan-05	10.21		51	5		16	1625	34323	54	138	420	12	0
05-Jan-05	2.09		55	6	0.01	12	1764	32337	50	145	589	7	0
10-Mar-05	64.07		52			7	1950	25416	34	100	455	5	0
26-Apr-05	46.69		48	7	0.01	10	2195	38756	61	173	848	10	0
06-Jan-06	255.03		54	4		21	2262	86473	96	238	1116	17	0
06-Jan-06	0.06		54		0.01								
27-Jun-06	172.34		47	3	0.01	16	2537	61877	74	188	1388	22	0
15-Jul-06	17.80												
13-Nov-06	120.86		69	4	0.01								
10-Jan-07	57.95		53	5	0.01	18	2792	69555	68	164	1490	8	0
10-Jul-07	181.35		24			107	17481	102225	88	183	2454	39	33
10-Jul-07	0.00		48	3	0.03	15	2352	58465	79	193	2436	29	0
25-Apr-08	289.73		50	6		13	609	59134	104	213	2108	28	0
03-Dec-08	221.88				0.01								
16-Sep-09	287.04			7	0.01	31	528	55057	108	184	2488	31	0
16-Sep-09	0.03	<0.001			0.01								
16-Sep-09	0.03		62			20	355	48019	97	181	2041	29	0
16-Sep-09	0.00		36			23	331	47985	97	179	2031	30	0
16-Feb-10	152.95												

22-Jul-10	155.89			4	0.01	11	4482	70939	112	188	2837	36	0
17-May-11	298.98			1	0.01	5	437	41480	142	175	2290	49	0
29-Sep-11	135.17	<0.001			0.01								
16-Mar-12	169.09			4									
17-Mar-12	1.02			6									
22-Mar-12	5.01			4		0	3953	16709	3	28	320	2	0
22-Mar-12	0.00			4		0	3226	18951	3	26	260	2	0
28-Mar-12	6.07			1		0	3199	23802	6	73	618	4	0
28-Mar-12	0.00			3		0	2724	17539	5	71	645	4	0
25-Apr-12	27.98			4		2	6678	33642	8	115	957	6	0

C: Arrhenius calculation

Using the Arrhenius equation from section 2.4 DP Prediction:

$$\frac{1}{DP_t} - \frac{1}{DP_o} = A \cdot e^{\left(\frac{-E}{RT}\right)} \cdot t$$

$$K = A \cdot e^{\left(\frac{-E}{RT}\right)}$$

$$\frac{1}{DP_t} - \frac{1}{DP_o} = K \cdot t$$

The data marked in green, was selected from the data in Appendix B as the best data for a three year period.

Table 11: Arrhenius calculation for DP using three years data projection

Sample date (best data)	Projected date (since 1986 installation year)	Period take to the next sample (days)	Period take to the next sample (hours)	Temperature (°C)	K	DP_t
25-Sep-97	25-Sep-86	0	0	56	4.84093E-09	950
03-Oct-97	03-Oct-86	8	192	65	1.28144E-08	947.7847
17-Oct-97	17-Oct-86	14	336	63	1.03683E-08	944.6656
23-Oct-97	23-Oct-86	6	144	67	1.57982E-08	942.6398
28-Oct-97	28-Oct-86	5	120	64	1.15303E-08	941.4119
04-Nov-97	04-Nov-86	7	168	66	1.42327E-08	939.2975
11-Nov-97	11-Nov-86	7	168	54	3.87097E-09	938.7241
28-Nov-97	28-Nov-86	17	408	53	3.45795E-09	937.4825
04-Feb-98	04-Feb-87	68	1632	47	1.73132E-09	935.0058
20-Feb-98	20-Feb-87	16	384	65	1.28144E-08	930.7236
11-Mar-98	11-Mar-87	19	456	30	2.10143E-10	930.6406
20-Mar-98	20-Mar-87	9	216	48	1.9464E-09	930.2767
25-Mar-98	25-Mar-87	5.45625	130.95	58	6.03761E-09	929.5929
02-Apr-98	02-Apr-87	7.54375	181.05	49	2.1866E-09	929.251
24-Apr-98	24-Apr-87	22	528	50	2.45467E-09	928.1331
04-May-98	04-May-87	10	240	54	3.87097E-09	927.3335
06-May-98	06-May-87	2.72152778	65.316667	70	2.15271E-08	926.126
15-May-98	15-May-87	8.27847222	198.68333	48	1.9464E-09	925.7944
25-May-98	25-May-87	10	240	49	2.1866E-09	925.3448
01-Jun-98	01-Jun-87	7	168	48	1.9464E-09	925.0649
05-Jun-98	05-Jun-87	4	96	46	1.53888E-09	924.9385
22-Jun-98	22-Jun-87	17	408	44	1.21309E-09	924.5153
25-Jun-98	25-Jun-87	3	72	43	1.07584E-09	924.4491
11-Jul-98	11-Jul-87	16	384	41	8.44221E-10	924.1721
11-Jul-98	11-Jul-87	0	0	41	8.44221E-10	924.1721
17-Jul-98	17-Jul-87	6	144	43	1.07584E-09	924.0398
27-Jul-98	27-Jul-87	10	240	41	8.44221E-10	923.8668
06-Aug-98	06-Aug-87	10	240	41	8.44221E-10	923.6939
18-Aug-98	18-Aug-87	12	288	43	1.07584E-09	923.4296
21-Aug-98	21-Aug-87	3	72	63	1.03683E-08	922.7935

21-Aug-98	21-Aug-87	0.5	12	44	1.21309E-09	922.7811
27-Aug-98	27-Aug-87	5.5	132	70	2.15271E-08	920.3678
08-Sep-98	08-Sep-87	12	288	50	2.45467E-09	919.7693
11-Sep-98	11-Sep-87	3	72	54	3.87097E-09	919.5336
23-Sep-98	23-Sep-87	12	288	51	2.75365E-09	918.8635
01-Oct-98	01-Oct-87	8	192	52	3.08685E-09	918.3634
02-Oct-98	02-Oct-87	1	24	50	2.45467E-09	918.3137
13-Oct-98	13-Oct-87	11	264	49	2.1866E-09	917.8272
20-Oct-98	20-Oct-87	7	168	50	2.45467E-09	917.4799
23-Oct-98	23-Oct-87	3	72	58	6.03761E-09	917.1141
03-Nov-98	03-Nov-87	11	264	50	2.45467E-09	916.5694
12-Nov-98	12-Nov-87	9	216	52	3.08685E-09	916.0096
16-Nov-98	16-Nov-87	4	96	56	4.84093E-09	915.6198
01-Dec-98	01-Dec-87	15	360	43	1.07584E-09	915.2952
01-Dec-98	01-Dec-87	0.5	12	48	1.9464E-09	915.2757
04-Feb-99	04-Feb-88	64.5	1548	68	1.75252E-08	893.0995
17-Feb-99	17-Feb-88	13	312	60	7.51014E-09	891.2345
18-Feb-99	18-Feb-88	1	24	87	1.12758E-07	889.0901
14-Mar-99	13-Mar-88	24	576	68	1.75252E-08	881.1816
24-Mar-99	23-Mar-88	10	240	60	7.51014E-09	879.7842
10-Apr-99	09-Apr-88	17	408	70	2.15271E-08	873.0381
10-Apr-99	09-Apr-88	0	0	60	7.51014E-09	873.0381
26-Apr-99	25-Apr-88	16.125	387	63	1.03683E-08	869.9904
26-Apr-99	25-Apr-88	0.125	3	65	1.28144E-08	869.9613
26-Apr-99	25-Apr-88	0.125	3	65	1.28144E-08	869.9322
26-Apr-99	25-Apr-88	0.375	9	65	1.28144E-08	869.845
06-May-99	05-May-88	9.25	222	59	6.73596E-09	868.715
06-May-99	05-May-88	0.5	12	54	3.87097E-09	868.6799
08-May-99	07-May-88	1.5	36	56	4.84093E-09	868.5484
08-May-99	07-May-88	0.5	12	59	6.73596E-09	868.4875
12-May-99	11-May-88	3.5	84	49	2.1866E-09	868.349
20-May-99	19-May-88	8	192	69	1.94292E-08	865.5452
31-May-99	30-May-88	11	264	54	3.87097E-09	864.7803
31-May-99	30-May-88	0.2	4.8	54	3.87097E-09	864.7664
31-May-99	30-May-88	0.2	4.8	49	2.1866E-09	864.7585
31-May-99	30-May-88	0.2	4.8	50	2.45467E-09	864.7497
31-May-99	30-May-88	0.2	4.8	50	2.45467E-09	864.7409
03-Jun-99	02-Jun-88	2.2	52.8	61	8.36786E-09	864.4107
03-Jun-99	02-Jun-88	0.33333333	8	51	2.75365E-09	864.3942
03-Jun-99	02-Jun-88	0.33333333	8	50	2.45467E-09	864.3795
04-Jun-99	03-Jun-88	0.33333333	8	50	2.45467E-09	864.3648
14-Jun-99	13-Jun-88	10	240	49	2.1866E-09	863.9729
14-Jun-99	13-Jun-88	0.5	12	46	1.53888E-09	863.9592
15-Jun-99	14-Jun-88	0.5	12	48	1.9464E-09	863.9417
29-Jun-99	28-Jun-88	14	336	57	5.40807E-09	862.5876
29-Jun-99	28-Jun-88	0.33333333	8	48	1.9464E-09	862.576
29-Jun-99	28-Jun-88	0.33333333	8	53	3.45795E-09	862.5554
30-Jun-99	29-Jun-88	0.33333333	8	48	1.9464E-09	862.5438
30-Jun-99	29-Jun-88	0.5	12	56	4.84093E-09	862.5006
02-Jul-99	01-Jul-88	1.5	36	52	3.08685E-09	862.4179
02-Jul-99	01-Jul-88	0.5	12	50	2.45467E-09	862.396
05-Jul-99	04-Jul-88	2.5	60	51	2.75365E-09	862.2732

07-Jul-99	06-Jul-88	2	48	50	2.45467E-09	862.1856
07-Jul-99	06-Jul-88	0.5	12	50	2.45467E-09	862.1637
13-Jul-99	12-Jul-88	5.5	132	50	2.45467E-09	861.9229
13-Jul-99	12-Jul-88	0.5	12	50	2.45467E-09	861.901
15-Jul-99	14-Jul-88	1.5	36	50	2.45467E-09	861.8354
15-Jul-99	14-Jul-88	0.5	12	50	2.45467E-09	861.8135
20-Jul-99	19-Jul-88	4.5	108	50	2.45467E-09	861.6166
08-Sep-99	07-Sep-88	50	1200	50	2.45467E-09	859.4354
08-Sep-99	07-Sep-88	0.2	4.8	50	2.45467E-09	859.4267
08-Sep-99	07-Sep-88	0.2	4.8	60	7.51014E-09	859.4001
08-Sep-99	07-Sep-88	0.2	4.8	52	3.08685E-09	859.3891
08-Sep-99	07-Sep-88	0.2	4.8	63	1.03683E-08	859.3524
09-Sep-99	08-Sep-88	0.2	4.8	50	2.45467E-09	859.3437
09-Sep-99	08-Sep-88	0.25	6	40	7.46976E-10	859.3404
09-Sep-99	08-Sep-88	0.25	6	40	7.46976E-10	859.3371
09-Sep-99	08-Sep-88	0.25	6	40	7.46976E-10	859.3338
27-Sep-99	26-Sep-88	17.25	414	63	1.03683E-08	856.1756
27-Sep-99	26-Sep-88	0.25	6	35	4.00296E-10	856.1738
27-Sep-99	26-Sep-88	0.25	6	56	4.84093E-09	856.1526
27-Sep-99	26-Sep-88	0.25	6	35	4.00296E-10	856.1508
11-Oct-99	10-Oct-88	13.25	318	64	1.15303E-08	853.4716
18-Oct-99	17-Oct-88	7	168	55	4.33035E-09	852.942
23-Oct-99	22-Oct-88	5	120	65	1.28144E-08	851.8247
25-Oct-99	24-Oct-88	2	48	58	6.03761E-09	851.6145
01-Nov-99	31-Oct-88	7	168	58	6.03761E-09	850.8795
30-Nov-99	29-Nov-88	29	696	74	3.22507E-08	834.9329
06-Dec-99	05-Dec-88	6	144	65	1.28144E-08	833.6485
20-Dec-99	19-Dec-88	14	336	65	1.28144E-08	830.6669
20-Dec-99	19-Dec-88	0.5	12	64	1.15303E-08	830.5715
21-Dec-99	20-Dec-88	0.5	12	50	2.45467E-09	830.5512
11-Jan-00	10-Jan-89	21	504	72	2.63797E-08	821.48
12-Jan-00	11-Jan-89	1	24	55	4.33035E-09	821.4098
27-Jan-00	26-Jan-89	15	360	64	1.15303E-08	818.6187
27-Jan-00	26-Jan-89	0.5	12	60	7.51014E-09	818.5583
09-Feb-00	08-Feb-89	12.5	300	65	1.28144E-08	815.9905
06-Mar-00	06-Mar-89	26	624	64	1.15303E-08	811.2278
06-Mar-00	06-Mar-89	0.5	12	58	6.03761E-09	811.1802
13-Mar-00	13-Mar-89	6.5	156	40	7.46976E-10	811.1035
16-Mar-00	16-Mar-89	3	72	68	1.75252E-08	810.2742
31-Mar-00	31-Mar-89	15	360	60	7.51014E-09	808.503
04-Apr-00	04-Apr-89	4	96	64	1.15303E-08	807.7801
04-Apr-00	04-Apr-89	0.5	12	65	1.28144E-08	807.6798
06-Apr-00	06-Apr-89	1.5	36	63	1.03683E-08	807.4364
13-Apr-00	13-Apr-89	7	168	57	5.40807E-09	806.8445
14-Apr-00	14-Apr-89	1	24	55	4.33035E-09	806.7768
04-May-00	04-May-89	20	480	62	9.31751E-09	803.8762
04-May-00	04-May-89	0.5	12	61	8.36786E-09	803.8114
11-May-00	11-May-89	6.5	156	61	8.36786E-09	802.9688
23-May-00	23-May-89	12	288	53	3.45795E-09	802.3272
23-May-00	23-May-89	0.16666667	4	58	6.03761E-09	802.3117
23-May-00	23-May-89	0.16666667	4	47	1.73132E-09	802.3072
23-May-00	23-May-89	0.16666667	4	53	3.45795E-09	802.2983

23-May-00	23-May-89	0.16666667	4	60	7.51014E-09	802.279
23-May-00	23-May-89	0.16666667	4	60	7.51014E-09	802.2596
30-May-00	30-May-89	6.16666667	148	50	2.45467E-09	802.0259
30-May-00	30-May-89	0.14284722	3.4283333	40	7.46976E-10	802.0242
30-May-00	30-May-89	0.14298611	3.4316667	41	8.44221E-10	802.0224
30-May-00	30-May-89	0.14284722	3.4283333	39	6.60414E-10	802.0209
30-May-00	30-May-89	0.14284722	3.4283333	51	2.75365E-09	802.0148
30-May-00	30-May-89	0.14284722	3.4283333	51	2.75365E-09	802.0088
30-May-00	30-May-89	0.14284722	3.4283333	50	2.45467E-09	802.0034
05-Jun-00	05-Jun-89	5.14277778	123.42667	47	1.73132E-09	801.8659
25-Sep-97	25-Sep-89	112	2688	56	4.84093E-09	793.5855
03-Oct-97	03-Oct-89	8	192	65	1.28144E-08	792.039
17-Oct-97	17-Oct-89	14	336	63	1.03683E-08	789.8596
23-Oct-97	23-Oct-89	6	144	67	1.57982E-08	788.4428
28-Oct-97	28-Oct-89	5	120	64	1.15303E-08	787.5837
04-Nov-97	04-Nov-89	7	168	66	1.42327E-08	786.1033
11-Nov-97	11-Nov-89	7	168	54	3.87097E-09	785.7016
28-Nov-97	28-Nov-89	17	408	53	3.45795E-09	784.8316
04-Feb-98	04-Feb-90	68	1632	47	1.73132E-09	783.0951
20-Feb-98	20-Feb-90	16	384	65	1.28144E-08	780.0891
11-Mar-98	11-Mar-90	19	456	30	2.10143E-10	780.0308
20-Mar-98	20-Mar-90	9	216	48	1.9464E-09	779.775
25-Mar-98	25-Mar-90	5.45625	130.95	58	6.03761E-09	779.2946
02-Apr-98	02-Apr-90	7.54375	181.05	49	2.1866E-09	779.0542
24-Apr-98	24-Apr-90	22	528	50	2.45467E-09	778.2684
04-May-98	04-May-90	10	240	54	3.87097E-09	777.7061
06-May-98	06-May-90	2.72152778	65.316667	70	2.15271E-08	776.8566
15-May-98	15-May-90	8.27847222	198.68333	48	1.9464E-09	776.6233
25-May-98	25-May-90	10	240	49	2.1866E-09	776.3069
01-Jun-98	01-Jun-90	7	168	48	1.9464E-09	776.1099
05-Jun-98	05-Jun-90	4	96	46	1.53888E-09	776.0209
22-Jun-98	22-Jun-90	17	408	44	1.21309E-09	775.723
25-Jun-98	25-Jun-90	3	72	43	1.07584E-09	775.6764
11-Jul-98	11-Jul-90	16	384	41	8.44221E-10	775.4814
11-Jul-98	11-Jul-90	0.5	12	41	8.44221E-10	775.4753
17-Jul-98	17-Jul-90	5.5	132	43	1.07584E-09	775.3899
27-Jul-98	27-Jul-90	10	240	41	8.44221E-10	775.2681
06-Aug-98	06-Aug-90	10	240	41	8.44221E-10	775.1463
18-Aug-98	18-Aug-90	12	288	43	1.07584E-09	774.9602
21-Aug-98	21-Aug-90	3	72	63	1.03683E-08	774.5121
21-Aug-98	21-Aug-90	0.5	12	44	1.21309E-09	774.5034
27-Aug-98	27-Aug-90	5.5	132	70	2.15271E-08	772.8026
08-Sep-98	08-Sep-90	12	288	50	2.45467E-09	772.3806
11-Sep-98	11-Sep-90	3	72	54	3.87097E-09	772.2144
23-Sep-98	23-Sep-90	12	288	51	2.75365E-09	771.7418
01-Oct-98	01-Oct-90	8	192	52	3.08685E-09	771.3889
02-Oct-98	02-Oct-90	1	24	50	2.45467E-09	771.3539
13-Oct-98	13-Oct-90	11	264	49	2.1866E-09	771.0106
20-Oct-98	20-Oct-90	7	168	50	2.45467E-09	770.7655
23-Oct-98	23-Oct-90	3	72	58	6.03761E-09	770.5073
03-Nov-98	03-Nov-90	11	264	50	2.45467E-09	770.1228
12-Nov-98	12-Nov-90	9	216	52	3.08685E-09	769.7276

16-Nov-98	16-Nov-90	4	96	56	4.84093E-09	769.4523
01-Dec-98	01-Dec-90	15	360	43	1.07584E-09	769.2231
01-Dec-98	01-Dec-90	0.5	12	48	1.9464E-09	769.2093
04-Feb-99	04-Feb-91	64.5	1548	68	1.75252E-08	753.4856
17-Feb-99	17-Feb-91	13	312	60	7.51014E-09	752.1576
18-Feb-99	18-Feb-91	1	24	87	1.12758E-07	750.6297
14-Mar-99	14-Mar-91	24	576	68	1.75252E-08	744.9848
24-Mar-99	24-Mar-91	10	240	60	7.51014E-09	743.9858
10-Apr-99	10-Apr-91	17	408	70	2.15271E-08	739.1558
10-Apr-99	10-Apr-91	0.5	12	60	7.51014E-09	739.1066
26-Apr-99	26-Apr-91	15.625	375	63	1.03683E-08	736.9887
26-Apr-99	26-Apr-91	0.125	3	65	1.28144E-08	736.9678
26-Apr-99	26-Apr-91	0.125	3	65	1.28144E-08	736.9469
26-Apr-99	26-Apr-91	0.375	9	65	1.28144E-08	736.8843
06-May-99	06-May-91	9.25	222	59	6.73596E-09	736.0732
06-May-99	06-May-91	0.5	12	54	3.87097E-09	736.048
08-May-99	08-May-91	1.5	36	56	4.84093E-09	735.9536
08-May-99	08-May-91	0.5	12	59	6.73596E-09	735.9098
12-May-99	12-May-91	3.5	84	49	2.1866E-09	735.8104
20-May-99	20-May-91	8	192	69	1.94292E-08	733.7962
31-May-99	31-May-91	11	264	54	3.87097E-09	733.2463
31-May-99	31-May-91	0.2	4.8	54	3.87097E-09	733.2364
31-May-99	31-May-91	0.2	4.8	49	2.1866E-09	733.2307
31-May-99	31-May-91	0.2	4.8	50	2.45467E-09	733.2244
31-May-99	31-May-91	0.2	4.8	50	2.45467E-09	733.218
03-Jun-99	03-Jun-91	2.2	52.8	61	8.36786E-09	732.9806
03-Jun-99	03-Jun-91	0.33333333	8	51	2.75365E-09	732.9688
03-Jun-99	03-Jun-91	0.33333333	8	50	2.45467E-09	732.9582
04-Jun-99	04-Jun-91	0.33333333	8	50	2.45467E-09	732.9477
14-Jun-99	14-Jun-91	10	240	49	2.1866E-09	732.6658
14-Jun-99	14-Jun-91	0.5	12	46	1.53888E-09	732.6559
15-Jun-99	15-Jun-91	0.5	12	48	1.9464E-09	732.6434
29-Jun-99	29-Jun-91	14	336	57	5.40807E-09	731.6693
29-Jun-99	29-Jun-91	0.33333333	8	48	1.9464E-09	731.661
29-Jun-99	29-Jun-91	0.33333333	8	53	3.45795E-09	731.6462
30-Jun-99	30-Jun-91	0.33333333	8	48	1.9464E-09	731.6379
30-Jun-99	30-Jun-91	0.5	12	56	4.84093E-09	731.6068
02-Jul-99	02-Jul-91	1.5	36	52	3.08685E-09	731.5473
02-Jul-99	02-Jul-91	0.5	12	50	2.45467E-09	731.5315
05-Jul-99	05-Jul-91	2.5	60	51	2.75365E-09	731.4431
07-Jul-99	07-Jul-91	2	48	50	2.45467E-09	731.3801
07-Jul-99	07-Jul-91	0.5	12	50	2.45467E-09	731.3643
13-Jul-99	13-Jul-91	5.5	132	50	2.45467E-09	731.1911
13-Jul-99	13-Jul-91	0.5	12	50	2.45467E-09	731.1753
15-Jul-99	15-Jul-91	1.5	36	50	2.45467E-09	731.1281
15-Jul-99	15-Jul-91	0.5	12	50	2.45467E-09	731.1123
20-Jul-99	20-Jul-91	4.5	108	50	2.45467E-09	730.9706
08-Sep-99	08-Sep-91	50	1200	50	2.45467E-09	729.4001
08-Sep-99	08-Sep-91	0.2	4.8	50	2.45467E-09	729.3939
08-Sep-99	08-Sep-91	0.2	4.8	60	7.51014E-09	729.3747
08-Sep-99	08-Sep-91	0.2	4.8	52	3.08685E-09	729.3668
08-Sep-99	08-Sep-91	0.2	4.8	63	1.03683E-08	729.3403

09-Sep-99	09-Sep-91	0.2	4.8	50	2.45467E-09	729.3341
09-Sep-99	09-Sep-91	0.25	6	40	7.46976E-10	729.3317
09-Sep-99	09-Sep-91	0.25	6	40	7.46976E-10	729.3293
09-Sep-99	09-Sep-91	0.25	6	40	7.46976E-10	729.3269
27-Sep-99	27-Sep-91	17.25	414	63	1.03683E-08	727.0508
27-Sep-99	27-Sep-91	0.25	6	35	4.00296E-10	727.0495
27-Sep-99	27-Sep-91	0.25	6	56	4.84093E-09	727.0342
27-Sep-99	27-Sep-91	0.25	6	35	4.00296E-10	727.0329
11-Oct-99	11-Oct-91	13.25	318	64	1.15303E-08	725.1
18-Oct-99	18-Oct-91	7	168	55	4.33035E-09	724.7177
23-Oct-99	23-Oct-91	5	120	65	1.28144E-08	723.9109
25-Oct-99	25-Oct-91	2	48	58	6.03761E-09	723.7591
01-Nov-99	01-Nov-91	7	168	58	6.03761E-09	723.2281
30-Nov-99	30-Nov-91	29	696	74	3.22507E-08	711.6749
06-Dec-99	06-Dec-91	6	144	65	1.28144E-08	710.7415
20-Dec-99	20-Dec-91	14	336	65	1.28144E-08	708.5731
20-Dec-99	20-Dec-91	0.5	12	64	1.15303E-08	708.5037
21-Dec-99	21-Dec-91	0.5	12	50	2.45467E-09	708.4889
11-Jan-00	11-Jan-92	21	504	72	2.63797E-08	701.8774
12-Jan-00	12-Jan-92	1	24	55	4.33035E-09	701.8262
27-Jan-00	27-Jan-92	15	360	64	1.15303E-08	699.7876
27-Jan-00	27-Jan-92	0.5	12	60	7.51014E-09	699.7435
09-Feb-00	09-Feb-92	12.5	300	65	1.28144E-08	697.8662
06-Mar-00	06-Mar-92	26	624	64	1.15303E-08	694.3797
06-Mar-00	06-Mar-92	0.5	12	58	6.03761E-09	694.3447
13-Mar-00	13-Mar-92	6.5	156	40	7.46976E-10	694.2886
16-Mar-00	16-Mar-92	3	72	68	1.75252E-08	693.6808
31-Mar-00	31-Mar-92	15	360	60	7.51014E-09	692.3823
04-Apr-00	04-Apr-92	4	96	64	1.15303E-08	691.8521
04-Apr-00	04-Apr-92	0.5	12	65	1.28144E-08	691.7785
06-Apr-00	06-Apr-92	1.5	36	63	1.03683E-08	691.5999
13-Apr-00	13-Apr-92	7	168	57	5.40807E-09	691.1656
14-Apr-00	14-Apr-92	1	24	55	4.33035E-09	691.1159
04-May-00	04-May-92	20	480	62	9.31751E-09	688.9863
04-May-00	04-May-92	0.5	12	61	8.36786E-09	688.9387
11-May-00	11-May-92	6.5	156	61	8.36786E-09	688.3196
23-May-00	23-May-92	12	288	53	3.45795E-09	687.8481
23-May-00	23-May-92	0.16666667	4	58	6.03761E-09	687.8367
23-May-00	23-May-92	0.16666667	4	47	1.73132E-09	687.8334
23-May-00	23-May-92	0.16666667	4	53	3.45795E-09	687.8269
23-May-00	23-May-92	0.16666667	4	60	7.51014E-09	687.8127
23-May-00	23-May-92	0.16666667	4	60	7.51014E-09	687.7985
30-May-00	30-May-92	6.16666667	148	50	2.45467E-09	687.6266
30-May-00	30-May-92	0.14284722	3.4283333	40	7.46976E-10	687.6254
30-May-00	30-May-92	0.14298611	3.4316667	41	8.44221E-10	687.6241
30-May-00	30-May-92	0.14284722	3.4283333	39	6.60414E-10	687.623
30-May-00	30-May-92	0.14284722	3.4283333	51	2.75365E-09	687.6185
30-May-00	30-May-92	0.14284722	3.4283333	51	2.75365E-09	687.6141
30-May-00	30-May-92	0.14284722	3.4283333	50	2.45467E-09	687.6101
05-Jun-00	05-Jun-92	5.14277778	123.42667	47	1.73132E-09	687.5091
25-Sep-97	24-Sep-92	111	2664	56	4.84093E-09	681.467
03-Oct-97	02-Oct-92	8	192	65	1.28144E-08	680.3263

17-Oct-97	16-Oct-92	14	336	63	1.03683E-08	678.7177
23-Oct-97	22-Oct-92	6	144	67	1.57982E-08	677.6713
28-Oct-97	27-Oct-92	5	120	64	1.15303E-08	677.0365
04-Nov-97	03-Nov-92	7	168	66	1.42327E-08	675.9422
11-Nov-97	10-Nov-92	7	168	54	3.87097E-09	675.6452
28-Nov-97	27-Nov-92	17	408	53	3.45795E-09	675.0018
04-Feb-98	03-Feb-93	68	1632	47	1.73132E-09	673.7169
20-Feb-98	19-Feb-93	16	384	65	1.28144E-08	671.4908
11-Mar-98	10-Mar-93	19	456	30	2.10143E-10	671.4476
20-Mar-98	19-Mar-93	9	216	48	1.9464E-09	671.2581
25-Mar-98	24-Mar-93	5.45625	130.95	58	6.03761E-09	670.902
02-Apr-98	01-Apr-93	7.54375	181.05	49	2.1866E-09	670.7239
24-Apr-98	23-Apr-93	22	528	50	2.45467E-09	670.1413
04-May-98	03-May-93	10	240	54	3.87097E-09	669.7243
06-May-98	05-May-93	2.72152778	65.316667	70	2.15271E-08	669.0943
15-May-98	14-May-93	8.27847222	198.68333	48	1.9464E-09	668.9212
25-May-98	24-May-93	10	240	49	2.1866E-09	668.6865
01-Jun-98	31-May-93	7	168	48	1.9464E-09	668.5403
05-Jun-98	04-Jun-93	4	96	46	1.53888E-09	668.4743
22-Jun-98	21-Jun-93	17	408	44	1.21309E-09	668.2532
25-Jun-98	24-Jun-93	3	72	43	1.07584E-09	668.2186
11-Jul-98	10-Jul-93	16	384	41	8.44221E-10	668.0738
11-Jul-98	10-Jul-93	0.5	12	41	8.44221E-10	668.0693
17-Jul-98	16-Jul-93	5.5	132	43	1.07584E-09	668.006
27-Jul-98	26-Jul-93	10	240	41	8.44221E-10	667.9156
06-Aug-98	05-Aug-93	10	240	41	8.44221E-10	667.8252
18-Aug-98	17-Aug-93	12	288	43	1.07584E-09	667.687
21-Aug-98	20-Aug-93	3	72	63	1.03683E-08	667.3544
21-Aug-98	20-Aug-93	0.5	12	44	1.21309E-09	667.3479
27-Aug-98	26-Aug-93	5.5	132	70	2.15271E-08	666.0848
08-Sep-98	07-Sep-93	12	288	50	2.45467E-09	665.7713
11-Sep-98	10-Sep-93	3	72	54	3.87097E-09	665.6478
23-Sep-98	22-Sep-93	12	288	51	2.75365E-09	665.2966
01-Oct-98	30-Sep-93	8	192	52	3.08685E-09	665.0343
02-Oct-98	01-Oct-93	1	24	50	2.45467E-09	665.0083
13-Oct-98	12-Oct-93	11	264	49	2.1866E-09	664.7531
20-Oct-98	19-Oct-93	7	168	50	2.45467E-09	664.5709
23-Oct-98	22-Oct-93	3	72	58	6.03761E-09	664.379
03-Nov-98	02-Nov-93	11	264	50	2.45467E-09	664.0931
12-Nov-98	11-Nov-93	9	216	52	3.08685E-09	663.7991
16-Nov-98	15-Nov-93	4	96	56	4.84093E-09	663.5944
01-Dec-98	30-Nov-93	15	360	43	1.07584E-09	663.4239
01-Dec-98	30-Nov-93	0.5	12	48	1.9464E-09	663.4136
04-Feb-99	03-Feb-94	64.5	1548	68	1.75252E-08	651.6848
17-Feb-99	16-Feb-94	13	312	60	7.51014E-09	650.6912
18-Feb-99	17-Feb-94	1	24	87	1.12758E-07	649.5474
14-Mar-99	13-Mar-94	24	576	68	1.75252E-08	645.3161
24-Mar-99	23-Mar-94	10	240	60	7.51014E-09	644.5664
10-Apr-99	09-Apr-94	17	408	70	2.15271E-08	640.9379
10-Apr-99	09-Apr-94	0	0	60	7.51014E-09	640.9379
26-Apr-99	25-Apr-94	16.125	387	63	1.03683E-08	639.2938
26-Apr-99	25-Apr-94	0.125	3	65	1.28144E-08	639.2781

26-Apr-99	25-Apr-94	0.125	3	65	1.28144E-08	639.2623
26-Apr-99	25-Apr-94	0.375	9	65	1.28144E-08	639.2152
06-May-99	05-May-94	9.25	222	59	6.73596E-09	638.6048
06-May-99	05-May-94	0.5	12	54	3.87097E-09	638.5858
08-May-99	07-May-94	1.5	36	56	4.84093E-09	638.5148
08-May-99	07-May-94	0.5	12	59	6.73596E-09	638.4818
12-May-99	11-May-94	3.5	84	49	2.1866E-09	638.407
20-May-99	19-May-94	8	192	69	1.94292E-08	636.8902
31-May-99	30-May-94	11	264	54	3.87097E-09	636.4759
31-May-99	30-May-94	0.2	4.8	54	3.87097E-09	636.4684
31-May-99	30-May-94	0.2	4.8	49	2.1866E-09	636.4642
31-May-99	30-May-94	0.2	4.8	50	2.45467E-09	636.4594
31-May-99	30-May-94	0.2	4.8	50	2.45467E-09	636.4546
03-Jun-99	02-Jun-94	2.2	52.8	61	8.36786E-09	636.2757
03-Jun-99	02-Jun-94	0.33333333	8	51	2.75365E-09	636.2668
03-Jun-99	02-Jun-94	0.33333333	8	50	2.45467E-09	636.2588
04-Jun-99	03-Jun-94	0.33333333	8	50	2.45467E-09	636.2509
14-Jun-99	13-Jun-94	10	240	49	2.1866E-09	636.0385
14-Jun-99	13-Jun-94	0.5	12	46	1.53888E-09	636.031
15-Jun-99	14-Jun-94	0.5	12	48	1.9464E-09	636.0216
29-Jun-99	28-Jun-94	14	336	57	5.40807E-09	635.2874
29-Jun-99	28-Jun-94	0.33333333	8	48	1.9464E-09	635.2811
29-Jun-99	28-Jun-94	0.33333333	8	53	3.45795E-09	635.2699
30-Jun-99	29-Jun-94	0.33333333	8	48	1.9464E-09	635.2636
30-Jun-99	29-Jun-94	0.5	12	56	4.84093E-09	635.2402
02-Jul-99	01-Jul-94	1.5	36	52	3.08685E-09	635.1954
02-Jul-99	01-Jul-94	0.5	12	50	2.45467E-09	635.1835
05-Jul-99	04-Jul-94	2.5	60	51	2.75365E-09	635.1168
07-Jul-99	06-Jul-94	2	48	50	2.45467E-09	635.0693
07-Jul-99	06-Jul-94	0.5	12	50	2.45467E-09	635.0574
13-Jul-99	12-Jul-94	5.5	132	50	2.45467E-09	634.9268
13-Jul-99	12-Jul-94	0.5	12	50	2.45467E-09	634.9149
15-Jul-99	14-Jul-94	1.5	36	50	2.45467E-09	634.8793
15-Jul-99	14-Jul-94	0.5	12	50	2.45467E-09	634.8674
20-Jul-99	19-Jul-94	4.5	108	50	2.45467E-09	634.7606
08-Sep-99	07-Sep-94	50	1200	50	2.45467E-09	633.5759
08-Sep-99	07-Sep-94	0.2	4.8	50	2.45467E-09	633.5712
08-Sep-99	07-Sep-94	0.2	4.8	60	7.51014E-09	633.5567
08-Sep-99	07-Sep-94	0.2	4.8	52	3.08685E-09	633.5508
08-Sep-99	07-Sep-94	0.2	4.8	63	1.03683E-08	633.5308
09-Sep-99	08-Sep-94	0.2	4.8	50	2.45467E-09	633.5261
09-Sep-99	08-Sep-94	0.25	6	40	7.46976E-10	633.5243
09-Sep-99	08-Sep-94	0.25	6	40	7.46976E-10	633.5225
09-Sep-99	08-Sep-94	0.25	6	40	7.46976E-10	633.5207
27-Sep-99	26-Sep-94	17.25	414	63	1.03683E-08	631.8026
27-Sep-99	26-Sep-94	0.25	6	35	4.00296E-10	631.8016
27-Sep-99	26-Sep-94	0.25	6	56	4.84093E-09	631.79
27-Sep-99	26-Sep-94	0.25	6	35	4.00296E-10	631.7891
11-Oct-99	10-Oct-94	13.25	318	64	1.15303E-08	630.3289
18-Oct-99	17-Oct-94	7	168	55	4.33035E-09	630.04
23-Oct-99	22-Oct-94	5	120	65	1.28144E-08	629.4302
25-Oct-99	24-Oct-94	2	48	58	6.03761E-09	629.3154

01-Nov-99	31-Oct-94	7	168	58	6.03761E-09	628.9139
30-Nov-99	29-Nov-94	29	696	74	3.22507E-08	620.1592
06-Dec-99	05-Dec-94	6	144	65	1.28144E-08	619.4503
20-Dec-99	19-Dec-94	14	336	65	1.28144E-08	617.8026
20-Dec-99	19-Dec-94	0.5	12	64	1.15303E-08	617.7498
21-Dec-99	20-Dec-94	0.5	12	50	2.45467E-09	617.7385
11-Jan-00	10-Jan-95	21	504	72	2.63797E-08	612.7063
12-Jan-00	11-Jan-95	1	24	55	4.33035E-09	612.6673
27-Jan-00	26-Jan-95	15	360	64	1.15303E-08	611.1132
27-Jan-00	26-Jan-95	0.5	12	60	7.51014E-09	611.0795
09-Feb-00	08-Feb-95	12.5	300	65	1.28144E-08	609.6473
06-Mar-00	06-Mar-95	26	624	64	1.15303E-08	606.9849
06-Mar-00	06-Mar-95	0.5	12	58	6.03761E-09	606.9582
13-Mar-00	13-Mar-95	6.5	156	40	7.46976E-10	606.9153
16-Mar-00	16-Mar-95	3	72	68	1.75252E-08	606.4508
31-Mar-00	31-Mar-95	15	360	60	7.51014E-09	605.4581
04-Apr-00	04-Apr-95	4	96	64	1.15303E-08	605.0526
04-Apr-00	04-Apr-95	0.5	12	65	1.28144E-08	604.9963
06-Apr-00	06-Apr-95	1.5	36	63	1.03683E-08	604.8597
13-Apr-00	13-Apr-95	7	168	57	5.40807E-09	604.5275
14-Apr-00	14-Apr-95	1	24	55	4.33035E-09	604.4895
04-May-00	04-May-95	20	480	62	9.31751E-09	602.8597
04-May-00	04-May-95	0.5	12	61	8.36786E-09	602.8232
11-May-00	11-May-95	6.5	156	61	8.36786E-09	602.3492
23-May-00	23-May-95	12	288	53	3.45795E-09	601.9881
23-May-00	23-May-95	0.16666667	4	58	6.03761E-09	601.9793
23-May-00	23-May-95	0.16666667	4	47	1.73132E-09	601.9768
23-May-00	23-May-95	0.16666667	4	53	3.45795E-09	601.9718
23-May-00	23-May-95	0.16666667	4	60	7.51014E-09	601.9609
23-May-00	23-May-95	0.16666667	4	60	7.51014E-09	601.95
30-May-00	30-May-95	6.16666667	148	50	2.45467E-09	601.8184
30-May-00	30-May-95	0.14284722	3.4283333	40	7.46976E-10	601.8175
30-May-00	30-May-95	0.14298611	3.4316667	41	8.44221E-10	601.8165
30-May-00	30-May-95	0.14284722	3.4283333	39	6.60414E-10	601.8156
30-May-00	30-May-95	0.14284722	3.4283333	51	2.75365E-09	601.8122
30-May-00	30-May-95	0.14284722	3.4283333	51	2.75365E-09	601.8088
30-May-00	30-May-95	0.14284722	3.4283333	50	2.45467E-09	601.8057
05-Jun-00	05-Jun-95	5.14277778	123.42667	47	1.73132E-09	601.7284
25-Sep-97	25-Sep-95	112	2688	56	4.84093E-09	597.0535
03-Oct-97	03-Oct-95	8	192	65	1.28144E-08	596.1777
17-Oct-97	17-Oct-95	14	336	63	1.03683E-08	594.942
23-Oct-97	23-Oct-95	6	144	67	1.57982E-08	594.1379
28-Oct-97	28-Oct-95	5	120	64	1.15303E-08	593.6499
04-Nov-97	04-Nov-95	7	168	66	1.42327E-08	592.8084
11-Nov-97	11-Nov-95	7	168	54	3.87097E-09	592.58
28-Nov-97	28-Nov-95	17	408	53	3.45795E-09	592.0849
04-Feb-98	04-Feb-96	68	1632	47	1.73132E-09	591.0961
20-Feb-98	20-Feb-96	16	384	65	1.28144E-08	589.3818
11-Mar-98	10-Mar-96	19	456	30	2.10143E-10	589.3485
20-Mar-98	19-Mar-96	9	216	48	1.9464E-09	589.2025
25-Mar-98	24-Mar-96	5.45625	130.95	58	6.03761E-09	588.9282
02-Apr-98	01-Apr-96	7.54375	181.05	49	2.1866E-09	588.7909

24-Apr-98	23-Apr-96	22	528	50	2.45467E-09	588.3419
04-May-98	03-May-96	10	240	54	3.87097E-09	588.0205
06-May-98	05-May-96	2.72152778	65.316667	70	2.15271E-08	587.5347
15-May-98	14-May-96	8.27847222	198.68333	48	1.9464E-09	587.4013
25-May-98	24-May-96	10	240	49	2.1866E-09	587.2203
01-Jun-98	31-May-96	7	168	48	1.9464E-09	587.1075
05-Jun-98	04-Jun-96	4	96	46	1.53888E-09	587.0566
22-Jun-98	21-Jun-96	17	408	44	1.21309E-09	586.8861
25-Jun-98	24-Jun-96	3	72	43	1.07584E-09	586.8594
11-Jul-98	10-Jul-96	16	384	41	8.44221E-10	586.7478
11-Jul-98	10-Jul-96	0.5	12	41	8.44221E-10	586.7443
17-Jul-98	16-Jul-96	5.5	132	43	1.07584E-09	586.6954
27-Jul-98	26-Jul-96	10	240	41	8.44221E-10	586.6257
06-Aug-98	05-Aug-96	10	240	41	8.44221E-10	586.5559
18-Aug-98	17-Aug-96	12	288	43	1.07584E-09	586.4494
21-Aug-98	20-Aug-96	3	72	63	1.03683E-08	586.1927
21-Aug-98	20-Aug-96	0.5	12	44	1.21309E-09	586.1877
27-Aug-98	26-Aug-96	5.5	132	70	2.15271E-08	585.2129
08-Sep-98	07-Sep-96	12	288	50	2.45467E-09	584.9709
11-Sep-98	10-Sep-96	3	72	54	3.87097E-09	584.8756
23-Sep-98	22-Sep-96	12	288	51	2.75365E-09	584.6044
01-Oct-98	30-Sep-96	8	192	52	3.08685E-09	584.4019
02-Oct-98	01-Oct-96	1	24	50	2.45467E-09	584.3818
13-Oct-98	12-Oct-96	11	264	49	2.1866E-09	584.1847
20-Oct-98	19-Oct-96	7	168	50	2.45467E-09	584.044
23-Oct-98	22-Oct-96	3	72	58	6.03761E-09	583.8958
03-Nov-98	02-Nov-96	11	264	50	2.45467E-09	583.6749
12-Nov-98	11-Nov-96	9	216	52	3.08685E-09	583.4479
16-Nov-98	15-Nov-96	4	96	56	4.84093E-09	583.2897
01-Dec-98	30-Nov-96	15	360	43	1.07584E-09	583.158
01-Dec-98	30-Nov-96	0.5	12	48	1.9464E-09	583.15
04-Feb-99	03-Feb-97	64.5	1548	68	1.75252E-08	574.0681
17-Feb-99	16-Feb-97	13	312	60	7.51014E-09	573.297
18-Feb-99	17-Feb-97	1	24	87	1.12758E-07	572.4089
14-Mar-99	13-Mar-97	24	576	68	1.75252E-08	569.1204
24-Mar-99	23-Mar-97	10	240	60	7.51014E-09	568.5372
10-Apr-99	09-Apr-97	17	408	70	2.15271E-08	565.7123
10-Apr-99	09-Apr-97	0.5	12	60	7.51014E-09	565.6835
26-Apr-99	25-Apr-97	15.625	375	63	1.03683E-08	564.442
26-Apr-99	25-Apr-97	0.125	3	65	1.28144E-08	564.4298
26-Apr-99	25-Apr-97	0.125	3	65	1.28144E-08	564.4175
26-Apr-99	25-Apr-97	0.375	9	65	1.28144E-08	564.3808
06-May-99	05-May-97	9.25	222	59	6.73596E-09	563.9049
06-May-99	05-May-97	0.5	12	54	3.87097E-09	563.8901
08-May-99	07-May-97	1.5	36	56	4.84093E-09	563.8347
08-May-99	07-May-97	0.5	12	59	6.73596E-09	563.809
12-May-99	11-May-97	3.5	84	49	2.1866E-09	563.7506
20-May-99	19-May-97	8	192	69	1.94292E-08	562.5675
31-May-99	30-May-97	11	264	54	3.87097E-09	562.2443
31-May-99	30-May-97	0.2	4.8	54	3.87097E-09	562.2384
31-May-99	30-May-97	0.2	4.8	49	2.1866E-09	562.2351
31-May-99	30-May-97	0.2	4.8	50	2.45467E-09	562.2314

31-May-99	30-May-97	0.2	4.8	50	2.45467E-09	562.2276
03-Jun-99	02-Jun-97	2.2	52.8	61	8.36786E-09	562.088
03-Jun-99	02-Jun-97	0.33333333	8	51	2.75365E-09	562.0811
03-Jun-99	02-Jun-97	0.33333333	8	50	2.45467E-09	562.0749
04-Jun-99	03-Jun-97	0.33333333	8	50	2.45467E-09	562.0687
14-Jun-99	13-Jun-97	10	240	49	2.1866E-09	561.9029
14-Jun-99	13-Jun-97	0.5	12	46	1.53888E-09	561.8971
15-Jun-99	14-Jun-97	0.5	12	48	1.9464E-09	561.8897
29-Jun-99	28-Jun-97	14	336	57	5.40807E-09	561.3166
29-Jun-99	28-Jun-97	0.33333333	8	48	1.9464E-09	561.3117
29-Jun-99	28-Jun-97	0.33333333	8	53	3.45795E-09	561.303
30-Jun-99	29-Jun-97	0.33333333	8	48	1.9464E-09	561.2981
30-Jun-99	29-Jun-97	0.5	12	56	4.84093E-09	561.2798
02-Jul-99	01-Jul-97	1.5	36	52	3.08685E-09	561.2448
02-Jul-99	01-Jul-97	0.5	12	50	2.45467E-09	561.2355
05-Jul-99	04-Jul-97	2.5	60	51	2.75365E-09	561.1834
07-Jul-99	06-Jul-97	2	48	50	2.45467E-09	561.1463
07-Jul-99	06-Jul-97	0.5	12	50	2.45467E-09	561.1371
13-Jul-99	12-Jul-97	5.5	132	50	2.45467E-09	561.0351
13-Jul-99	12-Jul-97	0.5	12	50	2.45467E-09	561.0258
15-Jul-99	14-Jul-97	1.5	36	50	2.45467E-09	560.998
15-Jul-99	14-Jul-97	0.5	12	50	2.45467E-09	560.9887
20-Jul-99	19-Jul-97	4.5	108	50	2.45467E-09	560.9053
08-Sep-99	07-Sep-97	50	1200	50	2.45467E-09	559.9801
08-Sep-99	07-Sep-97	0.2	4.8	50	2.45467E-09	559.9764
08-Sep-99	07-Sep-97	0.2	4.8	60	7.51014E-09	559.9651
08-Sep-99	07-Sep-97	0.2	4.8	52	3.08685E-09	559.9604
08-Sep-99	07-Sep-97	0.2	4.8	63	1.03683E-08	559.9448
09-Sep-99	08-Sep-97	0.2	4.8	50	2.45467E-09	559.9411
09-Sep-99	08-Sep-97	0.25	6	40	7.46976E-10	559.9397
09-Sep-99	08-Sep-97	0.25	6	40	7.46976E-10	559.9383
09-Sep-99	08-Sep-97	0.25	6	40	7.46976E-10	559.9369
27-Sep-99	26-Sep-97	17.25	414	63	1.03683E-08	558.5943
27-Sep-99	26-Sep-97	0.25	6	35	4.00296E-10	558.5936
27-Sep-99	26-Sep-97	0.25	6	56	4.84093E-09	558.5845
27-Sep-99	26-Sep-97	0.25	6	35	4.00296E-10	558.5838
11-Oct-99	10-Oct-97	13.25	318	64	1.15303E-08	557.4421
18-Oct-99	17-Oct-97	7	168	55	4.33035E-09	557.2161
23-Oct-99	22-Oct-97	5	120	65	1.28144E-08	556.7391
25-Oct-99	24-Oct-97	2	48	58	6.03761E-09	556.6492
01-Nov-99	31-Oct-97	7	168	58	6.03761E-09	556.3351
30-Nov-99	29-Nov-97	29	696	74	3.22507E-08	549.4734
06-Dec-99	05-Dec-97	6	144	65	1.28144E-08	548.9169
20-Dec-99	19-Dec-97	14	336	65	1.28144E-08	547.6226
20-Dec-99	19-Dec-97	0.5	12	64	1.15303E-08	547.5811
21-Dec-99	20-Dec-97	0.5	12	50	2.45467E-09	547.5723
11-Jan-00	10-Jan-98	21	504	72	2.63797E-08	543.6147
12-Jan-00	11-Jan-98	1	24	55	4.33035E-09	543.5839
27-Jan-00	26-Jan-98	15	360	64	1.15303E-08	542.3602
27-Jan-00	26-Jan-98	0.5	12	60	7.51014E-09	542.3337
09-Feb-00	08-Feb-98	12.5	300	65	1.28144E-08	541.2053
06-Mar-00	06-Mar-98	26	624	64	1.15303E-08	539.1061

06-Mar-00	06-Mar-98	0.5	12	58	6.03761E-09	539.085
13-Mar-00	13-Mar-98	6.5	156	40	7.46976E-10	539.0512
16-Mar-00	16-Mar-98	3	72	68	1.75252E-08	538.6847
31-Mar-00	31-Mar-98	15	360	60	7.51014E-09	537.9013
04-Apr-00	04-Apr-98	4	96	64	1.15303E-08	537.5813
04-Apr-00	04-Apr-98	0.5	12	65	1.28144E-08	537.5368
06-Apr-00	06-Apr-98	1.5	36	63	1.03683E-08	537.429
13-Apr-00	13-Apr-98	7	168	57	5.40807E-09	537.1667
14-Apr-00	14-Apr-98	1	24	55	4.33035E-09	537.1367
04-May-00	04-May-98	20	480	62	9.31751E-09	535.8495
04-May-00	04-May-98	0.5	12	61	8.36786E-09	535.8206
11-May-00	11-May-98	6.5	156	61	8.36786E-09	535.4461
23-May-00	23-May-98	12	288	53	3.45795E-09	535.1607
23-May-00	23-May-98	0.16666667	4	58	6.03761E-09	535.1538
23-May-00	23-May-98	0.16666667	4	47	1.73132E-09	535.1518
23-May-00	23-May-98	0.16666667	4	53	3.45795E-09	535.1479
23-May-00	23-May-98	0.16666667	4	60	7.51014E-09	535.1393
23-May-00	23-May-98	0.16666667	4	60	7.51014E-09	535.1307
30-May-00	30-May-98	6.16666667	148	50	2.45467E-09	535.0267
30-May-00	30-May-98	0.14284722	3.4283333	40	7.46976E-10	535.0259
30-May-00	30-May-98	0.14298611	3.4316667	41	8.44221E-10	535.0251
30-May-00	30-May-98	0.14284722	3.4283333	39	6.60414E-10	535.0244
30-May-00	30-May-98	0.14284722	3.4283333	51	2.75365E-09	535.0217
30-May-00	30-May-98	0.14284722	3.4283333	51	2.75365E-09	535.019
30-May-00	30-May-98	0.14284722	3.4283333	50	2.45467E-09	535.0166
05-Jun-00	05-Jun-98	5.14277778	123.42667	47	1.73132E-09	534.9555
25-Sep-97	25-Sep-98	112	2688	56	4.84093E-09	531.2573
03-Oct-97	03-Oct-98	8	192	65	1.28144E-08	530.5639
17-Oct-97	17-Oct-98	14	336	63	1.03683E-08	529.585
23-Oct-97	23-Oct-98	6	144	67	1.57982E-08	528.9477
28-Oct-97	28-Oct-98	5	120	64	1.15303E-08	528.5609
04-Nov-97	04-Nov-98	7	168	66	1.42327E-08	527.8937
11-Nov-97	11-Nov-98	7	168	54	3.87097E-09	527.7126
28-Nov-97	28-Nov-98	17	408	53	3.45795E-09	527.32
04-Feb-98	04-Feb-99	68	1632	47	1.73132E-09	526.5354
20-Feb-98	20-Feb-99	16	384	65	1.28144E-08	525.1747
11-Mar-98	11-Mar-99	19	456	30	2.10143E-10	525.1483
20-Mar-98	20-Mar-99	9	216	48	1.9464E-09	525.0324
25-Mar-98	25-Mar-99	5.45625	130.95	58	6.03761E-09	524.8145
02-Apr-98	02-Apr-99	7.54375	181.05	49	2.1866E-09	524.7055
24-Apr-98	24-Apr-99	22	528	50	2.45467E-09	524.3489
04-May-98	04-May-99	10	240	54	3.87097E-09	524.0936
06-May-98	06-May-99	2.72152778	65.316667	70	2.15271E-08	523.7077
15-May-98	15-May-99	8.27847222	198.68333	48	1.9464E-09	523.6017
25-May-98	25-May-99	10	240	49	2.1866E-09	523.4578
01-Jun-98	01-Jun-99	7	168	48	1.9464E-09	523.3682
05-Jun-98	05-Jun-99	4	96	46	1.53888E-09	523.3278
22-Jun-98	22-Jun-99	17	408	44	1.21309E-09	523.1923
25-Jun-98	25-Jun-99	3	72	43	1.07584E-09	523.1711
11-Jul-98	11-Jul-99	16	384	41	8.44221E-10	523.0823
11-Jul-98	11-Jul-99	0.5	12	41	8.44221E-10	523.0796
17-Jul-98	17-Jul-99	5.5	132	43	1.07584E-09	523.0407

27-Jul-98	27-Jul-99	10	240	41	8.44221E-10	522.9853
06-Aug-98	06-Aug-99	10	240	41	8.44221E-10	522.9299
18-Aug-98	18-Aug-99	12	288	43	1.07584E-09	522.8452
21-Aug-98	21-Aug-99	3	72	63	1.03683E-08	522.6412
21-Aug-98	21-Aug-99	0.5	12	44	1.21309E-09	522.6372
27-Aug-98	27-Aug-99	5.5	132	70	2.15271E-08	521.8622
08-Sep-98	08-Sep-99	12	288	50	2.45467E-09	521.6697
11-Sep-98	11-Sep-99	3	72	54	3.87097E-09	521.5939
23-Sep-98	23-Sep-99	12	288	51	2.75365E-09	521.3782
01-Oct-98	01-Oct-99	8	192	52	3.08685E-09	521.2172
02-Oct-98	02-Oct-99	1	24	50	2.45467E-09	521.2012
13-Oct-98	13-Oct-99	11	264	49	2.1866E-09	521.0444
20-Oct-98	20-Oct-99	7	168	50	2.45467E-09	520.9325
23-Oct-98	23-Oct-99	3	72	58	6.03761E-09	520.8145
03-Nov-98	03-Nov-99	11	264	50	2.45467E-09	520.6388
12-Nov-98	12-Nov-99	9	216	52	3.08685E-09	520.4581
16-Nov-98	16-Nov-99	4	96	56	4.84093E-09	520.3323
01-Dec-98	01-Dec-99	15	360	43	1.07584E-09	520.2274
01-Dec-98	01-Dec-99	0.5	12	48	1.9464E-09	520.2211
04-Feb-99	04-Feb-00	64.5	1548	68	1.75252E-08	512.9814
17-Feb-99	17-Feb-00	13	312	60	7.51014E-09	512.3655
18-Feb-99	18-Feb-00	1	24	87	1.12758E-07	511.656
14-Mar-99	14-Mar-00	25	600	68	1.75252E-08	508.918
24-Mar-99	24-Mar-00	10	240	60	7.51014E-09	508.4516
10-Apr-99	10-Apr-00	17	408	70	2.15271E-08	506.1911
10-Apr-99	10-Apr-00	0.5	12	60	7.51014E-09	506.168
26-Apr-99	26-Apr-00	15.625	375	63	1.03683E-08	505.1738
26-Apr-99	26-Apr-00	0.125	3	65	1.28144E-08	505.164
26-Apr-99	26-Apr-00	0.125	3	65	1.28144E-08	505.1542
26-Apr-99	26-Apr-00	0.375	9	65	1.28144E-08	505.1247
06-May-99	06-May-00	9.25	222	59	6.73596E-09	504.7435
06-May-99	06-May-00	0.5	12	54	3.87097E-09	504.7316
08-May-99	08-May-00	1.5	36	56	4.84093E-09	504.6873
08-May-99	08-May-00	0.5	12	59	6.73596E-09	504.6667
12-May-99	12-May-00	3.5	84	49	2.1866E-09	504.6199
20-May-99	20-May-00	8	192	69	1.94292E-08	503.6718
31-May-99	31-May-00	11	264	54	3.87097E-09	503.4126
31-May-99	31-May-00	0.2	4.8	54	3.87097E-09	503.4079
31-May-99	31-May-00	0.2	4.8	49	2.1866E-09	503.4053
31-May-99	31-May-00	0.2	4.8	50	2.45467E-09	503.4023
31-May-99	31-May-00	0.2	4.8	50	2.45467E-09	503.3993
03-Jun-99	03-Jun-00	2.2	52.8	61	8.36786E-09	503.2874
03-Jun-99	03-Jun-00	0.33333333	8	51	2.75365E-09	503.2818
03-Jun-99	03-Jun-00	0.33333333	8	50	2.45467E-09	503.2768
04-Jun-99	04-Jun-00	0.33333333	8	50	2.45467E-09	503.2718
14-Jun-99	14-Jun-00	10	240	49	2.1866E-09	503.139
14-Jun-99	14-Jun-00	0.5	12	46	1.53888E-09	503.1343
15-Jun-99	15-Jun-00	0.5	12	48	1.9464E-09	503.1284
29-Jun-99	29-Jun-00	14	336	57	5.40807E-09	502.6688
29-Jun-99	29-Jun-00	0.33333333	8	48	1.9464E-09	502.6649
29-Jun-99	29-Jun-00	0.33333333	8	53	3.45795E-09	502.6579
30-Jun-99	30-Jun-00	0.33333333	8	48	1.9464E-09	502.6539

30-Jun-99	30-Jun-00	0.5	12	56	4.84093E-09	502.6393
02-Jul-99	02-Jul-00	1.5	36	52	3.08685E-09	502.6112
02-Jul-99	02-Jul-00	0.5	12	50	2.45467E-09	502.6038
05-Jul-99	05-Jul-00	2.5	60	51	2.75365E-09	502.562
07-Jul-99	07-Jul-00	2	48	50	2.45467E-09	502.5323
07-Jul-99	07-Jul-00	0.5	12	50	2.45467E-09	502.5248
13-Jul-99	13-Jul-00	5.5	132	50	2.45467E-09	502.443
13-Jul-99	13-Jul-00	0.5	12	50	2.45467E-09	502.4356
15-Jul-99	15-Jul-00	1.5	36	50	2.45467E-09	502.4133
15-Jul-99	15-Jul-00	0.5	12	50	2.45467E-09	502.4058
20-Jul-99	20-Jul-00	4.5	108	50	2.45467E-09	502.3389
08-Sep-99	08-Sep-00	50	1200	50	2.45467E-09	501.5967
08-Sep-99	08-Sep-00	0.2	4.8	50	2.45467E-09	501.5938
08-Sep-99	08-Sep-00	0.2	4.8	60	7.51014E-09	501.5847
08-Sep-99	08-Sep-00	0.2	4.8	52	3.08685E-09	501.581
08-Sep-99	08-Sep-00	0.2	4.8	63	1.03683E-08	501.5684
09-Sep-99	09-Sep-00	0.2	4.8	50	2.45467E-09	501.5655
09-Sep-99	09-Sep-00	0.25	6	40	7.46976E-10	501.5643
09-Sep-99	09-Sep-00	0.25	6	40	7.46976E-10	501.5632
09-Sep-99	09-Sep-00	0.25	6	40	7.46976E-10	501.5621
27-Sep-99	27-Sep-00	17.25	414	63	1.03683E-08	500.4846
27-Sep-99	27-Sep-00	0.25	6	35	4.00296E-10	500.484
27-Sep-99	27-Sep-00	0.25	6	56	4.84093E-09	500.4767
27-Sep-99	27-Sep-00	0.25	6	35	4.00296E-10	500.4761
11-Oct-99	11-Oct-00	13.25	318	64	1.15303E-08	499.5594
18-Oct-99	18-Oct-00	7	168	55	4.33035E-09	499.3779
23-Oct-99	23-Oct-00	5	120	65	1.28144E-08	498.9947
25-Oct-99	25-Oct-00	2	48	58	6.03761E-09	498.9226
01-Nov-99	01-Nov-00	7	168	58	6.03761E-09	498.6702
30-Nov-99	30-Nov-00	29	696	74	3.22507E-08	493.1502
06-Dec-99	06-Dec-00	6	144	65	1.28144E-08	492.7018
20-Dec-99	20-Dec-00	14	336	65	1.28144E-08	491.6588
20-Dec-99	20-Dec-00	0.5	12	64	1.15303E-08	491.6254
21-Dec-99	21-Dec-00	0.5	12	50	2.45467E-09	491.6183

D: Arrhenius equation calculation using online data

In this section it is shown in detail the calculations of the Arrhenius equation using the online data measurement:

$$\frac{1}{DP_t} - \frac{1}{DP_o} = k \cdot t$$

$$DP_t = \frac{DP_o}{1 + k \cdot t \cdot DP_o}$$

-where: $\boldsymbol{DP_t}$ is the calculated DP in Figure 11
$\boldsymbol{DP_o}$ is the assumed DP of 950 for new transformer
$\boldsymbol{k}$ is given by:

$$k = A \cdot e^{\left(\frac{-E}{RT}\right)}$$

DP_o = 950, for new transformer
A = 3.65×10^7 h^{-1}, the chemical environment constant for thermally upgraded paper.
E = 100k J/mole, the activation energy for the thermal degradation of cellulose in oil.
R = 8.314 J/mole/K, the molar gas constant.
T = online temperature measured on the transformer, in ^oC.

Table 12: Arrhenius calculation for DP using online data

Date	Days	t(hours)	Time accumulation	Oil Temp	k	DP_t
03-Aug-92	0	0	0	49	2.1866E-09	950
15-Feb-93	196	4704	4704	55	4.3303E-09	931.9651
21-Feb-94	371	8904	13608	51	2.7536E-09	911.1451
07-Apr-94	45	1080	14688	65	1.2814E-08	899.7988
22-Aug-94	137	3288	17976	48	1.9464E-09	894.647
20-Sep-95	394	9456	27432	55	4.3303E-09	863.0309
27-Aug-97	707	16968	44400	70	2.1527E-08	656.1773
29-Sep-97	33	792	45192	65	1.2814E-08	651.8364
16-Oct-97	17	408	45600	63	1.0368E-08	650.0439
21-Oct-97	5	120	45720	67	1.5798E-08	649.2438
27-Oct-97	6	144	45864	64	1.153E-08	648.5447
04-Nov-97	8	192	46056	66	1.4233E-08	647.3973
25-Nov-97	21	504	46560	53	3.4579E-09	646.6677
28-Jan-98	64	1536	48096	47	1.7313E-09	645.5576
17-Feb-98	20	480	48576	65	1.2814E-08	643.0043
10-Mar-98	21	504	49080	30	2.1014E-10	642.9605
17-Mar-98	7	168	49248	48	1.9464E-09	642.8254
02-Apr-98	16	384	49632	49	2.1866E-09	642.4786
21-Apr-98	19	456	50088	50	2.4547E-09	642.0169
29-Apr-98	8	192	50280	54	3.871E-09	641.7107

11-May-98	12	288	50568	48	1.9464E-09	641.48
21-May-98	10	240	50808	49	2.1866E-09	641.2641
27-May-98	6	144	50952	48	1.9464E-09	641.1488
17-Jun-98	21	504	51456	44	1.2131E-09	640.8976
24-Jun-98	7	168	51624	43	1.0758E-09	640.8234
03-Jul-98	9	216	51840	41	8.4422E-10	640.7485
15-Jul-98	12	288	52128	43	1.0758E-09	640.6213
22-Jul-98	7	168	52296	41	8.4422E-10	640.5631
04-Aug-98	13	312	52608	41	8.4422E-10	640.4551
28-Aug-98	24	576	53184	70	2.1527E-08	635.409
09-Sep-98	12	288	53472	54	3.871E-09	634.9592
22-Sep-98	13	312	53784	52	3.0868E-09	634.5712
29-Sep-98	7	168	53952	50	2.4547E-09	634.4052
07-Oct-98	8	192	54144	49	2.1866E-09	634.2363
14-Oct-98	7	168	54312	50	2.4547E-09	634.0704
21-Oct-98	7	168	54480	58	6.0376E-09	633.6629
17-Nov-98	27	648	55128	48	1.9464E-09	633.1568
24-Nov-98	7	168	55296	43	1.0758E-09	633.0844
05-Feb-99	73	1752	57048	60	7.5101E-09	627.8544
25-Feb-99	20	480	57528	68	1.7525E-08	624.5557
10-Mar-99	13	312	57840	60	7.5101E-09	623.6431
07-Apr-99	28	672	58512	60	7.5101E-09	621.6864
15-Apr-99	8	192	58704	65	1.2814E-08	620.7369
20-Apr-99	5	120	58824	59	6.736E-09	620.4256
11-May-99	21	504	59328	49	2.1866E-09	620.0017
20-May-99	9	216	59544	69	1.9429E-08	618.3927
21-May-99	1	24	59568	54	3.871E-09	618.3571
24-May-99	3	72	59640	49	2.1866E-09	618.2969
26-May-99	2	48	59688	50	2.4547E-09	618.2519
27-May-99	1	24	59712	50	2.4547E-09	618.2294
02-Jun-99	6	144	59856	61	8.3679E-09	617.7692
07-Jun-99	5	120	59976	46	1.5389E-09	617.6987
14-Jun-99	7	168	60144	48	1.9464E-09	617.574
15-Jun-99	1	24	60168	48	1.9464E-09	617.5562
23-Jun-99	8	192	60360	56	4.8409E-09	617.2019
25-Jun-99	2	48	60408	50	2.4547E-09	617.157
28-Jun-99	3	72	60480	51	2.7536E-09	617.0815
30-Jun-99	2	48	60528	50	2.4547E-09	617.0366
05-Jul-99	5	120	60648	50	2.4547E-09	616.9245
07-Jul-99	2	48	60696	50	2.4547E-09	616.8797
22-Feb-00	230	5520	66216	68	1.7525E-08	582.1396
29-Feb-00	7	168	66384	40	7.4698E-10	582.0971
06-Mar-00	6	144	66528	65	1.2814E-08	581.4725
15-Mar-00	9	216	66744	60	7.5101E-09	580.9246
28-Mar-00	13	312	67056	63	1.0368E-08	579.8349
03-Apr-00	6	144	67200	55	4.3303E-09	579.6254
12-Apr-00	9	216	67416	57	5.4081E-09	579.2332
19-Apr-00	7	168	67584	61	8.3679E-09	578.7619
26-Apr-00	7	168	67752	61	8.3679E-09	578.2914
04-May-00	8	192	67944	53	3.4579E-09	578.0694
08-May-00	4	96	68040	60	7.5101E-09	577.8286
15-May-00	7	168	68208	58	6.0376E-09	577.4901

16-May-00	1	24	68232	53	3.4579E-09	577.4625
17-May-00	1	24	68256	47	1.7313E-09	577.4486
18-May-00	1	24	68280	50	2.4547E-09	577.429
19-May-00	1	24	68304	51	2.7536E-09	577.4069
20-May-00	1	24	68328	46	1.5389E-09	577.3946
23-May-00	3	72	68400	41	8.4422E-10	577.3744
24-May-00	1	24	68424	50	2.4547E-09	577.3547
25-May-00	1	24	68448	40	7.4698E-10	577.3487
26-May-00	1	24	68472	40	7.4698E-10	577.3428
27-May-00	1	24	68496	34	3.5248E-10	577.3399
28-May-00	1	24	68520	31	2.3946E-10	577.338
29-May-00	1	24	68544	40	7.4698E-10	577.3321
02-Jun-00	4	96	68640	38	5.8342E-10	577.3134
03-Jun-00	1	24	68664	39	6.6041E-10	577.3081
04-Jun-00	1	24	68688	38	5.8342E-10	577.3034
05-Jun-00	1	24	68712	40	7.4698E-10	577.2975
06-Jun-00	1	24	68736	38	5.8342E-10	577.2928
07-Jun-00	1	24	68760	48	1.9464E-09	577.2772
08-Jun-00	1	24	68784	43	1.0758E-09	577.2686
09-Jun-00	1	24	68808	40	7.4698E-10	577.2626
14-Jun-00	5	120	68928	40	7.4698E-10	577.2328
15-Jun-00	1	24	68952	41	8.4422E-10	577.226
19-Jun-00	4	96	69048	43	1.0758E-09	577.1916
20-Jun-00	1	24	69072	40	7.4698E-10	577.1856
21-Jun-00	1	24	69096	41	8.4422E-10	577.1789
22-Jun-00	1	24	69120	44	1.2131E-09	577.1692
26-Jun-00	4	96	69216	37	5.1499E-10	577.1527
27-Jun-00	1	24	69240	37	5.1499E-10	577.1486
28-Jun-00	1	24	69264	38	5.8342E-10	577.1439
29-Jun-00	1	24	69288	39	6.6041E-10	577.1387
30-Jun-00	1	24	69312	40	7.4698E-10	577.1327
01-Jul-00	1	24	69336	39	6.6041E-10	577.1274
02-Jul-00	1	24	69360	38	5.8342E-10	577.1228
03-Jul-00	1	24	69384	39	6.6041E-10	577.1175
04-Jul-00	1	24	69408	40	7.4698E-10	577.1115
05-Jul-00	1	24	69432	39	6.6041E-10	577.1062