

## Chapter 5: Model Testing

### 5.1. Description of test system

The test system selected is a quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers. The product of this plant (VCM) is the primary feedstock for the PVC (Polyvinyl Chloride) plant. The PVC plant produces PVC powder, which is sold to converters producing products such as piping, electric insulation, extrusion mouldings, flooring and sheeting. The specific pump set consists of two parallel pumps, numbered GA-1402 A and GA-1402 B, of which the one is normally in operation and the other one is on standby. The purpose of the quench reflux system is to control the quality in the quench column (a distillation column). The pumps were installed in 1994 and displayed low reliability, which is at least partly due to the severe duty to which it is exposed. Typical problem areas include the shaft sleeve, bearings, the mechanical seal, high system pressures and poor installation.

The plant's availability of historic data is very characteristic of the typical situation in industry. The plant changed over from one maintenance information system (a system they called MMS, which was based on the Fluor Daniel system of the late 1980's, with some modifications) to another (SAP/R3) in 1998. The history in the MMS system was not transferred to the SAP/R3 system. This is the typical situation found in the average industrial concern (a shortage of failure history due to loss of history during system changes). The raw data as supplied from the SAP/R3 system is shown in table 5.1.

Facts that become obvious when looking at table 5.1 are the following:

- The problems of the pump seem to be mainly related to the mechanical seal and its accompanying shaft sleeve.
- A secondary problem area is that of the sealing fluid accumulator - these failures are typically due to the pumped medium getting into the seal fluid system when the mechanical seal/shaft sleeve fails.
- The history is very difficult to interpret for the following reasons:
  - ❖ There is no information regarding the work done during overhauls.
  - ❖ The cost of overhauls (and other activities) is not consistent, which does not help the interpretation.
  - ❖ The 'type of work' column descriptors (which are supplied by the artisan) are not used consistently. This accentuates the comments of the company's artisans that the failure codes should be simpler to interpret.
- Most of the work was on pump A. This fact could be insignificant, but it could also point to the real problem - see later comment on page 5-14.

- These tables do not supply any information regarding pump lives (which is of course crucial to determine the lives of the various components).

An assembly drawing of the pump is shown in figure 5-1, while a cut-through drawing of the mechanical seal used in the pump is shown in figure 5-4. Figure 5-2 shows two photographic views of the pumps with some important parts highlighted while figure 5-3 shows a piping schematic of the seal-oil system. A part - breakdown structure for the pump is shown in figures 5-6 to 5-8.

The pump pumps a mixture of Ethylene Dichloride (EDC) and Anhydrous Hydrochloric Acid (HCl), which is later separated, at a discharge pressure of 2500 kPa. It uses an API plan 53 (figure 5-3) barrier fluid arrangement with an API seal arrangement 3 (double mechanical seal). The environment is protected from leakage by circulating a barrier fluid, which also provides lubrication, at a pre-set pressure of 2 700 kPa. To pre-charge the seal fluid system to the pre-set pressure, the system is equipped with a hand charge pump. The mechanical seal includes an internal screw pump arrangement (item 1.4 in figure 5-4) to pump this circulating fluid. To compensate for day/night temperature differences (to ensure that the pressure is maintained), the system is equipped with a compensating accumulator.

The accumulator failures evident in table 5.1, were caused by product getting into the barrier fluid. That was caused by the operations personnel allowing the barrier fluid pressure to fall below the product pressure. By upgrading operational vigilance and ensuring that the correct pressure gradient ( $\Delta P$ ) is maintained these failures were stopped. This highlights the fact that problems are often permanently solved during the RCM analysis process, because the various failure modes are systematically analysed.

## 5.2. Maintenance plan analysis results

### 5.2.1. Analysis using standard RCM

A previous RCM analysis, using the RCM 2 version of Moubray (1991), was done for the plant, the applicable analyses being given in Appendix A on pages 5-35 to 5-37 (for the pump) and Appendix B on pages 5-38 to 5-43 (for the mechanical seal).

When one contemplates utilising RCM in a practical manner for the design of a maintenance plan for an industrial facility, it immediately becomes clear that you have to limit the scope of the analysis in some or other way (refer to § 4.3.2.2, § 4.3.2.5 and § 4.3.5 in this regard). Some practitioners do this by simplifying the analysis process (the adherents of 'streamlined RCM' and 'reverse RCM'), while others use the approach of 'generic' RCM analyses as is apparent in this case. The thinking behind this is that 'a pump is a pump' and 'a mechanical seal is a mechanical seal.' A generic RCM analysis for all single stage centrifugal pumps was thus performed (pages 5-12 to 5-14) and another for normal double balanced mechanical seals' (pages 5-15 to 5-20).

Table 5.1: Failure History GA-1402 A&amp;B Quench Reflux pumps

Line No	Pump No	Description	Type of work	Date	Cost R
1	A	Capture cost angle bracket	Preventive - General	20-Nov-98	R 1 683.50
2	A	Return spares to store	Predictive - General	17-Dec-98	-R 2 250.00
3	B	Install spare pump <b>and send defective unit</b> for overhaul	Predictive - CM	20-Jan-99	R 13 315.49
4	B	Replace accumulator bladder	Reactive - Planned	21-Jan-99	R 651.54
5	A	Install spare pump <b>and send defective unit</b> for overhaul	Predictive - CM	21-Jan-99	R 1 210.00
6	A	Overhaul spare pump in workshop	Proactive - Precision Rebuild	26-Jan-99	-R 8 482.70
7	A	Recondition Accumulator	Reactive - Planned	27-Feb-99	R 7 850.00
8	A	RTS hand refill pump	Reactive - Planned	28-Feb-99	R 0.00
9	A	Replace mechanical seal on spare pump	Proactive - Precision Installation	1-Mar-99	R 9 601.75
10	A	Recondition Mechanical Seal	Preventive - Recondition	25-Mar-99	-R 6 271.00
11	A	Recondition Accumulator	Reactive - Planned	19-Apr-99	R 7 850.00
12	A	Replace Mechanical seal	Reactive - Planned	31-May-99	R 11 088.82
13	B	Recondition Accumulator	Reactive - Planned	9-Jun-99	R 7 850.00
14	A	Overhaul spare pump in workshop	Predictive - CM	21-Jun-99	R 5 988.99
15	A	Recondition Accumulator	Reactive - Planned	5-Jul-99	R 7 850.00
16	A	Repair seal	Predictive - Work Generated from Inspections	10-Jul-99	R 9 945.96
17	A	Replace bearings	Reactive - Planned	3-Aug-99	R 319.00
18	B	Replace accumulator	Reactive - Planned	20-Sep-99	R 7 850.00
19	B	Replace mechanical seal	Reactive - Planned	19-Nov-99	R 9 307.00
20	A	Recondition Mechanical Seal	Reactive - Planned	17-Jan-00	R 1 566.00
21	B	Replace mechanical seal	Predictive - CM	18-Jan-00	R 10 685.05
22	A	Replace mechanical seal	Predictive - Work Generated from Inspections	31-Jan-00	R 11 036.92
23	A	Replace mechanical seal	Predictive - Work Generated from Inspections	6-Feb-00	R 11 596.59
24	A	Repair clamp plate	Reactive - Planned	10-Feb-00	R 570.00
25	A	Repair & sort out seal failure	Reactive - Planned	15-Feb-00	R 6 977.47
26	A	Replace mechanical seal	Predictive - CM	10-Apr-00	R 10 253.54

Table 5.1: Failure History GA-1402 A&amp;B Quench Reflux pumps (continued)

Line No	Pump No	Description	Type of work	Date	Cost R
27	A	Recondition Mechanical Seal (2 off)	Reactive - Planned	26-Apr-00	R 1 434.00
28	A	Replace mechanical seal	Reactive - Planned	26-Apr-00	R 11 435.00
29	A	Replace mechanical seal (callout)	Predictive - CM	24-May-00	R 20 982.55
30	B	Recondition Mechanical Seal	Reactive - Planned	8-Jun-00	R 4 150.00
31	B	Repair leaking seal	Preventive - Replace	15-Jul-00	R 10 840.50
32	A	Repair leaking seal	Preventive - Recondition	8-Aug-00	R 22 244.99
33	A	Replace mechanical seal	Predictive - CM	22-Aug-00	R 11 404.49
34	A	Replace shaft and mechanical seal	Reactive - Planned	28-Aug-00	R 820.73
35	A	Replace mechanical seal	Preventive - Replace	19-Sep-00	R 10 840.50
36	A	Replace bearings	Preventive - Recondition	22-Sep-00	R 13 325.99
37	A	Replace mechanical seal	Predictive - CM	12-Oct-00	R 1 736.00
38	A	Recondition Mechanical Seal	Reactive - Planned	16-Oct-00	R 22 111.50
39	A	Recondition Mechanical Seal	Reactive - Planned	23-Oct-00	R 12 517.00
40	A	Recondition Accumulator	Reactive - Planned	8-Nov-00	R 5 980.00
41	B	Replace mechanical seal	Predictive - Work Generated from Inspections	14-Nov-00	R 0.00
42	B	Replace mechanical seal	Predictive - Work Generated from Inspections	16-Nov-00	R 4 476.90
43	A	Recondition Mechanical Seal	Reactive - Planned	24-Nov-00	-R 15 079.00
44	A	Recondition Mechanical Seal	Reactive - Planned	24-Nov-00	R 0.00
45	B	Replace non-return on seal pot	Reactive - Planned	24-Nov-00	R 932.00
46	B	Recondition Mechanical Seal	Reactive - Planned	24-Nov-00	R 1 130.00
47	A	Replace mechanical seal	Preventive - Gnl	28-Nov-00	R 1 745.74
48	B	Recondition Mechanical Seal	Reactive - Planned	7-Dec-00	-R 20 403.50
49	A	Spare hand refill kit	Reactive - Planned	11-Jan-01	R 2 653.00
50	A	Spare kit for oil hand pump	Reactive - Planned	7-Mar-01	R 0.00
51	A	Replace leaking seal	Reactive - Unplanned	6-Apr-01	R 9 556.50

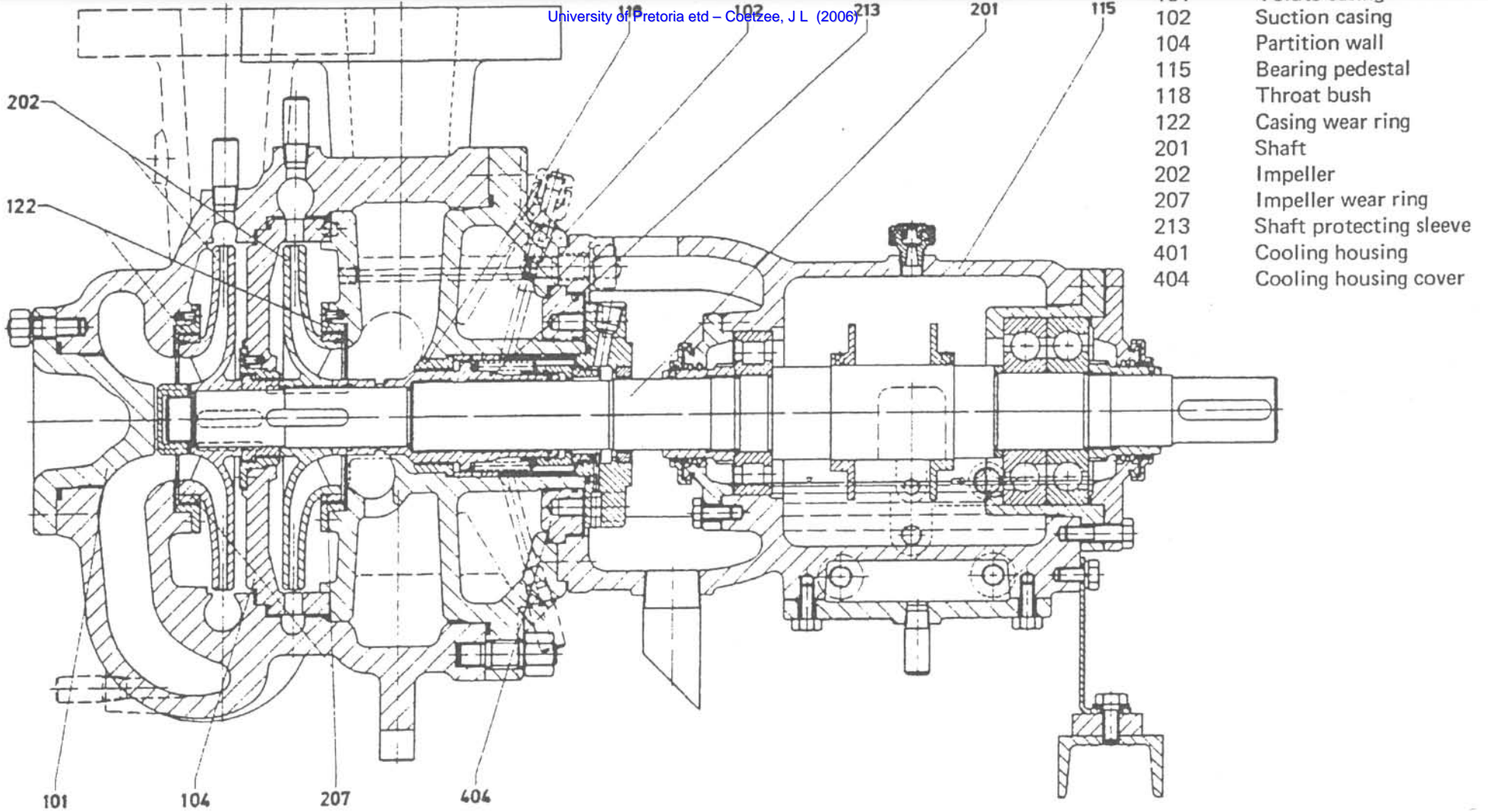


Figure 5-1: Sectional drawing KSB RPH 40-231

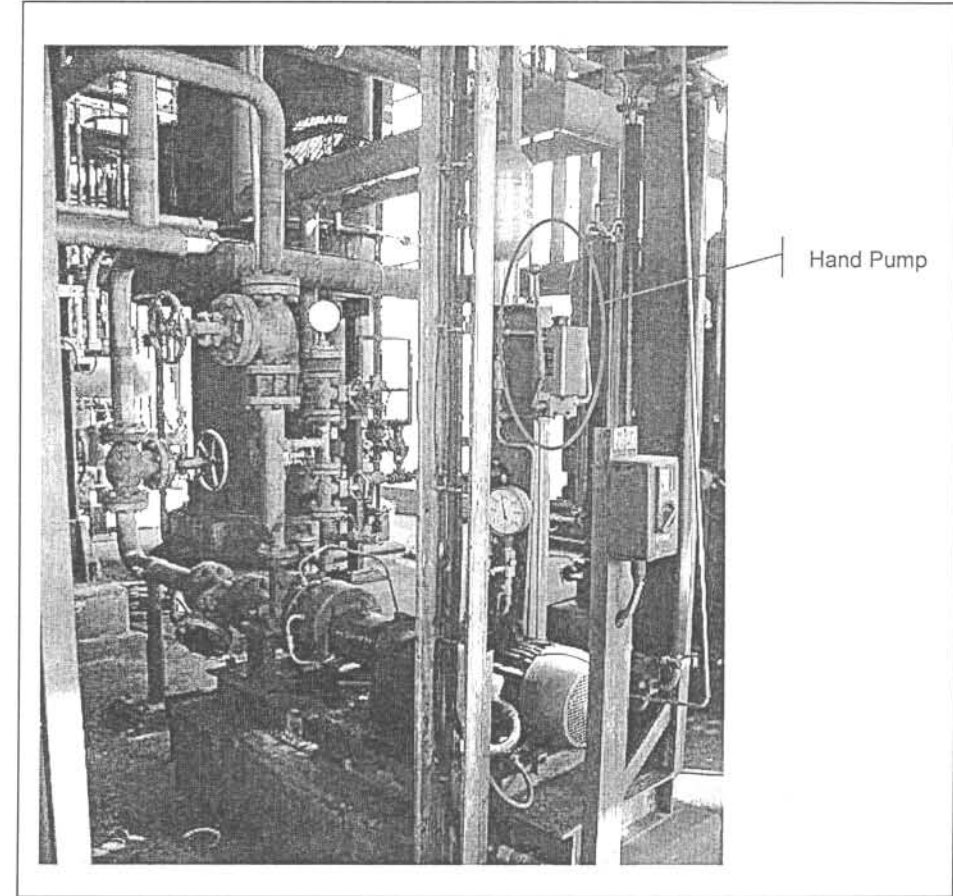
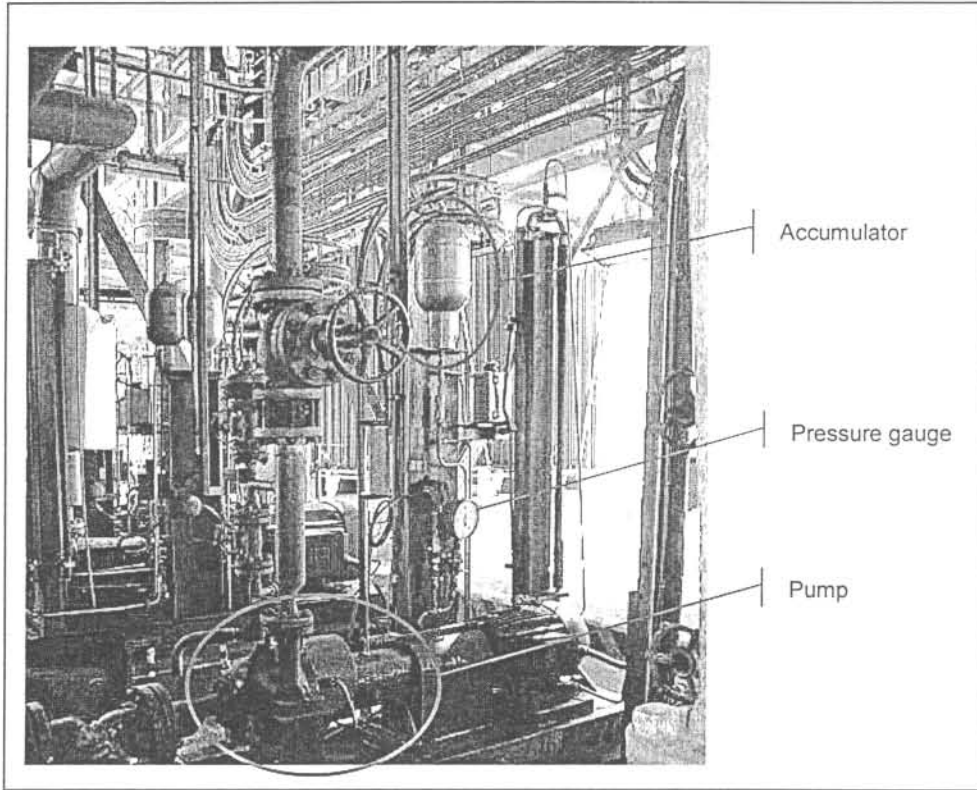


Figure 5-2: GA-1402 pumps

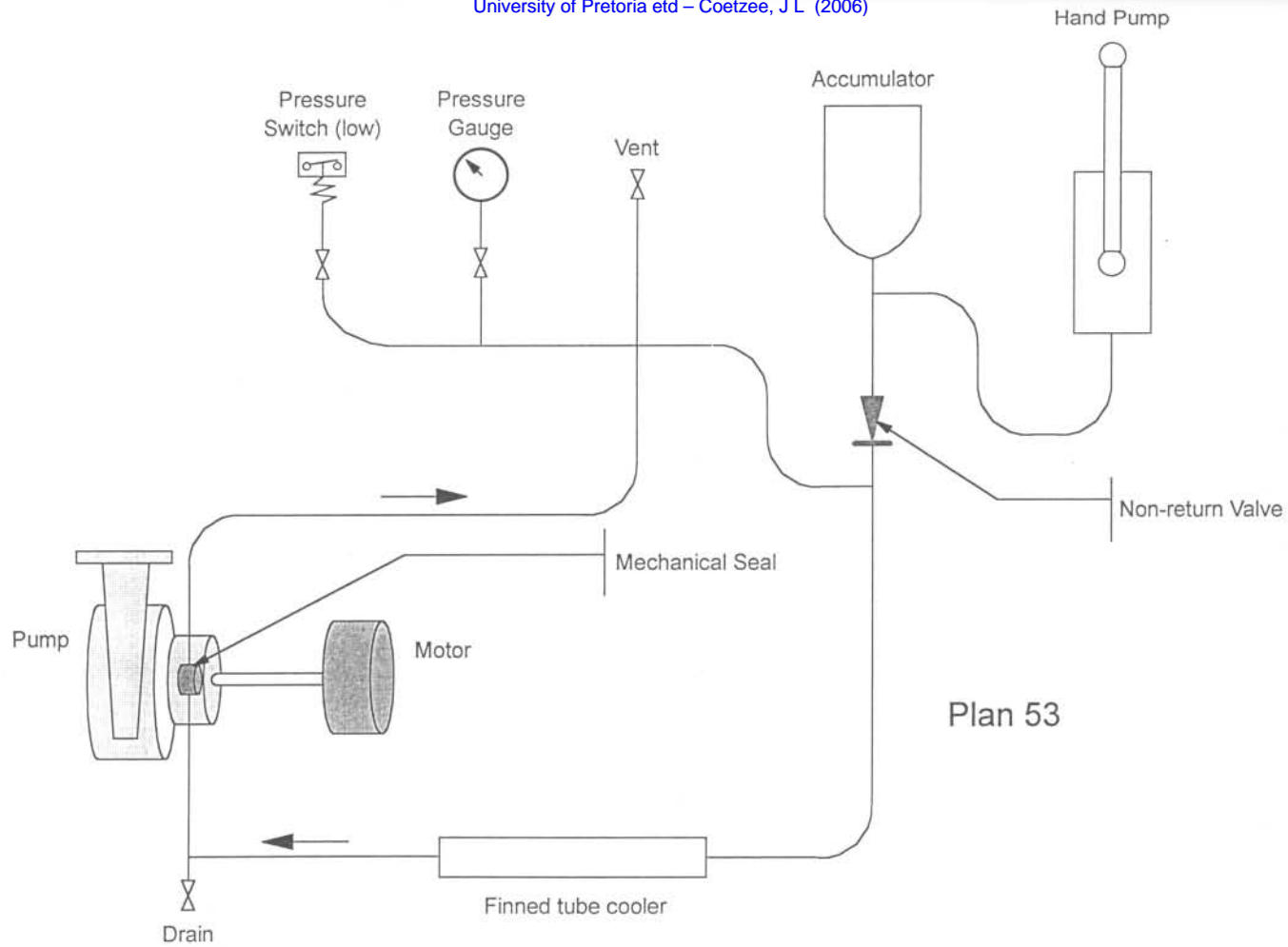


Figure 5-3: GA-1402 pumps seal-oil piping schematic

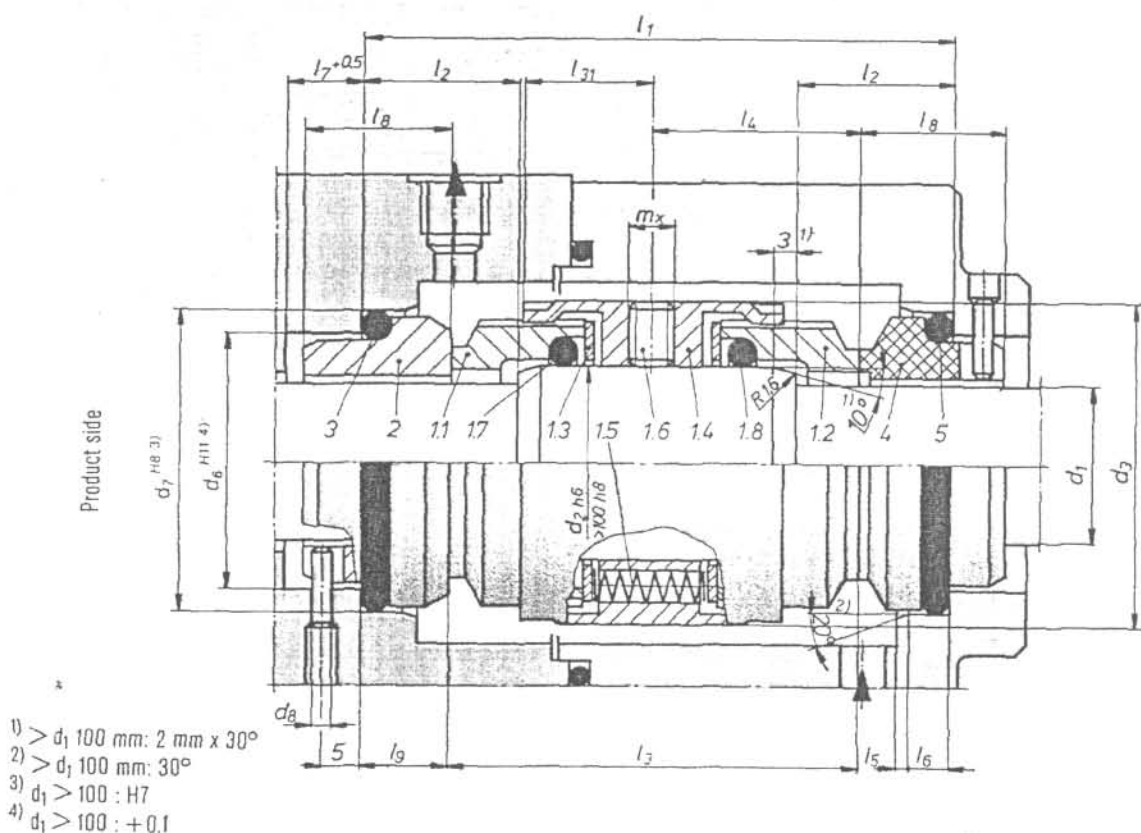


Figure 5-4: Sectional drawing of mechanical seal

Thus, while the risk involved can differ greatly from pump to pump (due to the difference in applicatory detail and operational circumstances), a 'generic' solution for the maintenance of all such units is proposed to limit the extent of the analysis to such an extent that it remains doable. This is grossly insufficient, taking into account the high safety risk involved in a plant of this nature. In order to make this type of approach work, the generic maintenance plan is then pitched to work for a high risk pump. This means that all pumps in the plant (44 pump pairs with mechanical seals) have to be maintained in the same rigorous way. The plant maintenance management's argument in defence of this is that they handle a product, which is many times as explosive as TNT. They would thus rather prefer to be overly rigorous. This makes sense, as is their second argument, that they do not want to confuse the workforce with too many versions of a specific type of unit's maintenance plan, to limit the negative effects of wrong maintenance actions. They concede that this is not very cost effective.

From experience, this type of approach can have serious implications for the long-term success of the maintenance plan, especially in less dangerous plants:

- It *firstly* proposes a plan that is resource intensive and,
- *Secondly*, both maintenance management and artisans will soon discover this fact and then only pay lip service to the plan (that is, if they do not actively disband it, as so often happens).

The major part of this analysis is probably perfectly valid for our two pumps, as they represent a high-risk situation in this plant. However, the fact remains that the outcomes from RCM analyses differ even from operating situation to operating situation utilising identical equipment, but with different fluids pumped and different pressures and flow rates.

### 5.2.2. Analysis using proposed improved model

One of the improved features of the proposed model is its funnelling approach, whereby the RCM energy is expended on items for which it matters most. For a first level prioritisation, refer to the Pareto analyses in figures 5-5 and 5-9. The first of these is a life-to-date Pareto cost analysis, while the second is a year-to-date Pareto cost analysis. For the life-to-date picture, the Pareto 'elbow' occurs at the fifth cost item, while it occurs at the fourth cost item in the year-to-date case. It is clear that the priorities in terms of high cost items have shifted somewhat over the longer term, indicating a change in priority based on cost profile. The results are shown in table 5.2

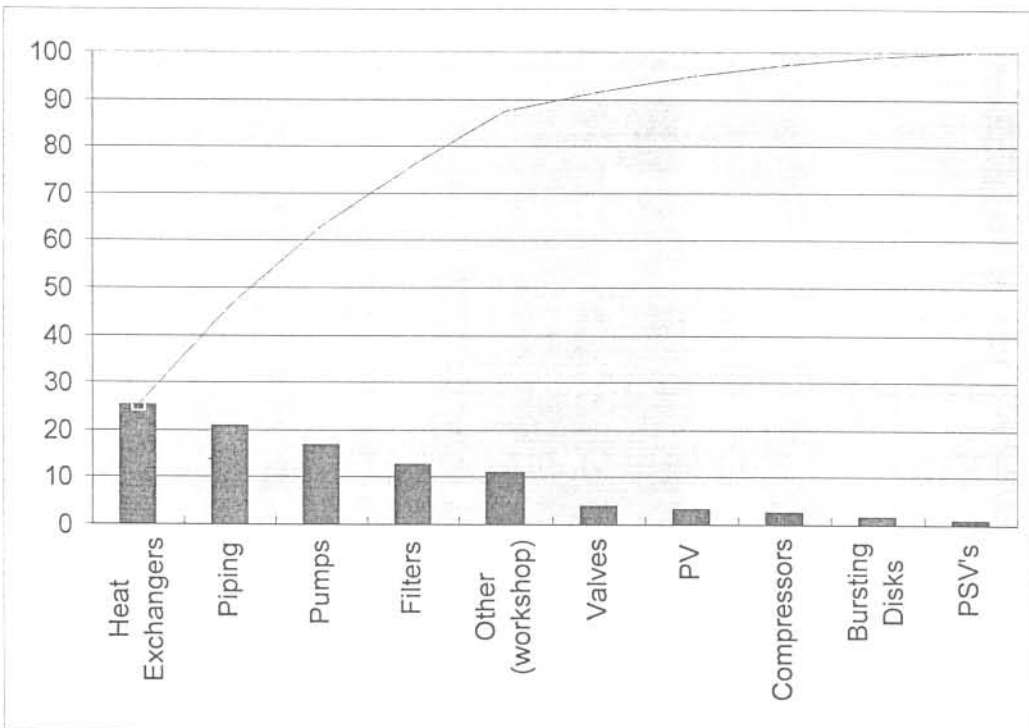


Figure 5-5: Life to date Pareto

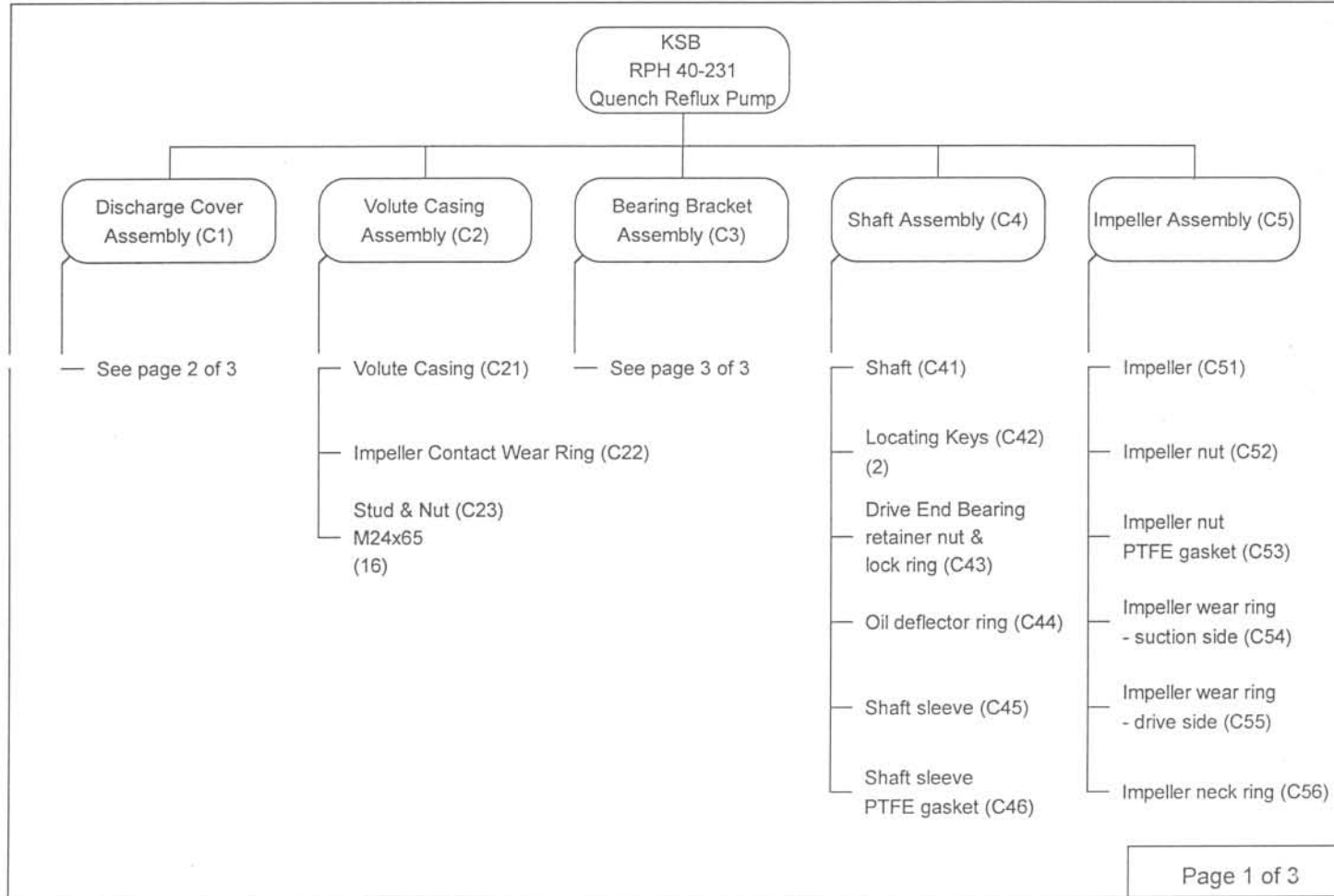


Figure 5-6: Pump breakdown structure

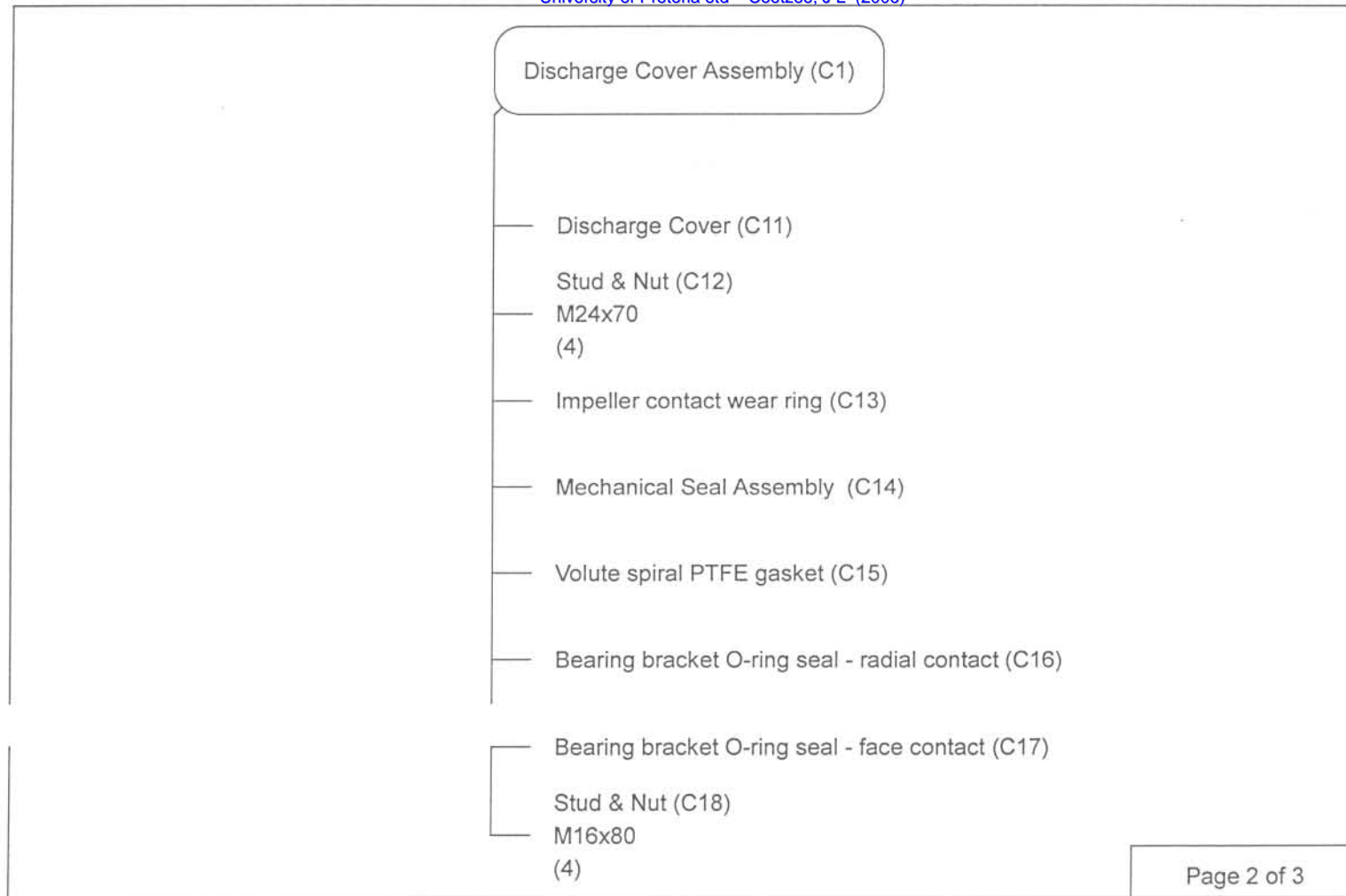


Figure 5-7: Pump breakdown structure

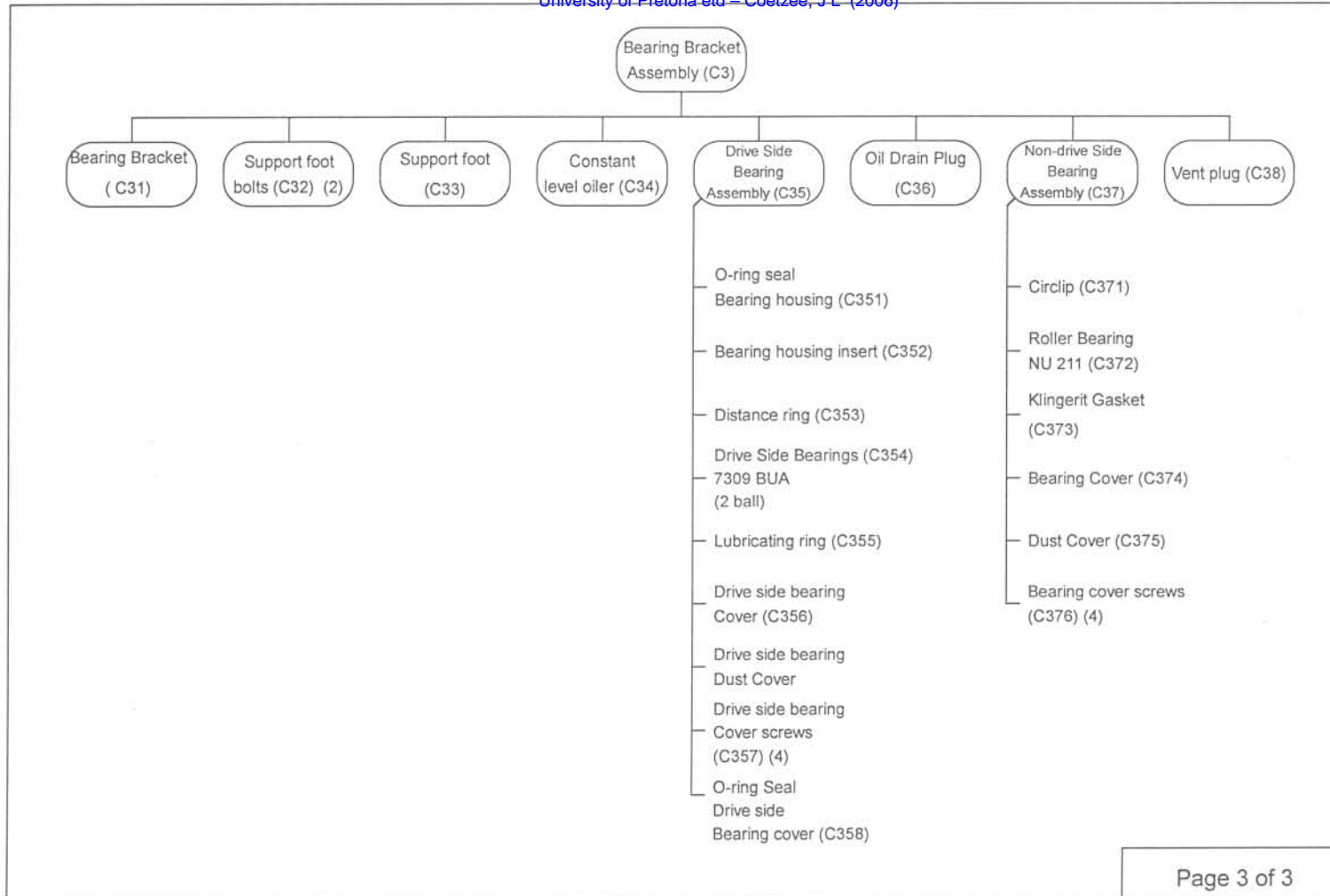


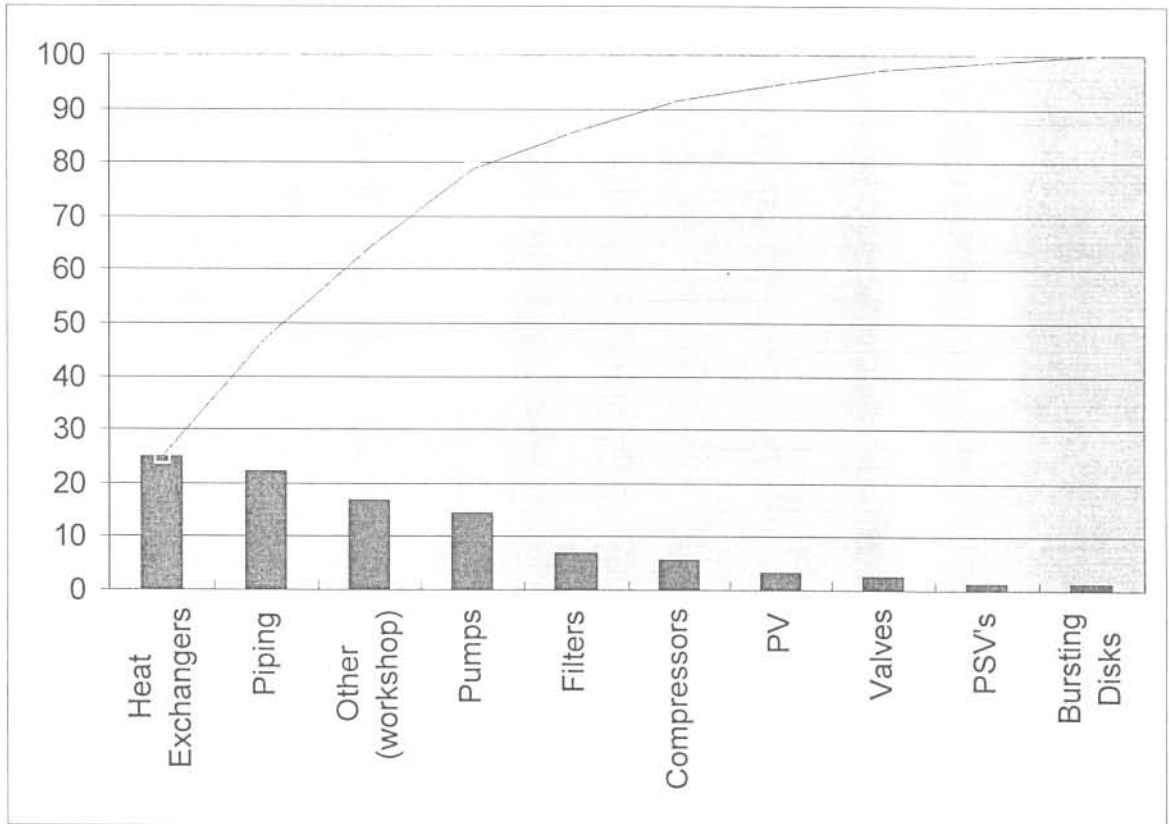
Figure 5-8: Pump breakdown structure

**Table 5.2: Order of importance for RCM analysis**

Year to Date	Life to Date
Heat Exchangers	Heat exchangers
Piping	Piping
Other (workshop)	Pumps
Pumps	Filters

It is clear that the original RCM effort should be expended on the heat exchangers, piping and pumps (in that order). Although the 'other' category plays a significant role in the costs, it consists of a conglomerate of cost items, and will have to be dealt with separately.

If one has the reliability and safety of plant at heart, a more complete risk analysis, based on the combination of cost, production loss and safety will have to be adopted. In this specific case, the plant management's goal was to reduce the cost of maintenance significantly using RCM analysis, as they were convinced that all the other risk factors are adequately dealt with using various other techniques.



**Figure 5-9: Year to date Pareto chart**

One of the outstanding contributors to high cost of maintenance was found to be a pair of pumps (one of the categories identified above), the GA-1402 A and B quench reflux pumps described in paragraph 5.1. These pumps have an average MTTF of 1,2 months, compared to the average MTTF of 28 months of all similar mechanical seal equipped pumps.

Figures 5-10 and 5-11 show the monthly and cumulative history of failures for the GA-1402 A and B pumps respectively, while figure 5-12 gives the combined history for both pumps.

In paragraph 5.1 it was stated that most of the work was on pump A, and the comment was made that, this fact could be insignificant, but that it could also point to the real problem. Figures 5-10 and 5-11 seem to reinforce this notion, as it is clear that pump A failed much more than pump B. However, when the two graphs are combined, as in figure 5-12, it becomes clear that this is not the case, as can be deduced from the stable inclination of the cumulative graph. Pump B is only used when pump A is not available, hence the lower number of breakdowns and the long periods of no breakdowns. An enquiry into the matter confirmed this deduction.

### GA-1402A Quench Reflux Pump

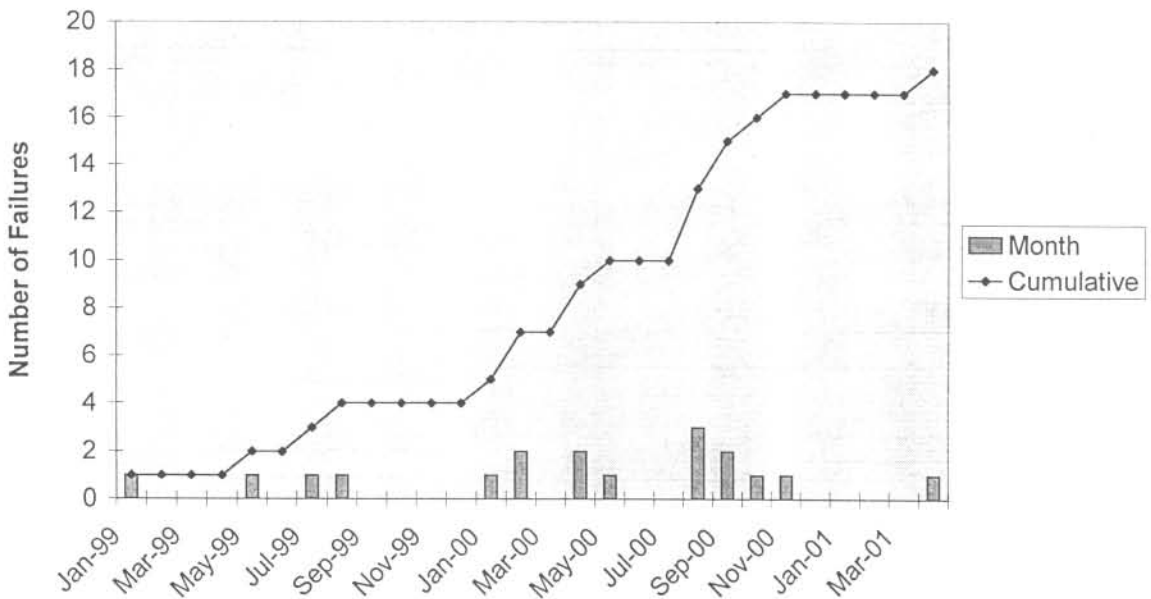


Figure 5-10: GA-1402A Quench Reflux Pump - number of failures

Although the full first stage of the funnelling process was not followed (a jump was made from the top Pareto analyses - figures 5-5 and 5-9 - to the GA-1402 pumps), it was done in enough detail by the plant's management<sup>1</sup> to show the worth of zooming in to the highest risk items. The next step is to identify the MSI's (Maintenance Significant Items) through the partitioning process of

<sup>1</sup> This was done as part of an RCM analysis under supervision of the author.

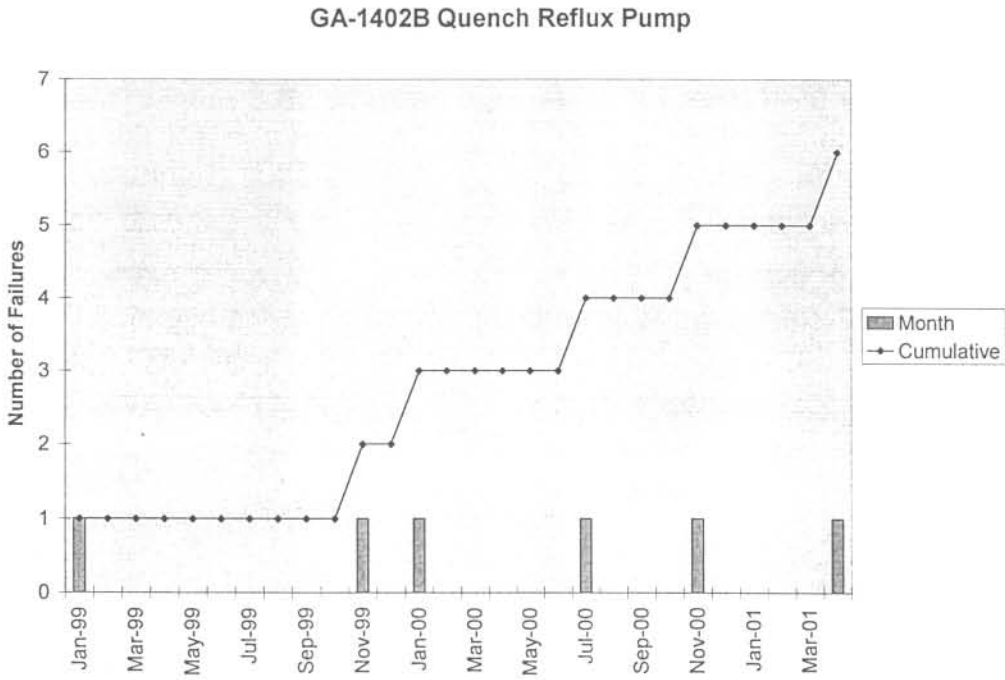


Figure 5-11: GA-1402B Quench Reflux Pump - number of failures

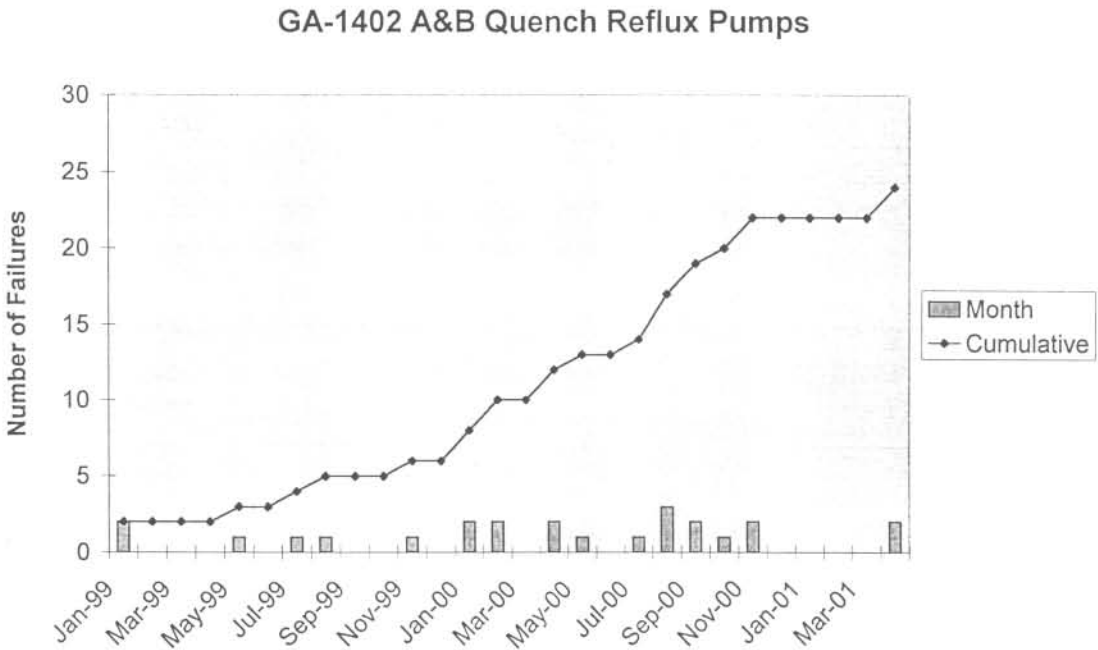


Figure 5-12: GA-1402 A&B Quench Reflux Pumps - number of failures

paragraph 4.3.2.4, using the diagram in figure 4-12. This was done in figures 5-6, 5-7 and 5-8, but in more detail than that envisaged using the *item breakdown decision diagram* shown in figure 4-12. The detail is important in this case, to illustrate a few concepts. Instead of interactively deciding on the proper level of analysis, using figure 4-12, the breakdown is done to the lowest level and then the best level(s) for the MSI's is chosen.

A coding system was used in figures 5-6 to 5-8 to uniquely identify each component as being part of the one above it. The top subassemblies, which make up the pump, was thus identified as being C1, C2, ..., C5 (C standing for 'component') (figure 5-6), while an example of a lowest level component (figure 5-8) is the 'Bearing Housing Insert' (C352), which is part of the 'Drive Side Bearing Assembly' (C35), which is part of the 'Bearing Bracket Assembly' (C3), which is one of the subassemblies making up the pump.

Because of the importance of the preservation of function in the RCM approach, it is expedient to define the function(s) of the pump. These were defined by the plant as:

*To pump liquid at the rated flow and rated delivery pressure*

**and**

*To contain the liquid being pumped*

The first of these describes the business function for which the pumps was chosen and purchased, while the second reflects the hazardous nature of the liquid being pumped. If any component has a significant bearing on either or both of these functions, then the component should be classified as significant. However, such effect should be verifiable from history or should be reasonably possible (where safety is involved).

It should be noted that no in-situ repair work is carried out on the pump. When a component fails, the pump is replaced by installing the spare unit, while the defective unit is repaired/rebuilt in the service workshops.

The name 'Maintenance Significant Item' implies firstly that the item is significant, that its failure matters at the system level. Remember the requirements for significance as specified by Nowlan and Heap (1978):

*The resultant level of MSI's should be low enough that no failure possibilities are overlooked, but high enough for the loss of function to have an impact on the equipment itself. (§ 4.3.2.4)*

Secondly, the failure of the item must have 'significant' safety and/or operational effects. To choose the correct MSI's from amongst the list of components, is consequently mostly a heuristic process, using a combination of historic information (table 5.1), the study of all the detailed information that was collected and the ability and experience of the analyst. This is not a process that lends itself to objective description and will also typically differ for each RCM analysis. This is one of the reasons why the organisation must have a well-trained and experienced RCM facilitator. RCM analyses cannot be performed by anyone. This is also the reason behind Nowlan and Heap (1978) and MSG-3 (1993)'s insistence on and accentuation of the importance of the critical evaluation of the resultant analysis result. Refer to paragraph 3.2.10 in this regard.

A set of reason codes was devised in this specific case to assist in the choice of MSI's and their prioritisation. This was done partly because figure 4-12 was not used (see explanation above) in the partitioning process, partly due to a scarcity of good failure history, and largely because of the need to make a heuristic process visible. These reason codes are as follows:

FE	Significant effect on pumping function (functional effect)
SE	Significant (proven)
PSE	Highly probable effect on containing function (safety)
NFE	No significant functional effect
NSE	No significant (or probable) safety effect
IR <sup>2</sup>	Installation requirement (if installed properly, it remains functional for the life of the pump)
LL	MSI's are defined at lower level

One normally does not use reason codes in this process, but decide on the MSI's during the partitioning process, using the principle as stated by the RCM handbook of the Naval Sea Systems Command (1983):

*"RCM is a methodology intended for use in developing ... **the preventive maintenance program for a ship**. If you are involved ... in the application of RCM, you should understand that intention. Otherwise, you may focus on some lesser level of assembly rather than **on how it, in concert with other hardware, provides all the function of the ship.**"* (accentuation added).

In the present analysis the reason codes are used in an attempt to make at least part of the thought process accompanying the analysis somewhat visible.

Table 5.3 lists the three levels of components, together with the choice of whether a specific component is significant or not, as well as the explanatory reason code. In this table a combination of the reasoning inherent in figure 4-12 and the prioritisation approach of § 4.3.2.5 is used to identify an item as being significant or not.

**Note:** If an item is significant, its parent level cannot be significant as well. For any specific item, a restrictive decision has to be made regarding its level of significance.

The last column comprises a type of pre-failure mode criticality allocation. Again, there is not a sufficient source of quantitative data to base the prioritisation on. The criticality allocation is thus not meant to be exact, but is a representation of the facts in the failure history (table 5.1), plus heuristic fuzzy data<sup>3</sup>. It shows that there are six components, for which decisions regarding

<sup>2</sup> This type of answer often flows from an RCM analysis. Although this does not add a task to the maintenance plan, it identifies a requirement that should be added to the installation/reconditioning/repair quality requirements for the unit. This is an important positive by-effect of the RCM analysis process.

<sup>3</sup> For this purpose the inputs of plant maintenance personnel was used in line with the methodologies of Moubray (1991) and Smith (1993).

the maintenance strategy must be taken. These are (in order of importance): Mechanical Seal, Drive End Bearings, Non-drive End Bearings, Impeller, Shaft and Pressure Envelope (Volute Casing and Discharge Cover). The 6<sup>th</sup> item (Pressure Envelope) is only included because of the safety implications, because the impeller should be worn long before the pressure envelope develops integrity problems). For each of these, the FMEA/FMECA is now completed, figure 4-15, resulting in the failure modes of these seven critical components.

Table 5.3: Prioritisation of MSI's

Component Number	Description	MSI?		Priority
		Y/N	Reason	
C1	Discharge Cover Assy	N	LL	
C11	Discharge Cover	Y	PSE	6
C12	Stud & Nut	N	NFE & NSE	
C13	Impeller wear ring	N	NFE & NSE	
C14	Mechanical Seal Assy	Y	SE	1
C15	Volute PTFE Gasket	N	IR	
C16	O-ring (radial contact)	N	IR	
C17	O-ring (face contact)	N	IR	
C18	Stud & Nut	N	NFE & NSE	
C2	Volute Casing Assy	N	LL	
C21	Volute Casing	Y	PSE	6
C22	Impeller Wear Ring	N	NFE & NSE	
C23	Stud & Nut	N	NFE & NSE	
C3	Bearing Bracket Assy	N	LL	
C31	Bearing Bracket	N	NFE & NSE	
C32	Support Foot Bolts	N	NFE & NSE	
C33	Support Foot	N	NFE & NSE	
C34	Constant Level Oiler	N	NFE & NSE	
C35	Drive Side Brg Assy	N	LL	
C351	O-ring Brg Housing	N	IR	
C352	Brg Housing Insert	N	NFE & NSE	
C353	Distance Ring	N	NFE & NSE	
C354	Drive Side Bearings	Y	FE & PSE	2
C355	Lubricating Ring	N	NFE & NSE	
C356	Drive Side Brg Cover	N	NFE & NSE	
C357	Drv S Brg Dust Cover	N	NFE & NSE	
C358	Drv S Brg Screws	N	NFE & NSE	
C359	O-ring Drv Side Cover	N	IR	

Table 5.3: Prioritisation of MSI's (continued)

Component Number	Description	MSI?		Priority
		Y/N	Reason	
C36	Oil Drain Plug	N	NFE & NSE	
C37	Non-drive Side Brg Assy	N	LL	
C371	Circlip	N	IR	
C372	Roller Bearing	Y	FE & PSE	3
C373	Klingerit Gasket	N	IR	
C374	Bearing Cover	N	NFE & NSE	
C375	Dust Cover	N	NFE & NSE	
C376	Brg Cover Screws	N	NFE & NSE	
C38	Vent Plug	N	NFE & NSE	
C4	Shaft Assembly	N	LL	
C41	Shaft	Y	FE	5
C42	Locating Keys	N	IR	
C43	Drv End Brg lock	N	IR	
C44	Oil Deflector Ring	N	NFE & NSE	
C45	Shaft Sleeve	N	NFE & NSE	
C46	Sleeve PFTE Gasket	N	IR	
C5	Impeller Assembly	N	LL	
C51	Impeller	Y	FE	4
C52	Impeller Nut	N	IR	
C53	Nut PFTE Gasket	N	IR	
C54	Impeller Wear Ring SS	N	NFE & NSE	
C55	Impeller Wear Ring DS	N	NFE & NSE	
C56	Impeller Neck Ring	N	IR	

The resultant FMEA is based on figure 4-15 and its associated text and is shown in figures 5-13 to 5-16. These analyses result in 13 failure modes, for which functional reference numbers were allocated. In practical RCM situations, these should now be prioritised using the methodology of paragraph 4.3.5. In this case, no such prioritisation is done, given the relatively small sample size. In this case the task analysis will thus be based on all 13 failure modes.

The failure consequence classification is done according to figure 4-23 and is shown in table 5.4. Due to the dangerous product pumped, most of these (critical) failure modes carry a Safety and Environmental Consequence classification.

**Table 5.4: Failure consequence evaluation**

FRef	Description	H	HO	S	O	NO
001	Mechanical Seal - barrier fluid pressure too low			X		
002	Mechanical Seal - barrier fluid pressure too high			X		
003	Mechanical Seal - wrong assembly/ installation			X		
004	Mechanical Seal - damage to graphite sealing faces			X		
005	Mechanical Seal - wear			X		
006	Drive Side Ball Bearing - failure			X		
007	Non-drive Side Roller Bearing - failure			X		
008	Impeller - does not rotate				X	
009	Impeller - wear				X	
010	Shaft - snapped				X	
011	Impeller Nut - loose			X		
012	Discharge Cover / Volute - integrity problems			X		

The task analysis is shown in figures 5-17 to 5-19. To illustrate how the methodology is used, the analysis process is described in some detail for a few lines of the analysis table. The first line is used as baseline description:

- Columns 1 and 2 are self-explanatory.
- Column 3 - Relative Risk - this column would carry the relative risk figure for prioritisation purposes (see § 4.3.5) - in this case, we are not using this column as was decided above.
- Column 4 (RC = Risk Check) is checked if the failure mode is to be analysed further due to its high level of relative risk (column 3) - in our case, all our failure modes will be investigated and will thus carry the risk check mark.
- Column 5 shows the Consequence Type, which for our first failure mode was shown to be 'Safety and Environmental' in table 5.4 above.
- Column 6 (Task Type) is completed using an appropriate task analysis tree. In this case the appropriate tree will be Task Decision Tree 1 (figure 4-19 - rigorous tree without truncation - this choice is made by consulting figure 4-23). Because this is an operational issue, lubrication and/or servicing is not applicable but quality improvement is. Refer to tables 4.3 and 4.4 regarding the applicable feasibility characteristics. A quality improvement task is selected, with as content 'Monitor fluid pressure - do a check on barrier fluid pressure (2 700 kPa)' (columns 8 and 9). The technical requirement (table 4.3) is that the task must reduce the risk to a low enough level - the present task will do this in the opinion of the plant personnel.

# Reliability Centred Maintenance Analysis - FMEA

University of Pretoria et al - Coetzee, J.L. (2006)

**System:** GA-1402 A&B  
**Reference:**

**Analyst:** Jasper Coetzee  
**Date:** 2001-09-22

**Reviewer:**  
**Rev. No.:** 0

**Approved:**  
**Page** 1 **of** 4

**System Function:** Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

XRef	Item	Function	Functional Failure	Failure Mode	FC	Comments	FRef
C14	Mechanical Seal	To protect people and the environment	Seal leaks	Barrier Fluid pressure too low	<input checked="" type="checkbox"/>	Happens when barrier fluid (seal oil) system is not charged to the pre-set pressure of 2700 kPa	001
				Barrier Fluid pressure too high	<input checked="" type="checkbox"/>	When barrier fluid is pre-charged to too high pressure	002
				Wrong assembly/ installation	<input checked="" type="checkbox"/>		003

FRef	001	002	003
<b>Local</b>	Product pressure passes O-rings and/or seal faces, damages seal faces, enters seal enclosure.	Damage to both (product side and atmosphere side) seals.	Damage to seals, product enters.
<b>System</b>	Damage to accumulator	Barrier fluid leak	Damage to accumulator
<b>Unit</b>	Possibility of venting product to atmosphere.	Possibility of venting product to atmosphere.	Possibility of venting product to atmosphere.

Figure 5-13: FMEA - GA 1402 A&B Sheet 1

## Reliability Centred Maintenance Analysis - FMEA

System: GA-1402 A&amp;B

Analyst: Jasper Coetzee

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System Function: Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

XRef	Item	Function	Functional Failure	Failure Mode	FC	Comments	FRef
C14	Mechanical Seal (continue)	To protect people and the environment	Seal leaks	Damage to graphite sealing faces	<input checked="" type="checkbox"/>	Grooves/marks caused by product entering	004
		To contain the product	Same as above	Wear	<input checked="" type="checkbox"/>		005
				Same as ref 001 to 005 above, but less critical	<input checked="" type="checkbox"/>		
				<input checked="" type="checkbox"/>			
<input checked="" type="checkbox"/>							
<b>FRef</b>	<b>004</b>	<b>005</b>					
<b>Local</b>	Product pushes back face spring mechanism, which 'hangs up'. Product flows through freely.	Product enters					
<b>System Unit</b>	Damage to accumulator Possibility of venting product to atmosphere	Damage to accumulator Vent product to atmosphere					

Figure 5-14: FMEA - GA 1402 A&amp;B Sheet 2

## Reliability Centred Maintenance Analysis - FMEA

**System:** GA-1402 A&B

**Analyst:** Jasper Coetzee

**Reviewer:**
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**Reference:**
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**Rev. No.:** 0

**Page** 3 **of** 4

**System Function:** Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

XRef	Item	Function	Functional Failure	Failure Mode	FC	Comments	FRef
C354	Drive Side Bearings	To support pump shaft, facilitate its rotation	Fails to support shaft; fails to facilitate rotation	Wear; seizure*	<input checked="" type="checkbox"/>	Both failure modes lead to same effects	006
C372	Non-drive Side Roller Bearing	To support pump shaft, facilitate its rotation	Fails to support shaft; fails to facilitate rotation	Wear; seizure*	<input checked="" type="checkbox"/>	Both failure modes lead to same effects	007
C51	Impeller	To pump product	Fails to pump product	Does not rotate	<input checked="" type="checkbox"/>	Bearing/external reason related	
				Vane wear	<input checked="" type="checkbox"/>		008
				Wear ring wear	<input checked="" type="checkbox"/>		009

FRef	006	007	008	009
<b>Local</b>	Bearing Failure	Bearing Failure	Does not displace product	Product bypass
<b>System</b>	Shaft failure; product leaks due to mechanical seal failure.	Shaft failure; product leaks due to mechanical seal failure.	No/weak product output	Inefficiency
<b>Unit</b>	Vent product to atmosphere	Vent product to atmosphere	Plant performance degradation	Plant performance degradation

Figure 5-15: FMEA - GA 1402 A&B Sheet 3

## Reliability Centred Maintenance Analysis - FMEA

System: GA-1402 A&amp;B

Analyst: Jasper Coetzee

Reviewer:

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Rev. No.: 0

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System Function: Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

XRef	Item	Function	Functional Failure	Failure Mode	FC	Comments	FRef
C51	Shaft	To transfer power to impeller	No power transfer	Snapped shaft	<input checked="" type="checkbox"/>		010
				Impeller nut loose	<input checked="" type="checkbox"/>		011
C11	Discharge Cover	To contain product	Lack of integrity	Wear; Corrosion	<input checked="" type="checkbox"/>		012
C21	Volute	To contain product	Lack of integrity	Wear; Corrosion	<input checked="" type="checkbox"/>	See FRef 013	

FRef	010	011	012
Local	No rotation	No effect	Product leak
System	No product pumped	Gasket between impeller / shaft sleeve fails - leaks between sleeve and shaft - product by-passes mechanical seal.	Product leak
Unit	Plant production stoppage	Fire hazard	Vent product to atmosphere

Figure 5-16: FMEA - GA 1402 A&amp;B Sheet 4

The fact that the failure consequences are 'safety and environment' makes financial feasibility of less importance (table 4.4), but the present task fulfils this requirement fully. Because this is a tree without truncation the preventive task types 'On Condition', 'Recondition' and 'Replace' must also be considered, but these are not technically feasible due to the operational nature of the failure mode. The last block in the decision tree then requires that the best task combination be sought, which in this case only consists of this one task.

- Column 7 (Trade-off study number) - no trade-off study is necessary as the financial feasibility is clear.
- Columns 8 and 9 (Task descriptions) - refer to discussion on column 6 above.
- Column 10 (task combination check column) - this task is checked because it is part of the best task combination (see discussion on column 6 above). Following the default analysis (figure 4-23), this is confirmed by a circle around the check block - only tasks with encircled check boxes will be included in the eventual maintenance plan.
- Column 11 (task frequency) - this carries one of the organisation's standard task frequency symbols (in this case 'S') for once per shift. This list of task frequency symbols for the specific organisation is as follows:

Frequency Symbol (F)	Description
S	Once per shift
D	Daily
W	Weekly
M	Monthly
Q	Quarterly
HY	Half Yearly
Y	Yearly
B	Bi-annually
H	Hourly basis (specify period in description)
3Y	Three yearly
6Y	Six yearly

- Column 12 (Trade) is 'O' for 'operator'. The trade list is:

Trade Symbol (T)	Description	Trade Symbol (T)	Description
B	Boilermaker	O	Operator
CM	Condition Monitor	PE	Production Engineer
EN	Engineer	R	Rigger
E	Electrician	W	Welder
F	Fitter		

## Reliability Centred Maintenance Analysis - Task Analysis

System: GA-1402 A&amp;B

Analyst: Jasper Coetzee

Reviewer:

Approved:

Reference:

Date: 2001-09-22

Rev. No.: 0

Page 1 of 3

**System Function:** Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

FRef	Failure Mode	RR	RC	Cons Type	Task Type	TO	Task	Task Detail	TC	F	T	ST	P	SG
001	Mech Seal - barrier fluid pressure low		<input checked="" type="checkbox"/>	S	QI		Monitor fluid pressure	Do a check on barrier fluid pressure (2 700 kPa)	<input checked="" type="checkbox"/>	S	O		P	OS
002	Mech Seal - barrier fluid pressure high		<input checked="" type="checkbox"/>	S	QI		Repeat of task above	Repeat of task above	<input type="checkbox"/>					
003	Mech Seal - wrong assembly/installation		<input checked="" type="checkbox"/>	S	QI		Improve procedures - see also FRef 011, FRef 012.	Draw up, implement and enforce improved assembly/installation procedures - must solve problem.*	<input checked="" type="checkbox"/>		EN			
004	Mech Seal - damage to sealing faces		<input checked="" type="checkbox"/>	S	QI		Investigate source of solids	Do a full investigation into the source of light solids in the pumped product - must solve problem. <sup>1</sup>	<input checked="" type="checkbox"/>		PE			

\* Reinforce this through a quality control plan with checkpoints for critical tolerances and manufacturing quality inspection.

<sup>1</sup> Reinforce this through a quality control plan with checkpoints for achieving success.

Figure 5-17: Task Analysis - GA 1402 A&B Sheet 1

**System:** GA-1402 A&B  
**Reference:**

**Analyst:** Jasper Coetzee  
**Date:** 2001-09-22

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**System Function:** Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

FRef	Failure Mode	RR	RC	Cons Type	Task Type	TO	Task	Task Detail	TC	F	T	ST	P	SG
005	Mech Seal - Wear		<input checked="" type="checkbox"/>	S	OC		Inspect	Do a visual inspection of pump - check for fluid, product leaks.	<input checked="" type="checkbox"/>	W	F		P	TW
			<input type="checkbox"/>		Rep		Replace	Replace seal with new unit every 163 days. This brings seal cost down from present R 235,02 / day to R 89,60 /day.	<input checked="" type="checkbox"/>	89 days	F		P	
006	Drive Side Bearing Failure		<input checked="" type="checkbox"/>	S	LSA		Check	Open vent plug, check oil level, top up, take sample, send for analysis.	<input checked="" type="checkbox"/>	M	F		P	TM
			<input type="checkbox"/>		OC		Vibration check	Measure vibration using FFT Analyser	<input checked="" type="checkbox"/>	W	CM		P	CW
007	Non-drive Side Bearing Failure		<input checked="" type="checkbox"/>	S			Same as for drive side bearing	Same as for drive side bearing	<input type="checkbox"/>					

Figure 5-18: Task Analysis - GA 1402 A&B Sheet 2

# Reliability Centred Maintenance Analysis - Task Analysis

University of Pretoria etd - Coetzee, J.L. (2006)

**System:** GA-1402 A&B

**Analyst:** Jasper Coetzee

**Reviewer:**

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**System Function:** Quench reflux pump in the VCM (Vinyl Chloride Monomer) plant of Sasol Polymers

FRef	Failure Mode	RR	RC	Cons Type	Task Type	TO	Task	Task Detail	TC	F	T	ST	P	SG
008	Impeller - Vane wear		<input checked="" type="checkbox"/>	O	OC		Check pump performance	Check output pressure, talk to operations personnel.*	<input checked="" type="checkbox"/>	W	F		P	TW
009	Impeller - ring wear		<input type="checkbox"/>				Same as 008	Same as 008	<input type="checkbox"/>					
010	Snapped shaft		<input checked="" type="checkbox"/>	O			Same as for FRef 006 and 007	Same as for FRef 006 and 007 - otherwise corrective maintenance	<input type="checkbox"/>					
011	Impeller nut loose		<input checked="" type="checkbox"/>	S	QI		See FRef 003	See FRef 003 - care should be taken that steps lead to complete elimination of problem.	<input type="checkbox"/>					
012	Wear, corrosion of outer casing		<input checked="" type="checkbox"/>	S	QI		See FRef 003	See FRef 003 - inspection standards for inspection of outer casing should be of such high standard that leaks due to wear, corrosion never occurs.	<input type="checkbox"/>					

\* If in doubt, switch over to standby pump, check results. If pump performance sub-standard, fit spare unit, send old unit for rebuild.

**Figure 5-19: Task Analysis - GA 1402 A&B Sheet 3**

University of Pretoria etd – Coetzee, J L (2006)

- Column 13 (Set-up type) - see § 4.3.9. In this case, no set-up is required, because of the operational nature of the failure mode, requiring only a visual check.
- Column 14 (Production Indicator) - refer to § 4.3.9 - the present work can be done during production.
- Column 15 (Schedule Group) - This is a unique check, requiring an own schedule group (see the discussion in § 4.3.9). The scheduling groups are:

Schedule Group	Description
CW	Condition Monitor Weekly
CM	Condition Monitor Monthly
OS	Operator once per shift
OW	Operator weekly
TD	Tradesman daily
TW	Tradesman weekly
TM	Tradesman monthly
TQ	Tradesman Quarterly
TY	Tradesman Yearly

Additional comments regarding the task analysis process (figures 5-17 to 5-19) are given in an open tabular format:

FRef	Comment
002	Use RCM Task Decision Tree 2 (figure 4-20) per figure 4-23
003	Use RCM Task Decision Tree 1 (figure 4-19) per figure 4-23 No schedule group as it is a one off project type task
004	Use RCM Task Decision Tree 1 (figure 4-19) per figure 4-23 No schedule group as it is a one off project type task
005	Use RCM Task Decision Tree 1 (figure 4-19) per figure 4-23 Utilise both On Condition and Reconditioning tasks Laplace Test = 1,7321 $\equiv$ Renewal / Moderate Degradation Weibull fit $\beta=1,445$ ; $\eta=40,296$ days; Model Accuracy = 90,76% Cost of failure repair, $C_f$ and that of preventive repair, $C_p$ is identical at R 5 500 : thus use based prevention (reconditioning) is not an option. Alternative NHPP fit $\alpha_0=-4,662$ ; $\alpha_1=0,00303172$ , Model Accuracy = 88,10%. Cost of repair $C_f = R 5 500$ . Cost of seal replacement $C_p=R 9104,50$ .

Optimal policy = replace seal every 163 days @ R 89,60 / day  
 Run to failure policy costs R 235,02 / day.

- 006 Use RCM Task Decision Tree 1 (figure 4-19) per figure 4-23
- 007 Repeat of FRef 006
- 008 Use RCM Task Decision Tree 2 (figure 4-20) per figure 4-23
- 009 Repeat of FRef 008
- 010 Use RCM Task Decision Tree 2 (figure 4-20) per figure 4-23  
 Same as for FRef 006 and 007 - otherwise corrective maintenance
- 011 Use RCM Task Decision Tree 1 (figure 4-19) per figure 4-23  
 Extension of FRef 003 - care should be taken that steps lead to complete elimination of problem.
- 012 Use RCM Task Decision Tree 1 (figure 4-19) per figure 4-23  
 Extension of FRef 003 - inspection standards for inspection of outer casing should be of such high standard that leaks due to wear, corrosion never occurs.

### 5.3. Comparison of results

The result of a 'classical' RCM analysis is an array of maintenance tasks, mostly of a preventive nature, grouped together in a logical maintenance plan, which, if rigorously performed, will lead to improved productivity of production machinery. The proposed method widens the scope of RCM somewhat to include repair and non-maintenance quality improvement tasks. This is very compatible with the practices sought by general industry.

Table 5.5 compares the task outputs from RCM 2 (which is really one of the best examples of 'classical' RCM) and the new proposed improved method. For this purpose, use is made of the failure modes identified using the proposed improved technique, as the 'classical' analysis was done using many 'maybe' failure modes. This makes it difficult to compare the two techniques on an even footing - however, the comparison still provides a worthwhile, albeit limited, insight into the relative worth of the two techniques.

A further complication is that it seems as though the RCM 2 analysis was done by a somewhat inexperienced RCM analyst, which makes comparison even more difficult. The various comments should thus not be seen as criticisms of RCM 2, but are primarily aimed at showing the improvement potential of the proposed method above 'classical' RCM and secondarily to show the typical analysis errors made by inexperienced analysts. This again stresses the need for well-trained and experienced analysts.

A full comparison between the proposed technique, 'classical' RCM and the TUE method are left for the closure (chapter 6).

Table 5.5: Comparison between 'Classical' RCM and the Proposed Improved Method

Failure Mode	'Classical' RCM		Proposed Improved Method	
	Task	Comments	Task	Comments
Barrier Fluid pressure too low	Artisan to inspect oil system fittings every morning for leaks.	This is a reactive task.	Operator to do a check on barrier fluid pressure (2 700 kPa) once per shift.	This is a proactive task, which can lead to one of the reactive tasks identified by 'Classical' RCM if necessary.
	Various installation checks, and corrective tasks.	Unfortunately these will have no effect unless transferred to standard installation procedures and training.*		
Barrier Fluid pressure too high	Not identified as failure mode.		Same task as above.	
Wrong assembly / installation of mechanical seal.	Various loosely identified assembly / installation problems. Examples are lines 1A4, 1A8, 1A9, 1A12, 2A3, 2A5, 2B1, 2B2, 3A1 and 3A4 in the seal RCM Decision Worksheet.	Refer to comment marked * above.	Section engineer to draw up, implement and enforce improved assembly / installation procedures - these must be such that they solve the (safety) problems.	Again the approach is very proactive. This approach extends to the assembly / installation of the pump (FRef 011, FRef 012).#

Table 5.5: Comparison between 'Classical' RCM and the Proposed Improved Method (continued)

Failure Mode	'Classical' RCM		Proposed Improved Method	
	Task	Comments	Task	Comments
Operational damage to the sealing faces of the mechanical seals.	Replace the mechanical seal (reaction).	Refer to lines 1A2 and 1A11 in the seal RCM Information Worksheet (pages 5-38 and 5-39) and the corresponding lines in the RCM Decision Worksheet (page 5-42).	Production engineer to do a full investigation into the source of light solids in the pumped product - must solve problem.	The problem is tackled at its root and the requirement is that it must be solved (proactive-ness).
Wear of the mechanical seal faces.	No preventive task identified (line 1A1 on pages 5-38 and 5-42).	Daily visual inspection (line 1A7) should cover this problem. Question is whether daily visual is necessary and practical.	Fitter to do a weekly visual inspection of pump - check for fluid, product leaks	This action does not only cover this failure mode, but is also a very logical act of 'care' for the whole pump installation.
			Replace seal with new unit every 163 days.	This brings seal cost down from present R 235,02 / day to R 89,60 /day.

**Table 5.5: Comparison between 'Classical' RCM and the Proposed Improved Method (continued)**

Failure Mode	'Classical' RCM		Proposed Improved Method	
	Task	Comments	Task	Comments
Drive Side Bearing Failure	No preventive action apart from 'lubricate as per schedule' (line 1A6, pages 5-35 and 5-37).	Question is: what is schedule? It is certainly something that has to be specified during the RCM analysis?	Fitter to open vent plug monthly, check oil level, top up, take oil sample, send for analysis plus Condition Monitor to measure vibration weekly using FFT Analyser.	Strategy includes two condition based tasks - a weekly vibration analysis and a monthly oil analysis, plus a 'care' check. This should suffice to virtually eliminate bearing caused failures.
Non-drive Side Bearing Failure	Same as above.		Same as above.	
Impeller vane wear.	Corrective Maintenance (line 1A2, pages 5-35 and 5-37).	The failure effect states that this condition can cause serious pump damage - nevertheless, no preventive action is specified.	Fitter to weekly check the pump's output pressure, and talk to operations personnel, and take action based on performance.	This approach will improve the credibility of the maintenance function considerably.
Impeller ring wear.	Same as above.		Same as above.	
Snapped Shaft	Not identified as failure mode, although it has definitely happened before.		Refer to maintenance actions specified for bearing failures. Otherwise Corrective Maintenance	

<b>RCM II - Information Worksheet</b>	<u>Item</u> Single Stage Centrifugal Pumps	<u>No.</u> 1	<u>Compiled by:</u> Owen Meredith	<u>Date:</u> 27/11/97	<u>Sheet</u> 1
	<u>Component</u> All	<u>Rev</u> 0	<u>Reviewed by:</u>	<u>Date:</u>	<u>Of</u> 2

	Function		Functional Failure		Failure Mode (Cause of Failure)	Failure Effect (What happens when it fails)
1	To pump a liquid at a rate Q and at a pressure P	A	Fails to pump at required rate Q and / or pressure P	1	Blocked suction strainer	Dirty liquid blocks strainer, will get low or no discharge and pump will trip on low flow (current).
				2	Worn pump wet parts	Dirty liquid and/or low/high pH will cause wear on pump's internal wetted parts which will adversely affect the pump's Q and P performance and could lead to serious pump damage.
				3	Faulty non-return valve	Dirty liquid (ferric or tars) can cause the valve to stick open, will then get flow through the spare pump, will get poor Q and P performance and can lead to loosening of the spare pump's impeller, OR can cause the valve to stick closed which will trip the motor on low flow.
				4	Pump runs in wrong direction	Caused by incorrect electrical wiring at installation, usually no effect if changed quickly but if left, can lead to serious pump failure as the impeller loosens leading to leak through the sleeve.
				5	Incorrect assembly	Using the incorrect impeller / old, worn or the wrong gaskets / using parts which are of an incorrect material / inaccurate clearances from assembly, these will give the pump poor Q and P performance and will lead to leaks or ultimately serious pump damage.
				6	Bearing failure	Misalignment / lack of lubrication / normal wear and tear / product ingress of bearing / cavitation / assembly errors or wrong bearings installed, all lead to bearing failure; damaged seals; leaks and potentially serious pump failure.
				7	Incorrect electrical settings: high / low / no flow or temperature trips	No protection on the pump can lead to serious pump failure OR overprotection on the pump will stop the pump from reaching it's desired operating condition.

<b>RCM II - Information Worksheet</b>	<u>Item</u> Single Stage Centrifugal Pumps	<u>No.</u> 1	<u>Compiled by:</u> Owen Meredith	<u>Date:</u> 27/11/97	<u>Sheet</u> 2
	<u>Component</u> All	<u>Rev</u> 0	<u>Reviewed by:</u>	<u>Date:</u>	<u>Of</u> 2

	Function		Functional Failure		Failure Mode (Cause of Failure)	Failure Effect (What happens when it fails)
				8	Process instrument failure	If the supply vessel level or pressure instruments fail, the pump will trip on low flow
				9	Worn / corroded / missing orifice in minimum bypass line	Process won't get the desired Q and P and the pump will trip on high flow
				10	Blocked minimum bypass line	Solids blocking the minimum bypass line will cause the pump to trip on low flow.
				11	Isolated bypass	Pump will trip on low flow when main delivery valve is closed.
2	To contain the liquid	A	Fails to contain the liquid	1	Pump leaks due to incorrect assembly	Wrong or worn gaskets used can lead to a leak and potential SHE consequences.
				2	Corroded volute or back plate	If the wrong spares are installed or the process conditions go out of spec (pH), the pump internals could get corroded and lead to a leak, with the aligned SHE consequences.
				3	Failed mechanical seal	Refer to RCM analysis of mechanical seals.

<b>RCM II - Decision Worksheet</b>	<b>Item</b> Single Stage Centrifugal Pumps	<b>No.</b> 1	<b>Compiled by:</b> Owen Meredith	<b>Date:</b> 27/11/97	<b>Sheet</b> 1
	<b>Component</b> All	<b>Rev</b> 0	<b>Reviewed by:</b>	<b>Date:</b>	<b>Of</b> 1

Information Reference			Consequence Evaluation				H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	Default Tasks			Proposed Task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O				H4	H5	S4			
1	A	1	Y	N	N	Y	N	N	N				Check strainer for any pump maintenance or if pump trips on low flow	On cond'n	Process
1	A	2	Y	N	N	N	Y						Repair when it breaks	On cond'n	Artisan
1	A	3	Y	N	N	N	Y						Repair when it fails	On cond'n	Artisan
1	A	4	Y	N	N	N	Y						Follow commissioning instructions	Commissioning	Elec/Artisan
1	A	5	Y	N	N	N	Y						Follow assembly procedures	Maintenance	Artisan
1	A	6	Y	N	N	N	Y						Follow installation and assembly procedures, lubricate as per schedule.	As per schedule	Artisan
1	A	7	Y	N	Y		Y						Follow installation procedures else check as per schedule.	Installat'n 6 Monthly	Electrician Artisan
1	A	8	Y	N	Y		Y						Check instruments as per schedule	Schedule	Instrument
1	A	9	Y	N	N	N	Y						Close min. bypass valve in event of low flow, if flow corrects, control min. bypass flow with isolation valve and repair orifice at shutdown.	On cond'n / shut-down	Artisan
1	A	10	N				N	N	N	N	N		Follow low flow trip procedure	On cond'n	Artisan
1	A	11	Y	N	N	N	Y						Follow low flow trip procedure	On cond'n	Artisan
2	A	1	Y	N	N	Y	Y						Follow assembly procedures correctly	Assembly	Artisan
2	A	2	Y	Y			N	N	N				Change wet end materials of construction as required	On cond'n	Artisan
2	A	3	Y	Y			Y						Replace the seal	On cond'n	Artisan

<b>RCM II - Information Worksheet</b>	<u>Item</u> Normal Double Balanced Mechanical Seals	<u>No.</u> 1	<u>Compiled by:</u> Owen Meredith	<u>Date:</u> 12/11/97	<u>Sheet</u> 1
	<u>Component</u> All	<u>Rev</u> 1	<u>Reviewed by:</u>	<u>Date:</u>	<u>Of</u> 4

	Function		Functional Failure		Failure Mode (Cause of Failure)	Failure Effect (What happens when it fails)
1	To prevent leaks of product to the environment where shaft enters a pump/ agitator casing	A	Fails to seal effectively	1	Normal wear and tear	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				2	Excessive wear and tear due to dirty product	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				3	Seal faces jam after pump has stood for a time with dirty product in it's casing	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				4	Incorrect seal setting	Possible heat generation leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				5	Incorrect 'O' ring used (material)	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				6	Wrong oil used	Leads to 'O' ring failure and loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak, also results in possible leak of incompatible oil into product stream.
				7	Excessive shaft vibration	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				8	Seal faces not set square to each other	This is an installation error, you may lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.

<b>RCM II - Information Worksheet</b>	<u>Item</u> Normal Double Balanced Mechanical Seals	<u>No.</u> 1	<u>Compiled by:</u> Owen Meredith	<u>Date:</u> 12/11/97	<u>Sheet</u> 2
	<u>Component</u> All	<u>Rev</u> 1	<u>Reviewed by:</u>	<u>Date:</u>	<u>Of</u> 4

Function	Functional Failure	Failure Mode (Cause of Failure)	Failure Effect (What happens when it fails)
		9 Incorrect or worn sleeve used	Incorrect seal setting / 'O' ring is ineffective, you then lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		10 Incorrect seal face used (material)	Will get excessive wear and tear, heat generation, possible fore risk and will lead to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		11 Cavitation, pressure fluctuation	Seal faces 'bounce' leading to loss of buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		12 Too much shaft float	Due to the wrong setting on the seal faces, will lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		13 Impeller gasket or 'O' ring fails	Seal is in normal, good condition, but product leaks along shaft under sleeve.
2 To maintain a positive pressure (100 kPa higher than pump discharge pressure) on the lubrication system to lubricate the seal faces	A Fails to maintain a positive pressure	1 Leaking lubrication system fittings	Will get an oil pressure drop leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		2 Worn seal (see 1.A.*)	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.

<b>RCM II - Information Worksheet</b>	<b>Item</b> Normal Double Balanced Mechanical Seals	<b>No.</b> 1	<b>Compiled by:</b> Owen Meredith	<b>Date:</b> 12/11/97	<b>Sheet</b> 3
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Function	Functional Failure	Failure Mode (Cause of Failure)	Failure Effect (What happens when it fails)
		3 Accumulator fails	Bladder fails then the oil system can't fluctuate with temperature or compensate for pressure losses, leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		4 Nitrogen pressure drops	Oil pressure drops, leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		5 Non-return fails on the oil system	Oil pressure drops, leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		6 Compression plate gasket fails	Oil leaks to the environment, oil pressure drops, leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
	B Fails to provide lubrication to the faces	1 Incorrect oil used	Oil pressure drops, leading to loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		2 Oil pressure drops away, see 2.A.*	Lose the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
		3 Air trapped in oil system	Will have no or ineffective oil circulation, temperature increase, pressure increase, excessive leakage of oil into product side, and ultimately loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.

<b>RCM II - Information Worksheet</b>	<u>Item</u> Normal Double Balanced Mechanical Seals	<u>No.</u> 1	<u>Compiled by:</u> Owen Meredith	<u>Date:</u> 12/11/97	<u>Sheet</u> 4
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	Function		Functional Failure		Failure Mode (Cause of Failure)	Failure Effect (What happens when it fails)
3	To cool the seal faces	A	Does not effectively cool the seal faces, allows heat generation on the faces	1	Incorrect pump scroll used	Will have no or ineffective oil circulation, temperature increase, pressure increase, excessive leakage of oil into product side, and ultimately loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				2	Cooling water drops away	Temperature increase, pressure increase, excessive leakage of oil into product side, and ultimately loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				3	Cooling fins blocked or dirty	Temperature increase, pressure increase, excessive leakage of oil into product side, and ultimately loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
				4	Air trapped in the oil system	Will have no or ineffective oil circulation, temperature increase, pressure increase, excessive leakage of oil into product side, and ultimately loss of the buffer liquid pressure leading to product entering the buffer liquid and ultimately to an environmental leak.
4	To provide a pressure and level alarm	A	Fails to alarm when required	1	Instrument failure	This is a hidden failure which could lead to an environmental excursion

<b>RCM II - Decision Worksheet</b>	<u>Item</u> Normal Double Balanced Mechanical Seals	<u>No.</u> 1	<u>Compiled by:</u> Owen Meredith	<u>Date:</u> 12/11/97	<u>Sheet</u> 1
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Information Reference			Consequence Evaluation				H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	Default Tasks			Proposed Task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O			H4	H5	S4				
1	A	1	Y	N	N	N	Y						When oil pressure drops, replace the mechanical seal	On cond'n	Artisan
1	A	2	Y	N	N	N	Y						When oil pressure drops, replace the mechanical seal	On cond'n	Artisan
1	A	3	Y	N	N	N	Y						Drain the pump when not in use	On cond'n	Process
1	A	4	Y	N	N	N	Y						Make seal setting a hold point during seal installation procedure	Seal installat'n	Artisan
1	A	5	Y	N	N	N	Y						When oil pressure drops, replace the mechanical seal	On cond'n	Artisan
1	A	6	Y	N	N	N	Y						'O' ring correctness to be checked	Delivery	Spares Co.
1	A	7	Y	N	N	N	Y						Do visual inspections / Do vibration analyses	Morning / Monthly	Artisan
1	A	8	Y	N	N	N	Y						Make the face 'squareness' a hold point in the assembly procedure	Seal installat'n	
1	A	9	Y	N	N	N	Y						Make the sleeve correctness a hold point in the assembly procedure	Seal installat'n	
1	A	10	Y	N	N	N	Y						Seal face correctness to be checked	Delivery	Spares Co.
1	A	11	Y	N	N	N	Y						When oil pressure drops, replace the mechanical seal	On cond'n	Artisan
1	A	12	Y	N	N	N	Y						Make shaft float a hold point in the assembly procedure	Seal installat'n	Artisan

<b>RCM II - Decision Worksheet</b>	<b>Item</b> Normal Double Balanced Mechanical Seals	<b>No.</b> 1	<b>Compiled by:</b> Owen Meredith	<b>Date:</b> 12/11/97	<b>Sheet</b> 2
	<b>Component</b> All	<b>Rev</b> 1	<b>Reviewed by:</b>	<b>Date:</b>	<b>Of</b> 2

Information Reference			Consequence Evaluation				H1 S1 O1 N1	H2 S2 O2 N2	H3 S3 O3 N3	Default Tasks			Proposed Task	Initial Interval	Can be done by
F	FF	FM	H	S	E	O			H4	H5	S4				
1	A	13	Y	N	N	N	Y						Repair the pump by replacing the gaskets / 'O' rings	On cond'n	Artisan
2	A	1	Y	N	N	N	Y						Inspect oil system fittings	Mornings	Artisan
2	A	2	Y	N	N	N	Y						When oil pressure drops, replace the mechanical seal	On cond'n	Artisan
2	A	3	Y	N	N	N	Y						Check accumulator pressure when installing pump	Pump installat'n	Artisan
2	A	4	Y	N	N	N	Y						None		
2	A	5	Y	N	N	N	Y						Check that oil system holds pressure at pump installation	Pump installat'n	Artisan
2	A	6	Y	N	N	N	Y						Replace the gasket	On cond'n	Artisan
2	B	1	Y	N	N	N	Y						Oil correctness to be checked before filling	On cond'n	Artisan
2	B	2	Y	N	N	N	Y						Bleed oil system of air	Pump installat'n	Artisan
2	B	3	Y	N	N	N	Y						Inspect and top up when alarm sounds	At alarm	Artisan
3	A	1	Y	N	N	N	Y						Make scroll correctness a hold point in the assembly procedure	Seal in-stallat'n	Artisan
3	A	2	Y	N	N	N	Y						Check temperature on gauge at pump	Mornings	Artisan
3	A	3	Y	N	N	N	Y						Inspect cleanliness of fins	Mornings	Artisan
3	A	4	Y	N	N	N	Y						Bleed oil system of air	Pump installat'n	Artisan
4	A	1	N				N	N	N	Y			Check trips and alarms	????????	Instrument