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Report

Evaluation of the Need for an Acoustic Backup Control System for the Snorre II BOP

Subtitle

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ABSTRACT

This report focuses on the need fro an acoustic backup control system for the Snorre II BOP. The following aspects have been discussed.

- Regulations and practices with respect to the use of acoustic backup control systems
- Fault tree analysis of the Snorre II BOP, with and without an acoustic backup system for relevant drilling situations
- Possible situations not covered by the fault tree analysis
- Aspects important to make blue and yellow pod independent

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Preface

Saga Petroleum is presently in a process of selecting the BOP stack to be used for the Snorre II production platform. Snorre II will be a floating production type platform. Drilling and production will be carried out simultaneously.

Saga asked SINTEF to evaluate the effect of excluding an acoustic backup system for the Snorre II BOP. Other aspects to investigate in the study were the government regulations concerning acoustic backup systems in other countries, and important aspects concerning independence of the pods in the BOP control system.

The present analysis is to a large degree based on results from the projects /1/ and /2/.

Summary and Conclusions

Snorre II will be a floating drilling and productions unit. The rig will be anchored with 16 anchor lines compared to eight lines for a conventional semisubmersible rig. All drilling carried out will be development drilling. They will utilise a subsea BOP with a conventional pilot control system with retrievable pods.

Norway has the most strict regulations concerning acoustic backup control for subsea BOPs. In Brazil all new rigs are required to have an acoustic backup system. Old rigs are not required unless they are dynamically positioned (DP). In UK there are no requirements, but the Health and Safety Executive (HSE) has indicated that DP rigs would need an acoustic backup system to be approved for drilling.

To include an acoustic backup system on the Snorre II BOP with the chosen control system design will have little effect on the safety availability during normal drilling operations, presupposed no drilling operations are allowed when a major pod failure occurs

Incidents that may physically separate the rig from the subsea BOP stack may occur on Snorre II as well as for regular semisubmersible rigs. The probability does, however, seem to be lower for Snorre II than for regular semisubmersibles, because the rig will be anchored with 16 anchor lines compared to eight lines for a conventional semisubmersible rig. The expected need for an acoustic backup system will be less for Snorre II than for a conventional semisubmersible rig.

Credit should be given to the redundancy that is present in a BOP stack, especially in the control system. Certain BOP control system failures will have very little effect on the safety availability, and should therefore be accepted. The repair might be postponed until the end of the well or the BOP is pulled for other reasons. From a safety availability point of view it will be better to continue operations if a pod pilot failure affecting only one BOP function occurs, instead of pulling the pod and continuing the drilling operation. A pilot failure for the blind shear ram should however not be accepted.

If the BOP has no acoustic backup system it should not be accepted to continue the operation if one pod is pulled for repair. With current practice using acoustic backup, Saga will not continue drilling operation if near or inside the reservoir formation if a pod fails. Operation may continue in a "safe" part of the well or if ROV "hot-stab" backup is available."

Some new BOP control systems have less independence of pods than older control systems. The main problems are connected to the hydraulic fluid supply. Single subsea failures may jeopardise the BOP control. It is recommended to:

- Have a separate hydraulic supply line for each pod.
- Have as little communication between the pods as possible.
- Where a communication is required, ensure that there are isolation possibilities present.
- Avoid a design where a single subsea failure can ruin the control of both pods.

1. Regulations and Practices with Respect to the use of Acoustic Backup Control Systems

Acoustic backup systems have been mandatory in Norway for subsea BOPs since 1981. In the guidelines to the NPD regulations /3/ it is stated in Re. Section 31 Requirements relating to blowout preventers with associated equipment:

> *when drilling with blowout preventer system installed on the seabed, an* ***acoustic or an alternative*** *control system for operation of pipe ram preventers, shear ram preventer and connection for marine riser shall in addition be installed. The accumulators shall have sufficient capacity for-closing of two (2) pipe ram preventers and one (1) shear ram preventer, as well as opening of the riser connection, plus 50%. The necessary loading pressure for the operation depth in question shall be used as basis for calculating the capacity. The acoustic accumulators shall have sufficient pressure for cutting the drillstring, after having closed a pipe ram preventer. In addition, the pressure shall be sufficient to carry out disconnection of the riser package (LMRP) after cutting of the drillstring has been completed. A portable unit (which can be handled by one person) shall be available for operation of the above mentioned functions in the event of evacuation from the platform;*

In **UK** there are no regulation that require an acoustic backup control system for subsea BOPs. According to the Health & Safety Executive (HSE) the only rigs that have an acoustic backup package are the rigs that have been drilling in the Norwegian sector of the North Sea before entering UK waters. HSE requires that Dynamically Positioned (DP) rigs ensure that they have appropriate equipment and procedures to handle a drive-off situation. This is likely an acoustic backup BOP control system.

The **US** regulations don't specifically require an acoustical backup control system for subsea BOP systems. According to the Mineral Management Service (MMS) there are three different types of backup subsea control systems in use in the US Gulf of Mexico: acoustical, ROV operated, and "deadman." The acoustical backup may be less common than in previous years.

In **Brazil** there are no government regulations. The state owned oil company, Petrobras, decides the rules.

Many of the present rigs do not have an acoustic system. All rigs or ships drilling in more than 1000 meters of water and all the DP rigs/ships are, however, required to have an acoustic. All new rigs coming to Brazilian waters are now required to have an acoustic backup system

In **Italy** there is no regulation regarding acoustic backup systems. BOP failure data from two deepwater rigs were collected in /1/. One of these had an acoustic backup system while the other had not.

2. Assumptions for the Fault Tree Analyses

An acoustic backup system has two main functions:

1. act as a backup for the primary control system during normal drilling operations
2. control selected BOP functions if the riser is accidentally disconnected or the control of the BOP is lost because of other accidents

The effect of taking away the acoustic system on the ability to close in the BOP during normal drilling operations has been modelled in a fault tree. Assumptions regarding the fault tree model are presented in this section and in Appendix 1 and 2 to this report.

2.1 The Snorre II BOP Stack Design

The fault tree analyses are based on the BOP stack design shown in Figure 1.

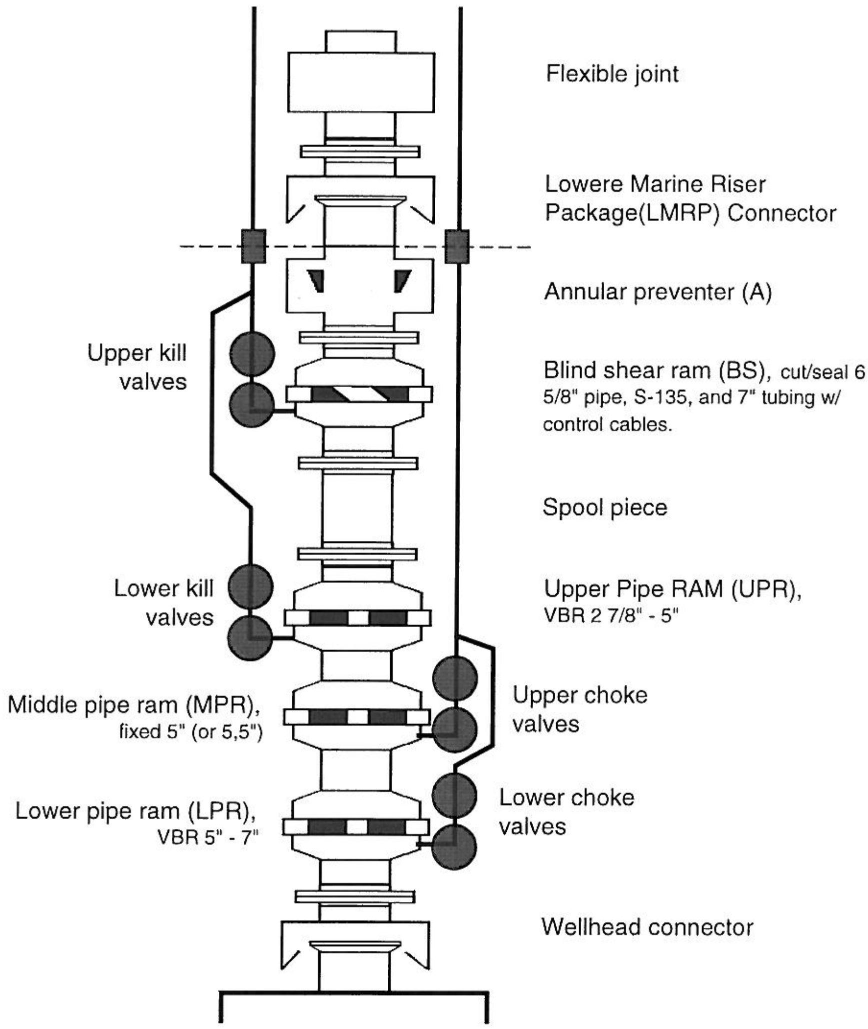

Figure 1 **The Snorre II BOP stack design**

Snorre II will be a floating drilling and productions unit. The rig will be anchored with 16 anchor lines compared to eight lines for a conventional semisubmersible rig. All drilling carried out will be development drilling.

The Snorre II BOP includes the following.

- One annular preventer located below the LMRP connector
- One shear ram preventer (single block)
- Tool joint flanged to the shear ram block and the triple ram block
- Three pipe ram preventers located in a triple ram block (sizes of rams are shown in Figure 1)
- Eight choke and kill valves (outlets are shown in Figure 1)
- Two hydraulic connectors (one LMRP connector and one wellhead connector)

They will utilise a subsea BOP with a conventional pilot control system with retrievable pods.

In addition to the main hydraulic pilot control system, the BOP is equipped with an acoustic control system that can operate the shear ram, middle pipe ram, and the lower pipe ram.

Assumptions regarding the design of the control system are presented in Appendix 1 to this report.

2.2 BOP Unavailability Calculation and Test Frequencies

The mean fractional deadtime (MFDT) of a component is the mean proportion of the time where the component is in a failed state. Consider a component with failure rate λ. Failures are only assumed to be discovered at tests, which are performed after fixed intervals of length τ. Failed components are repaired or replaced immediately after discovery.

The mean fractional deadtime of such a component is

$$MFDT = (\lambda * \tau)/2 \qquad (/4/),$$

provided that $\lambda * \tau << 1$

The availability (A) of such a component can be expressed by:

$$A = 1 - MFDT = 1 - (\lambda * \tau)/2$$

The expressions above assume that the test interval is fixed. In practical situations the test interval may vary. If a variation in the test interval exists and the τ value represents an average test interval, the formula will give too optimistic results.

Further, when this formula is used for each single component in a redundant system (like a subsea BOP) that is tested at the same time the results will be too optimistic.

For the purpose of these analyses it is assumed that the BOP failures relevant for the fault tree analysis are observed during BOP testing only. This is not correct because some of the failures in the control system are observed when they occur. From a safety point of view this is beneficial, i.e., the calculated results will be conservative.

It is further assumed that the failure rate is constant, i.e., independent of time, and that all components are independent.

The following test intervals have been chosen for the purposes of the fault tree analyses in this report unless other test intervals are specifically stated.

- The BOP preventers and choke and kill valves are pressure tested every two weeks (pressure test one pod function tested one pod)
- BOP is function tested every two weeks (both pods)

It should here be noted that for the wells Scarabeo 5 drilled on the Snorre field in /1/ the average time between pressure tests was 12,4 days. Since the test interval in practice is not fixed, using a fixed interval of 12,4 days will give too optimistic results. The use of 14 days gives a more correct result.

2.3 Initial Situation (Base Case) for Fault Tree Calculation

The situation when the well kicks and the response of the BOP is required is as follows:

- There are no known failures in the BOP or the controls for the BOP
- All pipe rams can seal around the drill pipe
- All choke and kill valves are closed
- Hard shut in, i.e., an annular preventer will be closed without opening the choke line first.
- There is an 80% probability that the acoustic system is functioning if demanded

2.4 Failure Input Data

The failure data used as input for the Fault Tree Analyses are based on the reliability data collected during this project. The overall reliability data is presented in /1/. To be able to use those data as input data for the fault tree analyses an evaluation of the collected data has been carried out.

Failure frequencies

Failures that have occurred on the rig, during running of the BOP and during the installation test have been disregarded when establishing a realistic total failure frequency for each of the BOP items, choke kill items and the control systems. I.e., only failures that have been observed during subsea BOP tests carried out after the installation test, and during normal operation of the BOP have been used to estimate the failure frequency. This period is regarded as "the safety critical" period.

Report /1/ lists no failures in the BOP clamped (or studded) connections. This type of failure was, however, observed in one of the previous BOP studies, that indicates that there is a certain probability that such failures may occur. The frequency of these failures has been estimated based on the assumption that one such failure would occur in a data collection period four times as long as the total data collection period in /1/.

It is assumed that there exist many, not reported, communication problems with the acoustic system. For the purposes of this study it has been assumed that the acoustic system will function on demand with a probability of 80%.

Failure mode distribution

For the BOP items (i.e., the annulars, rams and connectors) and the choke kill items (choke and kill lines and valves) the failures observed during "the safety critical period" have been used as basis for the fault tree input data. The safety critical period excludes the failures that are observed on the rig, during running of the BOP, or during the BOP installation test. All tests performed after the BOP is run the first or subsequent times are regarded as installation tests.

For the control system all the failures observed in the study have been used for establishing the failure distribution among the different control system components. Failures that have occurred outside the safety critical period have, however, been given less weight. Further, for some of the components, no failures have been observed in this study. The failure data used for these components are based on results from the previous BOP studies and engineering judgement. It should, however, be noted that the total frequency of failures will not be affected by this, only the relative failure mode distribution.

The failure data used for the base case calculations are shown in the fault trees in Appendix 3.

3. Fault Tree Analysis

The main intention with these fault tree analyses is to assess the effect of removing the acoustic system from the Snorre II BOP. The total probability of not being able to close in the BOP, given a kick, should be used with care.

The SINTEF developed program CARA Fault Tree has been used to construct and analyse the fault trees (/5/).

When reading the results please note the assumptions in Section 2, Appendix 2, and the description of the control system in Appendix 1

Fault tree analyses have been carried out to assess the probability of not being able to close in a kick – for each of the control systems and for the following main situations:

1. **Base case:** All the pipe rams are able to seal around the drill-pipe (i.e. 5" drill pipe).
2. **3,5" drill pipe or tubular through BOP:** LPR and MPR can not be used for closing in the well
3. **5,5" or larger drill pipe through BOP:** This means that MPR and UPR can not be used for closing in the well
4. **Open hole:** An open hole situation, where only the shear blind ram is available for sealing. The effect of using the annular preventer as well for sealing an open hole has also been considered [1]

For each of the situations different parameters have been altered. These alterations are typically:

- No acoustic system included
- One pod is known to be failing
- One pod is known to be failing, and no acoustic system

Appendix 3 shows the base case fault tree. The results from the fault tree calculations are shown in Table 1, Table 2 and Table 3. The results are discussed after the tables.

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[1] The annular preventer may also be used for sealing an empty hole in an emergency. This is rarely done and no reliability data exist for this application of the annular preventer.

Table 1 Effect of removing the acoustic system from the Snorre II BOP for the four main situations and no known failures in the BOP

Line no.	Changes from base case	Unavail-ability %	Successes per failure	Ratio base case	COMMENTS
With acoustic system	1. No (base case)	0,13621	734	1,0000	This calculation says that in one out 734 kick situations the BOP will fail to shut in the kick. The major contributors to the unavailability are external leakages in: the wellhead connector, lower BOP flange, LPR bonnets/doors and the LIC flange or stem leakage. The contribution from control system failures to this estimate is insignificant due to the redundancy.
	2. 3,5" drill pipe through BOP (can not use LPR and MPR)	0,19633	509	1,4414	Compared to the above situation the exposure of more possible leakage paths to sea is the major cause for the unavailability. The contribution from the control system failures is still insignificant due to the redundancy.
	3. 5,5" drill pipe through BOP (can not use MPR and UPR)	0,13625	734	1,0003	Since the LPR can close in the well no new leakage paths will be exposed, and the effect on unavailability will be insignificant.
	4. Open hole	0,60514	165	4,4427	There are two main reasons for increased unavailability compared to base case; 1 More possible leakage paths in the BOP will be directly exposed to the wellbore. 2 The leakage probability of the BS ram is significantly higher than for the pipe rams. The BS ram specific control system parts are still insignificant contributors due to the control system redundancy
	4b. Open hole and the annular may by a 80% probability seal off the well	0,31447	318	2,3087	Presupposed that the annular preventer will succeed to seal of an open hole in 4 out 5 cases, this will represent a significant improvement with respect to the open hole situation. Reliability data for annular preventers in open hole situations are, however, not known.
Without acoustic system	5. Base case without acoustic system	0,13820	724	1,0146	The effect of taking away the acoustic system is small when no known failure exists in any of the pods (compared with line 1)
	6. No acoustic system, 3,5" drill pipe through BOP (can not use LPR and MPR)	0,19832	504	1,4560	The effect of taking away the acoustic system is small when no known failure exists in any of the pods (compared with line 2)
	7. No acoustic system, 5,5" drill pipe through BOP (can not use MPR and UPR)	0,13824	723	1,0149	The effect of taking away the acoustic system is small when no known failure exists in any of the pods (compared with line 3)
	8. No acoustic system, open hole	0,60746	165	4,4597	The effect of taking away the acoustic system is small when no known failure exists in any of the pods (compared with line 4)
	8b. Open hole and the annular may by a 80% probability seal off the well	0,31653	316	2,3238	Presupposed that the annular preventer will succeed to seal of an open hole in 4 out 5 cases, this will represent a significant improvement with respect to the open hole situation. Reliability data for annular preventers in open hole situations are, however, not known.

Table 2 Effect of removing the acoustic system from the Snorre II BOP for the four main situations and one pod is known to be failing

Line no.	Changes from base case	Unavailability %	Successes per failure	Ratio base case (see Table 1)	COMMENTS
With acoustic system	1. One pod is known to be failing	0,19053	525	1,3988	The unavailability will increase with approximately 40 % if one pod is known to be failing. This increase is related to the control system. This is a rather normal situation when drilling at normal water depths (depths that allow retrieving of the pod only). Care should be taken if deciding to continue operation with one pod only.
	2. One pod is known to be failing, 3,5" drill pipe through BOP (can not use LPR and MPR)	0,25062	399	1,8400	Both the increased risk of control system breakdown and the exposure of more possible leakage paths contributes to the increased unavailability.
	3. One pod is known to be failing, 5,5" drill pipe through BOP (can not use MPR and UPR)	0,19057	525	1,3991	Since the LPR can be used the major contribution to increased unavailability stems from the control system
	4. *One pod* is known to be failing, *open hole*	0,67437	148	4,9510	Both the increased risk of control system breakdown and the exposure of more possible leakage paths contribute to the increased unavailability.
	4b. Open hole and the annular may by a 80% probability seal off the well	0,37284	268	2,7372	Presupposed that the annular preventer will succeed to seal of an open hole in 4 out 5 cases, this will represent a significant improvement with respect to the open hole situation. Reliability data for annular preventers in open hole situations are, however, not known.
Without acostic system	5. *One pod* is known to be failing, and *no acoustic* system	0,40976	244	3,0083	If drilling without an acoustic system (or system has failed), and one pod is known to be failing, the unavailability will increase significantly. The probability of not being able to close in a kick will be approximately 3 times as high as in the base case situation. The increase is caused by less control system redundancy.
	6. *One pod* is known to be failing, *no acoustic* system, *3,5" drill pipe* through BOP (can not use LPR and MPR)	0,46972	213	3,4485	The increase is caused by less control system redundancy.
	7. *One pod* is known to be failing, *no acoustic* system, *5,5"* drill pipe through BOP (can not use MPR and UPR)	0,40980	244	3,0086	The increase is caused by less control system redundancy.
	8. *One pod* is known to be failing, *no acoustic* system, *open hole*	0,94693	106	6,9520	The increase is caused by less control system redundancy.
	8b. Open hole and the annular may by a 80% probability seal off the well	0,60261	166	4,4241	Presupposed that the annular preventer will succeed to seal of an open hole in 4 out 5 cases, this will represent a significant improvement with respect to the open hole situation. Reliability data for annular preventers in open hole situations are, however, not known.

The BOP unavailability results in Table 1 and Table 2 have been sorted differently and are presented in Table 3.

Table 3 Effect of taking out the acoustic control system during "normal" operations

Conditions when a BOP closure is required			*"Normal", all pipe rams can be used to close around DP*	*5,5" drill pipe through BOP (can not use MPR and UPR)*	*3,5" drill pipe through BOP (can not use LPR and MPR)*	*Open hole**
No known control system failures	Unavail-ability (%)	With acoustic system	0,13621	0,13625	0,19633	0,60514
		No acoustic system	0,13820	0,13824	0,19832	0,60746
	Relative increased unavailability when removing the acoustic system		1,46 %	1,46 %	1,01 %	0,38 %
	Successes per failure	With acoustic system	734	734	509	165
		No acoustic system	724	723	504	165
One pod is known to be failing	Unavail-ability (%)	With acoustic system	0,19053	0,19057	0,25062	0,67437
		No acoustic system	0,40976	0,40980	0,46972	0,94693
	Relative increased unavailability when removing the acoustic system		115,06 %	115,04 %	87,42 %	40,42 %
	Successes per failure	With acoustic system	525	525	399	148
		No acoustic system	244	244	213	106

* Disregarded that the annular preventer may be used for sealing off an open hole

It is seen from Table 3 that during "normal" operations and with no known failures in the control system, the effect of taking out the acoustic backup control system from the BOP stack is small, only an increase in unavailability in the range of 1%.

The relative change in unavailability is, however, significant if one of the pods is known to be inoperable. This could typically be a situation where the pod is pulled for repair while the operation continues.

It is important to note that this fault tree analysis is based on a conventional *pilot control system* (see Appendix 1 and 2). For this control system the two pods (blue and yellow) are fairly independent. When the pods are independent the effect of taking out the acoustic control system will be low presupposed no known failures exist in any of the pods.

If it is decided to select a control system with less independence of pods for the Snorre II BOP the effect of taking out the acoustic backup control system on the safety availability will be much higher. In /2/ a BOP with a Multiplex control system was analysed (based on the Scarabeo 5 Cameron BOP control system). For this system the pods were less independent than for the pilot control system. The effect of taking out the acoustic system from the control system was thereby significant (see Table 5 on page 21).

4. Evaluation of Different Repair Strategies for Specific Pod Failures.

The evaluations of repair strategies are focusing on the BOP safety unavailability and lost drilling time. The evaluations are carried out for the Snorre II BOP *with and without an acoustic system.* The evaluations are based on fault tree analysis.

If a failure occurs in one of the pods one of the three following repair strategies may be selected:

Strategy 1 — Stop all operations until the pod is pulled and repaired (***Safe procedure*** presupposed no evidence or suspicion of gas in the open hole section)

Strategy 2 — Continue with the operation while pulling, repairing, and rerunning the pod (***reduced safety availability*** in a ***"short"*** repair period)

Strategy 3 — Accept the failure and continue with the operation until the well is finished (***limited reduced safety availability*** in a ***"long"*** repair period)

For repair Strategy 1 drilling time is lost. For repair Strategy 2 and 3 no drilling time is lost, but the safety availability will decrease. To quantify the reduction in safety availability for repair strategy 3 the effect of some typical failures in the pods has been calculated.

For each of the main situations (see Section 3 on page 10) the effect of the following failures in pods have been calculated:

1 Pilot valve (or signal) for LPR fails
2 Pilot valve (or signal) for MPR fails
3 Pilot valve (or signal) for UPR fails
4 Pilot valve (or signal) for BS fails
5 Pilot valve (or signal) for annular fails

The results from the calculations are shown in Table 4 alongside the safety availability results when operating with one pod only.

Table 4 Effect on safety availability from failed pilot valves

Type of failure in one pod	Unavailability (%)							
	Base case (all rams can seal around the pipe)		5,5" drill pipe (only LPR can seal)		3,5" drill pipe (only MPR and UPR can seal)		Open hole	
	With acoustic	No acoustic	With acoustic	No acoustic	With acoustic	No acoustic	With acoustic	No acoustic
No failures	*0,13621*	*0,13821*	*0,13625*	*0,13824*	*0,19633*	*0,19832*	*0,60514*	*0,60746*
Operating with one pod only	*0,19053*	*0,40976*	*0,19057*	*0,40980*	*0,25062*	*0,46972*	*0,67437*	*0,94693*
LPR pilot signal one pod failed	0,13623	0,13831	0,13629	0,13845	*Not rel.*	*Not rel.*	*Not rel.*	*Not rel.*
MPR pilot signal one pod failed	0,13621	0,13820	*Not rel.*	*Not rel.*	*Not rel.*	*Not rel.*	*Not rel.*	*Not rel.*
UPR pilot signal one pod failed	0,13621	0,13821	*Not rel.*	*Not rel.*	0,19649	0,19848	*Not rel.*	*Not rel.*
BS pilot signal one pod failed			0,13625	0,13824	0,19633	0,19832	0,67291	0,94612
Annular pilot signal one pod failed			0,13626	0,13829	0,19634	0,19837	*Not rel.*	*Not rel.*

If the BOP stack *has no acoustic backup system* pulling of the pod while continuing the operation (i.e. *Repair Strategy 2*) will cause a significant increase in the safety unavailability (approximately

3 times as high), and should therefore not be allowed. Repair Strategy 1 should therefore always be selected for BOPs without an acoustic system when pulling a pod.

If the BOP stack *has an acoustic backup system* Repair Strategy 2 will also cause a significant reduction in safety availability, but only approximately 50% times as high as the normal situation. This strategy can therefore be followed when the well is assumed to be in a "safe" well section and the repair is expected to have a short duration.

The effect of a single pilot valve failure for any of the *pipe* rams or the annular is insignificant on the ability for the BOP to close in a kick. This is explained by the fact that there is still redundancy in the control system and in the BOP stack. If the pod includes only one such failure it is recommended to use *Repair Strategy 3*, i.e. do not repair the pod before the BOP is pulled for other reasons. If selecting *Repair Strategy 2*, it is seen from Table 4 that a significant reduction in safety availability will result when operating with one pod only. If the stack in addition has no acoustic system the reduction in safety availability will be even worse.

If a pilot valve for the shear ram fails the failure should be repaired immediately.

If a pod failure that affects more than one BOP function occurs the failure should be repaired immediately.

Summary regarding repair strategies

- If the BOP is not equipped with an acoustic ***backup*** system, the drilling operation should always be stopped if one of two pods has to be pulled for repair.

- If the BOP is equipped with an acoustic system, drilling may proceed if one of the two pods has to be pulled for repair, presupposed the well is in a "safe" section and the repair is expected to be of short duration.

- If one of the pods has a pilot function failure (one function only) the repair may be postponed until the BOP or the pod is pulled for another reason, regardless whether the BOP includes an acoustic system or not. (***NOTE!*** *- This statement is* ***not*** *valid for the shear ram pilot valves*)

5. Situations not Covered by the Fault Tree Analysis

The fault tree calculations in the previous section are valid for *normal* drilling operations and for a pilot hydraulic control system with independent pods. From the results it is evident that the need for an acoustic ***backup*** system is low as long as the policy is to repair any failure in the BOP immediately when it is observed.

The other main function with the acoustic ***backup*** system is to act as a last resource in case a physical separation between the BOP stack and the rig.

Below some rare, but not unlikely, incidents that may cause physical separation of the BOP stack and the rig are briefly discussed.

UNINTENDED DISCONNECT OF THE LMRP

Unintended disconnect of the LMRP may occur and have occurred. By reviewing BOP failures from approximately 400 wells drilled from a floating unit in the North Sea and Brazilian waters some incidents that caused a spurious disconnect of the LMRP were observed. Some other incidents that caused spurious operation of other BOP functions were also observed. The review of the failures was rather brief, so some similar failures may have been overlooked.

Below the incidents are briefly described.

Phase I + II spurious operation *(wells drilled from 1976 until 1983)*
1. **Shear ram closed** on spherical function. This happened due to a blank plug being removed on pod receptacle **(Main control system)**

Phase IV spurious operation *(wells drilled from 1983 until 1986)*
1. **Shear ram closed** (tampered with the control unit for the **acoustic backup system**)
2. **LMRP** connector opened (tampered with the control unit for the **acoustic backup system**)

Phase V spurious operation *(wells drilled from 1987 until 1989)*
1. **Shear ram closed** and cut pipe and disconnected **LMRP** (electrical failure in control panel for emergency disconnect system) **(Main control system)**
2. **MPR closed** when arming the acoustic system (solenoid valve stuck in open position) **(acoustic backup system)**

Deepwater BOP study *(wells drilled from 1992 until 1997)*
1. They were testing the BOP when a spurious closure of the **Shear ram** occurred. They thereafter checked the auto-shear system, but found it to be OK. They turned it off because they suspected this to cause the failure. **(Main control system)**

Three of the above spurious operations were caused by the acoustic system (either a technical failure or a human error). The three remaining were caused by the main control system. Two of the main control system failures were caused by an auto-shear or an emergency disconnect system.

An emergency disconnect system, that is a system designed so that by pushing one button the blind shear ram will shear the drillpipe and disconnect the LMRP connector in a pre-set time sequence, will not be installed on the Snorre II BOP. Further, if an acoustic **backup** system is not installed on the Snorre II BOP, the chance of an unintended disconnect will be reduced.

A spurious disconnect of the BOP may occur, but it is not very likely.

RISER PARTING

The riser may part due to mechanical failure or overload. This has occurred. The frequency of such incidents is not known, but assumed to be low. One situation where the riser parted is known, but for this incident it did not jeopardise the hydraulic BOP control. The umbilical was not destroyed. If rigid conduit lines had been used they would most likely have parted as well.

Riser parting due to drift off caused by loosing one or more anchors may also occur. In such a situation the riser angle can prevent a LMRP disconnect. In most cases a controlled disconnect, however, can be achieved. It is, however, assumed that for Snorre II this is unlikely due to the redundancy in the mooring points, using 16 anchor lines versus the conventional 8 line system.

EXPERIENCED NEED FOR ACOUSTIC SYSTEM

The acoustic system had to be used to disconnect the LMRP on Scarabeo 5 in the end of March 1993. None of the pods were operable. One pod was on the rig for repair while the other pod failed.

In 1984 a blowout in Canadian waters occurred on the Vinland drilling rig. They had not enough accumulator capacity to shear the pipe on the regular control system. Then they attempted to use the acoustic system to shear the pipe. This acoustic closure failed because the transducer was on the rig pontoon and not in water.

How frequently the acoustic system is used in drilling operations or for safety purposes is not known.

POSSIBLE ACOUSTIC AND MAIN CONTROL SYSTEM COMMON FAILURE

According to Saga Petroleum once a pressure relief device failed and caused that all hydraulics were lost from both the acoustic and main control systems. The pressure relief device was installed to avoid rupturing accumulator bottles when relieving the seawater head for the acoustic system

Some BOPs have such devices and some not. The bottles are designed for 400 metres so such a pressure relief device will not be needed for Snorre II.

If BOPs without such devices are pulled from water depths more than 400 meters the pressure has to be bled off during pulling of the BOP. If the BOPs are equipped with such devices there should be a separate device for the acoustic bottles and the normal bottles. Further, in the main control system the device should be located such that the leakage can be isolated and the BOP operated by using the hydraulic supply from surface.

ACCUMULATOR CAPACITY BACKUP FOR SHEAR RAM ACTIVATION

A very important assumption for the fault tree analysis (from Appendix 2) regarding the need for the acoustic system was:

- A severe leakage in the subsea accumulator area will not affect the operation if the stack mounted accumulator isolator valve or the pod mounted accumulator isolator valve can be activated to isolate the leaking area. This failure will, however, *increase the preventer closing time.*

Further, a closure of the blind shear ram in an emergency is frequently carried out subsequent to other BOP operations. This will reduce the subsea accumulator pressure, and a closure of the blind shear ram by the regular control system may be impossible before the accumulator pressure has been regained. In such situation a separate acoustic system will be beneficial.

6. Aspects Important to Make Blue and Yellow Pod Independent.

The two pods are relatively independent for the conventional pilot hydraulic system. The two pods rely on a common subsea accumulator bank. However, if a severe leakage in the accumulator area occurs, the BOP can still be operated, but the activation of each function will require longer activation time.

With one accumulator bank for each pod the control system would be more independent. This would however, require a twice as big accumulator bank, which again would cause practical problems.

However, incidents may still occur that ruins both pods at the same time. This would typically be an incident that destroys either both umbilicals, or crucial surface control equipment.

In terms of the overall BOP reliability the independence of the pods is important. For some of the "new" BOP control systems the independence of the pods is less than for the conventional pilot hydraulic system.

In /2/ a Fault Tree for a BOP with a multiplex control system was established. The Scarabeo 5 Cameron multiplex control system was used as basis for the design of the Fault Tree. The calculated safety availability was less for this control system than for the BOP with the conventional pilot control system. The reason for the difference was less independence between pods. The area that caused this less independence was the main hydraulic supply.

Figure 2 shows the hydraulic schematic for the control fluid supply for a multiplexed control system.

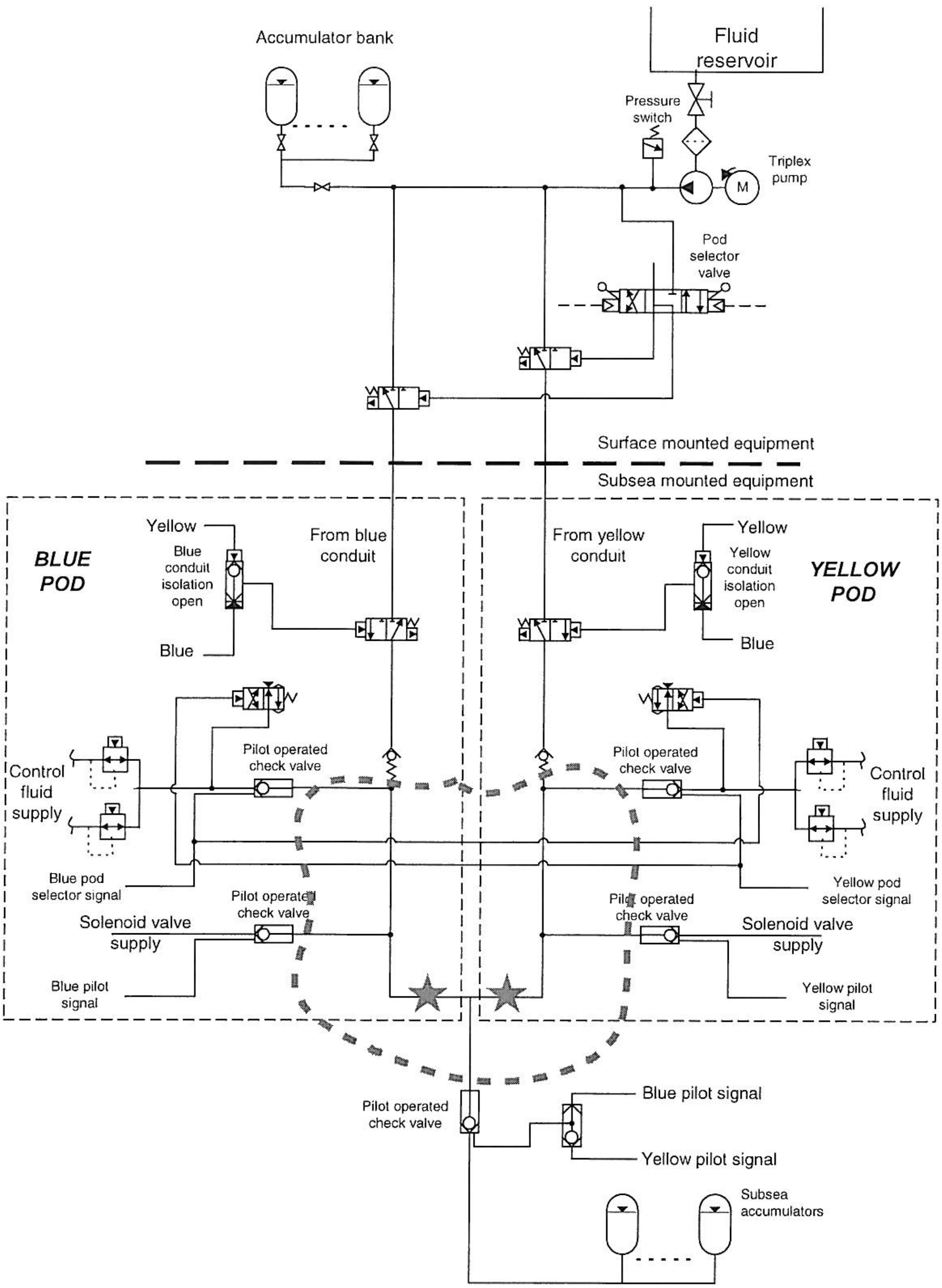


Figure 2 Hydraulic schematic for the control fluid supply for a multiplexed control system

From the conduit lines the fluid enters the subsea pods. At this point the conduit line can be isolated from the specific pod by a pilot valve. A check valve also prevents that fluid can be lost from the pod to the conduit line. In case of a leakage in one of the conduit lines the pod can still be used for operating the BOP by supplying fluid from the other line.

The conduit lines charge the subsea accumulators, which are common for both pods. The accumulators can be isolated in case of a leakage in the accumulator area. The BOP can then be operated by surface fluid supply. This will, however, increase the opening time.

The blue and yellow pod respectively supply the solenoid valves with pilot fluid and control fluid. Both the pilot fluid and control fluid supply can be isolated from the pod in case of a leakage in any of the circuits. If a severe leakage in the solenoid supply or the control fluid supply to the pilot valves occur, the respective pod will be inoperative.

In case of a leakage in the area between the five pilot operated check valves and the spring loaded check valves (indicated with the bold dotted line), the control system will be inoperative. This is the main problem regarding lack of independence for this control system.

The situation would be significantly improved if each pod included a pod isolation valve as indicated with the stars in Figure 2.

Due to the lack of independence, the importance of an acoustic system will be higher for a BOP with type of multiplex control system than for the conventional pilot hydraulic system.

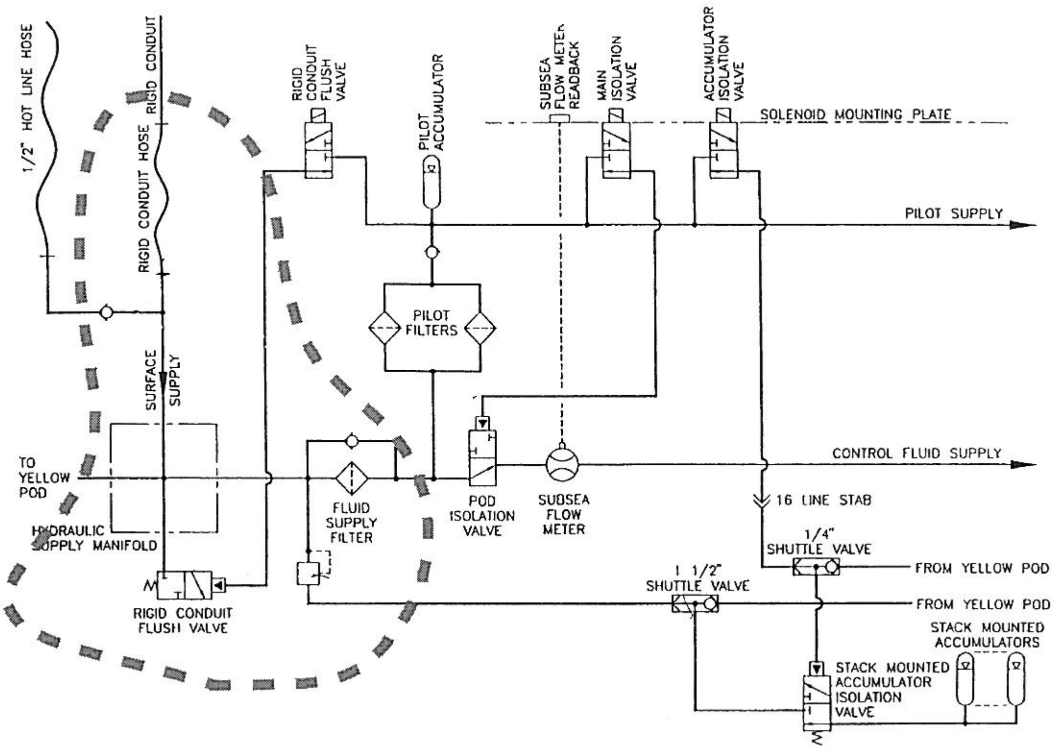
In Table 5 the effect on the safety availability of including an acoustic system is calculated (from /2/)

Table 5 Effect on the safety availability of including an acoustic system for a BOP with a multiplex control system (Scarabeo 5 type)

Conditions when a BOP closure is required			"Normal", all pipe rams can be used to close around DP	Open hole
No known control system failures	Unavail-ability	With acoustic system	0,15341	0,59437
		No acoustic system	0,2240	0,6650
	Relative reduced availability when removing the acoustic system		46,01 %	11,88 %

If comparing the results in Table 5 with the results in Table 3 on page 13, it is seen that the acoustic system is far more important in this multiplex control system than in the conventional pilot hydraulic system.

In Figure 3 an example of the BOP control and pilot fluid supply for another multiplex system is shown.



SUBSEA BOP CONTROL AND PILOT FLUID SUPPLY

Figure 3 BOP control and pilot fluid supply (example)

As seen from Figure 3 only one conduit line is supplying the BOP with hydraulic fluid. A hot line exists so it is possible to connect a ROV to supply the BOP. The sketch does likely not include all the details, but it seems that if a leakage occurs in the area where the rigid conduit is connected to the stack (indicated with the dotted line), the BOP control will be lost. In /1/ two incidents were observed where the control of the BOP was lost due to failures in this area for a rig with this type of arrangement was.

When designing control system today it seems that the good practices with nearly completely independent pods have been forgotten. Today control systems are frequently designed with one single conduit line and a BOP located manifold that distributes hydraulic fluid to each of the pods.

Regardless if the BOP includes an acoustic backup control system or not independent pods are important.

Main recommendations

- Have a separate hydraulic supply line for each pod.
- Have as little communication between the pods as possible.
- Where a communication is required, ensure that there are isolation possibilities present.
- Avoid a design where a single subsea failure can ruin the control of both pods.

References

/1/ Holand, P., Reliability of Subsea BOP Systems for Deepwater Application, SINTEF Report STF38 F97417, Trondheim, Norway, 1997.

/2/ Holand, P., Reliability of Subsea BOP Systems, Fault Tree Analysis, SINTEF Report STF38 F97425, Trondheim, Norway, 1997.

/3/ Acts, regulations and provisions for the petroleum activities, Norwegian Petroleum Directorate, 1 April 1997 (CD-rom version)

/4/ Høyland, A., and Rausand, M., System Reliability Theory; Models and Statistical Methods, John Wiley & Sons, New York, USA, 1994.

/5/ *CARA Fault Tree*, SINTEF Industrial Management, Safety and Reliability, Trondheim, Norway, 1996.

Appendix 1

BOP Control System Description

For redundancy purposes all subsea BOP control systems include two pods; the so-called yellow and blue pod. The BOP can be fully controlled by each of these pods. They are relatively independent of each other. The pod selector valve on the rig is common for the pods. Further the shuttle valves located on the preventers, connectors and valves are common. Otherwise there are some communication possibilities between the control fluid supply that may result in severe hydraulic leaks that may disable the BOP control.

1. Hydraulic Control System, General Description

Figure 1 on shows the layout of a typical pilot hydraulic control system.

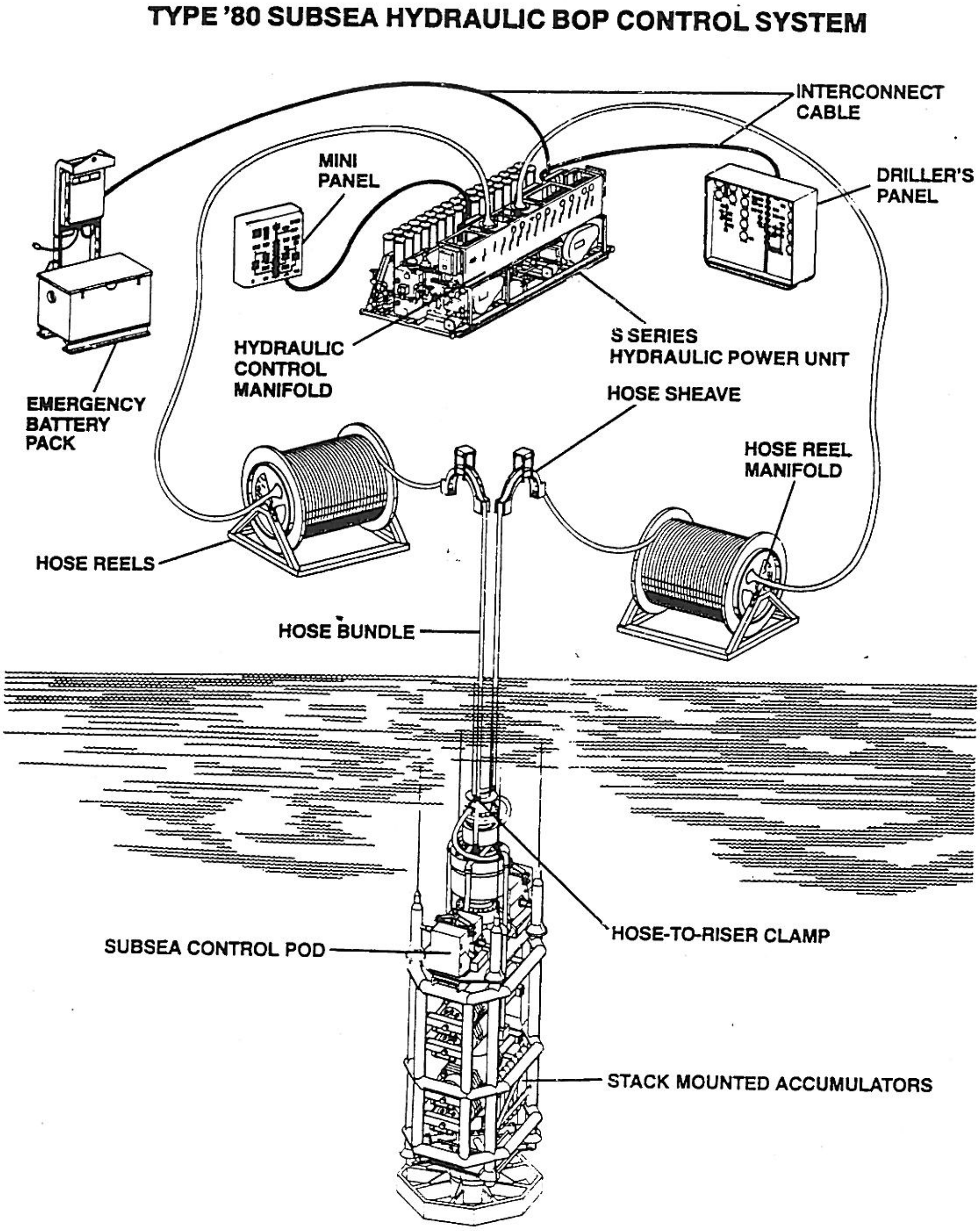


Figure 1 Typical hydraulic pilot control system layout

A pilot control system typically consist of the following components:

- Surface equipment located on the drilling rig including hydraulic power unit with master hydraulic control panel, driller's control panel, auxiliary remote control panel, battery bank and battery charger, accumulator bank, powered hose reels, and hose sheaves.
- A connecting hydraulic umbilical (hose bundle) for each pod. The hose bundle contains a 1" ID hydraulic supply hose in the centre surrounded by 60 – 70 3/16" ID pilot signal hoses.
- Subsea control system components located on the BOP stack include control pods, that mainly consist of pilot valves and pressure regulator valves, riser and stack female receptacles, accumulators, and shuttle valves.

A typical Shaffer control system that operates a two annulars, four rams and six failsafes BOP will include the following subsea valves:

- Seventy pilot valves. Forty-two pilot valves with ¾" diameter and 28 pilot valves with 1" diameter (35 pilot valves in each pod)
- Four 1 ½" regulator valves (two in each pod)
- Thirty-two shuttle valves. Fifteen shuttle valves with 1"diameter and 17 shuttle valves with ¾" diameter (not including the shuttle valves that connect the back-up control system to the main control system)

2. Pilot Signal Principles for a Pilot Hydraulic Control System

Figure 2 on page 4 shows the pilot control system principle.

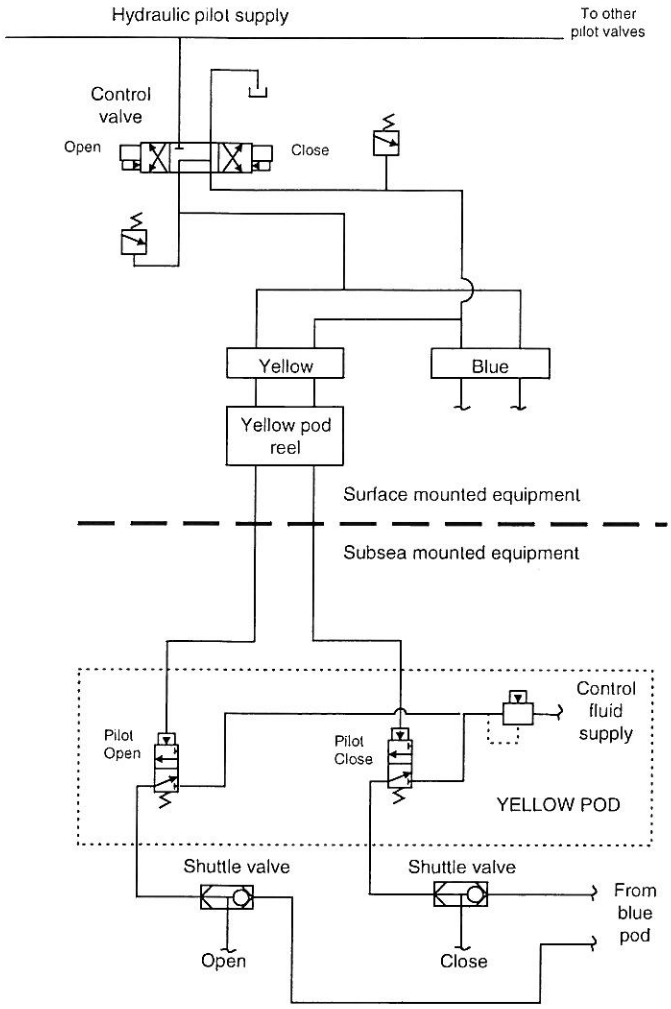


Figure 2 Pilot signal principles for a pilot control system

For a conventional pilot control system the BOP function is activated by a hydraulic pilot signal that is transmitted from the rig through the pilot hose bundle to a specific pilot valve. This pilot valve opens and allows for the control fluid supply to be directed to the BOP function. A pilot signal can normally be activated from the driller's cabin, from the toolpusher's office, or from the hydraulic unit. When activating from the driller's cabin or the toolpusher's office an electric signal is sent to a solenoid valve that opens for air to an air shuttle valve, which again operates the control valve on the hydraulic unit.

3. Control Fluid Supply

Figure 3 on page 5 shows the hydraulic schematic for the control fluid supply for a conventional hydraulic control system.

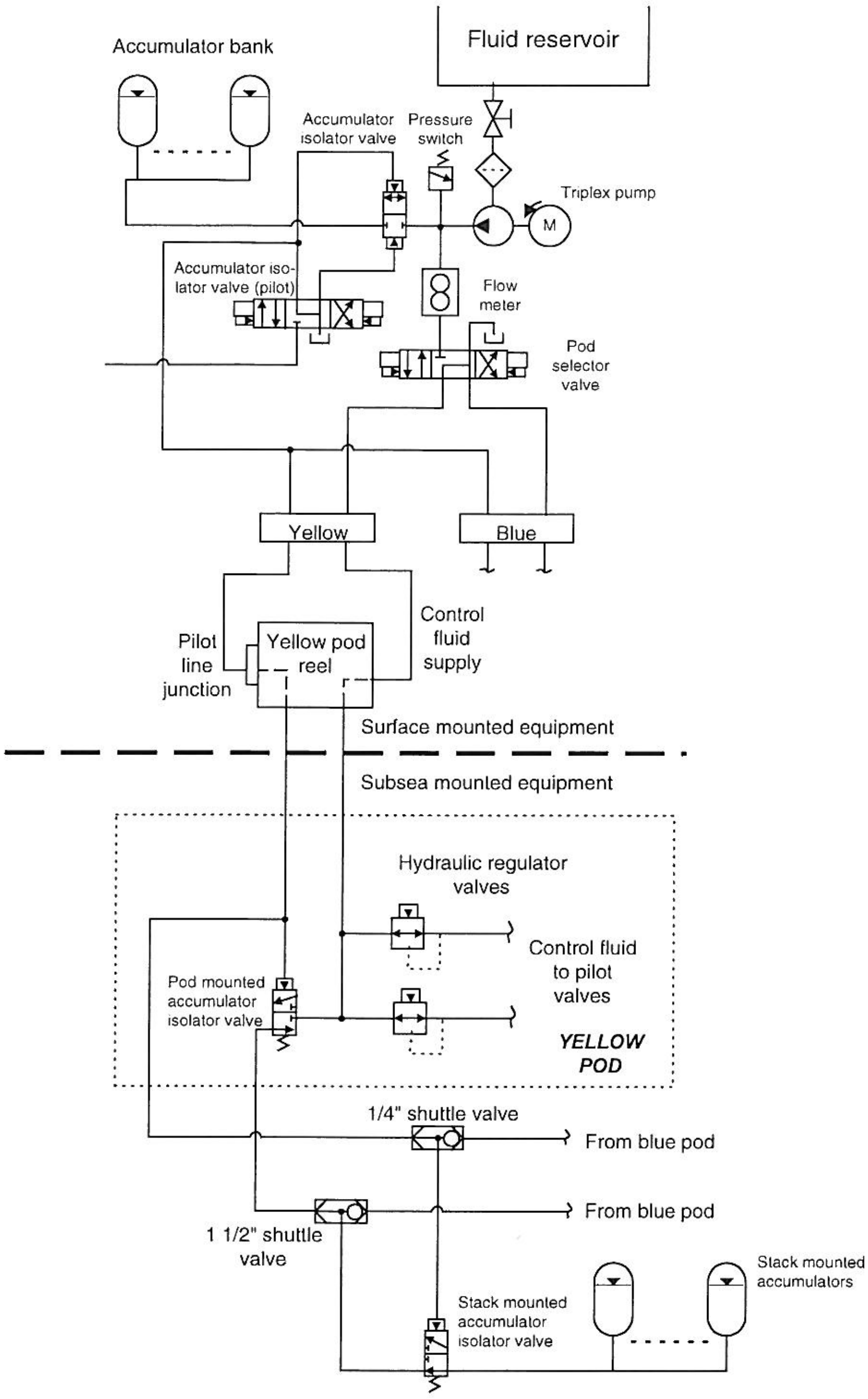


Figure 3 Hydraulic schematic, control fluid supply for a pilot hydraulic control system

Hydraulic power for charging the control fluid accumulators is delivered from two or three electric triplex pumps. Occasionally the third pump is air driven. The pumps deliver 3000 psi pressure. Pressure switches are controlling the pumps. The pressures corresponding to stop and restart are 3000 and 2700 psi.

The surface accumulators are typically pre-charged to 1000 psi, while the subsea accumulators are pre-charged to 1200 psi plus the hydrostatic pressure at the depth the BOP is located.

The control fluid is directed to the pod selector valve. The pod selector valve directs the control fluid either to the blue or yellow pod. The fluid passes the hose reel and then through the 1" hose in the centre of the hose bundle to the control pod located on the BOP.

In case of a leakage in the supply hose, the pod mounted isolation valve has to be activated, and the pod will be inoperative.

From the pod the subsea accumulators are charged. All the regulators associated to the pod and the pilot valves and can then be supplied with control fluid. In case of a severe leakage in the lines to the pilot valves occur, the pod will be inoperative and has to be isolated.

The accumulators are common for the blue and the yellow pod. The accumulators main objective is to decrease the closing time. In case there is a leakage in the accumulator area, or the accumulators have been discharged. The accumulator isolation valves on the rig, in the pod and on the stack can be closed, and the BOP operated directly from the pumps. This will, however, increase the closing time, compared to the time used with fully charged accumulators. The accumulator isolation valves are normally open.

Appendix 2

Fault Tree Construction

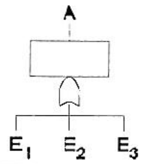
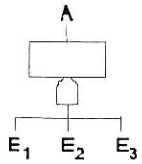
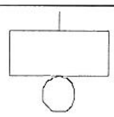
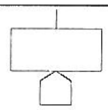
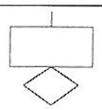
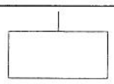
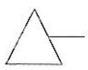
1. Fault Tree Symbols

A fault tree is a logic diagram that displays the connections between a potential system failure (TOP event) and the causes for this event. The causes (Basic events) may be environmental conditions, human errors, normal events and component failures. The graphical symbols used to illustrate these connections are called "logic gates". The output from a logic gate is determined by the input events.

The graphical layout of the fault tree symbols is dependent on what standard we choose to follow. Table 1 shows the most commonly used fault tree symbols together with a brief description of their interpretation.

Table 1

Fault tree symbols

Symbol			Description
Logic Gates	"OR" gate		The OR-gate indicates that the output event A occurs if any of the input events E_i occurs.
	"AND" gate		The AND-gate indicates that the output event A occurs only when all the input events E_i occur simultaneously.
Input Events	"BASIC" event		The Basic event represents a basic equipment fault or failure that requires no further development into more basic faults or failures.
	"HOUSE" event		The House event represents a condition or an event, which is TRUE (ON) or FALSE (OFF) (not true).
	"UNDEVEL-OPED" event		The Undeveloped event represents a fault event that is not examined further because information is unavailable or because its consequence is insignificant.
Description of State	"COMMENT" rectangle		The Comment rectangle is for supplementary information.
Transfer Symbols	"TRANSFER" out "TRANSFER" in	 	The Transfer **out** symbol indicates that the fault tree is developed further at the occurrence of the corresponding Transfer **in** symbol.

The logic events the basic events and the transfer symbol are the fault tree symbols mainly used in the Fault Trees constructed and analysed in this report. Fault Tree construction and analyses are described in many textbooks, among them /4/.

The SINTEF developed program CARA Fault Tree has been used for constructing and analysing the fault trees (/5/).

2. Design of Fault Trees

A fault tree for a subsea BOP will be rather complex and include many pages. Many of these pages are, however, similar. In the following some important sample pages are shown. These pages focus on the pilot signal and the main control fluid supply for the various control system principles. Appendix 3 shows the complete fault tree for a pilot hydraulic control system.

A fault tree will always represent an approximation of the reality, both in terms of the fault tree model, and the reliability data used for the calculations.

For each of the sample fault trees, assumptions made when constructing the fault trees have been listed. Other assumptions related to the fault tree construction and analyses are presented in Appendix 1 and in Section 2.

2.1 Activation of one BOP Function

The fault tree is based on the system shown in Appendix 1. It is assumed that the pilot pressure will always be available for the surface control valve, i.e., no critical failure can occur in the supply of the surface pilot hydraulics.

The following failures are addressed in the fault tree for one pilot function failure.

Control system function specific failures (one pod)
- Surface control valve failure
- External leak in pilot line (from surface control valve to pod)
- External leak in pilot line inside pod or in pilot valve
- Pilot valve fails to open
- Leakage of control fluid in line from pilot valve to shuttle valve
- Shuttle valve stuck in opposite position (will not affect the operation from the other pod)

Preventer specific failures
- Shuttle valve or line to preventer leak external (will affect both pods)
- Preventer internal hydraulic failure (causes fail to close preventer)
- Preventer internal leakage (will affect both pods)

Regulator failures
Manifold regulator or annular regulator fails to supply the required fluid pressure

Failures that affects the complete pod
Major pod failure (developed in separate sample fault tree in Figure 3 on page 7)

Failures that affects the complete control system
Major failure that causes both pods to fail (developed in separate sample fault tree in Figure 2 on page 6)

Figure 1 shows a sample fault tree for a conventional pilot control system, and single BOP function failure

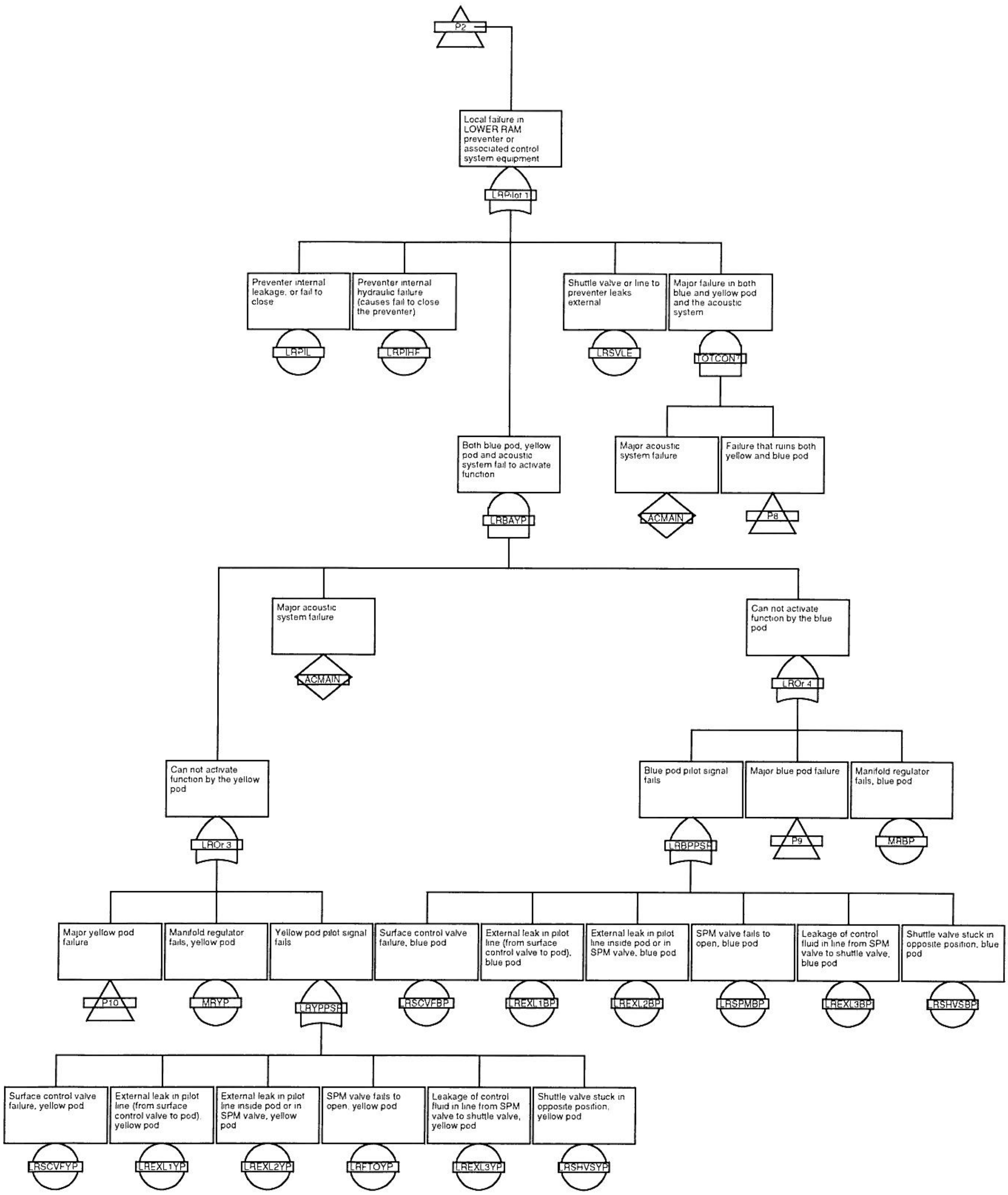


Figure 1 Sample fault tree, conventional pilot control systems, and single BOP function failure

2.2 Control Fluid Supply

Appendix 1 shows a sketch of the control fluid supply for this system. To be able to construct a fault tree of the control fluid supply some assumptions have been made.

- A severe leakage in the subsea accumulator area will not affect the operation if the stack mounted accumulator isolator valve or the pod mounted accumulator isolator valve can be activated to isolate the leaking area. This failure will, however, increase the preventer closing time. If none of these accumulator isolator valves can be activated the control of the BOP is lost.

- A severe leakage in the supply line between the surface and the pod mounted isolator valve will cause that the specific pod cannot be operated. It will not affect the other pod because of the pod mounted accumulator isolator valve that can be closed and a 1 ½" shuttle valve that will shift position.

- The pod selector valve will always be supplied with control fluid. This is obviously not correct, but considering that a severe surface control fluid leakage will be observed when it occur, and the repair time is short this approximation will not heavily affect the results.

- It is, further, assumed that a severe failure in the pod selector valve (external leakage) will cause that the control system may become inoperative.

Figure 2 shows a sample fault tree for the hydraulic supply for a pilot control system. Figure 3 shows a sample fault tree for single pod failure for a pilot control system.

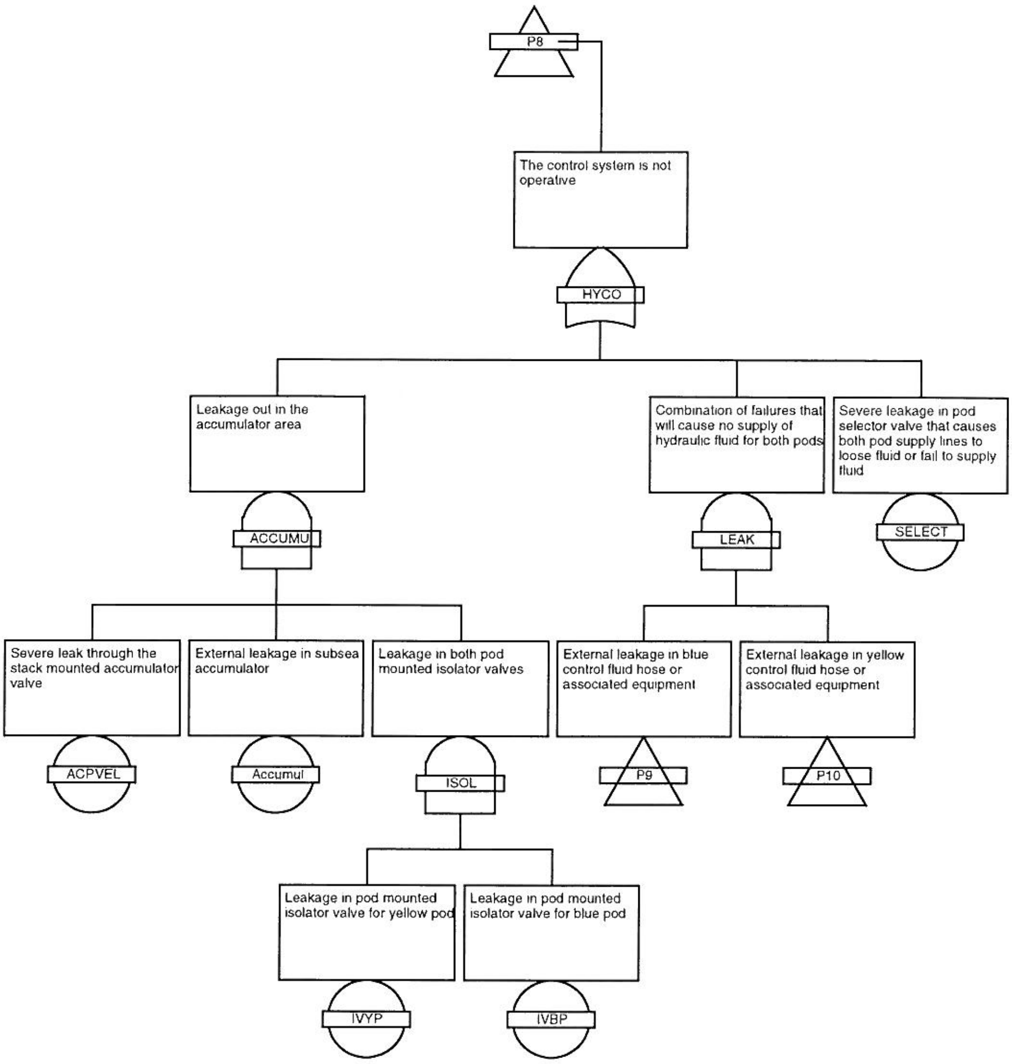


Figure 2 Sample fault tree, hydraulic supply pilot control system

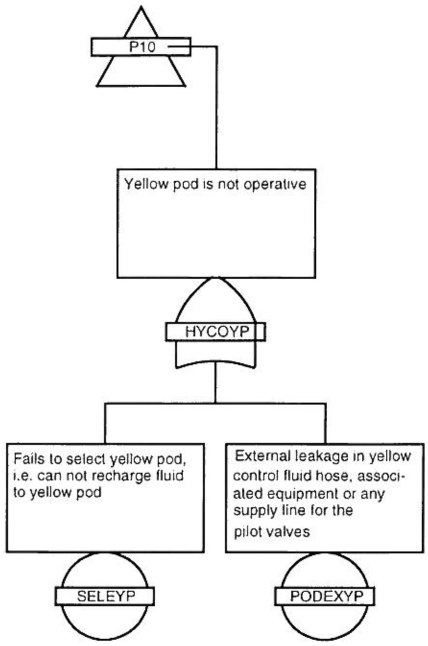
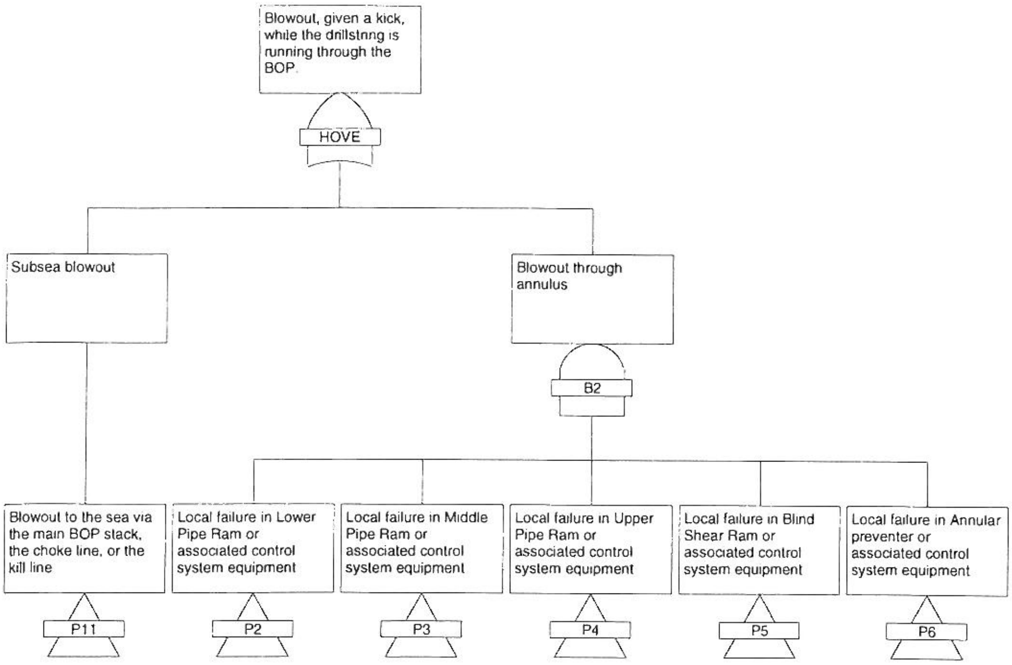


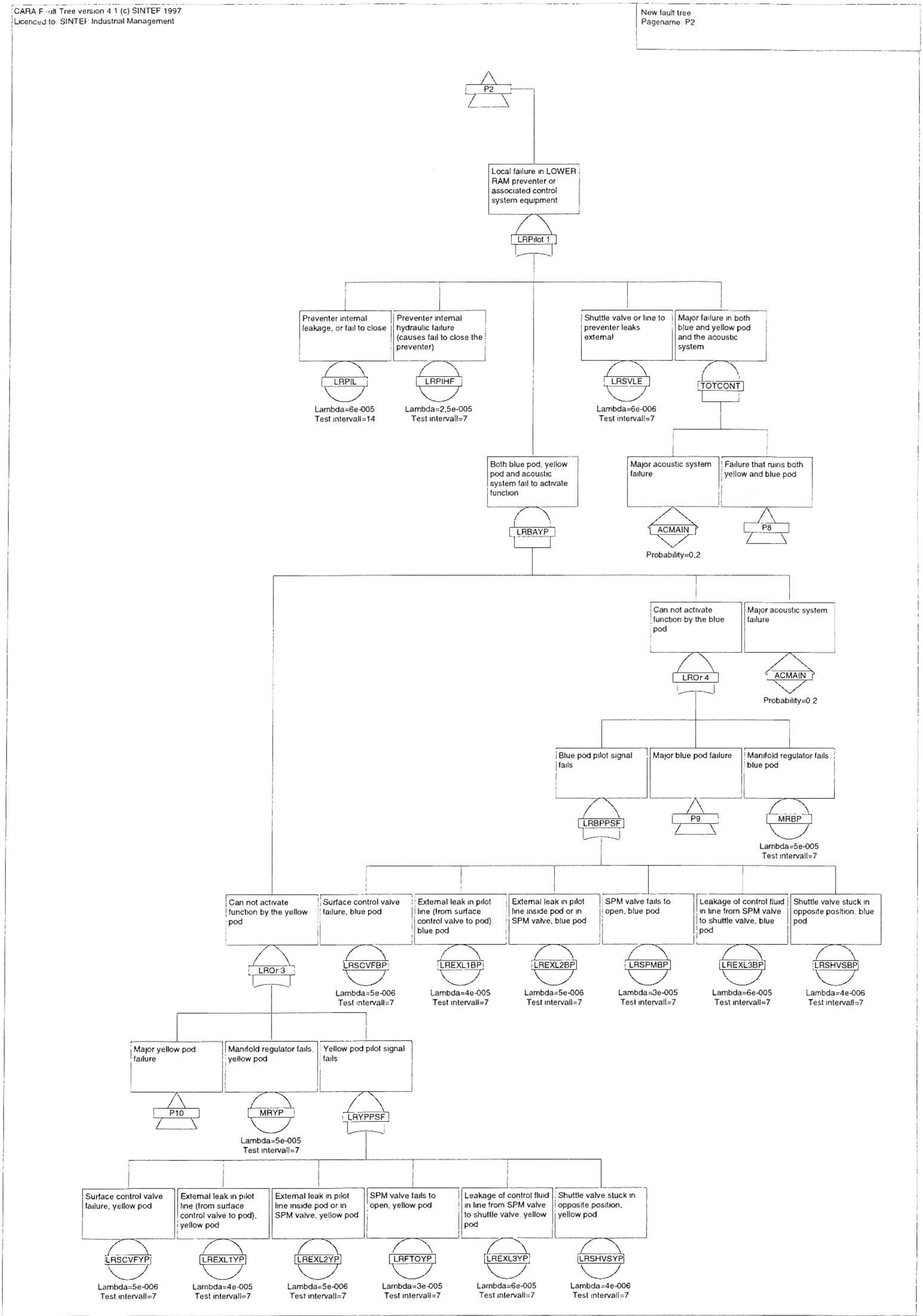
Figure 3 Sample fault tree, single pod failure pilot control system

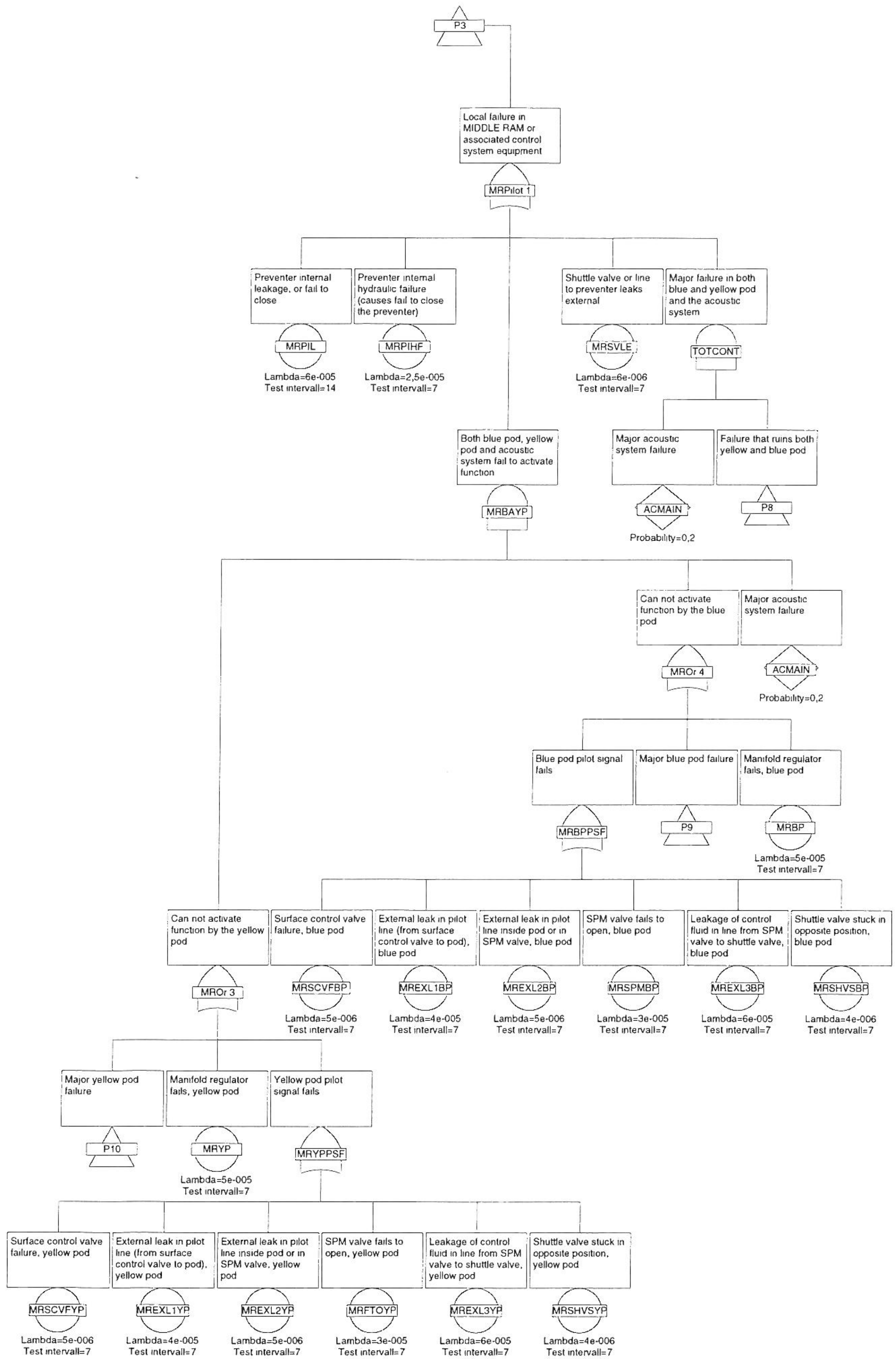
Appendix 3

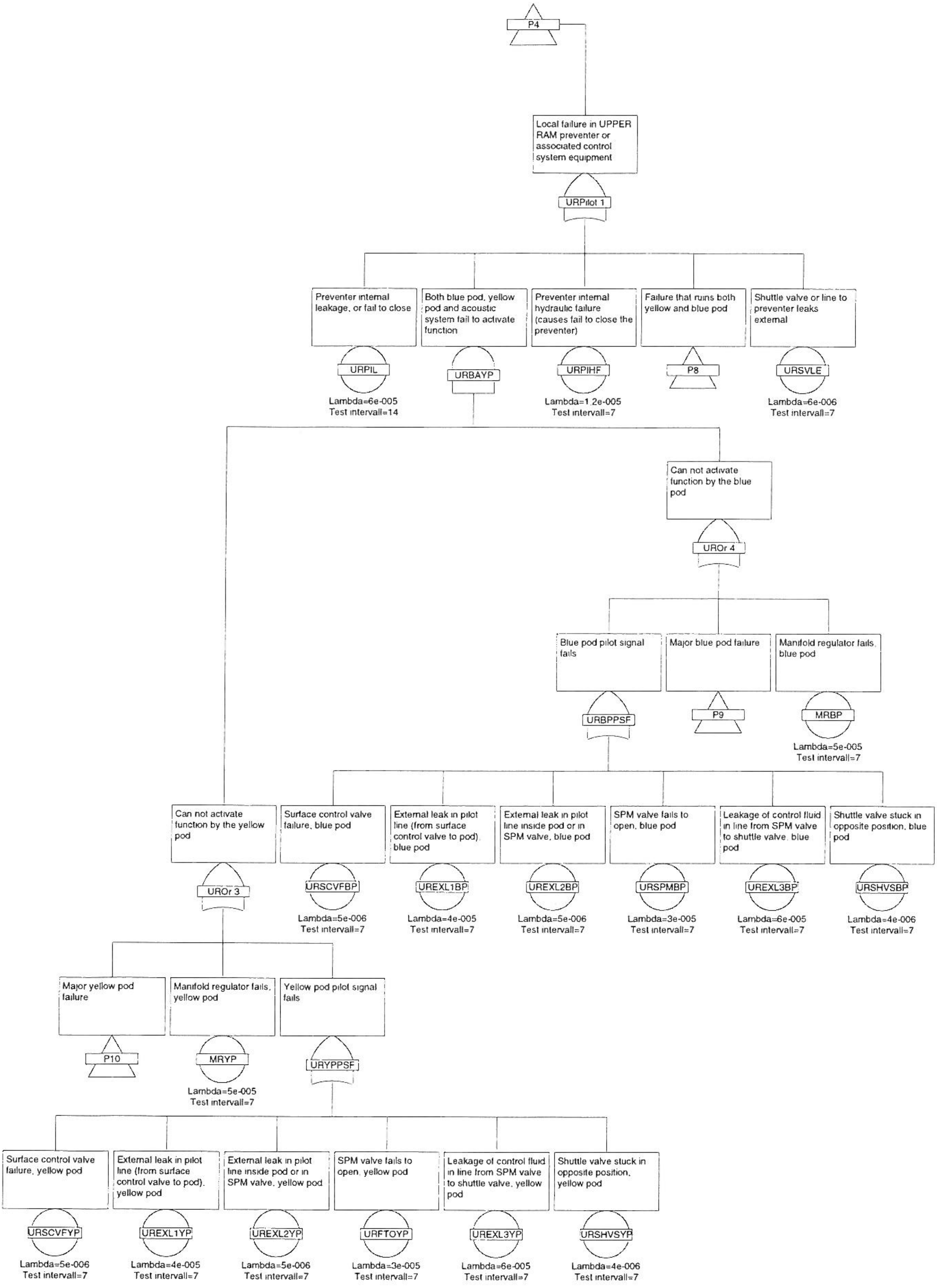
Base Case Fault Tree for the Snorre II BOP

Blowout to sea given a kick




CARA F ult Tree version 4.1 (c) SINTEF 1997
Licenced to: SINTEF Industrial Management
New fault tree
Pagename: P2
P2
Local failure in LOWER RAM preventer or associated control system equipment
LRPilot 1
Preventer internal leakage, or fail to close
LRPIL
Lambda=6e-005
Test intervall=14
Preventer internal hydraulic failure (causes fail to close the preventer)
LRPIHF
Lambda=2,5e-005
Test intervall=7
Shuttle valve or line to preventer leaks external
LRSVLE
Lambda=6e-006
Test intervall=7
Major failure in both blue and yellow pod and the acoustic system
TOTCONT
Major acoustic system failure
ACMAIN
Probability=0,2
Failure that ruins both yellow and blue pod
P8
Both blue pod, yellow pod and acoustic system fail to activate function
LRBAYP
Can not activate function by the blue pod
LROr 4
Major acoustic system failure
ACMAIN
Probability=0,2
Blue pod pilot signal fails
LRBPPSF
Major blue pod failure
P9
Manifold regulator fails, blue pod
MRBP
Lambda=5e-005
Test intervall=7
Can not activate function by the yellow pod
LROr 3
Surface control valve failure, blue pod
LRSCVFBP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), blue pod
LREXL1BP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, blue pod
LREXL2BP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, blue pod
LRSPMBP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, blue pod
LREXL3BP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, blue pod
LRSHVSBP
Lambda=4e-006
Test intervall=7
Major yellow pod failure
P10
Manifold regulator fails, yellow pod
MRYP
Lambda=5e-005
Test intervall=7
Yellow pod pilot signal fails
LRYPPSF
Surface control valve failure, yellow pod
LRSCVFYP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), yellow pod
LREXL1YP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, yellow pod
LREXL2YP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, yellow pod
LRFTOYP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, yellow pod
LREXL3YP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, yellow pod
LRSHVSYP
Lambda=4e-006
Test intervall=7


P3
Local failure in MIDDLE RAM or associated control system equipment
MRPilot 1
Preventer internal leakage, or fail to close
MRPIL
Lambda=6e-005
Test intervall=14
Preventer internal hydraulic failure (causes fail to close the preventer)
MRPIHF
Lambda=2,5e-005
Test intervall=7
Shuttle valve or line to preventer leaks external
MRSVLE
Lambda=6e-006
Test intervall=7
Major failure in both blue and yellow pod and the acoustic system
TOTCONT
Major acoustic system failure
ACMAIN
Probability=0,2
Failure that ruins both yellow and blue pod
P8
Both blue pod, yellow pod and acoustic system fail to activate function
MRBAYP
Can not activate function by the blue pod
MROr 4
Major acoustic system failure
ACMAIN
Probability=0,2
Blue pod pilot signal fails
MRBPPSF
Major blue pod failure
P9
Manifold regulator fails, blue pod
MRBP
Lambda=5e-005
Test intervall=7
Can not activate function by the yellow pod
MROr 3
Surface control valve failure, blue pod
MRSCVFBP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), blue pod
MREXL1BP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, blue pod
MREXL2BP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, blue pod
MRSPMBP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, blue pod
MREXL3BP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, blue pod
MRSHVSBP
Lambda=4e-006
Test intervall=7
Major yellow pod failure
P10
Manifold regulator fails, yellow pod
MRYP
Lambda=5e-005
Test intervall=7
Yellow pod pilot signal fails
MRYPPSF
Surface control valve failure, yellow pod
MRSCVFYP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), yellow pod
MREXL1YP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, yellow pod
MREXL2YP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, yellow pod
MRFTOYP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, yellow pod
MREXL3YP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, yellow pod
MRSHVSYP
Lambda=4e-006
Test intervall=7


P4
Local failure in UPPER RAM preventer or associated control system equipment
URPilot 1
Preventer internal leakage, or fail to close
URPIL
Lambda=6e-005
Test intervall=14
Both blue pod, yellow pod and acoustic system fail to activate function
URBAYP
Preventer internal hydraulic failure (causes fail to close the preventer)
URPIHF
Lambda=1.2e-005
Test intervall=7
Failure that ruins both yellow and blue pod
P8
Shuttle valve or line to preventer leaks external
URSVLE
Lambda=6e-006
Test intervall=7
Can not activate function by the blue pod
UROr 4
Blue pod pilot signal fails
URBPPSF
Major blue pod failure
P9
Manifold regulator fails, blue pod
MRBP
Lambda=5e-005
Test intervall=7
Can not activate function by the yellow pod
UROr 3
Surface control valve failure, blue pod
URSCVFBP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), blue pod
UREXL1BP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, blue pod
UREXL2BP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, blue pod
URSPMBP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, blue pod
UREXL3BP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, blue pod
URSHVSBP
Lambda=4e-006
Test intervall=7
Major yellow pod failure
P10
Manifold regulator fails, yellow pod
MRYP
Lambda=5e-005
Test intervall=7
Yellow pod pilot signal fails
URYPPSF
Surface control valve failure, yellow pod
URSCVFYP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), yellow pod
UREXL1YP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, yellow pod
UREXL2YP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, yellow pod
URFTOYP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, yellow pod
UREXL3YP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, yellow pod
URSHVSYP
Lambda=4e-006
Test intervall=7

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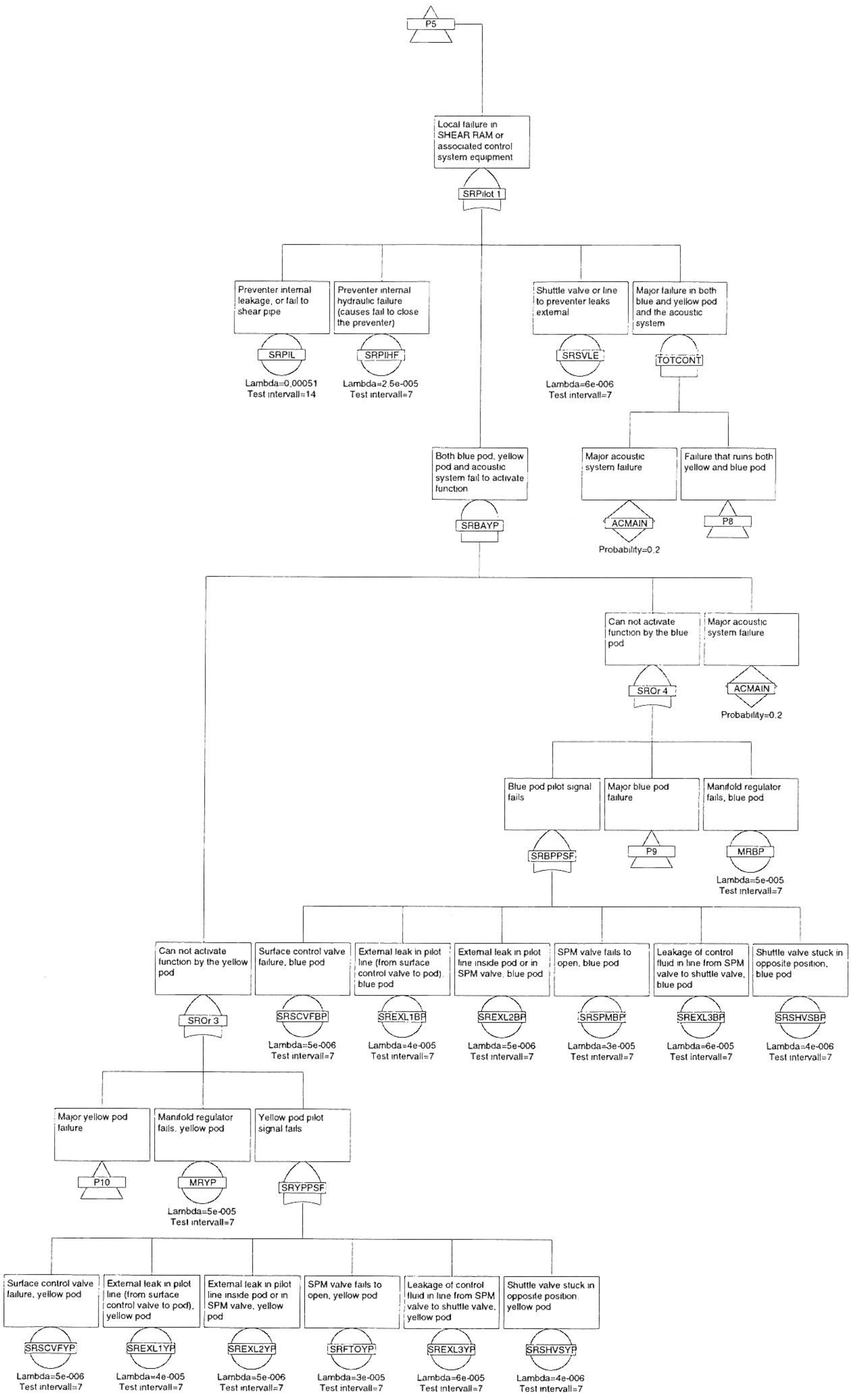
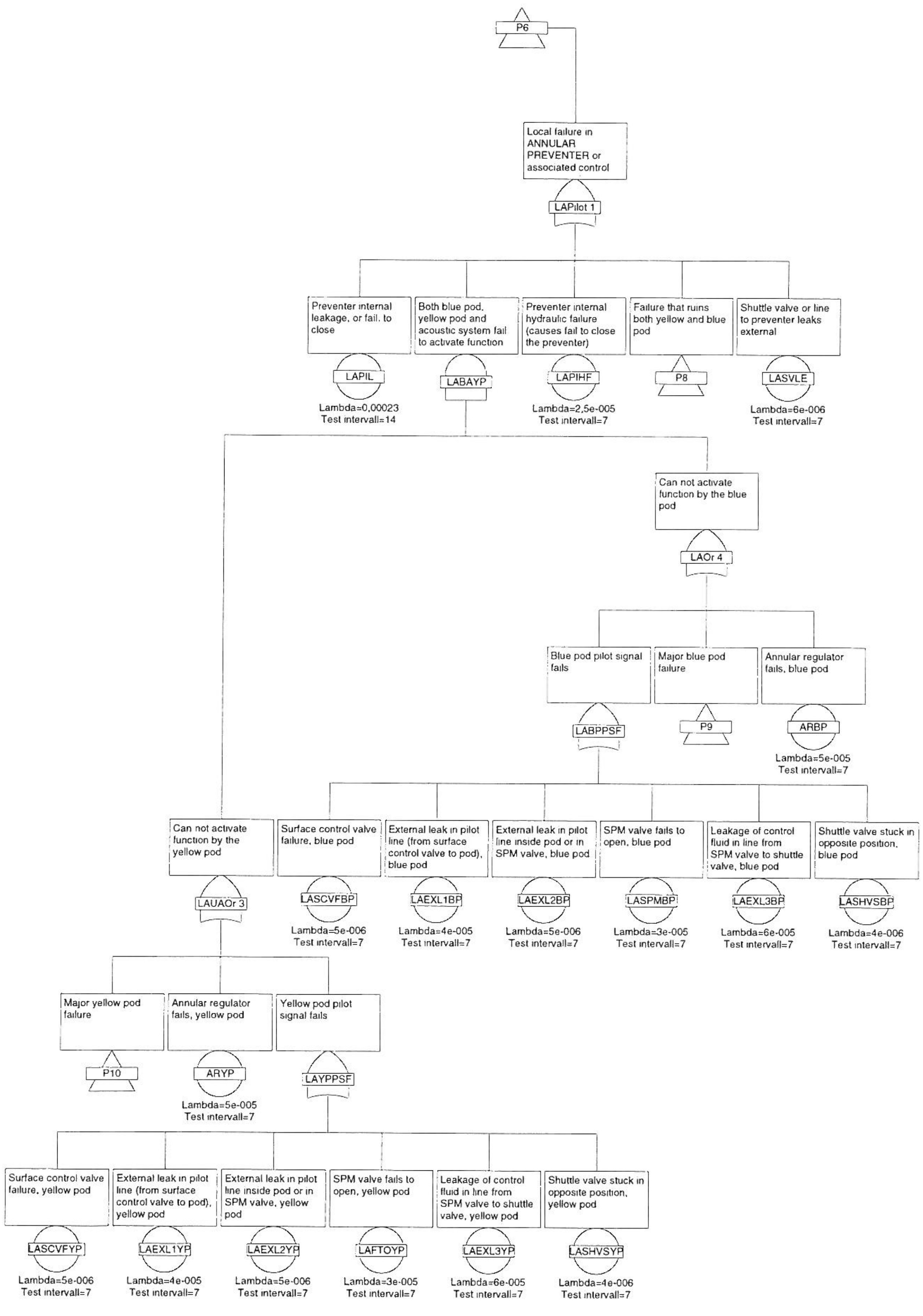
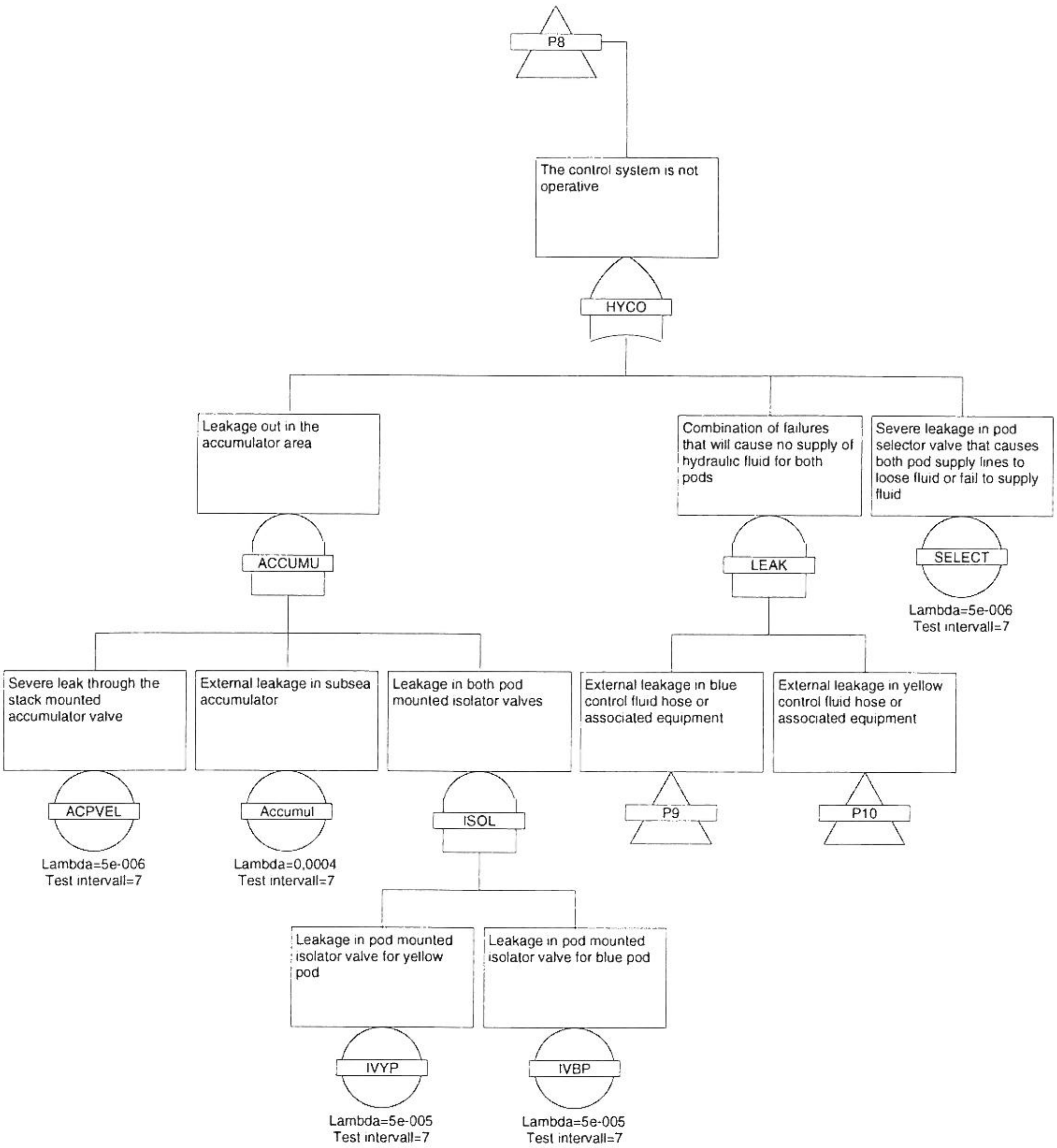
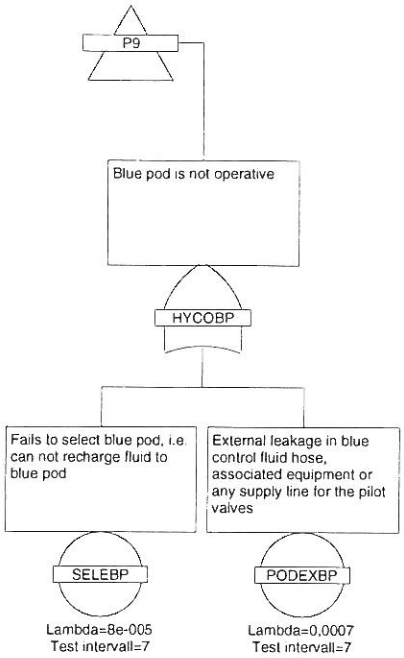
New fault tree
Pagename P5



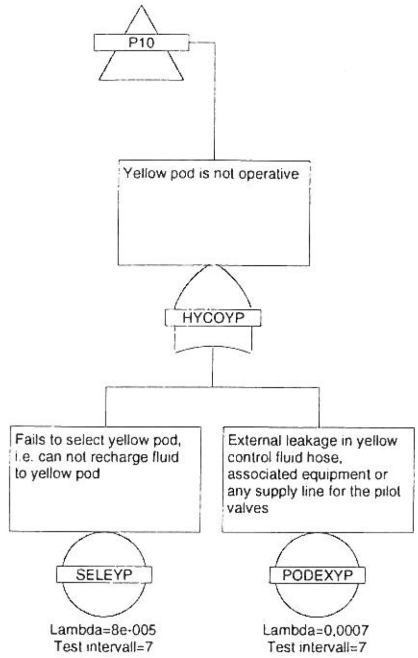

P6
Local failure in ANNULAR PREVENTER or associated control
LAPilot 1
Preventer internal leakage, or fail. to close
LAPIL
Lambda=0,00023
Test intervall=14
Both blue pod, yellow pod and acoustic system fail to activate function
LABAYP
Preventer internal hydraulic failure (causes fail to close the preventer)
LAPIHF
Lambda=2,5e-005
Test intervall=7
Failure that ruins both yellow and blue pod
P8
Shuttle valve or line to preventer leaks external
LASVLE
Lambda=6e-006
Test intervall=7
Can not activate function by the blue pod
LAOr 4
Blue pod pilot signal fails
LABPPSF
Major blue pod failure
P9
Annular regulator fails, blue pod
ARBP
Lambda=5e-005
Test intervall=7
Can not activate function by the yellow pod
LAUAOr 3
Surface control valve failure, blue pod
LASCVFBP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), blue pod
LAEXL1BP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, blue pod
LAEXL2BP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, blue pod
LASPMBP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, blue pod
LAEXL3BP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, blue pod
LASHVSBP
Lambda=4e-006
Test intervall=7
Major yellow pod failure
P10
Annular regulator fails, yellow pod
ARYP
Lambda=5e-005
Test intervall=7
Yellow pod pilot signal fails
LAYPPSF
Surface control valve failure, yellow pod
LASCVFYP
Lambda=5e-006
Test intervall=7
External leak in pilot line (from surface control valve to pod), yellow pod
LAEXL1YP
Lambda=4e-005
Test intervall=7
External leak in pilot line inside pod or in SPM valve, yellow pod
LAEXL2YP
Lambda=5e-006
Test intervall=7
SPM valve fails to open, yellow pod
LAFTOYP
Lambda=3e-005
Test intervall=7
Leakage of control fluid in line from SPM valve to shuttle valve, yellow pod
LAEXL3YP
Lambda=6e-005
Test intervall=7
Shuttle valve stuck in opposite position, yellow pod
LASHVSYP
Lambda=4e-006
Test intervall=7

New fault tree
Pagename: P8




P9
Blue pod is not operative
HYCOBP
Fails to select blue pod, i.e. can not recharge fluid to blue pod
External leakage in blue control fluid hose, associated equipment or any supply line for the pilot valves
SELEBP
PODEXBP
Lambda=8e-005
Test intervall=7
Lambda=0,0007
Test intervall=7

New fault tree
Pagename: P10



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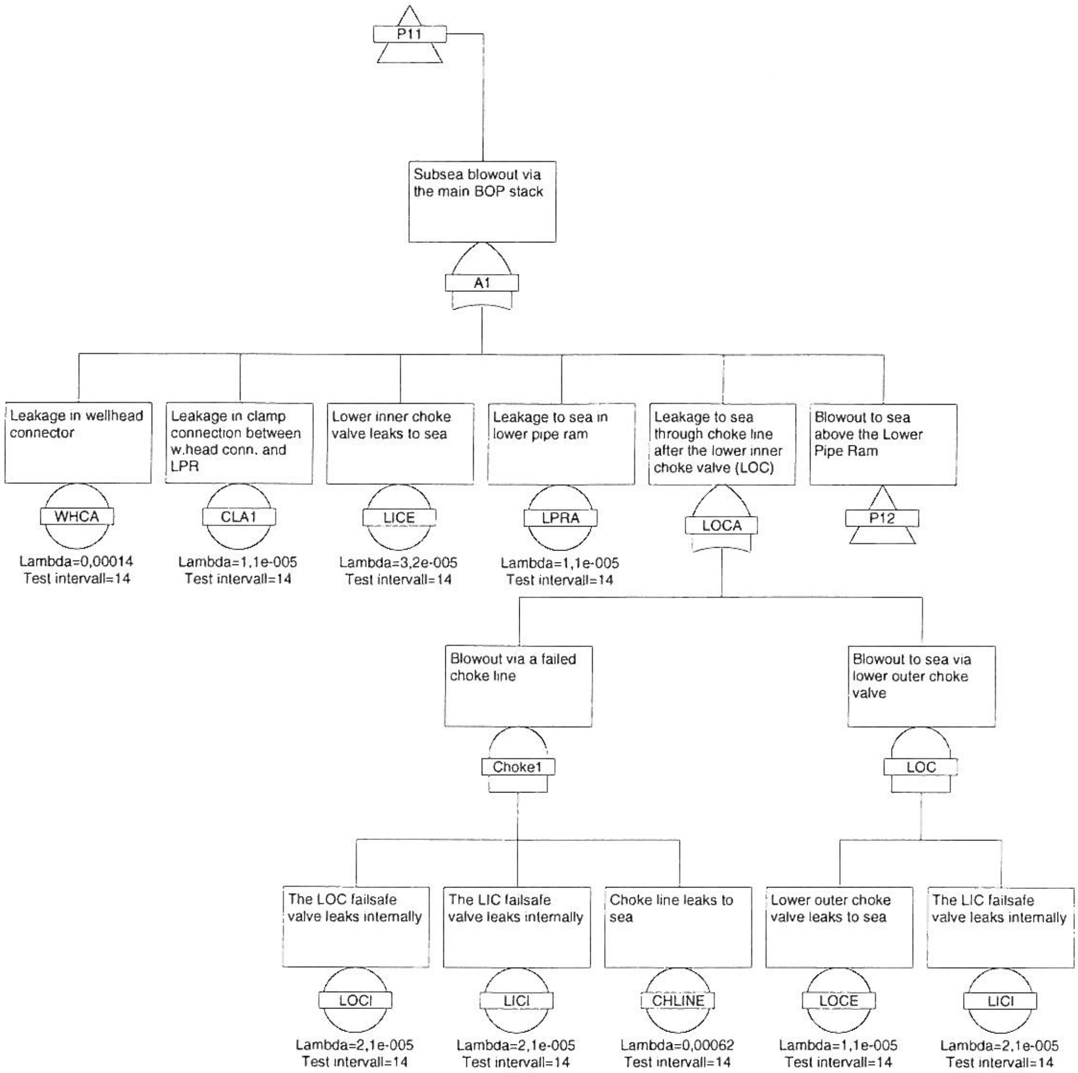
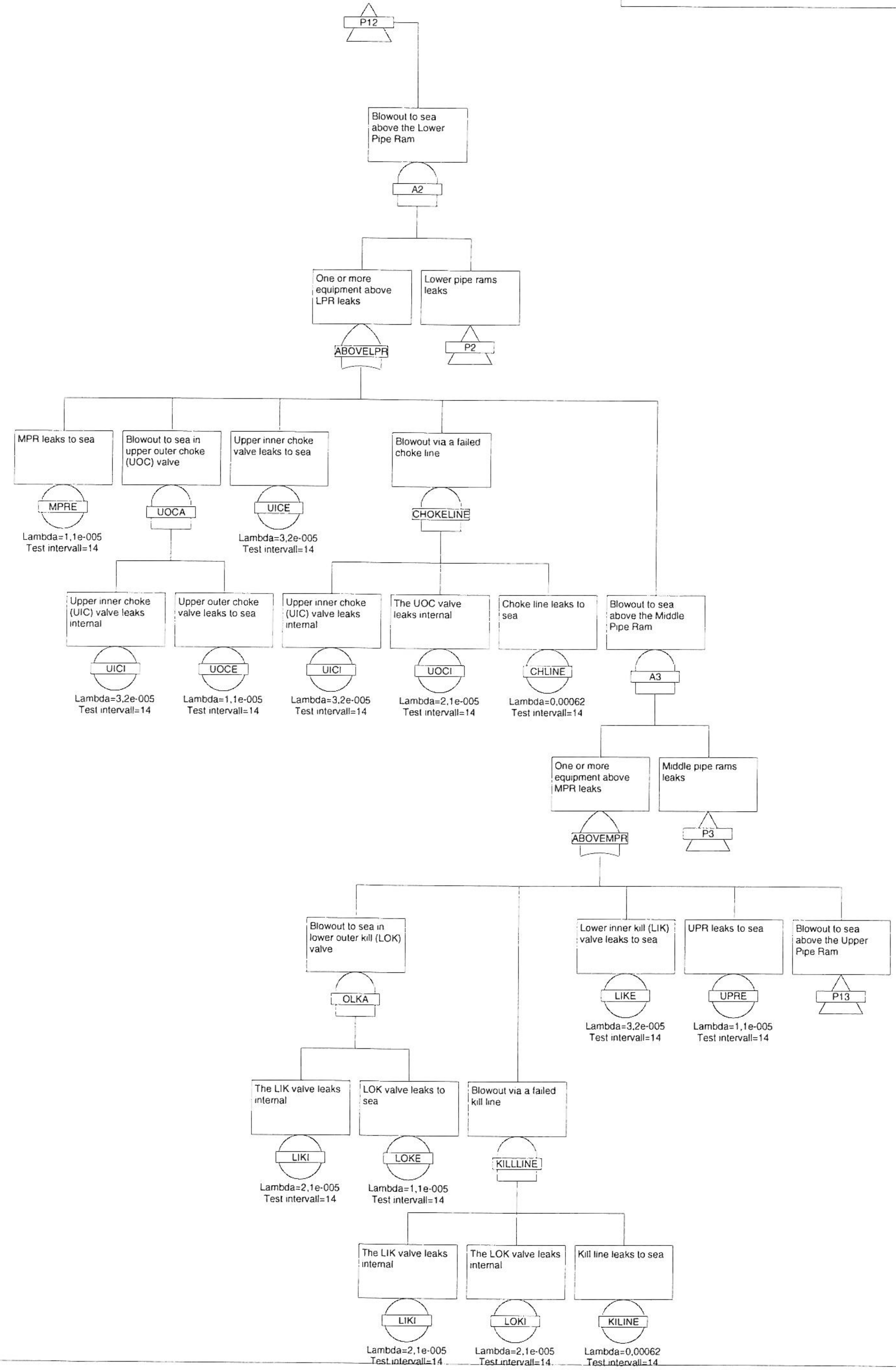
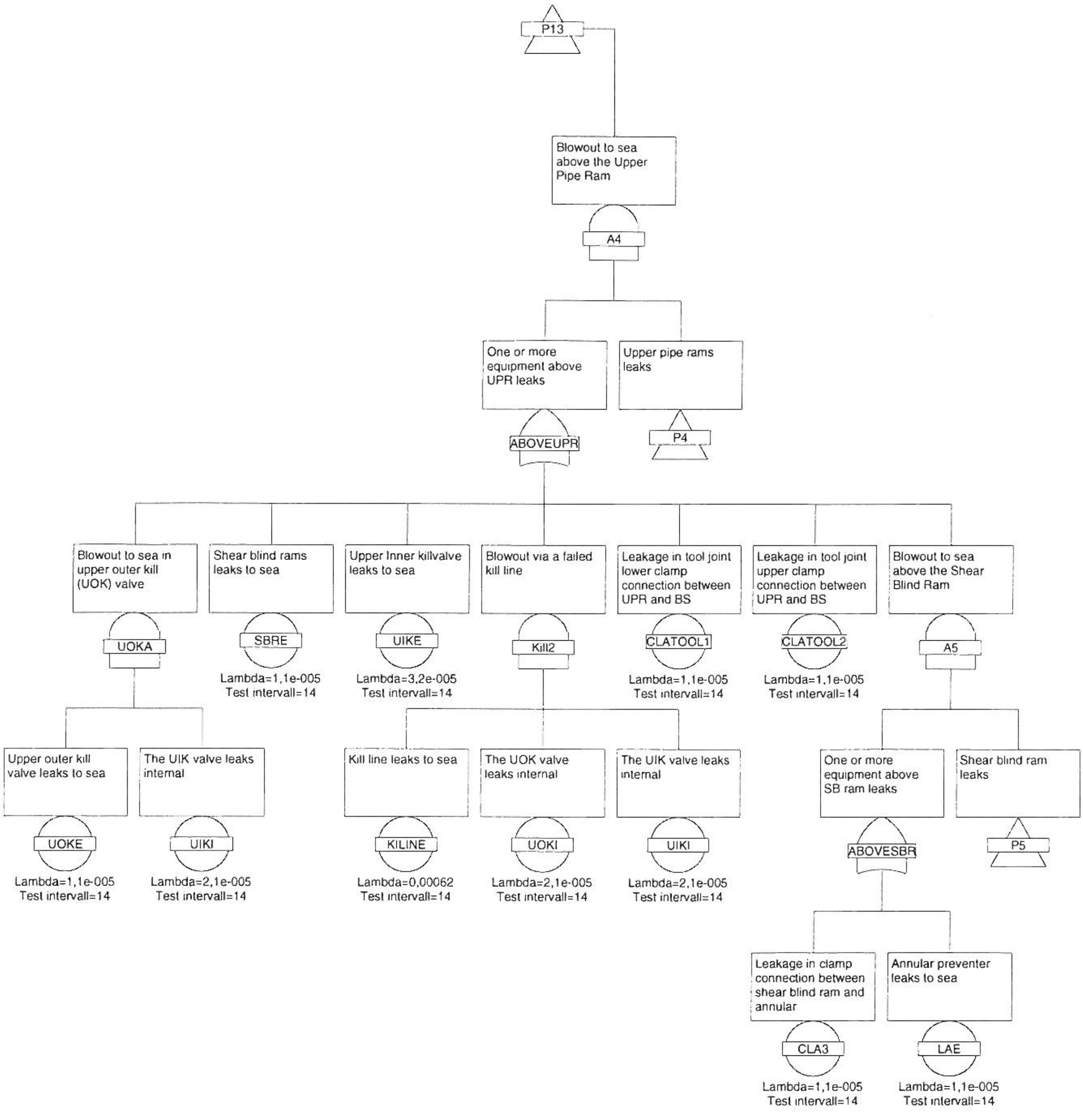
New fault tree
Pagename: P11




P12
Blowout to sea above the Lower Pipe Ram
A2
One or more equipment above LPR leaks
ABOVELPR
Lower pipe rams leaks
P2
MPR leaks to sea
MPRE
Lambda=1,1e-005
Test intervall=14
Blowout to sea in upper outer choke (UOC) valve
UOCA
Upper inner choke valve leaks to sea
UICE
Lambda=3,2e-005
Test intervall=14
Blowout via a failed choke line
CHOKELINE
Upper inner choke (UIC) valve leaks internal
UICI
Lambda=3,2e-005
Test intervall=14
Upper outer choke valve leaks to sea
UOCE
Lambda=1,1e-005
Test intervall=14
Upper inner choke (UIC) valve leaks internal
UICI
Lambda=3,2e-005
Test intervall=14
The UOC valve leaks internal
UOCI
Lambda=2,1e-005
Test intervall=14
Choke line leaks to sea
CHLINE
Lambda=0,00062
Test intervall=14
Blowout to sea above the Middle Pipe Ram
A3
One or more equipment above MPR leaks
ABOVEMPR
Middle pipe rams leaks
P3
Blowout to sea in lower outer kill (LOK) valve
OLKA
Lower inner kill (LIK) valve leaks to sea
LIKE
Lambda=3,2e-005
Test intervall=14
UPR leaks to sea
UPRE
Lambda=1,1e-005
Test intervall=14
Blowout to sea above the Upper Pipe Ram
P13
The LIK valve leaks internal
LIKI
Lambda=2,1e-005
Test intervall=14
LOK valve leaks to sea
LOKE
Lambda=1,1e-005
Test intervall=14
Blowout via a failed kill line
KILLLINE
The LIK valve leaks internal
LIKI
Lambda=2,1e-005
Test intervall=14
The LOK valve leaks internal
LOKI
Lambda=2,1e-005
Test intervall=14
Kill line leaks to sea
KILINE
Lambda=0,00062
Test intervall=14


P13
Blowout to sea above the Upper Pipe Ram
A4
One or more equipment above UPR leaks
Upper pipe rams leaks
ABOVEUPR
P4
Blowout to sea in upper outer kill (UOK) valve
Shear blind rams leaks to sea
Upper Inner killvalve leaks to sea
Blowout via a failed kill line
Leakage in tool joint lower clamp connection between UPR and BS
Leakage in tool joint upper clamp connection between UPR and BS
Blowout to sea above the Shear Blind Ram
UOKA
SBRE
UIKE
Kill2
CLATOOL1
CLATOOL2
A5
Lambda=1,1e-005
Test intervall=14
Lambda=3,2e-005
Test intervall=14
Lambda=1,1e-005
Test intervall=14
Lambda=1,1e-005
Test intervall=14
Upper outer kill valve leaks to sea
The UIK valve leaks internal
Kill line leaks to sea
The UOK valve leaks internal
The UIK valve leaks internal
One or more equipment above SB ram leaks
Shear blind ram leaks
UOKE
UIKI
KILINE
UOKI
UIKI
ABOVESBR
P5
Lambda=1,1e-005
Test intervall=14
Lambda=2,1e-005
Test intervall=14
Lambda=0,00062
Test intervall=14
Lambda=2,1e-005
Test intervall=14
Lambda=2,1e-005
Test intervall=14
Leakage in clamp connection between shear blind ram and annular
Annular preventer leaks to sea
CLA3
LAE
Lambda=1,1e-005
Test intervall=14
Lambda=1,1e-005
Test intervall=14

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