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PROCESSO N. 19489/2001

Representante: ______________________________

AUTUAÇÃO

Aos 09 de agosto de dois mil e quatro na Secretaria do Tribunal Marítimo autuo os presentes autos.

Do que fiz este termo.

CÓPIA FIEL DO DOCUMENTO ORIGINAL

JOSE CARLOS PIMENTEL GUSMÃO
DIRETOR
DIVISÃO DE SERVIÇOS CARTORIAIS

Diretor - Geral da Secretaria

5364-B

CERTIDÃO

CERTIFICO que nesta data é iniciado o 24º volume do processo nº 19489/01 com suas fls. numeradas a partir do 5364-B dos autos.
O referido é verdade e dou fé.
Aos 28 de abril de 2006.

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USA

Report - Into the P-36 Accident of 15 March 2001

Report For: Petroleo Brasilerio, SA (Petrobras)

Report By: Gary Kenney, B.Sc., M.Sc., Ph.D.

14 November 2005

INTRODUCTION

1.1. On 15 March 2001 the offshore Floating Production Unit owned and operated by Petroleo Brasileiro SA (Petrobras) and designated as the P-36 suffered what was described by the crew as a 'thud' at approximately 00:22 hours. Various alarms sounded in the control room and an emergency team and/or fire brigade was assembled to investigate the cause of the 'thud'. Approximately seventeen minutes later (i.e. at 00.39 hrs, 15 March) an explosion occurred in the starboard-aft column. This explosion would claim the lives of eleven members of the assembled fire brigade team. Despite various efforts of the operators and crew on board to address and rectify the subsequent events, decisions were taken to evacuate all non-essential personnel. The evacuation of these individuals was completed at 04.20 hours. The situation on the facility continued to deteriorate and on the loss of the general control system the decision was taken to abandon the platform. The removal of the remaining staff was completed at 06.03 hours.

Petrobras' Commission of Inquiry

1.2. Because of the nature and scale of the accident Petrobras convened a Commission of Inquiry to investigate and try and determine the cause of the accident and those factors which might have contributed to it. The Commission was also charged with making recommendations to prevent the recurrence of such an event. This Commission prepared an interim report of their work dated 20/04/01. On 20th June 2001 the Commission delivered its Final Report to the Senior Management of Petrobras.

1.3. The Commission developed and examined a number of scenarios each of which to try and explain the events that happened on the night of 14 March and into the early morning hours of 15 March. After testing these various scenarios the Commission concluded that the most viable hypothesis, considering the technical data available at the time, was that the initial event (i.e. the thud) was the result of the Drains Storage Tank located in the Starboard-Aft Column rupturing due to it being inadvertently pressured to approximately 10 barg. On rupturing, the contents of the Tank a mixture of water, oil and gas, was released into the open area of Fourth Level of the starboard column. Further the rupturing of the Tank wall was severe enough to sever the sea water line which ran adjacent to the Tank contributing further liquids into the column. As noted earlier, following this rupture an emergency team and/or fire brigade was marshalled and took steps to investigate the developing situation in the Starboard Aft Column. In the process of carrying out their investigations eleven members of this Team, who were within the column, were caught when the gases mixed with enough air to form a flammable cloud and subsequently ignited.

Petrobras' Continuing Investigations

1.4. The period of time (i.e. approximately three months) afforded the Commission to conclude its investigations and report was relatively short in comparison to other similar investigations and notably that of the Piper Alpha disaster. The Piper Alpha Disaster occurred in July 1988 yet it was not until November of 1990 that Lord Cullen completed his investigations and issued his Report on the cause of the disaster and means to prevent its recurrence. As a result, Petrobras as a responsible Operator has continued, after the initial work of the Commission, to research various issues and matters associated with the design, construction and operation of the P-36. These investigations have been primarily to assure Petrobras that any other factors, besides those already identified by the Commission, have been identified and well researched to prevent them from being repeated in future designs and/or operations. These ongoing investigations are a clear sign of Petrobras' intent, as a responsible Operator, to verify its internal processes as a means to achieving Continuous Improvement in the Oil & Gas Industry Worldwide.

1.5. As a part of those studies, Sine Rivali were contacted in September 2005 with the request to examine various issues associated with the design and operation of the closed drain system, as well as certain operator actions and activities preceding and following the tank rupture and secondary gas explosion. Our report of those examinations, along with our findings and conclusions follows.

2. CONTRACTUAL AGREEMENTS AND ENGINEERING SPECIFICATIONS

Background

2.1. Per the Commission's investigations and findings the initial failure or rupture of the Starboard Drains Storage Tank (DST) was a result of the Tank being pressured to approximately 10 barg. No work was being done on the Starboard Tank itself nor the associated piping, pumps or valves at the time it ruptured. Further there are no records that any work had been done to the Starboard portion of the closed drains system, of which the DST was a part, in the hours immediately prior to its failure. The night shift operators had aligned the various valves that were a part of the Closed Drain system to drain the contents of the Port Drains Storage Tank back to the Production Header. The procedure for draining these tanks is detailed in Section 14 of the P-36 Operating Manual and it was this procedure that the Operators were following. It was during this process that the Starboard Tank failed.

Contractual Arrangements for the Upgrade Project

2.2. In June of 1997 Petroleo Brasileiro S.A. (Petrobras); Braspetro Oil Services Co. (Brasoil); Petro-Deep Inc. and Petromec, Inc entered into an agreement whereby Petromec undertook the responsibility of supervising and coordinating the engineering and design aspects associated with upgrading a vessel titled the Spirit of Columbus. This vessel was to be renamed Petrobras-P36 or more simply the P-36. The vessel was originally designed as a drilling and production facility for the Emmerald Field in the North Sea. Its original design included a daily processing capacity of 100,000 barrels of oil and 2 million m^3 of gas. To meet the needs of the Roncador field, the production equipment had to be replaced with larger equipment and plant, and the marine elements of the Unit converted to that of a tension leg facility.

2.3. In June 1997, Petromec entered into an agreement with AMEC Process and Energy Ltd (APEL) of Cheshire, England for the upgrade of the Spirit of Columbus. The Engineering Scope of Work that AMEC was to undertake per this agreement included the following:

APEL are responsible for the engineering design for the Spirit of Columbus upgrade and will provide a Floating Production Unit comprising a production and processing plant for processing 180,000 barrels/day of crude oil, for gas and oil production in the Roncador Field, Campos Basin, offshore the north coast of the State of Rio de Janeiro, Brazil.

The Engineering Design shall assure that the following objectives will be met:

a) Provide safe facilities

b) Provide facilities that comply with technical requirements

c) Specify equipment that will allow optimum operation of the facility at the given design conditions while requiring a minimum of supervision, operating and maintenance

d) Avoid environmental pollution...

The scope for the engineering design contractor's responsibility and deliverables (i.e. APEL's) went on to include:

...The scope shall cover the full range of services necessary for the successful completion of the work, which shall include but not restricted to:

- *Basic Design*
- *Detailed Design ...*
- *Interface Management...*
- *Operating and Maintenance Manuals*
- *Document Control*
- *Safety Analysis*
- *Engineering Resource Planning*
- *Marine Engineering Co-Ordination of Noble Denton (non-technical)*

2.4. On 27 July 1997 Petromec and Noble Denton entered into an agreement to be effective as of the date of 13th June 1997 whereby Noble Denton were responsible for undertaking the engineering design of various marine related issues required to upgrade the Spirit of Columbus (P-36) for use within the Campos Basin. Noble Denton was responsible for the engineering and design of any required modifications to the hull, an analysis of the stability of the upgraded vessel, weight management, etc. Noble Denton were also responsible for preparing those sections of the Operating Manual that addressed the ballasting of the vessel and other issues that required modification or revision in line with the changes to the hull, mooring systems, etc. Noble Denton was to assure all documents were reviewed by nominated discipline engineers and submitted to both Petromec and Brasoil for review and approval. The overall project management of the engineering of the upgrade was the responsibility of AMEC and Petromec retained the responsibility for overall project co-ordination.

General Technical Specifications

2.5. With these agreements in place and as a part of the design process, Brasoil provided Petromec with a package of General Technical Specifications for the SANA-15000/P-36. The purpose in providing this package of specifications to Petromec was described in the Intent section of that material as – '*...to help the CONTRACTOR finding Brasoil's requirements.*' This section went on to stipulate:

> *Within the contracted scope of work, the CONTRACTOR shall develop the Basic Design and Detailed Engineering Design documents, studies, analysis, of all systems, materials, equipment...*

The Intent section of the General Technical Specifications also noted that:

> *The detailed Engineering Design and conversion shall be approved by the Classification Society.*

The requirement for approval by an appropriate classification society is to provide the purchaser or owner/operator with an independent third party review and check of the design. This assures the design is in accord with various class rules, as well as specific regulations and industry design standards, codes and/or practices.

2.6. Section M19 of the General Technical Specifications outlined the overall requirements for the Drainage System. Section M19.1 entitled General, stated;

> *A drainage system shall be provided in accordance to IMO-MARPOL, API rules and Class Society rules.*

Section M19.3 outlined the general scope of the closed drainage system:

> *All closed drainage and diesel closed drains shall be sent to the Slop Vessel...*

2.7. Section G3.4 of the General Technical Specifications entitled – *Special Documents and Instruction Books* – outlined the various documents, information, data, etc. that AMEC or APEL was to supply. Within this Section, sub-section G3.4.6 entitled Manuals provided an overview of the responsibility and requirements for various manuals to be supplied. One such manual was the Platform Operating Manual. A part of the requirements for the Operating Platform Manual included:

The CONTRACTOR shall provide a revised/updated operating manual containing all items required by the Classification Society and Regulatory Authorities. ... The Platform Operating Manual shall include, at least, the following:

- *Environment limiting operations, ...*
- *Ballasting and de-ballasting procedures,*
- *Emergency conditions such as oil and gas leakage, fire, flooding, emergency evacuation, accidents, etc.*

In addition to the Platform Operating Manual, the CONTRACTOR was to supply a Process Plant Operating Manual. The requirements for this Manual were outlined as follows:

The CONTRACTOR shall provide BRASOIL an operating manual which gives a good overview of the process plant and associated utility systems.

The Process Plant Operating Manual to include at least the following:

- *Flow diagram indicating the capacities of equipment*
- *Brief description of each system...*
- *Operating procedures such as initial start up... normal production (including normal control settings); possible abnormal conditions and symptoms; corrective actions...*

2.8. From the above, AMEC's responsibility for developing a detailed design as well as the performance of appropriate safety studies for all process and associated utility systems is clear. Further it is clear that it was AMEC's responsibility to prepare and deliver the necessary manuals to operate safely those systems.

Regulatory Requirements and Standard Design Practices

2.9. In 1992 the United Kingdom, Health and Safety Executive promulgated the Offshore Installations (Safety Case) Regulations. Sitting at the heart of these regulations is the requirement that the risks of all reasonably foreseeable major hazard accidents (e.g. explosions, fires, ship collisions, etc.) have been identified, assessed and measures taken to control those risks to levels that are 'As Low As Reasonably Practicable' (ALARP). Regulation 12 of the Offshore

Safety Case regulations requires that a management system is in place that is adequate to demonstrate, not only compliance with the relevant requirements of the regulations as well as assure the risks arising from all reasonably foreseeable hazards are controlled to levels 'as low as reasonably practicable'. The process(es) employed to meet this requirement is typically referred to as a 'Formal Safety Assessment' or FSA. The regulations require that a document called a 'Safety Case' be submitted to the HSE for their review. The primary purpose of this document is to demonstrate to the HSE that an FSA has been performed of the design and operations of the facility and that steps have been taken and systems are in place to control these risks to the ALARP level. The Regulations require that all new facilities submit a 'Design Safety Case' generally somewhere in the middle of the detailed design phase. In other words at a point where the design has been frozen and various hazard identification techniques such as HAZOP can be applied with some assurance that there are few if any major changes likely to occur to the general layout of the facility as well as to the major process and utility systems. The HSE will review the Design Safety Case and comment on whether they feel that the design for the proposed facility is in accord with all applicable industry standards and practices, and that all reasonably foreseeable major hazards have been identified and steps are in place to control the risks arising from those hazards will, to the best efforts of the engineering firms, be designed out of the system. In addition to this Design Safety Case, approximately six months prior to the commissioning and start-up of the offshore installation, an Operations Safety Case must be submitted to the HSE. The purpose of the Operations Safety Case is again to demonstrate that all reasonably foreseeable risks are controlled to 'As Low As Reasonably Practicable'. However where the Design Safety Case is focused almost entirely on controlling risks through good engineering and design, the Operations Safety Case recognizes that some risks will have to be controlled through operational and maintenance procedures and practices. The Operations Safety Case then presents a more complete picture of the control mechanisms than the Design Safety Case. Of import is that the Operations Safety Case must by statute be 'accepted' by the HSE. Should the HSE determine the Operations Safety Case does not well demonstrate that all reasonably foreseeable risks have been controlled to ALARP, the HSE can either require the Operator to review, revise and resubmit those sections deemed to be below standard or in an extreme case refuse to allow the Operator to proceed with the commissioning and start-up of the facility as planned until outstanding matters are addressed to the satisfaction of the HSE.

2.10. Within the United States, the US Minerals Management Society (MMS) has the responsibility for administering safety on offshore facilities operating in US territorial waters. In August 1996 the MMS issued a notice to Lessees and Operators of facilities on the US Outer Continental Shelf that any facility planned or operating in waters of 1000 feet or deeper would have to prepare and submit to the MMS a Deep Water Operating Plan (DWOP). The Notice identified that:

> *... MMS will review deepwater development activities from a total system perspective, emphasizing the operational safety, environmental protection, and conservation of natural resources.*

Similar to the UK's Safety Case, a DWOP is to be submitted in three parts. One part at the end of the concept selection, a second part at the end of preliminary engineering and review of various system alternatives with the selection of the final alternative and supporting reasons, and the third and final part approximately ninety days after the start of production. The Operator must obtain the approval of MMS for each part of the DWOP as described above to continue with the design and/or operation of the facility. MMS notified lessees and operators that as part of their DWOP they should undertake an evaluation of the various hazards that could occur on such a facility in accordance with the practices as described in API-RP 14J (1993). This Standard notes that the hazard identification process selected should be appropriate to the potential magnitude of the hazards and also have the ability to identify where a combination or sequence of events could lead to a major accident.

2.11. At the time the contracts were signed for upgrade of the Spirit of Columbus **all major international engineering and design companies had incorporated the practice of performing formal assessments on the facilities they were designing and building for the operators of offshore installations no matter where those installations were to be**

located in the world. This was especially true of those engineering and design companies whose home offices were located in the UK as with AMEC Process and Energy Ltd. By mid-1997 (i.e. the time of contract signing for the P-36 upgrade project) all major engineering design companies had incorporated the use of various safety techniques such as HAZOP, fire and explosion analyses, and in many cases quantitative risk analysis of the base and detailed design into their offshore projects.

2.12. A variety of terms are used within the engineering industry to describe the various phases of a major project such as was involved with the upgrading of the P-36 facility. These phases can be generically identified as:

- Concept selection and/or conceptual design,
- Preliminary engineering and design,
- Detailed engineering and design,
- Procurement and construction, and possibly integration for offshore facilities,
- Completion, commissioning and start-up

As the project moves forward in accordance with good industry standards, various safety analyses are performed. In the first stage, those studies would primarily entail what are termed 'conceptual or coarse hazard identification techniques'. These techniques include methods such as 'Structured What If Technique' (SWIFT), major hazard checklists, and 'coarse or conceptual HAZOP'. As the design progresses, further studies are carried out. When the design moves into Preliminary engineering phase, a preliminary HAZOP will be performed. At various stages in the detailed engineering phase, a second series of HAZOP's will be performed. The timing for the performance of this second series of HAZOP's will be determined by the completeness of the design of the various major systems. Typically this occurs when the Project Manager or Project Director 'freezes' the design of all the major systems. The term 'frozen' is used to denote that the design of a particular system will have reached a stage where no further major modifications to the system design are foreseen by the engineering team. This is important as major modifications will almost always result in a change in the hazards and risks that could either impact these systems or arise from the operation of that system.

2.13. Both the Offshore Safety Case regulations and API-RP 14J make provision for 'major modifications' to a system and require that when such a change has been made it is necessary to undertake a complete review of those modifications. The purpose of that review is to establish whether the modification(s) could give rise to new and/or different hazards versus those hazards and risk that were identified associated with the original design.

3. CLOSED DRAIN AND DRAINS STORAGE TANK SYSTEM

Design of the System

3.1. The actual design of the closed drain system and more specifically that of the Drains Storage Tank and its associated piping, pumps, valves and vents has been performed and reported on by Mr. Rod Sylvester-Evans. Mr. Sylvester-Evans identified a number of areas with respect to the design of this system that were not in accord with industry standards. As a part of his investigations, Mr. Sylvester-Evans noted that as the design of the drains progressed from the phase of Basic Design to that of Detailed Engineering, (i.e. from Rev 0 of the drawings to Rev A) a number of revisions were made to the closed drains system. Again Mr. Sylvester-Evans has examined those changes in some detail and commented on them individually and collectively.

3.2. Indeed, AMEC undertook a HAZOP of the early design changes and modifications planned for the P-36 over the period of 9/June to 10/July, 1997. A report of that work was published on 17 July 1997. In the Introduction to the Report it was recorded that:

> *The design that was HAZOP'ed was that supplied by Petrobras in the form of preliminary P&ID's which were copied by AMEC and brought into line with the new field processing requirements.*

Under section 3.0 – Limit of AMEC Responsibilities – the following points were noted:

> *For the purposes of this HAZOP the AMEC responsibilities were considered to include all topside process and utilities from inlet SDV to export SDV. ...*

The HAZOP was generally restricted to all new equipment in the above category plus any modifications needed to existing equipment.

Under section 7.0 – Problems that Delayed the HAZOP – the Report noted that certain factors contributed to the Team not completing the HAZOP work faster one of which being:

The existing equipment turned out to be inadequate in some way or other – e.g. the closed drains tank not big enough to contain all the fluids drained from the largest process vessels on maintenance.

In Appendix 1 of the Report a list of all the P&ID's that were HAZOP'ed is presented. The Closed Drains Drum P&ID and the Hazardous Open Drains Drum P&ID's (DE-3010.38-5336-944-AMK-392 and 394 Rev 0) were included in this list as being HAZOP'ed. However, the P&ID for the Drains Storage Tank (AMK 398 Rev 0 issued in April 1997) is not listed. The assumption must be made then that the Preliminary design for the Drains Storage Tank was not HAZOPed as a part of the June/July 1997 study.

3.3. AMEC's HAZOP of June/July 1997 would be viewed as a 'preliminary HAZOP' of the drains system as contained within those P&ID's that were actually HAZOPed.

3.4. The HAZOP work sheets recorded that the arrangement for the closed drains did not comply with Petrobras requirements that a 'slop vessel' be provided with capacity to hold the total volume of the largest production vessel plus 20% (i.e. the slop vessel should have a capacity of 120% of the largest production vessel). HAZOP Action item 523 noted that AMEC's Process Department should consider other alternatives for the Drains Storage Vessel.

3.5. One such alternative namely the re-use of the mud tanks as the Drains Storage Tank or vessels is discussed in HAZOP Action Item #493 dated 8/7/97. (see Annex One). This Sheet records that it was decided the use of the mud tanks was an unacceptable alternative. The Sheet does not clearly record the reason why the use of the mud tanks was determined to be unacceptable. There is mention, though, that the mud tanks were located below the accommodation block. The inference, then, is that as the mud tanks were located under the accommodation block the use as Drains Storage Tanks presented an unacceptable hazard to personnel and for that reason it was decided not to use mud tanks as Drains Storage Tanks. Nor does the sheet record who took this decision. I have seen no records that the use of the mud tanks as an alternative was referred to any group outside of AMEC and/or Petromec (i.e. ABS, RINA, Brasoil, etc.) for a decision. Further the manner in which the matter is presented on this Sheet and the date of the Sheet (i.e. 8/July) point to the conclusion that the decision was one taken within the Project Team of AMEC and Petromec in the course of the evolution of this part of the project design.

3.6. This HAZOP Sheet also outlines other possible alternatives for the Drains Storage Tanks, including:

1. Re-routing of the drains to the atmospheric separator,
2. Use of the structural base oil tanks in the port/aft leg,
3. Replacing the existing drains drum with a larger vessel.

At the bottom of the sheet there is a handwritten note dated 30/8/97 that proposal #2 (the use of the base oil tanks) "...has been declared acceptable..." The sheet is initialed by a "JR or JB" a "PC" and signed by a J.F. Haworth. (see Annex one). The only organization chart I have for AMEC identifies the Project Manager Engineering (K.A. Roberts) and the positions of Engineering Manager (B Freeman) and Project Services (J Glock). Below that it merely lists the functions or activities of Process, Mechanical, etc. but does not provide any names. As a result it is not possible for me at this time to take the matter of appropriate approval much further than as stated above. (Ref DE-3010.38-1000-912-AMK-950 Rev 0). The Health Safety and Environmental Plan (Ref ET-3010.38-5400—947-AMK-913 Rev A) contains a reference and appendix entitled Organization Charts, but in the copy I have there is nothing within that Appendix. It appears AMEC received agreement from PETROMEC on the concept that the Base Oil Tanks which formed a part of the aft Port and Starboard columns could be modified and used to address the 'slop vessel' requirements. Further and as earlier I have seen no e-mails, letters, variation orders, etc. that this matter was referred to any party outside of AMEC/Petromec for decision. This decision to use the base oil tanks appears to have been taken entirely within the AMEC/Petromec Project Design Organization.

3.7. In addition to the HAZOP sheet noted above, an excerpt from the HAZOP tables namely Table 392.42 dated 10/7/97 (i.e. two days after the above dated HAZOP sheet) also addresses the issue that the drains storage vessel as originally installed on the vessel would not meet Petrobras requirements. It also puts forward the alternatives of using the atmospheric separator, the base oil tanks, installing a new larger vessel or the use of the mud tanks. As with the HAZOP sheet number #493, the use of the mud tanks is noted to be unacceptable as they were located under the accommodation block. There is no reference or signature on this sheet that would identify who took that decision.

3.8. The HAZOP itself concluded on 10/July. It is noted within the HAZOP that the Drains system was one of the last sets of P&ID's to be HAZOP'ed. The date on these sheets being 8/July and 10/July, respectively, indicates the decision not to use the mud tanks was taken even before the HAZOP concluded. As noted earlier, this points to the conclusion that these decisions were made wholly within AMEC and possibly AMEC/Petromec together without referring it to other parties. However, following the decision not to use the mud tanks in early July, it was not for another six or seven weeks that the decision was taken to use the alternative of the base oil tank in the Port aft leg as recorded on HAZOP sheet #493 on 30/August. I have seen no trail of documents which details the reasoning for choosing the use of the base oil tank, nor that this decision was referred to other groups outside of AMEC/Petromec for review and comment over that six to seven week period. The matter of communications and resolution of issues within the Project must have been a concern within AMEC itself as in their weekly project meeting of 26/8/97 there is a note to the effect that their Lead Engineers were to discuss problems with each other versus sending emails to one another. (see Annex One)

3.9. Following the 30/Aug decision to use the base oil tanks, another six to seven weeks passes before Rev A of P&ID AMK 398 for the drains storage tanks was produced. Rev A of AMK 398 was issued on 10/Oct/1997. The total period of time then between the issue of Rev 0 for this drawing (i.e. 26/Apr/1997) to Rev A (i.e. 10/Oct) was approximately 24 weeks or on the order of five and half to almost six months. I have seen no documents that provide information or an explanation for the length of time between the issuance of Rev 0 and Rev A. In addition, Rev A of the drains storage tank P&ID, shows the use of the 'base oil tanks' in both the Port and Starboard aft legs. This is different from the recommendation in the HAZOP sheets that the base oil tank in the Port aft leg alone should be used to fulfill the requirements of a 'slop vessel'. I have seen no trail of documents that outlines or describes who, when, or why the decision was taken to use the base oil tanks in both the Port and Starboard aft legs. In deed had the original recommendation or alternative of using the base oil tank in the Port leg alone been followed through, that design may well have prevented the accident on March 15 from ever occurring.

3.10. These various changes in the design of the drains were of such a magnitude that they should have been agreed with Brasoil. This implies that PETROMEC should have forwarded this issue to Brasoil for review and approval. I did not find any evidence, to date, that Brasoil was consulted in this regard. I have seen no documents or materials that indicate PETROMEC sought or received the approval of BRASOIL for this modification. Rather than use the term 'slop vessels' the term Drains Storage Tanks was chosen. The location of these Tanks being at the Fourth Level of the two aft columns meant they were the ultimate low point in the closed drains system. They would therefore receive a variety of fluids including water, produced water, oil, treatment chemicals, etc. from the closed drains. As a result the flow to the Tanks always had to be available as noted in Section 14.7.5 of the Operating Manual. The second function that the Drains Storage Tanks served was to receive the contents of various process vessels when the production vessel needed to be drained for maintenance, inspection, etc. Their third function was to act as a capture point in the event of an emergency where either automatically or manually it was necessary to de-inventory the process plant and production equipment located on the main and secondary deck. <u>This was the second reason why the Tanks were designed to be constantly open to the production facilities.</u>

3.11. On October 10, 1997 Revision A of the P&ID for the Drains Storage Tanks (DE-3010.38-5536-944-AMK-398) was issued. The report of Mr. Rod Sylvester-

Evans notes the changes or modifications made between the Rev 0 version of this P&ID and Rev A. <u>In addition, I have reviewed the changes between the Rev 0 version and Rev A version of the proposed Drains Storage Tank system and from my experience would classify the modifications as being 'major'.</u> I would, therefore, as a matter of standard industry practice have expected AMEC to perform a HAZOP of the Rev A version of drawing AMK-398. I have seen no documents or statements which record that a HAZOP of the Rev A version of AMK 398 was performed by AMEC. Further the P&ID for the Drains Storage Tanks (i.e. AMK-398) records the following issues and/or changes:

- Rev B, 25/11/97 – Revised AFD (revised approved for design)
- Rev C, 02/02/98 - AFC (approved for construction)
- Rev D, 15/03/98 – Revised AFC
- Rev E, 23/05/98 – Revised AFC
- Rev F, no date – Revised AFC

A chart in Annex One presents a timeline of these revisions along with a timeline for other certain design activities related to the SANA1500/P36. It is standard practice in each instance following a change or revision to a system which has already been HAZOP'ed that, at a minimum, an inter-disciplinary team of the engineering design group would review such revisions and note whether the revisions or modifications were of nature that changed the original design intent. It might well be that the modifications or revisions in each of these instances were minor. In this case the normal practice is for each member of the discipline team to note whether there was a need to revise or upgrade any control measures or safeguards as seen from their individual expertise.

3.12. The contract with AMEC (APEL) required that the CONTRACTOR undertake various safety analyses (ref Para 2.3). Further as noted in Para 3.2 above, AMEC's HAZOP report does not list P&ID AMK-398 for the Drains Storage Tank as being one that was included in the June/July 1997 HAZOP. I have seen no documents or material that AMEC undertook additional HAZOP's and/or interdisciplinary engineering reviews for the Drains Storage Tanks as its design progressed through the above stages. As a result from the material, documents, and information I have seen I can come to no other conclusion than that AMEC never undertook a HAZOP (i.e. a basic safety study) of the final design for the Drains Storage Tank(s). It would appear that in this one area of not undertaking a standard set of safety analyses for the drains, AMEC did not comply fully with their contacted requirements. Further what I have described above are the safety analyses that are standard practice for the design and construction of an offshore facility expected of any international engineering design company. The fact of AMEC never undertaking a rigorous identification of the hazards that could arise from the operation of the closed drains system is not in accord with standard industry practice for a project of this nature.

Operation of the Drains Storage Tanks

3.13. A part of AMEC's contractual requirements was to develop a Process Plant Operating Manual. In accordance with that requirement AMEC developed document ET-3010.38-1200-941-AMK-924. Rev 0 of this document was issued by AMEC on 5 Nov 1999. The Manual was revised twice, Revision A issued on 15 February 2000 and Revision B, the final version, on 9 March 2000. Revision B of the Operating Manual consisted of some twenty individual sections with a total of 451 pages of procedures or instructions. The Manual was divided such that each of the major process and utility systems had its own section. Section 14 of the Manual addressed the closed drain system.

3.14. Procedural deficiencies have been identified as a contributing factor in various accidents by the US Occupational Health and Safety Administration (OSHA) and the US Chemical Hazards Safety Investigation Board. The need for clear, concise and complete operating and maintenance procedures is well understood and accepted through-out the oil and gas industry. To assist with developing clear, concise and complete procedures, OSHA issued the following guidance for the development of Operating Procedures:

> *5. Operating Procedures and Practices.*
>
> *Operating procedures describe tasks to be performed, data to be recorded, operating conditions to be maintained, samples to be collected, and safety and health precautions to be taken. The procedures need to be technically accurate, understandable to employees, and revised periodically to ensure*

that they reflect current operations. The process safety information package is to be used as a resource to better assure that the operating procedures and practices are consistent with the known hazards of the chemicals in the process and that the operating parameters are accurate. Operating procedures should be reviewed by engineering staff and operating personnel to ensure that they are accurate and provide practical instructions on how to actually carry out job duties safely.

Operating procedures will include specific instructions or details on what steps are to be taken or followed in carrying out the stated procedures. These operating instructions for each procedure should include the applicable safety precautions and should contain appropriate information on safety implications. For example, the operating procedures addressing operating parameters will contain operating instructions about pressure limits, temperature ranges, flow rates, what to do when an upset condition occurs, what alarms and instruments are pertinent if an upset condition occurs, and other subjects. Another example of using operating instructions to properly implement operating procedures is in starting up or shutting down the process. In these cases, different parameters will be required from those of normal operation. These operating instructions need to clearly indicate the distinctions between startup and normal operations such as the appropriate allowances for heating up a unit to reach the normal operating parameters. Also the operating instructions need to describe the proper method for increasing the temperature of the unit until the normal operating temperature parameters are achieved.

3.15. The terminology used in Section 14 of the Manual to describe the Closed Drain System <u>is not consistent</u> with terms used to describe the various systems or subsystems as per the P&ID's for the Drains Storage Tanks and the Closed Drain System. For example in the system overview it is stated that the closed drain system consists of three sub-systems:

- the normal closed drains
- the oil storage
- the tank top sump

The terms 'oil storage' and 'the normal closed drains' most likely refer to the Drains Storage Tanks and the Closed Drains Drum subsystem. The terms are later defined and described as such in the System Description (Section 14.2). However, the use of interchangeable terms for one system is not good practice with respect to the development of operating procedures especially where those procedures are to be interpreted from one language to another.

3.16. In the system description it is noted that the two Drains Storage Tanks are structural tanks with a capacity of 450 m^3 each and that they vent to the Atmospheric Vent. It is interesting and of importance to note that in the description of the Tank Top Deck Sump, which is part of the same Closed Drains System, it too is described as an atmospheric sump and is fitted with a blow-off cover and a local atmospheric vent with a flame arrestor. The important difference here, being that the Sump is fitted with two means of reducing or relieving pressure, that of its connection to the Atmospheric Vent and the blow-off cover. The Drains Storage Tanks on the other hand were fitted only with a single means to maintain their pressure at atmospheric level namely that of the connection to the Atmospheric Vent also through a flame arrestor. This indicates an application of two different safety philosophies toward protecting atmospheric tanks from being over pressured within the same system. I have seen no documents or evidence to explain why these two different approaches were taken by AMEC.

3.17. In the Equipment Summary (Section 14.3), the Port and Starboard Drains Storage Vessels are noted as having a DP (i.e. differential pressure) of Atmospheric. The same holds for the Tank Top Deck Sump. **Based on the information then contained in Section 14.1 and 14.3, the Operators of the P-36 would have an understanding that the two Drains Storage Tanks were designed and constructed in such a manner that the Tanks would not experience pressures above atmospheric (i.e. 0 barg) levels.**

3.18. Subsection 14.7.4 of the Section addresses abnormal conditions. It states that the closed drain system is provided with pre-alarms for pressure and level to give early indication of operating faults. It notes that the Drains Storage Tanks are fitted with Level Shutdown Low Low (LSLL) trips that will stop the respective pump if a low level is detected in the Tank being emptied. The Tanks were not fitted with Level Shutdown on sensing High High levels in the Tanks nor any pressure indication or pressure shutdown trips.

3.19. Subsection 14.7.8 describes the process for emptying the Drains Storage Tanks via their respective Drains Storage Pump.

Drains Storage Pumps Operation

The Drains Storage Pumps, B-533604A/B, are started manually when required. The oil is pumped to the production trains for reprocessing. The procedure below is for operating B-533604A which is typical for either pump.

Check that a production train is lined up to receive liquids from the drains recycle manifold.
Close V-534 and 535 in both tanks inlet line
Open XV53360004 in the line to the drains recycle manifold
Open the pump suction and discharge valves XV65002 and 65001 with PB65002 and 65001
Check the valve status on ECOS with ZLOC65002 and 65001
Start B-533604A with the local start push button
Check the operation of the pump with the discharge pressure gauge PI53360017
Monitor the level in the tank and when the level reaches close to the low level trip, stop the pump with the local stop push button.
Close the pump suction and discharge valves XV65002 and 65001 with PB65002 and 65001
Close XV53360004 in the line to the drains recycle manifold
Open V-534 in the tank inlet line

If the liquid in the Drains Storage Tanks, consists of a large volume of produced water, the liquid is pumped directly to the Production Caisson for disposal to sea. For this operation, V-533 is opened instead of XV53360004. The pumped liquid is sampled frequently to prevent the transfer of oil to the caisson.

The above operating instructions do provide specific instructions on the steps to be taken in lining up the Drains Storage Tanks and their respective pumps in order to empty the Tanks back to the Production header or in certain circumstances the Production Caisson. In that regard they comply with the guidance for the development of Operating Procedures as developed by OSHA and described in Para 2.17 earlier. However, the Operating Procedures for the emptying of the Tanks do not comply with the requirement that:

> *... operating instructions for each procedure should include the applicable safety precautions and should contain appropriate information on safety implications.*

The procedure provides no guidance on any applicable safety precautions such as the time that should be taken to empty the tanks, whether the area near the Tanks should be continuously attended while this process is being performed, if there is a possibility to over pressurize the system or not, etc. It does not discuss or describe any safety related implication that could occur or arise from carrying out these actions. These might range from a seal leak on the pump, damage to the pump if the Tanks are emptied to a level below the feed to the transfer line, etc. <u>The procedure for the particular operation of emptying one or</u>

other of the Drains Storage Tanks, therefore, does not comply with all the requirements or criteria that constitute a good Operating Procedure.

The Nexus of the Rupture of the Starboard Tank

3.20. Arising out of his inquiries into the 1998 Longford Gas Plant accident that fatally injured two employees and severely injured another eight, Sir Daryl Dawson, QC concluded that "The Real Causes" were:

> *"Those who were operating GP1 on 25 September 1998 did not have knowledge of the dangers associated with the loss of lean oil...*

This despite the fact that the average years of experience of those who were in the immediate area of the accident and trying to attend to various matters or issues when the rupture of the pressurized heat exchange occurred was approximately 18 years. In several cases the operating, maintenance and supervisory staff had over 25 years of direct experience in this particular plant. However from his investigations Sir Daryl found that over a period of time the knowledge of the hazards associated with the operation of the lean oil system was lost. This loss was due primarily to the fact that the plant had operated safely and without major disruption or downtime for approximately twenty five years of its life prior to the catastrophe that occurred in 1998.

3.21. The issue of knowledge, or more appropriately the lack of it, as a contributing factor in catastrophic accidents as identified by Sir Daryl above, however, is not new. In his Public Inquiry into the Flixborough disaster of 1974, Mr. R.J. Parker, QC found that the lack of engineering expertise and knowledge as applied to the design of a modification to the Flixborough facility was a primary contributing factor in that accident.

The Design and Operating Envelope

3.22. The following model was developed to try and 'visualize' how the lack of knowledge can contribute to a major accident.

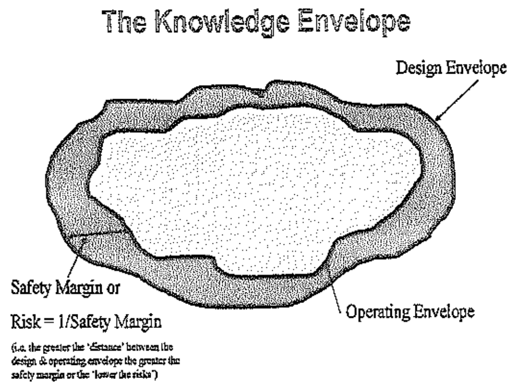

Figure 1

The engineering fraternity has long used a term entitled the 'design envelope' to invoke a picture of the overall capabilities or capacity of a particular facility. The design envelope defines the absolute maximum limit(s) for all the temperatures, pressures, flows, process materials or fluids, etc. associated with the safe production of commercially saleable product(s). Once the design envelope is established an 'operating envelope' is then created. This operating envelope can always be viewed as resting inside the design envelope. For example, a part of the plant, piping or equipment may be capable of handling pressures of 15 barg or temperatures to -40C before it would fail. As a result, the normal operating parameters to run that part of the plant would be set at say pressures of 14 barg and temperatures down to -30C. In general the operating envelope is established so that an upset or excursion in the operations will not exceed the physical limits of the equipment. In other words the operating envelope is set to prevent puncturing the design envelope. Potential consequences arising from an excursion or upset that pierces the design envelope can range from unexpected outages of equipment, the loss of production on through to major losses of containment and injury to personnel or damage to the environment.

3.23. The difference or gap between the design envelope and operating envelope has been, traditionally, referred to as the 'Safety Margin'. The thinking being that the greater the gap or margin between the two the 'safer' the operation as it provided greater room for error.

3.24. In today's world of 'risk' we can also view the inverse of the gap between the design and operating envelopes as being the level of risk at which the plant is operating. In other words the closer one pushes the operating envelope to the design envelope, the greater the risk that an upset could result in the design envelope being pierced.

The Consequences of Incomplete Knowledge

3.25. Figure 1 depicts the outer edge or boundary of the design and operating envelopes as a solid line. In other words at any one time we have total or complete knowledge of all the parameters that comprise both envelopes. That unfortunately is not the real world. The real world is more akin to that as found in Figure 2.

The Real World of Incomplete Knowledge of these Two Envelopes

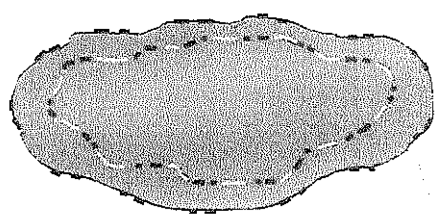

Figure 2

3.26. The actual knowledge of these two envelopes is never 100% complete. As with the case of the upgrading of the P-36 most plants are designed and constructed by specialist engineering firms. On completion the engineering company then 'hands-over' the operation of that facility to the owner or operating company. While various steps are taken to transfer the knowledge of the design from the engineering firm to the operator, it is impossible to affect a 100% handover of all that knowledge. The design and construction of a plant whose process(es) would be ranked as consisting of a moderate level of complexity and through-put, might entail the design and engineering efforts of a team of a hundred or more. On the operating side the staff assigned to this plant might consist of say 30-40 individuals and the bulk of these are unlikely to be engineers. Therefore, even on the start of a new plant despite the best efforts of the owner or operator of that facility, the knowledge of the design and operating envelopes transferred to the operating staff will be incomplete.

3.27. The model described above was developed out of the investigations into Flixborough, Piper Alpha and the Longford accidents cited above. From the information I have reviewed of the events leading up to the accident on the P-36, I believe there was a lack of understanding and knowledge among the P-36 staff of the dangers associated with the operation of emptying the Drains Storage Tanks. In other words, to use Sir Daryl's terms, 'The Real Cause' was that the operators were not provided the knowledge of the dangers associated with emptying the two Drains Storage Tanks. **The operators on the night of 14th March were never provided the proper information of these dangers.** They were never in a position to understand that in preparing the Port DST to be emptied that operation could pierce the design envelope of the Starboard DST as the Operating Procedures for this task contained no information or warnings of such dangers. That information and knowledge should have been contained within the Operating Procedures for the Drains Storage Tanks. ***Had they been provided that information the operators would have been in a position to identify, understand and take appropriate measures to protect themselves and the P-36 itself from these potential hidden dangers.***

3.28. The Operating Manual is the primary source of information on the correct procedures that are to be followed, as well as the potential hazards and consequences (i.e. the safety implications or consequences) associated with a process or procedure as described in the OSHA guidance. While the P&ID's for the process and all major utility systems are also, typically available to the operating and maintenance staff, by their nature the P&ID's themselves do not provide information on criticality of equipment, safety implications, etc. unless the design contractor specifically provides that on the P&ID's. The various P&ID's that were drafted which comprise the Closed Drains System, and there are many, do not provide such information on them. Secondly as noted one has to refer to at least five different P&ID's in order to obtain a complete picture of the various equipment, piping runs and connections, etc. which come together to form the Closed Drains System. For the operating staff then to try to develop their own picture of the overall operations and the hazards that might be associated with the closed drains as a whole they would first have to assemble together these various P&ID'. Next as the P&ID's were not noted with safety information, the operating staff would have to perform some sort of hazard identification exercise (i.e. a HAZOP) themselves. One problem with that is for any hazard identification exercise of this nature to be considered effective the team doing it must be comprised of various engineering staff, sometimes vendor representatives, as well as operations and maintenance staff. A situation that is not likely to occur in the normal course of operations. BUT more importantly this would be doing the exact task that AMEC was required to perform per the contractual requirement of '... undertake safety studies...'. As this requirement was in the contract I would not expect Petrobras to have undertaken such steps of convening its own staff to duplicate what was specifically required of the engineering and design contractor.

3.29. Sir Daryl noted that a contributing factor to this lack of knowledge among the operating and maintenance staff was the fact that the Operator of the Longford facility had not carried out a HAZOP of the process system that failed. Sir Daryl noted in his Report:

"Put simply, hazard identification creates knowledge" (Para 13.51)

AMEC's failure to carry out a HAZOP of the revised or modified Drains Storage Tank as designed in Revs A to F of AMK-398 meant that the knowledge necessary to prevent the accident that occurred on 14/15 March was never created. A competent HAZOP team would have identified the potential for the Tanks to be exposed to pressures far in excess of atmospheric when connected to the production header as called for in the Operating Procedures. They would also have examined that the arrangement of the discharge piping from each of the two pumps was common with the feed line to each of the two Tanks. This design had the potential to lead to a situation of backflow through valves 534/535 on the feed lines to the Tanks. As a result, the Tanks were exposed potentially to pressures far in excess of atmospheric each time they were emptied. The only protection afforded was that of a single valve (i.e. Valve 534 or 535). To protect the Tanks the seal of these valves had to be 100% effective in holding pressure. While a newly installed valve can be expected to be gas tight, as time progresses the seats, stems and seals will begin to degenerate and the valve will begin to pass. The only other protection designed into the Tanks to prevent them being over-pressured was the single connection to the atmospheric vent through a flame arrestor. However in only the most pristine of conditions is it likely that a flame arrestor will not begin to foul and plug over time. In fact the flame arrestor on the Atmospheric Vent had already begun to foul on the P-36 prior to the accident on 14 March. Temporary measures were taken to try and compensate for this problem.

3.30. The ideal correction to these faults would have been to rearrange the piping configurations and valves to prevent such a situation from occurring. Other alternatives such as installing additional means to relieve such pressures as was provided on the Tank Top Sump in the form of a blow-off panel or pressure safety valve as well as flow and pressure alarms and trips would have been available to the design and engineering team had they HAZOP'ed the Rev A design. Lacking these precautions and returning to the model described above the safety margin between the operating and design envelope was infinitesimally small. This means that it was vital for the Operating Procedures for which AMEC were responsible to contain a discussion of these potential safety concerns. Further the Procedures should have outlined the potential consequences that would occur if the Tanks were exposed to pressures as was the Starboard Tank on the night of 14th March. This is knowledge that a properly executed HAZOP would have developed. With out this knowledge the operators of the P-36 were blind to the hidden dangers that existed within the design of the Drains Storage Tank system when they undertook the process of emptying those Tanks as detailed in the written operating procedures.

3.31. As a result of failures in the design and arrangement of the piping and valves that connected the Port and Starboard Drains Storage tanks together and to/from the Production Header, fluids and pressures could 'backflow' through the system to the Tank that was not being emptied unbeknownst and undetected by the operators. This was a critical flaw in the design of the closed drain system. Further this flaw in the design was carried through into the operating procedures themselves as the procedures did not describe nor warn that there was a potential for this situation to occur. An operator, then, who was following the formal written procedure, would be blindfolded to the fact that the actions of draining one tank (i.e. either the port or starboard tank) could have a catastrophic effect on the other tank. The root cause of the rupture of the Starboard Drains Storage Tank lay in its design and the fact that a properly executed HAZOP or other appropriate Hazard Identification technique was not carried out on the design of the DST subsystem.

4. REMOVAL OF THE STARBOARD DST PUMP AND INSERTION OF SPADE

4.1. The pump to the starboard Drains Storage Tank had stopped working in early February. The feed line to and the discharge lines from the pump were spaded and the pump was removed and taken to the mechanical workshop where an attempt was made to repair it. However, no spares for the pump were held on board the P-36 itself. After re-installing the pump the crew tried to start the pump but it still did not work. The feed and discharge lines were again spaded and the pump removed and sent to shore for repair on the 14th February.

4.2. Over a period of months the operations staff had noticed that both of the Drains Storage Tanks were receiving liquids and they could not determine from exactly where or the reason why the Tanks were filling up with fluids. The staff had looked at various causes in trying to identify why this was occurring as well as the path that these fluids were following to enter the two tanks. Arising from the crew's best efforts in trying to ascertain the cause and path, the operators had come to a conclusion that the fluids were entering the Tanks through their connection to the Atmospheric Vent system.

4.3. The operating staff did not have a firm date on when the repairs to the Starboard Pump would be completed and returned to the P-36. As a result, it is understandable that they would become concerned that the Starboard Drains Tank would continue to be filled by fluids entering it via the Atmospheric Vent connection. With the pump removed and the lines to the pump properly spaded and Valve 535 closed it is again wholly understandable that the operations crew felt the Starboard Tank was essentially isolated from all other sources of fluids save via the Atmospheric Vent. As a result a decision to insert a spade into the Atmospheric Vent as a precaution to protect against the further drainage of fluids into the Tank via this path is also understandable.

4.4. Indeed, the design of the system meant the insertion of a spade was the only way they could protect the Tank from receiving further fluids via the Atmospheric Vent. As a result of past incidents where it was found that a valve or other device inserted into an atmospheric vent line had been closed and/or failed it would be against all recommended engineering practices to insert a valve in such atmospheric vent lines. However, it is also recognized that at times there is a need to isolate, positively, a Tank or other piece of equipment connected to the Atmospheric Vent from the rest of the system in order to affect repairs, inspections, etc. In fact under confined space entry rules in both the United States and United Kingdom such positive isolation via a spade or as a minimum a double block and bleed is mandatory prior to being allowed to enter a Tank to undertake inspection or repairs. As noted the insertion of valves in a vent line is against engineering codes. As a result, a flange connection is the only option available to provide for the ability to insert a spade in those cases where such positive isolation is required. It is this logic path that the operating staff was most likely taking when they came to the conclusion it was necessary to isolate the Starboard Drains Storage Tank from the rest of the Atmospheric Vent System.

4.5. Valves 534 and 535 are located on the feed lines to the Drains Storage Tanks. Each Tank is protected from over filling or over pressuring by only this one valve. In other words, during normal operation, there was only a single layer of protection to prevent against the hazards of over filling or pressuring the Tanks on their feed or active side. As these valves served such a critical function in this regard it would have been good practice for the design contractor to have noted the importance of these valves on the P&ID (i.e. AMK 398) and this note then carried through to the Operating Manual.

4.6. With the removal of the starboard pump for necessary repairs, the spading of the discharge line from the Drains Storage Tank plus being faced with the continuing problem of the Tanks continuing to fill with fluids via the suspected path of their connection to the atmospheric vent the decision to insert a spade into the vent system is understandable. The operators through these decisions and actions were, in good faith, trying to prevent a hazard from occurring not create one.

5. THE TIME BETWEEN LINING UP THE SYSTEM AND STARTING THE PUMP

5.1. Over the period of 11 to 14 March the operations and ballast teams measured the levels in both the Port and Starboard Drains Storage Tanks. The instrumentation for the Port Tank noted that the level in it was approximately 6% yet soundings on the Port Tank indicated the level of fluids in the Tank to be between 60 and 65%. Due to the discrepancy between the instruments and the soundings, the ballast team was asked to take further soundings and confirm their readings. They did this and reconfirmed that the level in the Port tank was indeed between 60 and 65%.

5.2. An operating practice had developed since the start-up of the platform that the Drains Storage Tanks should be emptied when the levels reached approximately 30% of their total capacity. Further as the crew recognized that the Starboard Pump had been removed and the Starboard Tank was isolated from the Closed Drains System hence the only Tank that was available was the Port Tank the decision was taken to empty the Port Tank. This was not the first time the Drains Storage Tanks had been emptied since start-up of the Platform. From the memories of the crew they may have undertaken the emptying of the Tanks either three or four times before this event. It was not then an activity that occurred daily, weekly or even monthly but on an as needed basis. The understanding of the proper practice for undertaking this activity then would have been derived from the procedures as contained within the Operating Manual.

5.3. The decision was taken at about 20.00 hours on the night of the 14th March to empty the Port Drains Storage Tanks. At about 22.00 hours the operators began the process of aligning the valves to the Port DST pump and the Production Header to start the process of draining the Tank to the Production

Header. This is in accordance with the operating procedure for emptying the two Tanks as described earlier in this report (Para 3.13). After aligning the valves the operators appeared to have to attend to other process related matters. After a period of time they returned and started the Port pump to begin the actual draining of the Port Tank.

5.4. The Operating Procedure makes no reference nor does it provide any guidance on the need to start the pumps and begin the process of draining the Tank immediately after aligning the valves or within a set a time period. Nor do the Procedures contain any warnings or guidance that the operators should remain at the Pumps or in the vicinity of the Tanks while the draining of them was underway. Further as the flow rate of the pumps was on the order of 50 or 60 m^3 per hour and the Tanks had a total capacity of 450 m3, the period of time to drain a tank could take upwards of nine hours to complete. As a result it is understandable that the operators would not see a need to rush the period of time between aligning the valves and starting the pumps.

5.5. The concern that the period of time between aligning the valves to the Production Header and the starting of the pumps as being a contributory factor to the rupture of the Tank is also misplaced. As noted earlier, the investigations into the rupture of the Starboard Tank found that it ruptured when the Tank reached a pressure of approximately of 10 barg. The inherent design flaw of the interconnection between the two tanks through their common discharge to either the Production Header or Caisson meant that on the starting of the Discharge pumps the Tanks could be exposed to pressures of 14 barg, the discharge pressure of the pumps. The issue then is not the period of time of connection to the Production Header but rather the design of the discharge system between the Pumps of the two tanks and its interconnection to the feed lines to the two Tanks. This design was in essence a 'short circuit' in the system. This 'short circuit' contributed to the catastrophic failure of the Starboard Tank.

6. THE VENTILATION OF THE STARBOARD BUOYANCY TANKS

6.1. Noble Denton who per contractual agreements between Petromec, and AMEC were assigned the duties and responsibilities for the engineering and design of the marine elements of the Spirit of Columbus (i.e. P-36) to meet the needs of the Roncador Field.

6.2. One of the modifications that Noble Denton made to the marine elements was the addition of what was identified as 'stability boxes'. These stability boxes were affixed to the pontoons and the two aft columns. The stability boxes were identified with the plant numbers of 61S and 61P for starboard and port. The design of the stability boxes was such that to gain entrance to them an individual would have to enter them through a structural void within the column themselves that were identified as 26S&P in order to undertake any type of inspection, repairs and/or other required maintenance. The entrance to both the structural voids and the stability boxes was through a hatch way. This restricted the ability of staff to gain access to the voids and the boxes.

6.3. Both of the stability boxes had developed leaks and repairs were undertaken to their externals by divers. There was a need to enter the stability boxes to inspect them and determine if these repairs had indeed fixed the leaks. Because of their design it was necessary to ventilate them for a sufficient period of time prior to an individual entering such an enclosed or confined space.

6.4. There are two ways such confined spaces can be ventilated. One is to open the confined space for a period of time and through the process of dilution allow the general ventilation in the area outside of the confined space to displace the air within the confined space itself. The second option is powered ventilation whereby a blower or other source of clean air from outside the confined enclosure is introduced into the space to be ventilated by a hose. Both cases are considered acceptable practice. It is important to note that whether using the general dilution or powered ventilation approach, the entrance to the facility must be open for some period of time. Further in the case of using powered ventilation the fact that a hose of some nature must be fed through the entrance way or hatch means that the hatch cannot be quickly closed until after the obstruction of the hose is removed.

6.5. There was no other maintenance or non-routine operating activity planned to occur in the Starboard Column for the period of 14 or 15 March. As a result, in order to prepare for the required inspections the entrances to both 26S and 61S (i.e. the starboard void and buoyancy tank) were opened to ventilate them. The ventilation approach employed was that of general dilution. Since the process of general dilution takes longer to displace the air within a confined space than powered ventilation, and considering that to dilute and displace the air in 61S, the air had first to enter, dilute and displace the air in 26S their was a need to keep the access hatches to these two confined spaces open for a sufficiently long period of time. As there was no planned non-routine activity to take place in the Starboard Column and to ascertain that 61S was properly ventilated the opening of the hatches of these two spaces in the late afternoon/early evening of the 14th March is wholly reasonable.

6.6. Earlier in this Report, the need to carry-out an appropriate and effective hazard identification exercise (e.g. SWIFT, HAZOP, etc.) when a major modification to a facility is made was discussed. The addition of the extra stability boxes would be, to my mind, a major modification of the marine design or elements of the P-36. As a result I would have expected that some type of hazard identification would have been performed on this change by Noble Denton and possibly Noble Denton in conjunction with Petromec. This in accordance with the contractual requirements that the engineering and design contractor carry-out various safety analyses of their design. I have seen no material or information that details such studies were performed or undertaken on the addition of the stability boxes. Similar to conclusions earlier in this Report the lack of such studies means that the knowledge of the associated hazards with respect to the addition of these stability boxes was not created and again the operators would not have been made aware of the precautions that they needed to take to prevent or control those hazards.

7. RESPONSE TO THE INITIAL RUPTURE OF THE TANK

7.1. Immediately following the rupture of the Starboard Drains Storage Tank, the general alarm was sounded and steps were taken to organize and mobilize the

Fire Response Team and an Emergency Response Team. The various levels in the Starboard Aft Column were not fitted with video cameras, nor were they fitted with any stationary gas detectors. As a result the Platform management, supervisors, ballast control operators, fire and emergency teams, etc. had no way of determining what, if anything, had happened within the Starboard Aft column, the situation within the Starboard Aft column itself, the extent of any damage, following the initial event, etc. As the P-36 almost immediately started to incline or list towards the Starboard Aft direction, they surmised that something happened either to the Column or Pontoon in that direction. The need to obtain further information to address the situation they faced is apparent and the only option available was for the emergency teams to inspect the general area and the column to gather that information and report it back to the Control Room.

7.2. The fire brigade team began to lay out fire houses in case they were needed. Further, various members of the response teams began to locate and don breathing apparatus, emergency rescue teams were formed, etc. On arrival at the tank top level no physical damage was noted. A cloud was encountered which was variously described as a mist, smoke, etc. It was said to contain no odor or smell. The ballast control operators surveying the waters in the starboard aft area could not see any bubbles rising to the surface of the water which would have indicated the hull or other sub-sea structures had been breached. As there were no video cameras located within the columns, nor other automated instrumentation and on first inspections of the tank top level and sub-sea structures, it is understandable, then, that a decision was taken to enter the Column. The purpose being to try and identified what had actually caused the 'thud', assess the extent of any damage and especially to try and determine the cause of the listing in order to prepare a plan of the next steps that could be taken.

7.3. It is impossible to train for each and every possible contingency or emergency that may occur or arise in a facility such as the P-36. As a result the general accepted practice within the oil and gas industry worldwide is to develop a set of 'representative scenarios' which encompass the various types of emergencies that can occur and base the emergency training of the platform management, supervision, emergency response teams, operators, etc. around those scenarios. Petrobras had developed approximately thirty different such scenarios and were in the process of developing another five such scenarios. Approximately every two weeks they were holding training sessions with the staff and crew on duty at that time on how to respond such emergencies. This program of training is in accord with world-wide standard or good industry practice for facilities of this kind. Further the actions of the various members of staff to the initial rupture of the Starboard DST were generally in accordance with such training. Certain actions of certain individuals may not have been in accordance with best practices (e.g. the donning of breathing apparatus prior to entering the Column). However, as noted earlier it is impossible to identify all the permutations of the different types of incidents that can arise and it is equally impossible despite all the training provided to predict how a particular individual will react when faced with a particular situation. That applies to the situation as it developed on the P-36 in the early morning hours of 15 March 2001.

8. THE SECOND EXPLOSION

8.1. Approximately seventeen minutes after the initial rupture of the Starboard DST a second event occurred in the Starboard Aft Column. For the sake of clarity through-out this Report the term has been used to described the first event, i.e. the failure of the Starboard DST, as a 'rupture' of the tank. In my review of various materials and documents I have seen this first event referred to using various terms as an 'explosion' a 'mechanical explosion', etc. The use of such terms to refer to the initial rupture I think is both confusing and from a technical standpoint incorrect. Technically the term 'explosion' defines a very narrow set of physical parameters. It is used to describe an event where a very large amount of energy is released in a very short time frame generally that of micro or milliseconds. That is not the case with the initial failure of the tank. The most appropriate and technically correct term that should be used to describe or define the first event is that of a 'rupture' of the tank wall. From the damage caused in the second 'event' the amount of energy released and the pressures generated would fall into the category of an explosion.

8.2. The second explosion occurred when lighter hydrocarbons that were contained within the DST and the drains lines were released into the column space and mixed with sufficient air to form into a flammable vapor cloud. As the area was unclassified a number of potential ignition sources existed within the column to ignite this mixture once it formed into a flammable cloud.

8.3. The second explosion is described by various witnesses as a 'big one'. The physical damage and fatal injuries it caused confirm that. The damage to various control systems as reported by the Control Room and Ballast Control Teams, meant that they lost their ability to take any form of effective actions to stabilize let alone correct the continuing listing of the P-36.

8.4. A recent study simulating two scenarios for the listing of the P-36, notes that the ballast actions undertaken by the crew following the rupture and explosions, controlled the list to approximately six degrees. Thus allowing for the removal of non-critical personnel and the eventual evacuation of all personnel some hours later. A second scenario simulating the listing of the vessel, where no such ballasting actions were taken meant that the Vessel would have rapidly listed to as much as sixteen degrees. It is doubtful that any form of safe removal or evacuation could be performed with such a severe list.

8.5. With the loss of control of the Starboard Aft Column following the second explosion, as reported by various staff, meant that the probabilities were the Platform could no longer be saved.

5400

REFERENCES

1. Petrobras P-36 Investigating Commission, Final Report; 20 June 2001
2. Operating Manual, P-36 Roncador Field Development; Revision B; 9 March 2000
3. Upgrade Agreement, Petro Deep Inc, Petromec Inc and Societa Armamenta Navi Appogigio, SA; 20 June 1997
4. Contract between Petromec Inc and AMEC Process and Energy Ltd for the Upgrade of the Spirit of Columbus; Undated
5. Supervision Agreement between Braspetro Oil Services Company, Petro Deep Inc., Petromec Inc and Petrobras in Respect of the Upgrade of the Spirit of Columbus; 20 June 1997
6. Contract between Petromec and Noble Denton for carrying out certain detailed engineering design for Naval Architecture, Weight Control and Resident Engineer during the Upgrade of the Spirit of Columbus (P-36) Upgrade; July 1997
7. General Technical Specifications for the SANA 1500/P-36; ET-3010.38-1200-940-PPC-001
8. Offshore Installations (Safety Case) Regulations 1992, U.K. HMSO, 1992
9. Compliance Guidelines and Recommendations for Process Safety Management; US Occupational Safety and Health Administration
10. Notice to Lessees and Operators (NTL) of Federal Oil, Gas and Sulphur Leases in the Outer Continental Shelf – Deepwater Operating Plan; August 19, 1996
11. Recommended Practice for Design and Hazards Analysis of Offshore Production Facilities, Recommended Practice RP-14J American Petroleum Institute.
12. Loss of Petrobras Semi-Submersible P-36. Report of Mr. Rod Sylvester-Evans; 31 May 2004
13. Atmospheric Separators and Booster Pumps P&ID DE-30101.38-5412-944-AMK-181
14. Production Caisson P&ID DE-3010.38-5412-944-AMK-397
15. HP Flare Drum P&ID DE-3010.38-5412-944-AMK-402
16. Atmospheric Vent P&ID DE-3010.38-5412-AMK-407
17. Closed Drain Drum P&ID – DE-3010.38-5336-944-AMK-392
18. Hazardous Open Drains Drum P&ID – DE-30101.38-5336-944-AMK-394

19. Drains Storage Tank P&ID – DE-3010.38-5336-944-AMK-398
20. HAZOP Report – RL-3010.38-5400-947-AMK-903
21. HAZOP Sheet #493 Dated – 8/7/97
22. HAZOP Table 392.42 Dated – 10/7/97
23. Timeline – Presentation by Rod Sylvester-Evans
24. Weekly Project Meetings, ENG-013, Dated – 26/8/97
25. The Esso Longford Gas Plant Accident, Report of the Royal Commission; June 1998
26. Petrobras Flooding of P-36 Platform without Ballast Adjustment, Technical Notice SAST 700929, Centro de Pesquisas e Desenvolvimento Leopoldo.
27. Witness statements of:
    a. Artur Cesar Hecht
    b. Carlos Alberto Sampaio
    c. Carlos Jose Mariel Azeredo
    d. Claudio Luiz Jacintho da Silva
    e. Claudio Marinho Machada
    f. Evanildo Souza Santos
    g. Jose Cardoso Sobral
    h. Manoel Sergio Filadelfo Leoncio
    i. Marco Fernandez
    j. Marcos Antonio Simoes Menzes
    k. Odilton Medrado Sobral Castelo Branco
    l. Paulo Roberto Viana
    m. Roberto Jose Qunitana
    n. Roberto Matos Santos
    o. Sergio Caruso de Melo
    p. Williams Perciano da Silva

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Annex One

- Timeline of certain project activities for the SANA1500/P36
- HAZOP Action Sheet #493
- HAZOP Table No. 392.42
- Weekly Project Minutes dated 26/8/97

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DIVISÃO DE SERVIÇOS CARTORIAIS

TIMELINE FOR CERTAIN DESIGN ACTIVITIES OF THE SANA1500/P36

ID	Task Name	Apr 1997 – Mar 2000
1	Basis of Design	12th June Rev 0; 1st Aug Rev A; 24th Feb Rev B
2	P&ID AMK-398; Drains Storage Tanks	26th April Rev 0; 10th Oct Rev A; 25th Nov Rev B; 2nd Feb Rev C; 15th March Rev D; 23rd Sept Rev E; Rev F is undated
3	Process Data Sheet; Drains Storage Tank	13th June Rev 0; 20th Oct (Prepared) to 11th Dec (Approved) Rev A; 24th Jan Rev B
4	Process Data Sheet; Drains Storage Pumps	13th June Rev 0; 23rd Oct (printed) & 16th Dec (signed) both Rev A; For AFD; 24th Jan Rev B; Revised for Design
5	Specification for Rotary Pump Packages	13th June Rev 0; 'For Enquiry'; 20th March Rev A; 'For Purchase'
6	Design Philosophy - Drains	26th June Rev 0
7	Safety Analysis Function Evaluation (SAFE) Charts	26th June Rev 0; 23rd Oct Rev A; 15th Dec Rev B
8	Safety Analysis Tables – API 14C	3rd July Rev 0; 12th Sept Rev A
9	Hazard & Operability (HAZOP) Study for EDT System	10th July HAZOP Study; 18th July Rev 0; 30th Aug Action Replies for EDT; 11th Nov Rev A; Issued for Design
10	Safety Data Sheets	24th Sept Rev 0
11	Fire Risk Assessment (FRA)	15th Aug Rev 0; 26th Sept Rev A
12	Hazardous Area Classification Drawings - Columns	22nd Aug Rev 0; 18th & 19th Sept; Rev A & B; 10th Dec Rev C
13	Hazardous Area Schedule	22nd Dec Rev 0; 23rd April Rev A
14	Pressure Switch Data Sheet & Instrument Field Loops for EDTs	6th Feb Rev 0; 2nd April Rev A; 24th Aug Rev B; 5th March Rev C (Issued for Construction)
15	General Piping Arrangement; Drains Storage System in aft starboard column	7th Sept Rev A; 'As-Built'
16	Closed Drains System Start-up Procedures	8th June Rev 0; 16th Sept Rev A
17	Process Operating Manual	16th March Rev 0 – section on Closed Drains; 5th Nov Rev 0; 15th Feb Rev A; 9th March Rev B

HAZOP ACTION SHEET #493 DATED 8/7/97

Date: 8/7/97 Client: Petromec
Project No: L0277 Project: ~~P36~~ RONCADOR FIELD DEVELOPMENT

HAZOP STUDY ACTION AND RESPONSE SHEET

ACTION ON: Process / Brasoil. RESPOND BY: 31-07-97

ACTION NO: 493 MEETING DATES: 9th June 1997 - 11th July 1997.

DOCUMENT REF: 392, 394
TITLE: Closed Drains Drum, Drains Storage Vessels. REVISION: 0

ITEM:
Line 42. Closed drains system. (Hazop Table 392.42)

CAUSE:
Proposed re-use of mud tanks for periodic closed drains storage beneath accommodation block. (All.)

CONSEQUENCE:
Hazard to personnel.

SAFEGUARDS:
Tanks are installed in semi-sub leg with a deck plating and 2 deck levels between them and accommodation block.

ACTION:
The proposed re-use of the mud tanks is unacceptable. 1. Re-route the closed drains outlet to the atmospheric separator.
If that route proves unacceptable (possibly because of water contamination of oil product), consider instead:
2. Use the alternative structural base oil tanks in the port/aft leg, but see action 523.
3. Replace the existing drains drum with a vessel of large enough capacity, but see action 523.

RESPONSE: DATED: 30/8/97.

Proposal # 2 of the above has been declared acceptable for re-engineering for this service.

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SIGNED: J.F. Haworth P.E.

ENTER YOUR RESPONSE IN THE BOX ABOVE, THEN SIGN AND RETURN TO:
Jos Rapanakis JB

FURTHER ACTION	ON	DATE AND RESPONSE

ACTION FINALISED:

Data File: RONCAD4

5404

HAZOP TABLE 392.42, DATED 10/7/97

5405

Date: 10/7/97 Client: Petromec
Project No: L0277 Project: P36-RONCADOR FIELD DEVELOPMENT

TABLE NO: 392.42 DOCUMENT REF: 392, 394 REVISION: 0
DOCUMENT TITLE: Closed Drains Drum, Drains Storage Vessels.

ITEM: Line 42. Closed drains system.
Closed drains lines terminate at the existing closed drains drum V-45002, which contains the new closed drains drum heater P-533601 which is an electrically heated bayonet inserted through the manhole cover. New closed drains pumps, B-533603A/B, return the drains fluids to the oil feed line to the oil/produced water heat exchangers P-122300A/B. (The existing pumps feed drains fluids to the atmospheric separator and do not have enough head to reach the oil/produced water heat exchange line).

During maintenance shutdowns the oil dehydrator and separators may need to be emptied. The existing closed drains drum is too small to accommodate the total volume. It is proposed to discharge this surplus liquid to the drains storage vessels V-533604A/B which are existing mud storage tanks in the semi-sub legs beneath the accommodation block. The design pressures of the closed drains drum and old mud tanks are 10 and 5 bar respectively. An alternative storage could be the tanks in the port aft leg, but those are structural tanks designed to atmospheric pressure. Drains storage vessel pumps B-533604A/B ultimately return the stored drains liquids to the production heaters P-122300A/B.

Vapors from the closed drains drum and the drains storage vessels feed to the LP flare.

DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
Flow More	Draining any large process vessel.	Closed drains drum not large enough and surplus flow has to be decanted.		Consider the following alternatives for surplus flow collection with a view to overall operability and topsides safety; 1. Bypass to FSO via atmospheric separator (minor carryover of water into FSO). 2. Flow to base oil tank in port aft leg of semi-sub (tanks are part of structural system and are rated for 1atm design pressure). 3.Install new closed drain drum large enough to accept the inventory of the largest single process vessel (but large inventories of HC fluids undesirable). 4. Flow to existing bulk storage tanks (beneath accommodation block and therefore considered unacceptable). <>
ACTION: 523 DIRECTED TO: Process / Brazil.				
Flow More	Draining any large process vessel.	Closed drains drum not large enough and surplus flow has to be decanted.		In view of uncertainty with destination of surplus drain flow, the line 4" 800G including SDV has not been HAZOPed. <>
ACTION: 524 DIRECTED TO: Process.				
Flow Also	The closed drains drum subject to vessel movement.	Sloshing.		Check that anti-sloshing baffles are already installed. <>
ACTION: 521 DIRECTED TO: Process.				

Data File: RONCAD4 82

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PROJECT WEEKLY MINUTES DATED 28/8/97

AMEC Process and Energy

Minutes of Meeting

AMEC Process and Energy Limited
12/34 Gt. Eastern Street, London EC2A 3EH
Telephone 0171-894-4000 Fax 0171-894-4055

Contract No:	L0277	**Minutes of meeting no:**	ENG-013.DOC
Contract name:	P36 - Roncador Field Development	**Date of meeting:**	26/8/97
Subject:	Weekly Project Meeting	**Location:**	Gt. Eastern Street

Purpose of meeting:

To update weekly progress.

DISTRIBUTION: All attendees + B Freeman
H Stitt
E Abbott
AMEC Project file

Present:

AMEC	PETROMEC
Boyman	C Galvao
P Cavallo	
Dines	
Etheridge	
J Glock	
L Kirby	
J Rapanakis	
K Roberts	
D Taylor	
E Trigg	

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Signature of originator: Karl Roberts	**Date:** 28/8/97.
Reviewed by:	**Date**

Minutes of Meeting
Page 2 of 4

Minutes no.	Description	ACTION BY
	Outstanding actions from minutes INM007	
2.0	Safety reported that the gas dispersion study required by Brasoil would need to be performed by outside consultants. DnV Technica to be contracted by Petromec to carry out: • CFD gas dispersion modelling • Blast overpressure/probabilistic analysis • QRA relating to riser events	
	Outstanding action from IN010	
[illegible].0	Inclusion of the compression MCC's in the package is still awaiting a decision from Petromec. Nuovo Pignone has provided quotation. In-house estimate to be prepared as check. John Glock to expedite.	JG
2.0	Resolution to the problem of Battery room gas group designation required. Electrical to review N.P. proposal for battery type. Worst case scenario to be considered	M Milne
	Outstanding actions from minutes INM011	
1.0	SDDR listing is still required from Nuovo Pignone. (NP on August shutdown).	AE
5.0	HAZOP action sheets still awaited from Process. Approximately 100 outstanding, mainly on wellheads.	PC
	Outstanding actions from minutes IMN012	
1.0	Mechanical noted that data sheets for rotary pumps were currently under revision. TBE to be completed on current listing, data sheets to be re-issued during a BCM of preferred Vendors.	AE
[illegible].0	TQ raised 22/8/97 confirming Brasoil's apparent acceptance of an IRCD.	
[illegible].0	Requisition issued for seawater pumps. No filter package required.	AE 22/8
4.0	Following some discussion on the blast requirements, it was felt that it was better to include some basic criteria into the Vendor packages at this stage. ABS has no criteria. AMEC to prepare vendor guidelines for design for blast. Actual overpressure criteria will be confirmed from Technica work.	JB
7.0	Meeting with Petromec to be arranged for 19/8 to discuss fire risk assessment recommendations and external consultancy studies (including blast analysis). Meeting held and way forward agreed (i.e. Technica studies and AMEC guidelines for blast design).	KR 18/8
9.0	ABS meeting re-arranged for Friday 22nd at 1100 hours. Meeting held with relevant engineers present. Minutes (by ABS) to be circulated when received.	KR
	New minutes	
1.0	**Benefit of weekly meeting** Following discussion, it was agreed that the meeting was useful in terms of disseminating Project information, it was not the best forum for resolving/ progressing problems.	

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Minutes of Meeting
Page 3 of 4

Minutes no.	Description	ACTION BY

	The following changes to the project control were agreed to be implemented forthwith for a trial period:
	
	- All Lead Engineers to discuss problems and general issues with each other. (more discussion less writing/Emails).
	
	- Weekly meeting to discuss general project information – all invited.
	
	- 0900 hour meeting, Tuesday, Wednesday, Thursday to discuss and resolve problems (TQ's, response to Brasoil comments, desk top IDC's, survey team responses, progress updates on critical items). Attendees initially limited to disciplines with largest workscope or interface:-
	    - Mechanical
	    - Layout
	    - Process
	    - E&I
	
	- Any other Lead Engineers are welcome to join the meeting to resolve any issues affecting other disciplines.
	
	- Internal weekly reports to continue, but need to demonstrate that 'we' are collectively managing the Project problems in terms of missing or late information. (i.e. we agree to take risks based on assumptions or early data).	

2.0	Survey Team A progress report has been received from the vessel survey team and will be issued to Lead Engineers.	
3.0	ABS Meeting – 22/8/97 No real issues raised. Many points clarified. The most important to Petromec / AMEC is to ensure that all ABS comments are adequately addressed in our response. (ABS contract based on one submission and re-submission to address their comments). Minutes to be circulated to all Lead Engineers.	
4.0	Variation Orders Petromec have issued a response to all 8 VO's. Their position is that they will only approve VO's if they relate to a change originating from Brasoil. All other changes are perceived to be design development and included in the original man-hour estimate. Notwithstanding the above, <u>all</u> VO's raised to date should be assumed to be approved and actioned accordingly. (Andrew Drummond has VO file/register if required).	
5.0	Weight engineering All Lead Engineers reminded to discuss any issues relating to equipment changes as the design develops (e.g. deck generator, subsea cable, piping, etc).	

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Minutes of Meeting
Page 4 of 4

Minutes no.	Description	ACTION BY
6.0	**Recycle line** Cost differential between JG individual and overall recycle lines on compressors to be estimated ASAP. John Glock to expedite. Next Meeting **Monday 1st September 1997 at 11.00am in Conf. Room 1 (3rd floor).**	

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Tradução Nº J-3036/05

O documento entregue para tradução é um CURRÍCULO. --

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Nome: SYLVESTER-EVANS, Rod ---------------------

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Posição Atual: Diretor – RSE Consultants Limited -----

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1995 – RSE Consultants Limited-------------------------

1974-95 – Cremer & Warner (Consultores de Engenharia) --

(90-94) - Diretor --

(87-90) - Diretor Associado --------------------

(85-87) - Consultor de Staff -----------------------------

(83-85) - Engenheiro Principal --------------------------

(74-82) - Engenheiro & Engenheiro Sênior ------------

RESUMO DE EXPERIÊNCIA PROFISSIONAL RELEVANTE ---

TECNOLOGIA:--

Processamento e transmissão de gás, projeto de processamento e sistemas de óleo e gás onshore e offshore, sistemas de controle de derramamento e vapor, sistemas de proteção e combate a incêndios, sistemas de detecção de gás, sistemas de isolamento e purga de emergência, sistemas de evacuação para mitigação de incêndio/explosão (offshore), instalações de separação de ar, armazenagem em baixa temperatura/criogênica, desenvolvimento de planta-piloto, derivados de etileno e "downstream", fabricação e manuseio de cloro, preparação e manuseio de carvão,

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combustão de leito fluidificado, formaldeído, ácido/óleo sulfúrico, amônia, manuseio de gases altamente tóxicos especiais para indústria eletrônica, petroquímicos, produtos químicos finos e farmacêuticos, transporte de materiais perigosos (rodoviário, ferroviário e marítimo), sistemas de transporte, projeto de terminal marítimo, armazenagem em caverna, armazém e armazenagem geral de materiais perigosos, segurança ferroviária, segurança geral/prevenção de perdas. ------------------------

FUNÇÕES: --

Investigação de acidentes, auditoria de segurança, técnicas de identificação de riscos e estudos de risco e capacidade operacional, análise de risco (incêndio, explosão e liberação de gases tóxicos), análise quantitativa de risco (QRA, "quantified risk assessment"), preparação de caso de segurança, layout e disposição de instalações, modificação de instalações, projeto de engenharia de processo & segurança, desenvolvimento de planta-piloto, avaliações técnicas e estudos de viabilidade, estudos de confiabilidade, gerenciamento de risco, desenvolvimento de sistema de gerenciamento de segurança (SMS, "Safety

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Management System"), consultoria de planejamento, testemunha especialista, consultor e coordenador legal/técnico, controles de emissão ambiental. ----------

LOCAIS DE TRABALHO:--------------------------------

Reino Unido, Irlanda, Alemanha, Holanda, Bélgica, Noruega, Canadá, África do Sul, Singapura, Kuwait, Emirados Árabes, Austrália, Brasil. ----------------------

EXPERIÊNCIA DETALHADA ----------------------------

PROJETO DE PROCESSO E ESTUDOS DE VIABILIDADE TÉCNICA: ----------------------------

Envolvido no projeto de processo de uma grande refinaria no exterior, protelado por dois anos, comparando capacidades de projeto com produção operacional e desempenho, além da avaliação de possíveis futuras capacidades de produto. Realização de um estudo de viabilidade e projeto de processo de planta-piloto especializada para preparação seletiva de cetonas complexas. Participação, ainda, no desenvolvimento e progressão de trabalhos farmacêuticos com respectiva programação de produção e estudos econômicos. ---------------------------------

Participação em litígios e arbitragens cíveis, realizando estudo em profundidade de alegadas deficiências de

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DIVISÃO JUDICIÁRIA Nº 541

projeto e segurança de processo de instalações de processamento de gás, plataformas marítimas, planta de Ciclo Combinado com Gaseificação Integrada (IGCC - "Integrated Gasification Combined Cycle") e refinarias. Esses estudos incluíram o uso de modelagem de simulação de processo HYSYS, quando necessária. OS casos envolveram "engenharia forense" detalhada, com o exame de questões envolvendo o cliente/ gerenciamento de projeto, projeto de engenharia detalhado e básico, aspectos de comissionamento e pré-comissionamento e operação dessas instalações para identificar se e onde deficiências "fundamentais" ocorreram. Participação semelhante de estudo das condições de distúrbio de processo que levaram a produtos fora de especificações e contaminados em produtos de óleo & gás e aditivos alimentares, como parte do processo de mediação. ------------------

CÓPIA FIEL DO DOCUMENTO ORIGINAL

Com diversas investigações de acidentes, estudos e auditorias de segurança, forneceu consultoria em questões de engenharia relacionada s projeto de processo, leiaute de instalações e implementação de instalações e sistemas associados. Esse trabalho foi igualmente realizado para empreiteiras, empresas

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operadoras e autoridades reguladoras. Realização, ainda, de exame técnico minucioso de aplicações de planejamento para Autoridades Locais do Reino Unido e para governos estrangeiros.-----------------------------

EXPERIÊNCIA EM OFFSHORE:-------------------------

Participação em tempo integral da Sindicância da Piper Alpha, trabalhando diretamente para Lorde Cullen e a Coroa (ver Investigação de Acidente). Além disso, fornecimento de consultoria técnica para parte representada na Sindicância sobre Acidente Fatal da Ocean Odissey. Isso incluiu o estudo de todas as evidências disponíveis relacionadas à perda de controle do poço, ocorrência de incêndio e explosão a bordo, evacuação de pessoal e causas e circunstâncias envolvendo falha da mangueira submarina de choke.---

Desenvolvimento e minuta de Casos de Segurança em Offshore para Operadores e Empreiteiras de Perfuração. Criação do modelo inicial de Caso de Segurança para projeto de novas instalações em janeiro de 1990, 11 meses antes da publicação do relatório de Lorde Cullen. Responsável pelo desenvolvimento técnico das Diretrizes de Casos de Segurança para Perfuradoras, trabalhando em conjunto com o Grupo Diretor do

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IADC, além de avaliação dos principais riscos associados à operação de semi-submersíveis e unidades de elevação.--

Consultoria para empresas de offshore no desenvolvimento de Sistemas de Gerenciamento de Segurança, incluindo estudo e auditoria de sistemas corporativos antes e durante a preparação de Casos de Segurança. --

Responsável por Estudos Conceituais de Segurança, QRAs e Estudos Subseqüentes de Cullen, por exemplo, Análise de Risco de Incêndio, Estudos sobre Admissão de Fumaça/Gás, e Estudos sobre Evacuação, Fuga e Resgate para instalações fixas e móveis. Liderança de diversas equipes de estudo e de reuniões de avaliação para clientes. Participação na revisão e desenvolvimento de modelagem offshore de incêndio e explosão, incluindo efeitos da fumaça. Liderança de revisões de segurança de projeto para clientes na fase de detalhamento de projeto. Realização de numerosos estudos HAZOP de instalações e dutos em offshore.----

Obtenção de considerável conhecimento prático da legislação de offshore e seu ambiente de desenvolvimento. Consultoria para clientes sobre a

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regulamentação de plataformas fixas, instalações submarinas e unidades de perfuração. Consultoria sobre Regulamentos de Projeto e Construção e questão de verificação e Gerenciamento de Integridade. ------------

Participação na investigação e acompanhamento da perda da Unidade Flutuante de Produção brasileira, P-36. --

Atuação como testemunha especializada e consultor/coordenador técnico em muitos casos legais, tanto de menor quanto de maior porte, envolvendo acidentes em offshore, processos e disputas comerciais (ver Serviços Legais/Testemunha Especializada). -------

INVESTIGAÇÃO DE ACIDENTE: ----------------------

Participação em tempo integral do Desastre de Flixborough (1974), incluindo exame forense de provas, teste de simulação das instalações e análise de modos potenciais de falha e subseqüente apresentação de provas. ---

Investigação de incêndios e explosões (domésticos, industriais e relacionados a petróleo, gás e produtos químicos) durante o tempo com a Cremer & Warner e após. Investigação da explosão de gás que destruiu um bloco de apartamentos em Dublin (1986) e

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envolvimento posterior no processo movido contra a Transco após a explosão de gás em Larkhall (1999). Investigação de incêndio e explosões em offshore. -----
Participação na equipe de investigação do Desastre de King Cross (1986), analisando os sistemas de gerenciamento empregados pela London Underground, ajudando a desenvolver as linhas de evidência do Conselho a Coroa tanto em questões técnicas quanto administrativas.-----------------------------------
No período de outubro de 1988 a março de 1990, participação integral na Sindicância da Piper Alpha, sendo responsável por todos os aspectos técnicos do trabalho da Cremer & Warner como Investigadores Técnicos da Coroa. Isso envolveu a liderança da equipe que examinou o conjunto de causas potenciais e modos de progressão, culminando com o fornecimento de prova antes da Sindicância na Parte 1. Durante a Parte 2 da Sindicância, que foi voltada para "lições a serem aprendidas" e recomendações, a tarefa envolveu a coordenação de consultoria técnica independente necessária para testar a prova de outras partes representadas e fornecer suporte para Lorde Cullen, Assessores Técnicos e o Conselho da Coroa. ------------

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Participação na Sindicância Pública de Ladbroke Grove, examinando as circunstâncias envolvendo o motivo do acidente ferroviário fora da Estação de Paddington em Londres (1999). --------------------------

Membro da Equipe da Comissão Real que investigou a Explosão da Usina de Gás de Longford no estado de Vitória, Austrália, em setembro de 1998. Forneceu prova para o processo que se seguiu em março de 2001. Esse trabalho proporcionou uma oportunidade única de aquisição de conhecimento em Sistemas de Gerenciamento de Segurança e os problemas encontrados por empresas na implementação efetiva de seus SMS. --

SERVIÇOS LEGAIS / TESTEMUNHA ESPECIALIZADA:---

Fornecimento de Serviços Legais para advogados e para a Coroa em diversas capacidades. Atuação como testemunha especializada ou Consultor e Coordenador Técnico em litígios de pequeno e grande porte, arbitragens e mediações, bem como em processos envolvendo Saúde e Segurança, fornecendo opiniões sobre engenharia de processo e segurança, identificação

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de riscos, avaliação de riscos e gerenciamento de segurança.---

Consultor Técnico e perito residente dos requerentes no maior litígio da história jurídica do Reino Unido - as Ações das Empreiteiras da Piper Alpha - envolvendo uma proposta de vários milhões de libras a título de indenização por danos após o Desastre da Piper Alpha. Testemunha especializada, implicando o fornecimento de evidência por períodos significativos em processos criminais e litígios cíveis, particularmente os referentes a acidentes e disputas relacionados com petróleo e gás. Testemunha especializada em diversas Sindicâncias de Planejamento, no Reino Unido e na República da Irlanda, e em processos relacionados a saúde e segurança. Testemunha especializada para Comissão de Inquérito sobre diversos aspectos da investigação do Desastre de Flixborough e sobre as causas potenciais do Desastre da Piper Alpha. Assistência para o Conselho de Inquérito no gerenciamento de segurança e casos de segurança durante a Sindicância Pública de Cullen sobre o Acidente Ferroviário de Ladbroke Grove. Fornecimento de evidência como Presidente de um grupo de especialistas em avaliação de risco.-------

ESTUDOS DE ANÁLISE DE PERIGOS E RISCOS:----

Realização de estudos de risco e perigo detalhados de mais de quarenta e cinco instalações em todo o mundo, fabricando e manuseando, por exemplo, cloro, etileno, óxido de etileno, amônia, dióxido de enxofre, trióxido de enxofre, ácido sulfúrico, fosgênio, monômero de cloreto de vinil, fluoreto de hidrogênio, sulfeto de hidrogênio e um amplo conjunto de petroquímicos.-----

Participação em muitas avaliações detalhadas de instalações em offshore, instalações de processamento de gás, usinas de LPG, LNG e NGL e instalações de exportação. Participação, ainda, na avaliação de instalações manuseando gases altamente tóxicos, como fosfina e arsenamina para a indústria eletrônica e avaliação de formulação e instalação de armazenagem de inseticida e pesticida.-----------------------------------

Participação em avaliação detalhada de perigo e riscos das seis seções de instalações formando parte do estudo-piloto principal para a Área Industrial de Rijnmond. Participação semelhante em auditoria técnica e avaliação de risco co complexo petroquímico construído na Ilha de Merbau de Singapura.

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Análises envolvendo estudos de transporte de ácido sulfúrico, oxigênio líquido e cloro. Ainda, análise de perigos e riscos marítimos relacionados a diversos leiautes de porto, incluindo o Complexo de Jubail, na Arábia Saudita, e uma proposta para um Sistema de Terminal Marítimo e Armazenamento em Caverna para LPG, em Dublin.--

Estudo de análises de risco, avaliação de risco e casos de risco como parte de investigações de acidente e casos legais.---

CASOS DE SEGURANÇA:-----------------------------

Assistência a clientes na preparação e atualização de diversos Casos de Segurança, necessários conforme os Regulamentos do Controle de Principais Riscos de Acidentes Industriais (CIMAH, "Control of Industrial Major Accident Hazards") do Reino Unido. Essa assistência incluía usinas e locais de armazenamento de cloro, instalações de acrilonitrila, usuários de estireno e butadieno e três terminais de gás.-------------

Extensa participação na preparação e teste de desenvolvimento de casos de segurança para plataformas e unidades de perfuração em offshore (ver Offshore) e estudo de casos de segurança ferroviários.

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ESTUDOS DE RISCOS E CAPACIDADE OPERACIONAL: --

Experiência extensa em organização e liderança de Estudos HAZOP para empresas operacionais e empreiteiras, compreendendo um total acumulado de 3 homens-ano de estudo. Experiência adquirida em pelo menos 15 grandes estudos, envolvendo: ------------------

Diversos projetos de Terminais de Gás e modificações de plantas; redes de dutos, instalações em offshore, sistemas de manuseio de combustor de leito fluidificado pressurizado e material associado, caldeiras de leito fluidificado e sistemas associados, terminal de recebimento de LPG com sistemas de transferência rodoviário, ferroviário e marítimo, instalações de acrilonitrila e armazenagem de cloro, além de recursos de manuseio. ------------------

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Liderança de estudos HAZOP adicionais de sistemas novel, projetos e modificações de planta, incluindo o exame da possibilidade de descomissionar com segurança sistemas de descarte de vapor/líquido com a planta ainda em serviço. Liderança, ainda, de estudos para projetos especializados envolvendo, por exemplo, a indústria eletrônica. ----------------------------------

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AUDITORIA DE SEGURANÇA: -------------------------

Participação e liderança em equipes envolvidas em auditorias de segurança de grandes empresas no exterior, examinando os muitos processos para identificação dos principais riscos potenciais de acidentes, bem como auditando normas de segurança da empresa em locais individuais. Realização, ainda, de diversas auditorias de segurança de instalações e armazéns industriais, além de instalações de óleo, gás e produtos químicos no Reino Unido e no exterior. -------

SISTEMAS E AUDITORIAS DE GERENCIAMENTO DE SEGURANÇA: -----------------------------------

Inspeções e auditorias administrativas de empresas industriais e de produtos químicos fizeram parte do trabalho realizado durante investigações de acidentes, auditorias de segurança e gerenciamento de risco. Avaliações foram feitas de empresas internacionais em nível corporativo, bem como de pequenos empreendimentos industriais. Como Consultor Técnico para Casos Legais de grande porte, o exame de sistemas administrativos foi um fator fundamental. -------

Sistemas de Gerenciamento de Segurança foram desenvolvidos e auditados para Empreiteiras e Operadoras de Perfuração em Offshore.-------------------

GERENCIAMENTO DE RISCO---------------------------

Muitas auditorias de risco de grande porte foram realizadas. Por exemplo, a vasta experiência no campo de análise de perigos e riscos e de auditorias de segurança possibilitou o desenvolvimento de estratégias para a implementação de uma Filosofia de Gerenciamento de Risco em grandes empresas de produtos químicos. Possibilitou, ainda, o desenvolvimento de planos de contingência de longo prazo para perdas e desastres de grande porte. ----------

PLANEJAMENTO DE EMERGÊNCIA---------

Fornecimento de consultoria detalhada sobre planejamento de emergência para instalações de manuseio de explosivos, materiais inflamáveis e tóxicos. Discussão detalhada com serviços de emergência e autoridades locais, necessária para uma decisão sobre soluções mais práticas a serem adotadas em caso de possíveis acidentes. Conclusão de estudo de sistemas de incêndio e de emergência em planta de processo de grande porte, visando garantir que os

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procedimentos de emergência existentes, assim como níveis de equipagem, fossem adequados. Participação no exame de estratégias de comando e sistemas de evacuação, fuga e resgate para instalações em offshore.

EXPERIÊNCIA GERENCIAL: ----------------------------

Responsável por diversos projetos relacionados a segurança. Obtenção de experiência única na investigação e gerenciamento de grandes acidentes, culminando com o gerenciamento técnico/de projeto de processos e sindicâncias jurídicas montando a milhões de libras. --

Durante os anos de 1980, desenvolvimento conjunto da atividade comercial de Gerenciamento de Segurança e Risco da Cremer & Warner, até que a empresa foi assumida pela Robertson plc, depois pela Simon Engineering Limited, e daí pela ENTEC, uma divisão da Northumbrian Water. Em 1990, nomeação de Diretor da Cremer & Warner e, em 1991, abertura de novo escritório em Aberdeen, que operou com sucesso e lucratividade, angariando significativa parcela do mercado após o trabalho de Cullen. Saída da empresa em 1994 para fundar a RSE Consultants Limited. -------

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Cursos de treinamento de gerenciamento incluem Desenvolvimento de Negócios e Gerenciamento Estratégico. ---

ATIVIDADES PROFISSIONAIS:-------------------------

Membro do Institution of Chemical Engineers e Membro do American Institution of Chemical Engineers. No registro "Safety Professionals" do I.Chem.E. É, ainda, membro da Equipe de Trabalho I.Chem.E. que produziu o livreto original intitulado "Nomenclature for Hazard and Risk". Membro do Energy Institute---

Antigo membro do Human Factor and Reliability Group (HFRG) e Líder da Equipe de Trabalho que produziu um pequeno guia sobre "Erro de Gerenciamento Que Leva a Grandes Acidentes". Anteriormente membro do Conselho Editorial do "Process Safety and Environmental Protection" - Transações I.Chem.E. -----

Apresenta regularmente palestras e sessões de treinamento em diversos simpósios, conferências e cursos. --

Janeiro de 2005 ---

Rio de Janeiro, 17 de outubro de 2005. -- -----------

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CURRICULUM VITAE (GENERAL)

Name:	**SYLVESTER-EVANS, Rod**	
Address:	**'Purvesholm', Sandy Loan, Gullane, East Lothian, EH31 2BH**	**Tel No: 01620 843871 Mobile: 07775 783272 Fax No: 01620 842232 e-mail: rse.consultants@dial.pipex.com**

Education and Qualification:	1971-74	University College of Swansea, 1st Class Honours Chemical Engineering, Awarded Harold Hartley Medal,
	B.Sc., C.Eng. F.I.Chem.E., M.Inst Eng. IChemE Register of Safety Professionals.	
Current Position:	**Director,**	**RSE Consultants Limited**
Career Summary:	**1995-**	**RSE Consultants Limited**
	1974-95	**Cremer & Warner (Consulting Engineers)**
	(90-94)	Director
	(87-90)	Associate Director
	(85-87)	Staff Consultant
	(83-85)	Principal Engineer
	(74-82)	Engineer & Senior Engineer

SUMMARY OF RELEVANT PROFESSIONAL EXPERIENCE

TECHNOLOGY:

Gas processing and transmission, onshore and offshore oil and gas processing and system design, spill and vapour control systems, fire-fighting/protection systems, gas detection systems, emergency isolation and blowdown systems, fire/explosion mitigation evacuation systems (off-shore), air separation plants, low temperature/cryogenic storage, pilot plant development, ethylene and downstream derivatives, chlorine manufacture and handling, coal preparation and handling, fluidised bed combustion, formaldehyde, sulphuric acid/oleum, ammonia, handling of specialist highly toxic gases for electronic industry, petrochemicals, fine chemicals and pharmaceutical, transportation of hazardous materials (road, rail and sea), transport systems, marine terminal design, cavern storage, warehouse and general storage of hazardous materials, railway safety, general safety/loss prevention.

FUNCTIONS:

Accident investigation, safety auditing, hazard identification techniques and hazard and operability studies, hazard analysis (fire, explosion and toxic releases), quantified risk assessment (QRA), safety case preparation, plant layout and sitting, plant modifications, process & safety engineering design, pilot-plant development, technical appraisals and feasibility studies, reliability studies, risk management, safety management system (SMS) development, planning advice, expert witness, legal/technical adviser and co-ordinator, environmental emission controls.

WORK LOCATIONS:

UK, Ireland, Germany, Netherlands, Belgium, Norway, Canada, South Africa, Singapore, Kuwait, UAE, Australia, Brazil.

DETAILED EXPERIENCE

PROCESS DESIGN AND TECHNICAL FEASIBILITY STUDIES:

Involved in the process design of a major overseas refinery, mothballed for two years, comparing design capacities with operational throughputs and performance, and evaluating possible future product capacities. Conducted a feasibility study and process design of a specialised pilot plant for selective preparation of complex ketones. Also involved in de-bottlenecking and scale-up of a pharmaceutical works with associated production scheduling and economic studies.

Involved in major civil litigations and arbitrations, conducting in-depth review of alleged process design and safety deficiencies of gas processing facilities, offshore platforms, an Integrated Gasification Combined Cycle (IGCC) plant and refineries. These studies have included the use of the HYSYS process simulation modelling, where required. These cases have involved detailed 'forensic engineering' with the examination of issues involving the client/project management, basic and detailed engineering design, pre-commissioning and commissioning aspects and operation of such facilities to identify if and where 'root' deficiencies occurred. Similarly, involved in the review of process upset conditions leading to off-specification and contaminated product in oil & gas products and food additives as part of the mediation process.

With numerous accident investigations, safety studies and audits, advised on engineering features relating to process design, plant layout and the siting of plant and associated systems. This work has been undertaken for contractors, operating companies and regulatory authorities alike. Also conducted technical vetting of planning applications for UK Local Authorities and overseas Governments.

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OFFSHORE EXPERIENCE:

Full time involvement in the Piper Alpha Inquiry working directly for Lord Cullen and the Crown (see Accident Investigation). Also provision of technical advice to a represented party at the Ocean Odyssey Fatal Accident Inquiry. This included reviewing all available evidence relating to loss of well control, explosion and fire development onboard, the evacuation of personnel and the causes and circumstances surrounding the failure of the subsea choke hose.

Developed and drafted Offshore Safety Cases for Operators and Drilling Contractors. Originated initial Safety Case template for design of new facilities in January 1990, 11 months prior to publication of Lord Cullen's Report. Responsible for the technical development of the Drillers Safety Case Guidelines working in conjunction with the IADC Steering Group; assessing major hazards associated with the operation of semi-submersibles and jack-out units.

Advised offshore companies on the development of Safety Management Systems including review and auditing of company systems before and during preparation of Safety Cases.

Responsible for Conceptual Safety Studies, QRA's and Cullen's Forthwith Studies e.g.; Fire Risk Analysis, Smoke/Gas Ingress Studies and Evacuation, Escape and Rescue Studies for fixed and mobile installation. Chaired numerous team reviews and screening meetings for clients. Involved in the review and development of fire and explosion modelling offshore, including smoke effects. Led project safety reviews for clients at the detailed design stage. Conducted numerous HAZOP studies of offshore facilities and pipelines.

Gained considerable working knowledge of the offshore legislation and their background development. Advised clients on regulations for fixed platform, subsea facilities and drilling units. Advised on the Design & Construction Regulations and the issue of verification and Integrity Management.

Involved in the investigation and follow-up of the loss of the Brazilian Floating Production Platform, P-36.

Acted as expert witness and technical adviser/co-ordinator in many legal cases, both small and large, involving offshore accidents, prosecutions and commercial disputes (See Legal Services/Expert Witness).

ACCIDENT INVESTIGATION:

Involved full-time on the investigation into the Flixborough Disaster (1974), including the forensic examination of evidence, simulation testing of plant, and analysis of potential failure modes and subsequent submission of proofs of evidence.

Investigated fires and explosions (domestic, industrial and oil, gas & chemical related) throughout the time with Cremer & Warner and thereafter. Investigated the gas explosion, which destroyed a block of flats in Dublin (1986) and latterly involved in the prosecution of Transco following the gas explosion at Larkhall (1999). Investigation of offshore fires and explosions.

Part of the investigation team for the Kings Cross Disaster (1986), analysing the management systems employed by London Underground and assisting in developing the lines of evidence for Crown Counsel on both technical and managerial issues.

For the period of October 1988 to March 1990, fully involved in the Piper Alpha Inquiry, being responsible for all the technical aspects of Cremer & Warner's work as Technical Investigators for the Crown. This involved leading the team who examined the range of potential causes and modes of escalation and culminated in giving evidence before the Inquiry in Part 1. During Part 2 of the Inquiry, which was directed towards the "lessons to be learnt" and recommendations, the task involved co-ordinating independent technical advice necessary to test the evidence of other represented parties and to provide support to Lord Cullen, the Technical Assessors, and Crown Counsel.

Involved in the Ladbroke Grove Public Inquiry, examining the background circumstances to the reason for the rail accident outside Paddington Station in London (1999).

A member of the Royal Commission team investigating the Longford Gas Plant Explosion in the State of Victoria, Australia, in September 1998. Gave evidence in the subsequent prosecution in March 2001.

Such work has provided a unique opportunity to gain an insight into Safety Management Systems and the problems facing companies in the effective implementation of their SMS.

LEGAL SERVICES/EXPERT WITNESS

Provision of Legal Services to solicitors and the Crown in varying capacities. Acted as expert witness or Technical Adviser and Co-ordinator in small and major litigations, arbitrations and mediations as well as in Health & Safety prosecutions, providing opinions on process design & safety engineering, hazard identification, risk assessment and safety management.

Technical Adviser and resident expert for the pursuers in the largest litigation in U.K. legal history - Piper Alpha Contractors Actions - involving the multi million pound bid to recover claims made following the Piper Alpha Disaster. Expert witness, involving giving evidence for substantive periods in criminal prosecutions and civil litigations particularly involving oil & gas related accidents and disputes.

Expert witness at a number of Planning Inquiries, in the UK and the Republic of Ireland, and health & safety related prosecutions. Expert witness at the Court of Inquiry on various aspects of the investigation into the Flixborough Disaster and on the potential causes of the Piper Alpha Disaster. Assisted Inquiry Counsel in the management of safety and safety cases during Part 2 of Lord Cullen's Public Inquiry into the Ladbroke Grove Rail Accident. Gave evidence as Chairman of a panel of experts on risk assessment.

HAZARD AND RISK ASSESSMENT STUDIES:

Undertaken detailed hazard and risk assessment studies of more than forty-five plants worldwide manufacturing and handling, for example, chlorine, ethylene, ethylene oxide, ammonia, sulphur dioxide, sulphur trioxide, sulphuric acid, phosgene, vinyl chloride monomer, hydrogen fluoride, hydrogen sulphide and a wide range of petrochemicals.

Involved with many detailed assessments of offshore installations, gas processing facilities, LPG, LNG and NGL plants and export facilities. Also involved in the assessment of facilities handling highly toxic gases, such as phosphine and arsine for the electronics industry and assessment of insecticide and pesticide formulation and warehouse facilities.

Participated in the detailed hazard and risk assessment of the six plants sections, which formed part of a major pilot study for the Rijnmond Industrial Area. Similarly, participated in the technical audit and hazard assessment of the petrochemical complex built on Merbau Island of Singapore.

Assessments have involved transportation studies involving sulphuric acid, liquid oxygen and chlorine. Also assessment of marine hazards and risks associated with various harbour layouts, including the Jubail Complex in Saudi Arabia and a proposed LPG Marine Terminal and Cavern Storage System in Dublin.

Review of hazard analyses, risk assessments and safety cases as part of accident investigations and legal cases.

SAFETY CASES:

Assisted clients in the preparation and update of a number of Safety Cases required under the original Control of Industrial Major Accident Hazards (CIMAH) Regulations in the UK. This has included chlorine plants and storage sites, acrylonitrile facilities, styrene and butadiene users and three gas terminals.

Involved extensively in the development preparation and testing of safety cases for offshore platforms and drilling units (See Offshore) and review of railway safety cases.

HAZARD AND OPERABILITY STUDIES:

Extensive experience of organising and leading HAZOP Studies for operating companies and contractors comprising accumulatively over 3 man-years of studies. Experience of at least 15 major studies has been gained involving: -

Numerous Gas Terminal designs and plant modifications; pipeline networks, offshore installations, pressurised fluidised bed combustor and associated material handling systems, fluidised bed boilers and associated systems, LPG Reception terminal with road, rail and ship transfer systems, acrylonitrile facilities and chlorine storage and handling facilities.

Led further HAZOP studies on novel systems, designs and modifications to plant, including examining the possibility of safety decommissioning vapour/liquid disposal systems with a plant remaining in service. Also led HAZOP studies for specialised design projects involving, for example the electronics industry.

SAFETY AUDITING:

Participated in, and led, teams involved in safety audits of major international companies overseas, examining the many processes to identify the potential for major accident hazards to occur, as well as auditing company safety standards at individual sites. Also undertaken numerous safety audits of industrial plants & warehouses and oil, gas and chemical facilities in the UK and abroad.

SAFETY MANAGEMENT SYSTEMS AND AUDITS:

Surveys and audits of the management of industrial and chemical companies have been an integral part of the work when undertaking accident investigations, safety audits and risk management assignments. Assessments have been made at the corporate level of international companies as well as for small industrial enterprises. As Technical Adviser to major Legal Cases, the examination of management systems has been a key factor.

Safety Management Systems have been developed and audited for Offshore Drilling Contractors and Operating Companies.

RISK MANAGEMENT

Many major risk management audits have been undertaken. For example, wide experience in the field of hazard and risk assessment and safety audits has enabled strategies to be developed for implementation of a Risk Management Philosophy with major chemical companies. Also development of long-term contingency plans following major losses/disasters.

EMERGENCY PLANNING

Provision of detailed advice on emergency planning for facilities handling explosive, flammable and toxic materials. Detailed discussion with emergency services and local authorities has been necessary to reach the most practical solutions to meet foreseeable accidents. Completed a review of fire and emergency systems at a major processing plant with the objective being to ensure that the existing emergency procedures and manning levels were adequate. Involved in the examination of command strategies and evacuation, escape and rescue system for offshore installations.

MANAGERIAL EXPERTISE: -

Responsible for numerous safety related projects. Gained a unique experience investigating and managing major accidents, which has culminated in the technical/project management of multi-million pound legal cases and inquiries.

During the 1980's jointly developed Cremer & Warner's Safety and Risk Management business until the company was taken over by Robertson plc, then Simon Engineering Limited and then by ENTEC, a division of Northumbrian Water. In 1990 became a Director of Cremer & Warner and in 1991 started up a new office in Aberdeen, which operated as a successful and profitable business unit obtaining a significant market share of the post-Cullen work. Left at the end of 1994 to start RSE Consultants Limited.

Management training courses include Business Development and Strategic Management.

PROFESSIONAL ACTIVITIES:

Fellow of the Institution of Chemical Engineers and Member of the American Institution of Chemical Engineers. On the register of "Safety Professionals" of the I.Chem.E. Also a team member of the I.Chem.E. Working Party who produced the original booklet entitled *"Nomenclature for Hazard and Risk"*. Member of the Energy Institute.

Former member of the Human Factor and Reliability Group (HFRG) and Chairman of a Working Party to produce a short guide on *"Management Error Leading to Major Accidents"*. Formerly member of the Editorial Board of the "Process Safety and Environmental Protection" - Transactions of the I.Chem.E.

Regularly presents papers and training sessions at various symposia, conferences and courses.

---oooOooo---

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DIVISÃO JUDICIÁRIA Nº 5478

Tradução Nº J-3037/05

O documento entregue para tradução é um Laudo.

PERDA DA PLATAFORMA SEMI-SUBMERSÍVEL PETROBRAS P-36 --

CAMPO DE RONCADOR, BACIA DE CAMPOS, OFFSHORE BRASIL------------------------------------

Relatório Sumário --

Julho de 2005 --

Preparado por ROD SYLVESTER-EVANS -------------

Relatório preparado por: ----------------------------------

Rod Sylvester-Evans, Diretor ------------------------

RSE Consultants Limited ------------------------------

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1.1.1 Rod Sylvester-Evans chefiou as investigações técnicas da Resseguradora sobre a perda da P-36, investigações essas realizadas por uma equipe de peritos. Sylvester-Evans é experimentado em investigação de acidentes, gestão de segurança e realização de estudos de segurança e risco para a indústria de petróleo e gás, tanto em instalações em terra quanto em offshore. Liderou as investigações técnicas do Gabinete da Coroa do Reino Unido e de Lorde Cullen sobre o desastre da Piper Alpha, tendo participado de diversas investigações de acidentes de grande porte, atuando para diversas partes interessadas.

1.1.2 As investigações técnicas da Resseguradora concluíram que o acidente ocorreu por excesso de pressurização e ruptura do Tanque de Armazenamento

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de Drenagem (DST, "Drains Storage Tank")[1]. Subseqüentemente, documentos adicionais foram colocados à disposição por terceiros, tendo sido realizado um exame profundo desses documentos juntamente com aqueles obtidos durante a investigação, concentrando-se esse exame nas causas raiz por trás da seqüência do acidente. Até esta data, a investigação identificou uma série de fraquezas de projeto, que estão reunidas neste relatório.-----------------------------------

1.2 Formato do Relatório Sumário-------------------------

1.2.1 Este relatório sumário está dividido em três partes. Na seção 2, são examinadas as questões de planejamento de processo associadas ao sistema de Tanque de Armazenamento de Drenagem (DST). Isto inclui uma análise de como o projeto de DST foi desenvolvido, já que essa análise tem a ver com o porque do projeto do sistema DST não ter sido incluído na maioria dos estudos de segurança realizados. --------

1.2.2 Na seção 3, são examinadas as características de projeto de segurança da coluna de popa, enquanto que na seção 4 são consideradas questões de projeto de segurança. ---

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1.2.3 Ao final de cada seção, são feitos comentários sobre as respectivas conclusões da Comissão de Investigação da Petrobras.---------------------------------

[abertura de nota de rodapé]--------------------------------

[1] O Tanque de Armazenamento de Drenagem (DST) também é referido como Tanque de Drenagem de Emergência (EDT, "Emergency Drainage Tank") em diversos documentos. --

[fechamento de nota de rodapé]------------------------------

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2.0 QUESTÕES DE PLANEJAMENTO DE PROCESSO

2.1 Desenvolvimento do Projeto do Sistema DST ------ Esquema inicial---

2.1.1 A Petrobras solicitou que o "vaso de refugos" (ou tanque de drenagem) da P-36 fosse "capaz de acomodar a drenagem do maior dos vasos da planta de processo", com margem de segurança de 20% do volume total do vaso[2]. O dimensionamento do sistema de drenagem foi discutido na reunião de Esclarecimento Técnico de Roncador, em 4 e 5 de março de 1997, ocasião em que a Petrobras confirmou a solicitação de um tanque de drenagem dimensionado para receber o conteúdo total do maior dos vasos. O documento "Basis of Design"

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(Bases de Projeto) da AMEC estabelece[3] que a "capacidade de drenagem de refugos" deve "acomodar a drenagem de um desidratador de óleo (o maior dos vasos do trem de separação)". -----------------------------

2.1.2 A AMEC considerou diversas opções de possibilidades de projeto para "vaso de refugos". O esquema inicial elaborado pela AMEC[4] foi reutilizar dois Tanques de Armazenamento de Granel (T-05001C/D), que chamaram de "Tanques de Armazenamento de Drenagem", localizados na coluna de bombordo de proa. --------------------------------

Esses tanques foram projetados para 5 barg e atuariam como esgotamento ("rundown") intermediário do sistema de drenagem. A vaporização instantânea proveniente desses tanques seria direcionada para o sistema do queimador de baixa pressão (BP) (ver Figura 1). Uma vez que esses Tanques de Armazenamento de Granel proporcionavam somente 82% da capacidade do maior dos vasos de processo, era necessário permitir que o líquido extravasasse desses tanques para o Tanque de Óleo Básico de bombordo. Não havia intenção de utilizar o Tanque de Óleo Básico de boreste de popa. O plano era instalar duas bombas

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100% na coluna de bombordo, ou no flutuador de bombordo, para transferir o óleo do Tanque de Óleo Básico de bombordo de volta para os trens de produção (ver a Figura 2). --

2.1.3 A folha de dados, emitida pela AMEC em 13 de junho de 1997 para o tanque de armazenamento de drenagem[5] dizia que, se o Tanque de Óleo Básico fosse utilizado, seria então necessário analisar a estabilidade mecânica, a pressão de projeto, o potencial de corrosão e identificar o impacto da possibilidade de haver uma mudança na classificação existente de área não-perigosa da coluna. ----------------------------

[abertura de nota de rodapé]--------------------------------

[2] Seção M19.5 do Capítulo M19 da Especificação Técnica Geral (GTS, "General Technical Specification") da Petrobras para a P-36. ----------------

[3] Seção 26.1 do documento "Basis of Design" [Base de Projeto] da AMEC (ET-3010.38-1200-941-AMK-921)

[4] "Design Philosophy for Drain System" [Filosofia de Projeto para Sistema de Drenagem], (ET-3010.38-5336-941-AMK-906, Rev 0 – emitido em 26 de junho de 1997) --

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[5] "Drains Storage Tanks Process Data Sheet" [Folha de Dados de Processo de Tanques de Armazenamento de Drenagem], (FD-3010.38-5336-511-AMK-797; Rev A - 13 de junho de 1997)--

[fechamento de nota de rodapé] ---------------------------

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2.1.4 Um estudo de HAZOP e de capacidade operacional (HAZOP) foi realizado pela AMEC em junho e julho de 1997[6]. O conceito de projeto geral do sistema DST original foi examinado no último dia do estudo, 10 de julho de 1997. A equipe considerou que o uso dos Tanques de Armazenamento de Granel existentes na coluna de proa de bombordo era inaceitável, uma vez que estes estavam localizados abaixo do bloco de acomodações. A equipe recomendou o exame de outras alternativas. A equipe notou, ainda, que os Tanques de Óleo Base eram tanques estruturais, projetados para pressão atmosférica, presumivelmente reconhecendo o fato de que, se fosse utilizado o Tanque de Óleo Base de bombordo, seria necessária proteção contra excesso de pressão.-------------------

Esquema Final --

2.1.5 O projeto final do Sistema DST compreendeu o uso dos Tanques de Óleo Base tanto de bombordo quanto de boreste, sendo diretamente conectados ao manifolde (header) de produção (ver Figuras 3 e 4). O uso dos Tanques de Óleo Base proporcionou capacidade suficiente para a drenagem proveniente do maior dos vasos de processo. O líquido coletado em cada um dos DSTs poderia ser bombeado de volta para o Manifolde de Produção usando-se uma bomba com 100% de capacidade para cada DST. A bomba de DST foi dimensionada para esvaziar o conteúdo de um DST e devolvê-lo ao Manifolde de Produção dentro de 5 horas. Os detalhes do projeto final são mostrados no diagrama de tubulação e instrumentos (P&ID)[7] e nas folhas de dados de processo[8] para os DSTs. Contudo, o documento Filosofia de Drenos nunca foi atualizado.---

2.1.6 Havia diferença significativa entre os projetos inicial e final de sistema DST da AMEC. A configuração final produziu diversos riscos inerentes. O esquema final não contemplava qualquer tanque de esgotamento (rundown) intermediário que protegesse os DSTs da alta pressão proveniente dos equipamentos de processo. No esquema inicial, os Tanques de

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Armazenamento de Granel eram tanques de pressão conectados ao queimador de baixa pressão. Além disso, no esquema final, os DSTs atmosféricos estavam, agora, conectados diretamente ao Manifolde de Produção de alta pressão ao serem esvaziados, havendo somente uma única válvula para evitar o fluxo reverso de fluidos de poço de alta pressão de volta para dentro dos DSTs. Ainda, com o uso tanto dos Tanques de Óleo Base quando de um manifolde (header) comum, criou-se o potencial para fluxo reverso entre eles durante operações de transferência.-----------------------------

[abertura de nota de rodapé]------------------------------

6 "Estudo HAZOP" (RL-3010.38-5400-947-AMK-903, Rev 0, 18 de julho de 1997) -----------------------------

7 P&ID "Drains Storage Tanks" [Tanques de Armazenamento de Drenagem] (DE-3010.38-5336-944-AMK-398, Rev A em diante) -----------------------------

8 "Process Data Sheet – Drains Storage Tanks, V-533604A/B" [Folha de Dados de Processo - Tanques de Armazenamento de Drenagem] (FD-3010.38-5336-511-AMK-797, Rev A, 11 de dezembro de 1997.) -----------

[fechamento de nota de rodapé]---------------------------

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2.1.7 Conseqüentemente, o projeto da AMEC teria exigido um exame cuidadoso para garantir que salvaguardas adequadas e suficientes fossem incorporadas ao projeto de engenharia do sistema DST para permitir que o sistema fosse operado e mantido com segurança. Contudo, não foi encontrada evidência documental até o momento de que a AMEC tivesse realizado investigação e estudo cuidadosos do projeto do sistema DST. Como discutido adiante, todos os principais estudos de segurança foram realizados no esquema DST inicial Exceto por um estudo de segurança, nenhum outro foi atualizado reexaminar o projeto do sistema DST final. Assim sendo, a escolha da AMEC do projeto final de sistema DST introduziu sérios e latentes defeitos de projeto.---------------------

Cronograma de Desenvolvimento do Projeto do Sistema DST ---

2.1.8 Os cronogramas resumindo as revisões do documento DST, bem como o desenvolvimento do projeto do sistema DST, são mostrados nas Figuras 5 & 6. Em seguida a conclusão da fase de projeto da AMEC e da reunião de esclarecimento técnico de março de 1997, a AMEC iniciou a fase de projeto detalhado no

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final de abril de 1997, que foi programada para conclusão em 29 de dezembro de 1997. Durante o período de maio a agosto de 1997, a AMEC desenvolveu o projeto inicial do sistema DST sobre o qual realizaram a maioria dos estudos de segurança. Todavia, como discutido acima, a equipe HAZOP identificou problemas no uso dos Tanques de Armazenamento de Granel localizados abaixo do bloco de acomodações. A resposta interna da AMEC ao questionamento HAZOP sobre possíveis opções de projeto apontou, em 30 de agosto de 1997, que os Tanques de Óleo Básico foram "declarados aceitáveis" para uso como DSTs[9].------------------------------------

2.1.9 Houve um período de transição durante setembro até o início de dezembro de 1997, no qual alguns desenhos e folhas de dados ainda mostram o sistema DST inicial, sendo que em meados de outubro de 1997 a Rev A de P&ID (AMK-398) mostrava o esquema final de DST[10]. Contudo, não há evidência de que o projeto final do sistema DST tenha sido estabelecido "como aprovado" pela Petrobras.--------------------------------

2.1.10 A conversão dos Tanques de Óleo Base aconteceu nos estaleiros Davie Shipyard em Quebec,

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tendo sido o desenho de arranjo geral "as built" (conforme construído) para a tubulação de DST emitido em 7 de setembro de 1999. ------------------------------

[abertura de nota de rodapé]------------------------------

[9] Estudo HAZOP "Action and Response Sheet for Action" [Ação e Folha de Resposta para Ação] Nº 493, 30 de agosto de 1997------------------------------------

[10] P&ID "Drains Storage Tanks" [Tanques de Armazenamento de Drenagem] (DE-3010.38-5336-944-AMK-398, Rev A)---

[fechamento de nota de rodapé] -------------------------

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As revisões finais das folhas de dados de processo de DST para tanques e bombas não foram emitidas até 24 de janeiro de 2000[11]. ------------------------------------

2.1.11 Não existe evidência documental sugerindo que o projeto final do sistema DST, conforme instalado, foi devidamente reexaminado, ou reexaminado de qualquer forma, pela AMEC.---------------------------------------

2.2 Falta de Estudos de Segurança no Projeto Final do Sistema DST --

2.2.1 A verificação de segurança da AMEC do planejamento de processo do sistema DST deveria ter

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incluído um estudo HAZOP adicional, a conclusão de Tabelas de Análise e a preparação de Gráficos de Avaliação de Função de Análise de Segurança (gráficos SAFE - "Safety Analysis Function Evaluation").--------

2.2.2 Um estudo de segurança, como um estudo HAZOP, é um excelente técnica para detecção de defeitos no estágio de elaboração. É prática normal das empreiteiras internacionais de engenharia a realização de tais estudos, tendo a AMEC incluído um em seu escopo de trabalho[12]. Todavia, a AMEC deixou de realizar um estudo completo do tipo HAZOP do sistema DST final. Este foi um grave erro de projeto da AMEC. Além disso, o Relatório HAZOP compilado mostrava que o processo de aprovação da AMEC era suspeito. ---

2.2.3 Considerando a Tabela de Análise de Segurança preparada pela AMEC[13] (consoante a API-14C), se esta se referia à conversão dos Tanques de Óleo Base em DSTs, então a mesma se apresentava imprecisa e incompleta. Se a tabelas se referiam ao esquema de projeto inicial da AMEC , que envolvia a utilização dos Tanques de Armazenamento de Granel na coluna de bombordo de proa, então a AMEC deixou de completar

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qualquer Tabela de Análise de Segurança para o projeto DST final. --

2.2.4 Os Gráficos de Avaliação de Função de Análise de Segurança (SAFE) preparados pela AMEC[14], de novo consoante a API-14C, continha erros e incoerências, pela qual havia um descompasso entre as intenções de projeto e operacionais para o sistema DST (ver Figura 7). --

[abertura de nota de rodapé]------------------------------

11 "Drains Storage Tanks Process Data Sheet" [Folha de Dados de Processo de Tanques de Armazenamento de Drenagem], (FD-3010.38-5336-511-AMK-797; Rev B) & "Drains Storage Pumps Process Data Sheet" [Folha de Dados de Processo para Bombas de Armazenamento de Drenagem], (FD-3010.38-5336-313-AMK-798; Rev B) ---

12 "Health, Safety and Environment Plan – Topsides Design" [Plano de saúde, Segurança e Meio Ambiente - Projeto de Instalações] (ET-3010.38-5400-947-AMK-913, Rev A), seção 5.2 e "Safety/Environmental – Job Design Specification" [Segurança/Meio Ambiente - Especificação de Projeto de Serviço] (ET-3010.38-5400-947-AMK-912, Rev A), seção 3.4. ----------------

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13 "Safety Analysis Tables" [Tabelas de Análise de Segurança] (DE-3010.38-5400-947-AMK-600, Rev A, 12 de setembro de 1997)------------------------------------

14 '"Safety Analysis Function Evaluation (SAFE) Charts" [Gráficos de Avaliação de Função de Análise de Segurança] (DE-3010.38-1200-941-AMK-601, Rev B, 15 de dezembro 1998) ---------------------------------

[fechamento de nota de rodapé] ---------------------------

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Essas questões nunca foram levantadas em nenhum procedimento para o sistema DST fornecido pela AMEC, como o Manual de Operações[15] ou a Filosofia de Projeto de Drenagem.---------------------------------

2.2.5 Por exemplo, código "A5b4" foi usado para os tanques, o que indica que nenhuma válvula de segurança de pressão (PSV, "Pressure Safety Valve") era necessária, uma vez que se presumiu que "o vaso não apresentava fontes de pressão (exceto gás inerte e/ou drenos manuais), sendo equipado com suspiro adequadamente dimensionado". Este pressuposto estava errado. Os DSTs eram conectados ao Manifolde de Produção, que continha fluidos de poço de alta pressão. Além disso, o código A5c2 foi utilizado, indicando não

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haver necessidade de chave de segurança ("trip switch") de nível alto no DST, uma vez que se presumiu que as "operações de enchimento são continuamente atendidas". Este pressuposto também estava errado. O Manual de Operação da AMEC permitia que operação fosse deixada desacompanhada. Este pressuposto errôneo também foi a razão de diversas salvaguardas operacionais de bomba, na forma de dispositivos de segurança ("trips") para pressão alta e baixa, não terem sido fornecidos para as bombas DST.---

2.3 Falta de Salvaguardas de Engenharia para o Sistema DST --

Falta de Proteção contra "Fluxo Reverso"---------------

2.3.1 A conexão do sistema DST ao Manifolde de Produção era de finalidade dupla, com permissão de escoamento em ambos os sentidos. Contudo, faltava um sistema de proteção contra fluxo reverso para os DSTs durante a utilização de bombas DST na transferência de líquido para o Manifolde de Produção. (Ver a Figura 8).--

2.3.2 Os meios físicos para evitar o fluxo reverso indesejado de fluidos de poço de alta pressão para

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dentro de um DST eram três válvulas; uma válvula com atuação remota (XV-5336-0004) no manifolde comum de DST, válvulas de parada de segurança (SDVs, "Shut-Down Valves") conectando cada Trem de Produção e a válvula de enchimento de DST (V-534 & V-535) em cada DST. Normalmente, a XV seria fechada, as SDVs seriam abertas (sendo fechadas somente em um desarme de processo de um Trem de Produção) e as válvulas de enchimento de DST seriam travadas abertas. Assim, em uma emergência, a XV poderia ser aberta e os fluidos de poço poderiam ser derramados do Manifolde de Produção para dentro dos DSTs. Para essa operação, havia uma restrição "de procedimento" ao ser aberta XV (apontada em alguns documentos AMEC). Contudo, não havia nenhuma restrição na utilização de bombas DST para transferência de líquido para o Manifolde de Produção. ---

[abertura de nota de rodapé]-----------------------------

[15] "Manual de Operações" (ET-3010.38-1200-941-AMK-924, Rev B) --

[fechamento de nota de rodapé] -------------------------

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Nesse caso, a XV foi aberta (as SDVs permaneceriam fechadas) e as duas válvulas de enchimento de DST teriam que ser destravadas e fechadas. ------------------

2.3.3 Portanto, o fechamento dessas válvulas de enchimento de DST era o único meio de proteção contra o fluxo reverso de líquido para dentro de um DST proveniente do Manifolde de Produção ou da bomba de transferência de DST quando em operação. Não havia travamentos intermediários instalados na abertura de XV ou no fechamento das válvulas de enchimento de DST. Se o operador falhasse ao fechar a válvula ou esta estivesse dando passagem, então o líquido escoaria para aquele DST. Foi um erro de projeto confiar no fechamento de uma única válvula para evitar fluxo reverso indesejado para dentro de um DST. ---

2.3.4 Além disso, conforme apontado mais tarde, o projeto do sistema DST carecia de isolamento suficiente para manutenção de cada DST. ----------------

Falta de Proteção contra Pressão -------------------------

2.3.5 Como no caso do fluxo reverso de fluidos, a passagem de alta pressão e o excesso de pressurização de equipamento de baixa pressão tem sido a causa de

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muitos acidentes. Nenhuma evidência documental indica que a AMEC investigou as implicações de projeto da passagem de alta pressão proveniente do Manifolde de Produção para dentro de um DST. --------

2.3.6 Os DSTs eram tanques atmosféricos, ainda que formassem parte da estrutura da coluna. A única proteção contra pressão proporcionada para os DSTs era uma conexão para um Suspiro Atmosférico. Não havia nenhum alívio secundário, suspiro ou alarme e dispositivo de segurança ("Trip") para alta pressão (ver Figura 9).--

2.3.7 Ao ser aberta a válvula XV no manifolde comum de DST, fluidos de poço de alta pressão poderiam escoar do Manifolde de Produção para dentro de um DST, ou de ambos. Os cálculos mostram que um DST estava sujeito a excesso de pressão nessas condições, com o tamanho do suspiro sendo muito pequeno para um tanque atmosférico. Sob essas condições, os DSTs deveriam ter sido classificados como "vasos de pressão". ---

2.3.8 A AMEC considerou os DSTs como tanques atmosféricos. Os sistemas de alívio deveriam ter sido projetados para lidar com a passagem de alta pressão

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proveniente de fluidos de poço para dentro dos DSTs de baixa pressão.---

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Conforme a API RP-14C[16], havia a necessidade do fornecimento de um segundo suspiro ou de válvula de segurança de pressão (PSV, "pressure safety valve"), a menos que (a) pudesse ser demonstrado que os DSTs eram vasos de pressão e não estavam sujeitos a colapso, ou (b) que não estavam conectados a qualquer fonte de pressão.---

2.3.9 Primeiro, no que tange ao item (a), a AMEC deixou de demonstrar que os DSTs eram vasos de pressão não sujeitos a colapso. Quando em serviço, os DSTs poderiam sofrer excesso de pressão mesmo com as conexões de suspiro abertas. Além disso, é fato conhecido que suspiros atmosféricos podem estar sujeitos a bloqueios e restrições. A Tabela de Análise de Segurança da AMEC ressaltou esse problema potencial[17].---

2.3.10 Segundo, no que tange ao item (b), os DSTs eram tanques de projeto atmosférico, conectados a um manifolde de produção de alta pressão. Os DSTs não poderiam atender a pressão operacional total

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proveniente do Manifolde de Produção. Contudo, como discutido acima, os pressupostos da AMEC reunidos em seus Gráficos SAFE de Avaliação de Função de Análise de Segurança presumiam que "o vaso não apresenta fontes de pressão (exceto gás inerte e/ou drenos manuais), sendo equipado com suspiro adequadamente dimensionado". Este pressuposto estava claramente errado.---

2.3.11 Além disso, como tanque atmosférico, o projeto dos DSTs deveria atender aos requisitos da Norma API 2000[18]. Esta diz que "o dispositivo de alívio de pressão ou suspiro de emergência deve ser adequado para alívio da capacidade de vazão determinada, sem limitações, para a maior contingência individual, ou qualquer combinação razoável e provável de contingências...". As Regras para Instalações da ABS ("ABS Facility Rules")[9] requerem que vasos de drenagem sejam "dotados de válvula(s) de alívio de pressão, que devem ser dimensionadas para lidar com a máxima vazão de gás ou líquido que possa ocorrer em condições de bloqueio de saída (ou seja, um bloqueio de suspiro atmosférico).---

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2.3.12 A AMEC falhou ao deixar de providenciar recursos de alívio adequados para os DSTs, quando classificados como "tanques atmosféricos". Falhou, ainda, ao deixar de proporcionar recursos de alívio adequados para os DSTs se estes tivessem sido classificados como "vasos de pressão".-------------------

[abertura de nota de rodapé]-------------------------------

[16] API RP-14C ('Recommended Practice for Analysis, Design, Installation and Testing of Basic Surface Safety Systems for Offshore Production Platforms' [Práticas Recomendadas para Análise, Projeto, Instalação e Teste de Sistemas de Segurança Básicos de Superfície] – 5ª edição, março de 1994 & 6º edição, março de 1998.) ---

17 "Safety Analysis Tables" [Tabelas de Análise de Segurança] (DE-3010.38-5400-947-AMK-600, Rev A, 12 de setembro de 1997) ----------------------------------

[18] Norma API 2000 intitulada 'Venting Atmospheric and Low Pressure Storage Tanks' [Ventilação de Tanques de Armazenamento Atmosféricos e de Baixa Pressão] (5ª edição, abril de 1998)-----------------------

[19] Regras da ABS para Instalações Facility Rules ("ABS Facility Rules"), Capítulo 3, Seção 3, parágrafo 13.9.1

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2.3.13 Se os DSTs fossem classificados como vasos de pressão, então, conforme a API RP-14C, os DSTs exigiriam uma válvula de segurança de pressão (PSV) como proteção "primária". Ainda, quando um vaso recebe fluidos de poços, este deve ser também protegido por um dispositivo de segurança ("trip") de alta pressão que isole a vazão de admissão do vaso. ----

2.3.14 De modo geral, os DSTs deveriam ter sido dotados de uma proteção secundária contra excesso de pressão, para o caso de uma linha de suspiro estar bloqueada. --

Falta de Isolamento e Instalações de Manutenção -------

2.3.15 O projeto não considerou devidamente o isolamento e a drenagem do sistema DST. A realização de um estudo HAZOP no projeto final do sistema DST teria identificado essas fraquezas de projeto. (Ver a Figura 10). ---

2.3.16 Era necessário cuidado e atenção com o projeto do sistema DST, não somente devido às modificações finais introduzidas pela AMEC no projeto, mas também devido ao fato de ser este destinado a utilização como

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sistema de descarga de "emergência". O sistema precisava estar disponível 100% do tempo. Como um DST tinha capacidade suficiente para as necessidades de descarga de emergência, era importante, portanto, ser possível isolar e fazer a manutenção de um DST sem ser preciso paralisar ambos os DSTs, o que implicaria uma parada da produção. ----------------------

2.3.17 A instalação de somente uma única válvula manual (válvulas de enchimento de DST; V-534 & V-535), demandando fechamento por um operador, foi uma falha de projeto. Era necessário um meio adicional de proteção dos DSTs no projeto final da AMEC para evitar o excesso de pressurização potencial de um sistema de baixa pressão por um sistema de alta pressão, além de fornecer proteção contra o excesso de enchimento de um DST durante bombeamento de outro DST. --

2.3.18 Além disso, em seus procedimentos operacionais, a AMEC claramente deixou de ressaltar a importância crítica do fechamento das válvulas de enchimento (V-534 e V-535), para assim evitar o excesso de pressurização e de enchimento de um DST.-

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2.3.19 Ainda, com um DST contendo líquido, não era possível a inserção de uma raquete na linha de enchimento e assim conseguir um isolamento físico sem que o conteúdo do tanque fosse derramado no Nível 4 de maneira não controlada. Conseqüentemente, a fim de inserir uma raquete na linha de enchimento, seria necessária a retirada do sistema DST de serviço, além da drenagem do manifolde de DST comum. Isso contraria o uso do DST como sistema de emergência e demonstra a falta de consideração dada no projeto do sistema DST.--

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2.3.2 O projeto do sistema DST carecia de meios adequados de drenagem para manter o sistema seguro dentro de sua localização confinada nas colunas de popa. A AMEC não proporcionou meios físicos ou procedimentos para drenagem do conteúdo residual de um DST. Além disso, não foram proporcionados recursos de drenagem, além de uma conexão de drenagem coberta, para drenagem segura do conteúdo de uma bomba de DST. Havia risco significativo de derramamento de hidrocarbonetos inflamáveis no Nível 4.--

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2.3.21 A falta de instalações de drenagem e procedimentos indica orientação de projeto inadequada e, conforme discutido adiante, causou sério impacto na classificação de área de perigo da coluna, o que nunca foi plenamente considerado pela AMEC.-----------------

2.4 Resumo das Falhas de Projeto que causaram a Perda

2.4.1 O principal problema foi que o sistema DST final não foi projetado adequadamente para que ambos os DSTs fossem conectados a um Manifolde de Produção de alta pressão. Houve falta de consideração de projeto para o sistema de DST final. Não houve avaliação suficiente, por parte dos projetistas, dos perigos e riscos. Estudos de segurança de projeto, ou não foram feitos, ou não foram adequadamente concluídos para o sistema DST final. Havia um *"acidente esperando para acontecer"*. (Ver a Figura 11). --------------------------

2.4.2 Houve falta de salvaguardas para evitar a passagem de alta pressão durante a descarga de fluidos de poço para os DSTs e durante o bombeamento de líquidos para o Manifolde de Produção. Havia falta de alarme e dispositivo de segurança ("trip") de alta pressão e/ou um sistema de alívio alternativo para os DSTs. Ainda, havia falta de isolamento mecânico

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adequado para um DST de fontes de alta pressão, além de haver falta de instalações de drenagem.---------------

(Ver Figura 12). --

2.4.3 Além disso, havia falta de procedimentos e instruções nos manuais de projeto avisando dos perigos e riscos inerentes ao projeto final do sistema DST. -----

2.5 Comentários sobre as Conclusões da Comissão de Investigação da Petrobras --------------------------------

2.5.1 Um dos fatores apontados pela Comissão de Investigação da Petrobras, identificado na seção 6.2 de seu Relatório Final, foi a ruptura do DST quando houve fluxo reverso de fluidos de poço via válvula de enchimento de DST com o suspiro de DST isolado (com pá), não havendo isolamento físico (raquete) para a linha de enchimento de DST.------------------------------

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2.5.2 Conquanto isso forneça uma descrição precisa das circunstâncias físicas da falha, o acidente não teria ocorrido mesmo com o suspiro isolado com raquete, se o sistema DST tivesse sido devidamente projetado. Um alívio secundário ou alarme e desarme de alta pressão deveriam ter sido fornecidos para proteção contra excesso de pressão. Além disso, o projeto da linha de

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enchimento deveria ter considerado seu isolamento físico enquanto o sistema DST ainda estivesse em serviço.---

2.5.3 Outro fator mencionado pela Comissão de Investigação da Petrobras foi que o DST de bombordo estava alinhado com o Manifolde de Produção, e não com o Caisson de Produção. Todavia, a transferência por bombeamento para o Manifolde de Produção era permitida pelo Procedimento Operacional da AMEC[20].-

2.5.4 Ainda, um terceiro fator mencionado pela Comissão de Investigação da Petrobras foi a demora em colocar em funcionamento a bomba de transferência do DST de bombordo, o que permitiu a ocorrência de fluxo reverso de fluidos de poço. Freqüentemente são encontrados problemas de processo indicando haver um atraso na entrada em funcionamento de um sistema ou item de equipamento. Contudo, se um atraso é "'crítico para a segurança", então salvaguardas de projeto adicionais são necessárias. Nenhuma foi proporcionada pelo projeto da AMEC. ---------------------------------

[abertura de nota de rodapé]-------------------------------

[20] 'Closed Drains System Start-up Procedures' [Procedimentos para Partida de Sistema de Drenos

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Fechados] (ET-3010.38-1200-950-AMK-939; Rev A, 16 de setembro de 1998);--------------------------------------
'Manual de Operações' (ET-3010.38-1200-941-AMK-924, Rev B, Seção 14.7.8, página 14-15)-----------------
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3.0 QUESTÕES DE PROJETO DE SEGURANÇA DE COLUNA---

3.1 Projeto da Coluna de Popa ----------------------------

3.1.1 Para o projeto de atualização, o sistema de ventilação dentro da coluna permaneceu inalterado em relação ao projeto original Fincantieri, embora os dutos de admissão e exaustão tenham sido elevados para reduzir o risco de transbordamento descendente ("downflooding"). A alimentação de ar era feita na altura do Segundo Convés, através de dutos para cada nível de coluna e flutuador, com dampers estanques sendo instalados em cada limite estanque. A ventilação de exaustão era retirada do flutuador utilizando-se o Poço de Acesso antes de ser direcionada por dutos através dos Níveis 3 e 2 para a saída de exaustão no Nível do Segundo Convés. (A Figura 20 mostra um

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desenho do sistema de ventilação). A Figura 13 mostra um corte transversal da coluna de boreste de popa. -----

3.1.2 As colunas de popa eram dotadas somente de detectores de fumaça em cada nível. (Ver Figura 14). Não haviam detectores de gás instalados dentro da coluna ou na exaustão de ventilação da coluna. Havia dois detectores de gás instalados na admissão de ventilação da coluna. A finalidade deles era interromper a ventilação da coluna se houvesse passagem de gás para a coluna proveniente da atmosfera exterior. (Ver a Figura 15).-------------------

3.1.3 No que se refere à Classificação de Área de Perigo, o Nível 4 era uma zona não classificada com os Tanques de Óleo Base originais. Para o projeto de atualização da P-36, foi estimado que a conversão dos Tanques de Óleo Base em DSTs necessitaria de uma "área" limitada classificada como Divisão 2, com 3m de raio, designada ao redor de válvulas e flanges. Equipamentos elétricos, como motor da bomba e iluminação, foram especificados para atender os requisitos da Divisão 2 (Ver Figura 16). ----------------

3.2 Falta de Revisões de Segurança para Segurança de Coluna --

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3.2.1 A verificação de segurança da AMEC do local do sistema DST final dentro das colunas de popa deveria ter sido incluída nos estudos, conforme discutido na seção 2.2 acima, juntamente com a conclusão das Folhas de Dados de Segurança, a Análise de Incêndio e Explosão, a Classificação de Área de Perigo, a Filosofia de Proteção contra Incêndio e a Filosofia de Detecção de Fogo e Gás.---------------------------------

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3.2.2 Como discutido acima, nenhum estudo HAZOP adicional foi realizado para o projeto do sistema DST final. Ainda, nenhuma Folha de Dados de Segurança foi completada para as colunas de popa[21]. ------------------

3.2.3 A AMEC deixou de realizar uma Análise de Incêndio e Explosão, conforme indicado em seu escopo de trabalho de segurança[22]. Foi um erro confiar em uma "Análise de Explosão" anterior e numa avaliação quantificada de risco (QRA, "Quantified Risk Assessment") realizada para a "Spirit of Columbus", quando foi proposta uma grande modificação de uso com a conversão dos Tanques de Óleo Básico para DSTs. A "Avaliação de Risco de Incêndio" realizada pela AMEC[23] não levou em consideração a conversão

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posterior por eles dos Tanques de Óleo Básico para DSTs. --

3.2.4 A AMEC deixou de implementar sua "Filosofia de Detecção de Fogo e Gás"[24] e a recomendação feita pelas "Tabelas de Análise de Segurança"[25], que recomendavam a instalação de detectores de gás para detecção de vazamentos (ver a Figura 17). Nenhum detector de gás foi instalado na exaustão de ar de ventilação ou dentro das colunas de ré para identificação de potenciais vazamentos de hidrocarboneto inflamável a partir do sistema DST. ----

3.2.5 A Tabela e Desenhos de Classificação de Área de Perigo estavam incompletos, continham erros e eram enganosas, significando que o pessoal da Petrobras não estava ciente do potencial de liberação de gás dentro das colunas de popa. Essas questões são discutidas ainda na seção 3.3 abaixo. --------------------------------

3.3 Falta de Salvaguardas de Engenharia para Segurança de Coluna ---------------------------------------

Classificação de Área de Perigo---------------------------

3.3.1 A Classificação de Área de Perigo é utilizada para estimar a probabilidade da presença de gás ou vapor inflamável, de modo a avaliar corretamente a

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escolha e localização do equipamento elétrico, além do controle e localização de fontes não elétricas de ignição nessas áreas. É utilizada, ainda, para mostrar onde há necessidade de medidas de segurança adicionais. A determinação final das zonas de Classificação de Área de Perigo é uma questão de análise de engenharia, que foi feita pela AMEC. --------

[abertura de nota de rodapé]------------------------------

21 'Safety Data Sheets' [Folhas de Dados de Segurança], (ET-3010.38-5400-947-AMK-602, Rev 0, 24 de setembro de 1997)----------------------------------

22 "Health, Safety and Environment Plan – Topsides Design" [Plano de saúde, Segurança e Meio Ambiente - Projeto de Instalações] (ET-3010.38-5400-947-AMK-913, Rev A - Atualizado) e "Safety/Environmental – Job Design Specification" [Segurança/Meio Ambiente - Especificação de Projeto de Serviço] (ET-3010.38-5400-947-AMK-912, Rev A, de 5 de junho de 1997) ---

23 'Fire Risk Assessment' [Avaliação de Risco de Incêndio] (ET-3010.38-5400-947-AMK-908, Rev A, 26 de setembro de 1997) -------------------------------------

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[24] 'Fire and Gas Detection Philosophy' [Filosofia de Detecção de Fogo e Gás] (ET-3010.38-5400-947-AMK-911, Rev 0, 23 de junho de 1997). -----------------------

[25] "Safety Analysis Tables" [Tabelas de Análise de Segurança] (DE-3010.38-5400-947-AMK-600, Rev A, 12 de setembro de 1997) ---------------------------------

[fechamento de nota de rodapé] --------------------------

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3.3.2 A Classificação de Área de Perigo não cuida de liberações "catastróficas" de hidrocarbonetos inflamáveis. Contudo, no contexto da perda da P-36, levanta importantes questões referentes a a) como a AMEC apresentou suas informações de projeto e b) acentua a necessidade de outras salvaguardas, como o fornecimento de detectores de gás, o planejamento do sistema de ventilação (como o fornecimento de sistemas de ventilação segregados e a criação subpressão para compartimentos) e o controle de fontes de ignição. --

3.3.3 Conforme estabelecido em sua "Base de Projeto", a AMEC usou a API RP-500 para avaliar a classificação da área de perigo, e não a norma IEC 60079-10[26]. Uma ou outra era permitida pela

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Petrobras[27], embora a norma IEC tivesse recebido prioridade em relação à API RP-500. Contudo, a AMEC optou por usar a API RP-500, que é amplamente utilizada em offshore e aceita em todo o mundo. De fato, a ABS (American Bureau of Shipping) trabalha com a API RP 500 e a RINa estabelece que, embora trabalhem conforme a norma IEC, aceitam o uso da API RP 500. A AMEC não faz menção do uso da norma IEC em nenhuma documentação de classificação de área de perigo para a atualização da P-36. Não existe referência indireta a "IEC" na Folha de Dados de Segurança, porém esta foi preparada pela AMEC consoante o formato da Folha de dados da Petrobras[28]. --------------

3.3.4 A AMEC preparou uma "Tabela de Área de Perigo" com base na API RP-500[29], a qual estava errada (ver a Figura 18). Por exemplo, a localização designada para o sistema DST era incorreta, a saber, o Nível do Tank Top. As fontes potenciais de liberação estavam incompletas. (Não havia menção a vedações de bomba ou drenos). A extensão da área Divisão 2, com raio de 3m, não estava de acordo com a abordagem dada pela API RP-500, primeira e segunda edições. A aplicação da API RP-500 ao Nível 4 nas colunas de popa deveria

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ter classificado todo o recinto como área Divisão 2, e não somente um raio de 3m ao redor de flanges e válvulas associados ao sistema DST. Ainda, havia referência incorreta pela AMEC à seção de código API (B.6.c). Essa referência era aos Vasos de Armazenamento de Drenagem como sendo vasos de pressão ao invés de tanques atmosféricos. ---------------

3.3.5 A AMEC deveria ter aplicado critérios de engenharia confiáveis e classificado todo o Nível 4 nas colunas de popa como área Classe 1, Divisão 2. Não é prática comum classificar parcialmente um recinto e, portanto, se isto é feito, estudos e aprovações adicionais são necessários. -------------------------------

[abertura de nota de rodapé]-------------------------------

26 "Basis of Design" [Base de Projeto] (ET-3010.38-1200-941-AMK-921)-----------------------------------

27 'Index of Applicable Standards' [Índice de Normas Aplicáveis] (LD-3010.38-1200-940-PPC-002).----------

28 'Safety Data Sheets' [Folhas de Dados de Segurança], (ET-3010.38-5400-947-AMK-602, Rev 0, 24 de setembro de 1997)----------------------------------

29 "Hazardous Area Schedule (Complete Vessel)" [Tabela de Área de Perigo (Embarcação Completa)]

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(LI-3010.38-5400-947-AMK-603, Rev 0, 22 de dezembro de 1997). --

[fechamento de nota de rodapé] --------------------------

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A norma IEC não permite classificação parcial de áreas onde haja múltiplas fontes de liberação – este era o caso do sistema DST. Caso todo o recinto tivesse sido classificado, isto traria ramificações para o Nível 3 acima e para o sistema de ventilação. Além disso, o flange da linha de suspiro de DST no Nível 3 das colunas de popa deveria ter sido incluído na "Tabela de Área de Perigo". Isto foi omitido pela AMEC. ----------

3.3.6 Se a AMEC utilizou a norma IEC 60079-10 para limitar as áreas de perigo (a 3m de raio) ao redor do sistema DST pelo uso de "ventilação de diluição", então deveria ter havido referência explícita de tal fato na documentação da AMEC. Nenhuma referência havia, e se foi intenção da AMEC utilizar a norma IEC, isto foi um erro de sua parte. --------------------------------

3.3.7 Os Desenhos de Classificação de Área de Perigo preparados pela AMEC[30] incorriam em erro em relação ao sistema DST (ver a Figura 19). Eles não mostram um raio de 3m de Classe 1, Divisão 2, para os sistemas

DST nas colunas de popa. Conseqüentemente, o interior dos DSTs não foi classificado. A falta de qualquer ilustração gráfica das Áreas de Perigo nas colunas de popa para o sistema DST foi um erro de projeto da AMEC. --

3.3.8 A falta de qualquer Classificação de Área de Perigo para as colunas de popa nos desenhos, juntamente com a subseqüente falta de qualquer detecção de gás, significava que o pessoal de operação da Petrobras não foi avisado do potencial de liberação de gás dentro das colunas de popa. ----------------------

3.3.9 A falha da equipe de projeto em dar consideração apropriada à Classificação de Área de Perigo para as colunas de popa implicou a existência de falhas de projeto relacionadas a sistemas de detecção de gás e de ventilação para as colunas de popa.----------------------

3.3.10 No que tange aos argumentos apresentados pelas Sociedades Classificadoras ao Tribunal Marítimo, a ABS declarou que seu papel envolvia somente a "certificação" da P-36, enquanto a RINa era responsável por sua "classificação". A ABS mantém que a classificação de área do sistema DST estava fora de seu escopo de trabalho, uma vez que esta não fazia

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parte das áreas de processo das instalações. E ainda, que não tinha qualquer informação que servisse de base para julgamento das especificações, como sistemas de ventilação, etc.---

[abertura de nota de rodapé]-------------------------------

[30] Desenhos "Hazardous Area Classification" [Classificação de Área de Perigo] (DE-3010.38-5400-947-AMK-120 a 126 inclusive) --------------------------

[fechamento de nota de rodapé] --------------------------

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3.3.11 A RINa mantém que nunca viu qualquer desenho mostrando os antigos Tanques de Óleo Base sendo convertidos para Vasos de Armazenamento de Drenagem e que nunca classificou a revisão final dos desenhos de Classificação de Área de Perigo. Não existe evidência sugerindo que a RINa tenha recebido os desenhos finais. É responsabilidade do projetista assegurar que os desenhos corretos sejam colocados à disposição da Sociedade Classificadora de modo oportuno. As modificações posteriores feitas pela AMEC no esquema de DST e os erros nos desenhos da AMEC possivelmente foram a causa imediata dessa confusão. ---

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3.3.12 A RINa argumenta que a atmosfera interna dos DSTs poderia ser classificada como Divisão 2, uma vez que seria usada somente para manutenção ou emergência e. portanto, isso permitiria que a área fora dos DSTs no Nível 4 fosse classificada com menos rigor como "não classificada". Isto é incorreto. Com base na consideração de projeto, os DSTs foram projetados para conterem hidrocarbonetos inflamáveis. Além disso, não era possível uma drenagem completa dos DSTs e, portanto, óleo e vapores residuais permaneceriam continuamente presentes dentro de um DST. --

Detecção de Gás --

3.3.13 A AMEC deixou de seguir as recomendações de suas próprias análises de segurança e de sua filosofia de detecção de fogo e gás, ao não instalar detecção de gás dentro da coluna de popa e na saída de exaustão de ar de ventilação (ver a Figura 17). -----------------------

3.3.14 Com a instalação de detecção de gás na coluna, fontes potenciais de ignição poderiam ser interrompidas automaticamente se fosse detectado gás e, assim, minimizar as chances de ignição. Isso forneceria um

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aviso essencial para o pessoal de que havia gás inflamável dentro da coluna. ----------------------------

Sistemas de Ventilação -----------------------------------

3.3.15 A "Filosofia de Segurança"[31] da Fincantieri estabelecia que "sistemas de ventilação para áreas de perigo e não perigosas não devem ser combinados. Quando necessário, ´para evitar o ingresso de gás proveniente de área de perigo em área não perigosa, esta última deveria ser positivamente pressurizada em um diferencial de, pelo menos, 50 Pa". Similarmente, a Filosofia de Segurança da Petrobras[32] demandava que "compartimentos fechados que possam conter fontes de gases ou vapores inflamáveis sejam dotados de nível de pressão mais baixo que aquele de ambientes adjacentes".

[abertura de nota de rodapé]------------------------------

[31] "Filosofia de Segurança" Fincantieri (SC-800-00-012), seção 4.5.3. Ver também "Filosofia HVAC" Fincantieri (SC-700-77-009); seção 4.1. ----------------

[32] "Maritime Production Installation Safety Philosophy" [Filosofia de Segurança para Instalações Marítimas de Produção], (ET-3010.00-5400-947-PGT-001), Capítulo 8.--

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Esta medida de segurança garantia que qualquer vazamento dentro do compartimento não migraria para áreas não classificadas adjacentes. O GTS da Petrobras também apontou[33] que espaços contendo equipamento de gás ("áreas classificadas") precisavam de um sistema de ventilação separado. De modo similar, "espaços classificados" (zona 1 ou zona 2) precisavam de 100% de redundância para sistemas de ventilação. Essas disposições foram elaboradas para evitar a transmissão de gases e vapores inflamáveis via dutos interconectados de ventilação. O requisito de redundância de 100% foi uma medida de segurança para evitar o acúmulo de gás e a perda de pressão diferencial entre compartimentos adjacentes em caso de paralisação da ventilação. --------------------------------

3.3.16 A ventilação para o Nível 4 deixou de atender os requisitos da Petrobras e a filosofia original da Fincantieri, segundo a qual, em se tratando de área classificada, a ventilação deveria ter sido segregada de áreas não classificadas, com 100% de redundância. O Nível 4 deveria ter sido mantido em uma pressão mais

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baixa para evitar qualquer migração de liberações inflamáveis. Além disso, durante o processo de planejamento, deveria ter sido levado em consideração o descarte seguro de acúmulos de liberações inflamáveis dentro da coluna de popa, usando-se o sistema de ventilação.-------------------------------------

3.3.17 O sistema de ventilação fornecido pela Fincantieri produzia cerca de 15 trocas de ar por hora. Não houve modificações no sistema interno de ventilação da coluna durante o projeto de atualização (ver a Figura 20). A alimentação e a exaustão do Nível 4 não foram especificamente projetadas para proporcionar "ar de ventilação de diluição". Além disso, o estudo interno da AMEC dos sistemas HVAC baseou-se nos Desenhos de Classificação de Áreas de Perigo, que não faziam referência à conversão dos Tanques de Óleo Básico em DSTs[34]. --------------------

3.4 Resumo das Falhas de Projeto que causaram a Perda

3.4.1 A AMEC deixou de considerar adequadamente o impacto da conversão dos Tanques de Óleo Base em DSTs na Classificação de Área de Perigo das colunas de popa. A documentação da Classificação da Área de Perigo por ela produzida para o sistema DST e para as

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colunas de popa era errônea e enganosa. (Ver a Figura 21). --

3.4.2 Uma consideração apropriada da Classificação de Área de Perigo nas colunas de popa pela AMEC resultaria na instalação de detectores de gás para detecção de liberações inflamáveis de dentro da coluna.

[abertura de nota de rodapé]-------------------------------

[33] "General Technical Specification" [Especificação Técnica Geral], seção M17.3 -----------------------------

[34] "HVAC Site Survey" [Inspeção de Local HVAC], (ET-3010.38-5251-947-947-AMK-900; Rev A)----------

[fechamento de nota de rodapé] --------------------------

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E ainda, caso houvesse a detecção de gás, fontes potenciais de ignição conhecidas poderiam ser eliminadas ou interrompidas.----------------------------

3.4.3 Uma consideração adequada da Classificação de Área de Perigo, além dos requisitos de projeto da Petrobras e da Fincantieri, também significariam que o sistema de ventilação minimizaria o acúmulo e expansão de concentração perigosas de gás e sua ignição nas colunas de popa. Isto não ocorreu. ----------

3.4.4 A Classificação de Área de Perigo da AMEC para o sistema DST não estava de acordo com os requisitos da API RP 500. Se a AMEC fez uso da norma IEC, então deixou de atualizar o sistema de ventilação e de obter aprovação para as modificações. De qualquer forma, a AMEC falhou ao deixar de fornecer salvaguardas adequadas dentro da coluna. ---------------

3.4.5 Além disso, havia falta de procedimentos e instruções adequados, preparados pelos projetistas em seus manuais de projeto, para avisar dos perigos e riscos inerentes a vazamentos de hidrocarboneto dentro das colunas de popa. --

3.5 Comentários sobre as Conclusões da Comissão de Investigação da Petrobras --------------------------------

3.5.1 Um fator apontado pela Comissão de Investigação da Petrobras na seção 6.2 de seu Relatório Final foi o mau funcionamento dos atuadores dos dampers de ventilação por não fecharem, o que permitiu que a água inundasse a coluna inferior e o flutuador abaixo do Nível 4.---

3.5.2 Não existe evidência direta disponível do estado e ações dos atuadores de ventilação e dos dampers imediatamente após a ruptura do DST. A água pode ter

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passado pelo poço de acesso para os compartimentos abaixo do Nível 4. Além disso, alguma água pode ter passado através do sistema de ventilação para dentro dos compartimentos inferiores. Isso pode ter sido causado por avaria dos dampers estanques ou por estes estarem impossibilitados de fechar completamente, devido à ruptura do DST e à falha do manifolde de água do mar, além do escoamento rápido de líquido para dentro do Nível 4. ---------------------------------------

3.5.3 Questões foram levantadas sobre a falta de confiabilidade dos atuadores de damper durante o projeto de atualização da P-36. Como resultado, a Petrobras fez uma revisão geral e teste de todos os dampers no sistema de ventilação. Embora o sistema atendesse os requisitos da RINa como Sociedade Classificadora, a Petrobras havia planejado substituir os atuadores e, no momento do acidente, os primeiros atuadores haviam sido entregues a bordo para substituição. ---

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4.0 QUESTÕES DE PROJETO DE SEGURANÇA MARÍTIMA ---

4.1 Questões de Estabilidade após o "1° Evento" 2------

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4.1.1 A ruptura do DST causou a falha do manifolde de água do mar no Nível 4 da coluna de boreste à popa. Isso foi registrado pela ativação de uma chave de baixa pressão na linha do anel de incêndio às 00 h 22 min 12 seg. Como conseqüência, a perda de pressão na linha do anel de incêndio causou a partida automática de duas bombas de água do mar (XA-039C e 039D), além da partida automática de duas das bombas de incêndio (XA-401A/B/C/E), colocando a plataforma, assim, no que foi conhecido como "Modo de Combate a Incêndio". Uma vez nesse modo, as válvulas da caixa de mar não fechariam mesmo se a bomba de água do mar parasse. Elas permaneceriam abertas, já que a prioridade era fornecer água para o combate ao incêndio. ---

4.1.2 A liberação proveniente do DST, assim como o escoamento de água proveniente do defeituoso manifolde de água do mar, encheu o Nível 4 com líquido, que extravasou para a Sala de Bombas e para a Sala de Propulsores no flutuador abaixo. Isso acionou os alarmes de alta inundação em ambas as salas, que foram observados pelos Operadores de Lastro pouco após sua chegada à Sala de Controle. Nesse momento, a

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P-36 havia adernado rapidamente cerca de 2 graus (Figura 22). A quantidade de água liberada de um manifolde de água do mar devido à operação das bombas de água do mar é suficiente para causar tal adernamento.--

4.1.3 Logo após o primeiro evento, os Operadores de Lastro iniciaram o lastreamento por gravidade dos tanques de proa de bombordo para "acertar" (nivelar) a Unidade, conforme recomendado pelo Manual de Operação. Eles continuaram com esse procedimento, e quase tiveram sucesso na tarefa, quando ocorreu a 2ª explosão. ---

4.1.4 Um Operador de Lastro também se dirigiu para boreste e popa da Unidade, para ver se havia alguma ruptura evidente de casco ou coluna, causada, por exemplo, por impacto de embarcação de suprimentos. Investigações subseqüentes mostraram que não havia rupturas de casco. Outro Operador de Lastro verificou se era possível entrar na coluna de boreste de popa. ---

4.1.5 Os Operadores de Lastro notaram que a bomba de água do mar D no flutuador de popa de boreste estava operando, porém sem descarregar. Em torno das 00 h 31 min, a bomba parou. Depois disso, a água continuou

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a entrar no Nível 4, tanto por escoamento por gravidade proveniente das válvulas de caixa de mar abertas quanto do manifolde de água do mar, que era alimentado pela bomba de água do mar C no flutuador de proa de boreste. --

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4.2 Questões de Estabilidade após a"2ª Explosão" ------

4.2.1 Após a 2ª explosão ocorrida nos níveis superiores da coluna de boreste de popa, houve a descarga contínua de água proveniente do coletor de água do mar através das válvulas de caixa de mar abertas para a bomba de água do mar D. Não havia método possível pelo qual as válvulas de caixa de mar para a bomba D pudessem ser fechadas (ver a Figura 23). Ainda, houve perda de alimentação elétrica principal, o que fez com que a bomba de água do mar C (XA-03C) parasse (00 h 30 min 58 seg). --

4.2.2 A inundação interna continuou no flutuador de boreste de popa, incluindo o Tanque de Lastro 26S e a Caixa de Estabilidade 61S. (Mesmo se 26S e 61S estivessem fechados no momento do acidente, os cálculos de estabilidade prevêem que a inundação progressiva ainda ocorreria, consideradas as ações dos

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Operadores de Lastro para acertar a Unidade por alimentação dos tanques de proa de bombordo por gravidade, conforme determinado pelo Manual de Operação.) Aproximadamente às 08 h 10 min houve súbita perda de estabilidade, com ocorrência de inundação através dos suspiros de tanque e das áreas danificadas no alto da coluna e dos paióis de amarras (cujo projeto não incluía vedações) (Figuras 24 a 26). Após isso, houve progressiva inundação e a Unidade foi perdida às 11 h 41 min de 20 de março de 2001. --------

4.3 Falhas de Projeto que Causaram a Perda-------------

Projeto e/ou Construção Deficiente das Caixas de Estabilidade de Flutuador---------------------------------

4.3.1 As Caixas de Estabilidade de Flutuador (61P & 61S) foram instaladas no alto dos flutuadores adjacentes à coluna de popa. Foram projetadas pela Noble Denton e fabricadas na Davie Shipyard durante o projeto de atualização da P-36.---------------------------

4.3.2 Rachaduras se desenvolveram em ambas as caixas de estabilidade de bombordo e de boreste na costura da solda de topo a ré de cada caixa. As rachaduras eram de tamanho e localização similar em cada caixa de estabilidade. A rachadura permitiu o ingresso de água

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do mar em cada caixa, que era descartada para o sistema de esgoto de porão. ------------------------------

4.3.3 Logo antes do acidente, a rachadura na Caixa de Estabilidade do Flutuador de Bombordo (61P) foi reparada com resina epóxi, aplicada externamente. A Caixa de Estabilidade do Flutuador de Boreste (61S) foi reparada, porém demandava inspeção interna que foi programada para as primeiras horas da manhã de 15 de março. --

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A fim de ventilar 61S antes da inspeção, o sistema de ventilação da coluna foi usado e as escotilhas para o Tanque 26S e 61S foram deixadas abertas para o Poço de Acesso.--

4.3.4 A rachadura das Caixas de Estabilidade de Flutuador não deveria ter ocorrido e deveu-se, mais provavelmente, a deficiência de projeto e/ou construção das caixas. (Ver a Figura 27). ---------------------------

Falta de Acesso Adequado às caixas de Estabilidade de Flutuador --

4.3.5 O único acesso às Caixas de Estabilidade de Flutuador (61S & P) era através do Tanque 26 (S & P). Quando tal acesso era necessário, a abertura do Tanque

26 e da Caixa de Estabilidade 61 para o Poço de Acesso aumentava o volume máximo de inundação, para o qual os Projetistas não ofereceram orientação clara. O método de acesso encorajava que tanto o Tanque 26 quanto 61 fossem abertos, sendo isso particularmente necessário para o reparo das rachaduras causadas por deficiência de projeto/construção nas Caixas de Estabilidade. ---

4.3.6 Era prático fornecer acesso interno separado através do Tanque 26 a cada nova Caixa de Estabilidade (61), via entroncamento de acesso ou coferdam. Este era um projeto de bom senso. Todos os outros compartimentos de casco da P-36 eram dotados de entroncamento de acesso ou similar. (Ver a Figura 27). ---

Falta de Avaliação de Projeto Adequada e Eficiente de Inundação Interna ---------------------------------------

4.3.7 Os perigos e riscos de inundação interna são um problema previsível, sendo responsabilidade de um projetista experiente avaliar esse risco e adotar uma perspectiva geral ao fazê-lo.-------------------------------

4.3.8 Não havia análise das hipóteses possíveis de inundação interna realizada pela Noble Denton e

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incluída no Manual de Estabilidade da P-36. Nenhuma evidência documental foi identificada que demonstre ter sido dada qualquer consideração à probabilidade de inundação interna, quando da realização do projeto de atualização da P-36. (Ver a Figura 27). ------------------

Falta de Instruções e Avisos referentes a Riscos de Inundação Interna --

4.3.9 Houve falta de instruções adequadas e suficientes, além de avisos, referentes a inundação interna da P-36. É responsabilidade do projetista preparar um Manual de Operações competente. ---------

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O manual preparado pela Noble Denton[35] não continha orientação sobre como lidar com cenários de inundação interna. (Ver a Figura 27).---------------------------------

4.3.10 Essa falta de orientação e instrução foi agravada por filosofias conflitantes em termos de sistemas de combate a incêndio, água de resfriamento e controle de lastro (ver abaixo). --

Projeto Inapropriado dos Sistemas de Controle de Água do Mar e de Isolamento ------------------------------------

4.3.11 Havia filosofias de projeto conflitantes entre os sistemas de combate a incêndio, água de resfriamento e

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controle de lastro. Por exemplo, se um incêndio confirmado fosse registrado pelo sistema de detecção de incêndio, então a P-36 passaria para o "Modo de Combate a Incêndio" e o controle das bombas de água do mar e as válvulas de caixa de mar seriam controladas pelo sistema de controle de combate a incêndio, que inibia ações de outros sistemas de controle. Isso significava que mesmo que as bombas de água do mar parassem, as válvulas de caixa de mar permaneceriam abertas (falha estática). ------------------

4.3.12 Os projetistas falharam ao deixar de fornecer um projeto seguro para as válvulas de caixa de mar, além de suficiente independência no projeto. Houve, ainda, falta de redundância nos sinais de controle de lastro e alarmes, de modo que, quando o sistema de controle foi danificado no primeiro e segundo eventos na coluna de boreste de popa, não havia método pelo qual as válvulas de caixa de mar pudessem ser fechadas no pontão. (Ver a Figura 27). -------------------------------

Falta de Avaliação de Projeto Coerente da Maior Vulnerabilidade a Perda de Instabilidade em Caso de Avaria ---

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4.3.13 Houve falta de avaliação de projeto coerente da maior vulnerabilidade a perda de estabilidade se a Unidade sofresse avaria. Os projetistas deixaram de levar em consideração eventos razoavelmente previsíveis, além de não considerarem o impacto de conseqüências realistas de avarias. ----------------------

4.3.14 A decisão dos projetistas durante o projeto de atualização da P-36 de subdividir os tanques ao invés de aumentar a altura das caixas de guia de linha de amarração não foi um projeto competente. Os projetistas falharam ao deixar de assegurar que a P-36 atendesse normas IMO MODU para estabilidade após avaria. --

[abertura de nota de rodapé]--------------------------

35 "Manual de Operações" (MA-3010.38-1320-915-NBD-909, Rev A, 30 de setembro de 1999). ------------

[fechamento de nota de rodapé] --------------------------

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Essas decisões levaram à súbita perda de estabilidade observada, além de progressiva inundação e conseqüente perda da Unidade (Ver a Figura 27). -------

Falta de Instruções e Avisos referentes a Maior Vulnerabilidade a Perda de Estabilidade por Avaria ----

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4.3.15 Os projetistas falharam ao deixar de fornecer instruções e avisos referentes à maior vulnerabilidade a perda de estabilidade em caso de avaria da Unidade. Houve falta de orientação sobre potenciais conseqüências subseqüentes a uma avaria da Unidade. Houve, ainda, falta de orientação referente a capacidade de equipamento e que equipamento deveria operar em condições de avaria. (Ver a Figura 27). ------

4.4 Comentários sobre as Conclusões da Comissão de Investigação da Petrobras --------------------------------

4.4.1 Um dos fatores apontados pela Comissão de Investigação da Petrobras identificado na seção 6.2 de seu Relatório Final foi que a escotilha de acesso do Poço de Acesso para o Tanque 26S e a caixa de Estabilidade caverna 61S foi deixada aberta, dessa forma aumentando o maior volume de inundação.-------

4.4.2 Como descrito acima, a razão da necessidade de acesso à caverna 61S se devia a deficiência de projeto/construção das caixas de estabilidade que foram acrescentadas como parte do projeto de atualização da P-36. Além disso, o acesso fornecido à caverna 61S era ineficiente, sem nenhum entroncamento de acesso através do Tanque 26S. E ainda, o Manual de Operação

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não fornecia orientação sobre o volume de inundação, além de perigos e riscos, referentes a inundação interna. ---

4.4.3 Outro fator mencionado pela Comissão de Investigação da Petrobras foi que duas das bombas de água do mar foram retiradas de serviço para manutenção sem haver um plano de contingência implementado. Todavia, a questão é se a presença de uma terceira bomba teria feito diferença e evitado a perda da Unidade. Os Operadores de Lastro seguiram a orientação básica fornecida pelo Manual de Operação, que era de nivelar a unidade. Eles estavam em vias de alcançar seu objetivo quando a segunda explosão ocorreu. Isso causou a perda dos sistemas de lastro e da alimentação elétrica principal. Assim, a quantidade de bombas de água do mar disponíveis não foi decisiva para a perda da Unidade.-----------------------------------

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4.4.4 Um outro fator apontado pela Comissão de Investigação da Petrobras foi a alegada falta de procedimentos de emergência para controle de estabilidade e treinamento dos Operadores de Lastro. Qualquer crítica deve tomar por base a "sobrecarga de

É CÓPIA FIEL DO DOCUMENTO ORIGINAL

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informações" e a falta de tempo disponível para avaliação e resposta dos problemas em andamento. Diversos alarmes foram recebidos na Sala de Controle entre o 1° evento e a 2ª explosão. O sistema de alarme não foi projetado para priorizar ou apresentar hierarquia de alarmes críticos para os operadores. Havia questões complexas a serem analisadas, com informações freqüentemente conflitantes. Além disso, era necessário esforço para a restauração de sistemas críticos. Houve, ainda, falta de orientação nos manuais de projeto sobre como avaliar e responder a uma condição de inundação interna. Todavia, a orientação básica fornecida foi de nivelar a Unidade, o que os Operadores de Lastro quase haviam conseguido no momento da 2ª explosão. -----------------------------

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Rio de Janeiro, 17 de outubro de 2005. -- -----------

LOSS OF PETROBRAS SEMI-SUBMERSIBLE PLATFORM P-36 RONCADOR FIELD, CAMPOS BASIN OFFSHORE BRAZIL

Summary Report

July 2005

Prepared by

ROD SYLVESTER-EVANS

Report prepared by: -

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1.0 INTRODUCTION

1.1 Background

1.1.1 Mr Rod Sylvester-Evans has led the Re-Insurer's technical investigations into the loss of the P-36. The investigation has been conducted by a team of experts. Mr Sylvester-Evans is experienced in accident investigation, safety management and the conducting of safety and risk studies in the oil and gas industry both onshore and offshore. He led the technical investigations for the UK Crown Office and Lord Cullen into the Piper Alpha disaster and has been involved in a number of investigations into major accidents, acting for various parties.

1.1.2 The Re-Insurer's technical investigations concluded that the accident was due to the over-pressurisation and rupture of the starboard Drains Storage Tank (DST)[1]. Subsequently, further documents were made available by third parties and an in-depth examination of these documents, together with those obtained during the investigation, was carried out concentrating on the root causes behind the accident sequence. To date, this investigation has identified a series of design weaknesses which are summarised in this report.

1.2 Format of Summary Report

1.2.1 This summary report is divided into three parts. In section 2, the process design issues associated with the Drains Storage Tank (DST) system are examined. This includes a review of how the DST design developed, because it has a bearing on why the final DST system design was <u>not</u> included in most of the safety studies undertaken.

1.2.2 In section 3, the aft column safety design features are examined, whilst in section 4, the marine safety design issues are considered.

1.2.3 At the end of each section comments are made on the relevant findings of the Petrobras Investigation Commission.

[1] The Drains Storage Tank (DST) is also referred to as the Emergency Drainage Tank (EDT) in various documents.

2.0 PROCESS DESIGN ISSUES

2.1 Development of the DST System Design.

Initial Scheme

2.1.1 Petrobras required the *'slop vessel'*, (or drainage tank) on the P-36 to be *'able to accommodate the drainage of the largest vessel in the process plant'* with a safety margin of 20% for the vessel total volume[2]. The sizing of the drainage system was discussed at the Roncador Technical Clarification meeting on 4th/5th March 1997 where Petrobras confirmed the requirement for a drainage vessel sized to receive the total inventory from the largest vessel. AMEC's *'Basis of Design'* document states[3] that the *'slops drainage capacity'* had to *'accommodate drainage from one oil dehydrator (largest separation train vessel)'*.

2.1.2 AMEC considered a number of possible design options for the *'slop vessel'*. The initial scheme devised by AMEC[4] was to re-utilise two Bulk Storage Tanks (T-05001C/D), which they called *'Drains Storage Tanks'*, located in the forward port column. These tanks were designed for 5 barg and would act as an intermediate rundown for the drain system. Flash vapours from these tanks would be routed to the low pressure (LP) flare system (see Figure 1). As these Bulk Storage Tanks provided only 82% of the capacity of the largest process vessel, it was necessary to allow liquid to overflow from these tanks into the port Base Oil Tank. There was no intention to use the aft starboard Base Oil Tank. The plan was to install two 100% pumps in the port column, or port pontoon, to transfer oil from the port Base Oil Tank back to the production trains (see Figure 2).

2.1.3 The data sheet, issued by AMEC on 13th June 1997 for the drains storage tank,[5] noted that, if a Base Oil Tank was used, then it would be necessary to investigate the mechanical stability, design pressure, potential corrosion and identify the impact of whether there would be a change on the existing non-hazardous area classification of the column.

[2] Section M19.5 of Chapter M19 of the Petrobras *'General Technical Specification'* (GTS) for the P-36.
[3] Section 26.1 of AMEC's *"Basis of Design"* document (ET-3010.38-1200-941-AMK-921)
[4] *'Design Philosophy for Drain System'*, (ET-3010.38-5336-941-AMK-906, Rev 0 – issued 26 June 1997)
[5] *'Drains Storage Tanks Process Data Sheet'*, (FD-3010.38-5336-511-AMK-797; Rev A - 13th June 1997)

2.1.4 A Hazop and Operability (HAZOP) study was conducted by AMEC during June and July 1997[6]. The general design concept of the initial DST system design was examined on the last day of the study, 10th July 1997. The team considered that the use of the existing Bulk Storage Tanks in the port forward column was unacceptable because they were located beneath the accommodation block. They recommended other alternatives be examined. They also noted the Base Oil Tanks were structural tanks designed to atmospheric pressure; presumably acknowledging that, if the port Base Oil Tank was to be used, protection from overpressure would be required.

Final Scheme

2.1.5 The final DST system design comprised the use of <u>both</u> the port and starboard Base Oil Tanks being linked directly to the Production Header (see Figures 3 & 4). The use of the Base Oil Tanks provided sufficient capacity for drainage from the largest process vessel. The liquid collected in each of the DSTs could be pumped back to the Production Header using one 100% capacity pump for each DST. The DST pump was sized to empty the contents of a DST and return it to the Production Header within 5 hours. Details of the final design are shown in the piping and instrument diagram (P&ID)[7] and in the process data sheets[8] for the DSTs. However, the Drains Philosophy document was <u>never</u> updated.

2.1.6 There was a material difference between AMEC's initial and final DST system designs. The final configuration produced several inherent hazards. The final scheme had no intermediate rundown tank that protected the DSTs from high pressure breakthrough from process equipment. With the initial scheme the Bulk Storage Tanks were pressure tanks linked to the low pressure flare. Further, with the final scheme the atmospheric DSTs were now linked directly to the high pressure Production Header when being pumped out and there was only a single valve to prevent the reverse flow of high pressure well fluids back into the DSTs. Also, with the use of both Base Oil Tanks and a common header there was the potential for backflow between them during transfer operations.

[6] 'HAZOP Study' (RL-3010.38-5400-947-AMK-903, Rev 0, 18th July 1997)
[7] P&ID *'Drains Storage Tanks'* (DE-3010.38-5336-944-AMK-398, Rev A onwards)
[8] *'Process Data Sheet – Drains Storage Tanks, V-533604A/B'* (FD-3010.38-5336-511-AMK-797, Rev A, 11th Dec 1997.

2.1.7 Accordingly, AMEC's design would have required careful scrutiny to ensure suitable and sufficient safeguards were incorporated into the DST system engineering design to allow the system to be operated and maintained safely. However, there is no documentary evidence, found to date, that AMEC conducted a thorough investigation and review of the DST system design. As discussed below, all the key safety studies were undertaken on the initial DST scheme. With the exception of one safety study, none were updated to re-examine the final DST system design. Therefore, AMEC's selection of the final DST system design introduced serious, latent, design defects.

Time Line for Developing the DST System Design

2.1.8 Time-lines summarising the DST document revisions and the development of the DST system design are shown in Figures 5 & 6. Following completion of AMEC's design phase and the technical clarification meeting in March 1997, AMEC commenced the detailed design phase towards the end of April 1997, which was scheduled for completion by 29th December 1997. During the period of May to August 1997, AMEC developed the initial DST system design on which they conducted most of the safety studies. However, as discussed above, the HAZOP team identified problems with the use of the Bulk Storage Tanks located beneath the accommodation block. The internal AMEC response to the HAZOP questions about possible design options noted, on 30th August 1997, that the Base Oil Tanks were '*declared acceptable*' for use as DSTs[9].

2.1.9 There was a transition period during September to the beginning of December 1997 where some drawings and data sheets still show the initial DST system, whereas by the middle of October 1997 P&ID Rev A (AMK-398) showed the final DST scheme[10]. However, there is no evidence that the final design of the DST system was signed off 'as approved' by Petrobras.

2.1.10 The conversion of the Base Oil Tanks took place at the Davie Shipyard in Quebec and the 'as-built' general arrangement drawing for the DST pipework was issued

[9] HAZOP Study Action and Response Sheet for Action No 493, 30th Aug 1997
[10] P&ID '*Drains Storage Tanks*' (DE-3010.38-5336-944-AMK-398, Rev A)

on 7th September 1999. Final revisions to the DST process data sheets for the tanks and pumps were not issued until 24th January 2000[11].

2.1.11 There is no documentary evidence to suggest that the final design of the DST system, as installed, was re-examined properly, or at all, by AMEC.

2.2 Lack of Safety Reviews for Final DST System Design.

2.2.1 AMEC's safety verification of the process design of the DST system should have included a further HAZOP study, completion of Safety Analysis Tables and the preparation of Safety Analysis Function Evaluation (SAFE) Charts.

2.2.2 A safety study, such as a HAZOP study, is an excellent technique whereby potential defects are detected at the design stage. It is normal practice for international engineering contractors to undertake such studies and AMEC included for one in their work scope[12]. However, AMEC failed to undertake a full HAZOP-type study of the final DST system. This was a serious design error by AMEC. Further, the HAZOP Report that was compiled showed AMEC's approval process was suspect.

2.2.3 Regarding the *Safety Analysis Table* prepared by AMEC[13] (in accordance with API-14C), if it referred to the conversion of the Base Oil Tanks to DSTs, then they were inaccurate and incomplete. If the Tables referred to AMEC's initial design scheme which involved using the Bulk Storage Tanks in the forward port column, then AMEC failed to complete any *Safety Analysis Tables* for the final DST design.

2.2.4 The *Safety Analysis Function Evaluation* (SAFE) Charts prepared by AMEC[14], again in accordance with API-14C, contained errors and inconsistencies, whereby there was a mis-match between the design and operational intentions for the DST system (see Figure 7). These matters were never stated in any procedures for the

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11 *'Drains Storage Tanks Process Data Sheet'*, (FD-3010.38-5336-511-AMK-797; Rev B) & *'Drains Storage Pumps Process Data Sheet'*, (FD-3010.38-5336-313-AMK-798; Rev B)
12 *'Health, Safety and Environment Plan – Topsides Design'* (ET-3010.38-5400-947-AMK-913, Rev A), section 5.2 and *'Safety/Environmental – Job Design Specification'* (ET-3010.38-5400-947-AMK-912, Rev A), section 3.4.
13 *'Safety Analysis Tables'* (DE-3010.38-5400-947-AMK-600, Rev A, 12th Sept 1997)
14 *'Safety Analysis Function Evaluation* (SAFE) *Charts'* (DE-3010.38-1200-941-AMK-601, Rev B, 15th December 1998)

DST system provided by AMEC, such as the Operations Manual[15] or Drainage Design Philosophy.

2.2.5 For example, code *'A5b4'* was used for the tanks, which indicates that no pressure safety valve (PSV) was necessary as it was assumed the *'vessel had no pressure sources (except blanket gas and/or manual drains) and is equipped with an adequately sized vent'*. This assumption was wrong. The DSTs were connected to the Production Header that contained high pressure well fluids. Further, code *A5c2* was used which indicates no high level trip switch in the DST was necessary as it was assumed that the *'fill operations are continuously attended'*. This assumption was also wrong. The AMEC Operating Manual permitted the operation to be left unattended. This erroneous assumption was also the reason why several pump operating safeguards, in the form of high and low pressure trips, were not provided for the DST pumps.

2.3 Lack of Engineering Safeguards for the DST System.

Lack of 'Backflow' Protection

2.3.1 The connection of the DST system to the Production Header was dual-purpose, with flow permitted it both directions. However, there was a lack of backflow protection for the DSTs when using the DST pumps to transfer liquid to the Production Header. (See Figure 8).

2.3.2 The physical means to prevent unwanted 'backflow' of high pressure well fluids into a DST were three valves; a remotely actuated valve (XV-5336-0004) in the common DST header, safety shutdown valves (SDVs) linking each Production Train and the DST filling valve (V-534 & V-535) on each DST. Normally, the XV would be closed, the SDVs would be open (being closed only on a process trip of a Production Train) and the DST filling valves would be locked open. Thus in an emergency, the XV could be opened and well fluids could be dumped from the Production Header into the DSTs. For this operation there was a 'procedural' restriction on opening the XV (noted in some AMEC documents). However, there was no such restriction when using the DST pumps to transfer liquid to the

[15] *'Operations Manual'* (ET-3010.38-1200-941-AMK-924, Rev B)

Production Header. In that case, the XV was opened (the SDVs would remain open) and the two DST filling valves would have to be unlocked and closed.

2.3.3 Therefore, the closing of these DST filling valves was the only means to protect backflow of liquid into a DST from either the Production Header or the other DST transfer pump when operating. There were no interlocks installed on opening the XV or closing the DST filling valves. If either an operator failed to close a filling valve, or it did not close fully and was passing, then liquid would flow into that DST. It was a design error to rely on closing a single valve to prevent unwanted backflow into a DST.

2.3.4 Further, as noted later, the DST system design lacked sufficient isolation for maintenance of each DST.

Lack of Pressure Protection

2.3.5 As with backflow of fluids, high pressure breakthrough and over-pressurisation of low pressure equipment has been the cause of many accidents. No documentary evidence indicates that AMEC investigated the design implications of high pressure breakthrough from the Production Header into a DST.

2.3.6 The DSTs were atmospheric tanks, albeit that they formed part of the column structure. The only pressure protection provided for the DSTs was a connection to the Atmospheric Vent. There was no secondary relief, vent or high pressure alarm and trip (see Figure 9).

2.3.7 On opening the XV valve in the common DST header, high pressure well fluids could flow from the Production Header into one or both DSTs. Calculations show and DST could be over-pressurised under these conditions with the vent size being too small for an atmospheric tank. Under these conditions the DSTs should have been classed as 'pressure vessels'.

2.3.8 AMEC considered the DSTs atmospheric tanks. The relief system should have been designed to cater for high pressure breakthrough of well fluids into the low pressure DSTs. In accordance with API RP-14C[16], there was a requirement to provide a second vent or pressure safety valve (PSV) unless (a) it could be shown that the DSTs were pressure vessels and not subject to collapse or (b) they were not linked to any pressure sources.

2.3.9 First, with regard to item (a), AMEC failed to show the DSTs were pressure vessels not subject to collapse. When in service the DSTs could be over-pressurised even with the vent connection open. Further, it is well known that atmospheric vents can be subject to blockage and restrictions. AMEC's Safety Analysis Table highlighted this potential problem[17].

2.3.10 Second, with regard to item (b), the DSTs were atmospheric design tanks connected to a high pressure production header. The DSTs could not meet the full operating pressure from the Production Header. However, as discussed above, AMEC's assumptions embodied in their *'Safety Analysis Function Evaluation Charts (SAFE)'* assumed the *'vessel has no pressure sources (except blanket gas and/or manual drains) and is equipped with an adequately sized vent'*. This assumption was clearly wrong.

2.3.11 Further, as an atmospheric tank, the design of the DSTs should have met the requirements of API Standard 2000[18]. This required *'the pressure relief device or emergency vent shall be suitable to relieve the flow capacity determined for but not limited by the largest single contingency or any reasonable and probable combination of contingencies… '* The ABS Facility Rules[19] require drain vessels to be *'provided with pressure relief valve(s), which are to sized to handle the maximum flow of gas or liquid that can occur under blocked outlet condition'* (i.e. a blockage in the atmospheric vent).

2.3.12 AMEC failed to provide adequate relief provisions for the DSTs when classed as *'atmospheric tanks'*. They also failed to provide adequate relief provisions for the DSTs if they had been classed as *'pressure vessels'*.

16 API RP-14C (*'Recommended Practice for Analysis, Design, Installation and Testing of Basic Surface Safety Systems for Offshore Production Platforms'* – 5th edition March 1994 & 6th edition March 1998.)
17 *'Safety Analysis Tables'* (DE-3010.38-5400-947-AMK-600, Rev A, 12th Sept 1997)
18 API Standard 2000 entitled *'Venting Atmospheric and Low Pressure Storage Tanks'* [5th edition April 1998]
19 ABS Facility Rules, Chapter 3, Section 3, para 13.9.1

2.3.13 If the DSTs were classed as pressure vessels, then according to API RP 14C the DSTs required a pressure safety valve (PSV) as the 'primary' protection. Also, where a vessel received well fluids, it should also be protected by a high pressure trip which isolated the inlet flow to the vessel.

2.3.14 Overall, the DSTs should have had some secondary over-pressure protection in the event the vent line was blocked.

Lack of Isolation and Maintenance Facilities

2.3.15 There was lack of design thought given to the isolation and drainage of the DST system. Conducting a HAZOP study on the final DST system design would have identified these design weaknesses. (See Figure 10).

2.3.16 Considerable care and attention was necessary for the design of the DST system, not only because of AMEC's late changes in design but also as it was intended to be used as an 'emergency' dump system. The system required to be available for 100% of the time. As one DST had sufficient capacity for the emergency dump requirements, it was important, therefore, to be able to isolate and maintain one DST without having to shut down both DSTs which would require a production shutdown.

2.3.17 The installation of only a single manual valve (DST filling valves; V-534 & V-535), requiring closure by an operator, was a <u>design error</u>. A further means to positively protect the DSTs was required in AMEC's final design to prevent the potential over-pressurisation of a low pressure system by a high pressure system and to protect against overfilling of one DST when pumping from the other DST.

2.3.18 Further, in their operations procedures AMEC failed to clearly warn of the critical importance of closing the filling valves (*V-534* and *V-535*) in order to prevent over-pressurisation and overfilling of a DST.

2.3.19 Also, with a DST containing liquid, it was not possible to insert a spade into the filling line and achieve physical isolation without the contents of the tank being spilt onto Level 4 in an uncontrolled manner. Accordingly, in order to insert a spade in the filling line it would have been necessary to withdraw the DST system from service and drain the common DST header. This was contrary to the use of the

DST as an emergency system and demonstrates the lack of thought that went into the DST system design.

2.3.20 The DST system design lacked suitable means of drainage to maintain the system safely within its confined location in the aft columns. AMEC provided no physical means or procedures to drain the residual contents of a DST. Further, they provided no drainage facilities, other than a capped drain connection, to safely drain the contents from a DST pump. There was a significant risk of a spillage of flammable hydrocarbons onto Level 4.

2.3.21 The lack of drainage facilities and procedures indicate inadequate design thought and, as discussed later, have a serious impact on the hazardous area classification for the column, which was never considered fully by AMEC.

2.4 Summary of Design Flaws causing the Loss

2.4.1 The principal problem was that the final DST system was not designed properly for both DSTs to be linked to a high pressure Production Header. There was a lack of design thought of the final DST system. There was insufficient assessment of the hazards and risks by the designers. Design safety studies were either not done or not completed properly for the final DST system. It was *'an accident waiting to happen'*. (See Figure 11).

2.4.2 There was a lack of safeguards to prevent high pressure breakthrough when dumping well fluids to the DSTs and when pumping liquids to the Production Header. There was a lack of a high pressure alarm & trip and/or an alternative relief system for the DSTs. Further, there was a lack of suitable mechanical isolation of a DST from high pressure sources and a lack of drainage facilities. (See Figure 12).

2.4.3 In addition, there was a lack of procedures and instructions in the design manuals warning of the hazards and risks inherent in the final DST system design.

2.5 Comments on the Petrobras Investigation Commission Findings

2.5.1 One of the factors noted by the Petrobras Investigation Commission identified in section 6.2 of their Final Report was that the DST ruptured when there was a backflow of well fluids via the DST filling valve with the DST vent isolated (spaded) and there was no physical isolation (spade) for the DST filling line.

2.5.2 Whilst this provides an accurate description of the physical circumstances of the failure, the accident would not have happened even with the vent spaded had the DST system been designed properly. A secondary relief or high pressure alarm and trip should have been provided to guard against excessive over-pressure. Further, the design of the filling line should have allowed it to be isolated physically whilst the DST system was in service.

2.5.3 Another factor listed by the Petrobras Investigation Commission was that the port DST was aligned with the Production Header and not the Production Caisson. However, pumped transfer to the Production Header was permitted by the AMEC Operating Procedures[20].

2.5.4 Further, a third factor listed by the Petrobras Investigation Commission was the delay in starting the port DST transfer pump, which allowed the backflow of well fluids to occur. Often process problems are encountered that mean there is a delay in starting a system or item of equipment. However, if the delay is 'safety critical' then additional design safeguards are required. None were provided by the AMEC design.

[20] *'Closed Drains System Start-up Procedures'* (ET-3010.38-1200-950-AMK-939; Rev A, 16th Sept 1998); *'Operations Manual'* (ET-3010.38-1200-941-AMK-924, Rev B, Section 14.7.8, page 14-15)

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3.0 COLUMN SAFETY DESIGN ISSUES

3.1 Design of the Aft Column.

3.1.1 For the upgrade project, the ventilation system within the column remained unchanged from the original Fincantieri design, although the intake and exhaust ducting were raised to reduce the risk of downflooding. The air was supplied at the height of the Second Deck, through ducting to each level of the column and pontoon, with watertight dampers being installed at each watertight boundary. The exhaust ventilation was taken from the pontoon using the Access Shaft before being routed via ducting through Levels 3 & 2 to the exhaust outlet on the Second Deck Level. (A sketch of the ventilation system is given in Figure 20). A cross-section of the aft starboard column is shown in Figure 13.

3.1.2 The aft columns were only fitted with smoke detectors at each level. (See Figure 14). There were no gas detectors installed within the column or in the column ventilation exhaust. There were two gas detectors installed in the column ventilation intake. The purpose of these was to stop the column ventilation in the event gas was drawn into the column from the atmosphere outside. (See Figure 15)

3.1.3 With regard to Hazardous Area Classification, Level 4 was a non-classified zone with the original Base Oil Tanks. For the P-36 upgrade project, the conversion of the Base Oil Tanks to the DSTs was assessed as requiring a limited 'area' classified as Division 2, with a 3m radius assigned around valves and flanges. Electrical equipment, such as the pump motor and lighting were specified to meet the requirements for Division 2. (See Figure 16).

3.2 Lack of Safety Reviews for Column Safety.

3.2.1 AMEC's safety verification of the location of the final DST system within the aft columns should have included the studies as discussed in section 2.2 above, together with completion of the Safety Data Sheets, the Fire & Explosion Analysis, Hazardous Area Classification, the Fire Protection Philosophy, and the Fire and Gas Detection Philosophy.

3.2.2 As discussed above, no further HAZOP study was conducted on the final DST system design. Also, no Safety Data Sheets were completed for the aft columns[21].

3.2.3 AMEC failed to undertake a *Fire & Explosion Analysis* as indicated in their scope of safety work[22]. It was an error to rely on an earlier 'Explosion Analysis' and quantified risk assessment (QRA) undertaken for the *Spirit of Columbus* when a major change of use was proposed with the conversion of Base Oil Tanks to the DSTs. The *'Fire Risk Assessment'* conducted by AMEC[23] took no account of the late conversion by them of the Base Oil Tanks to DSTs.

3.2.4 AMEC failed to implement their *'Fire and Gas Detection Philosophy'*[24] and the recommendation made in the *'Safety Analysis Tables'*[25], which recommended gas detectors be installed to detect leaks (see Figure 17). No gas detectors were installed in the ventilation air exhaust or within the aft columns to identify potential flammable hydrocarbon leaks from the DST system.

3.2.5 The Hazardous Area Classification Schedule and Drawings were incomplete, contained errors and were misleading and meant Petrobras personnel were not warned of the potential for gas releases within the aft columns. These issues are discussed further in section 3.3 below.

3.3 Lack of Engineering Safeguards for Column Safety

Hazardous Area Classification

3.3.1 Hazardous Area Classification is used to assess the likelihood of a flammable gas or vapour being present in order to correctly assess the selection and location of electrical equipment and the control and location of non-electrical sources of ignition in those areas. It is used also to show where additional safety measures are required. The final determination of Hazardous Area Classification zones is a matter of engineering judgement, which was made by AMEC.

21 *'Safety Data Sheets'*, (ET-3010.38-5400-947-AMK-602, Rev 0, 24th Sept 1997)
22 *'Health, Safety and Environmental Plan – Topsides Design'* (ET-3010.38-5400-947-AMK-913, Rev. A – Undated) & *'Safety/Environmental – Job Design Specification'* (ET-3010.38-5400-947-AMK-912, Rev. A, dated 5th June 1997)
23 *'Fire Risk Assessment'* (ET-3010.38-5400-947-AMK-908, Rev A, 26th Sept 1997)
24 *'Fire and Gas Detection Philosophy'* (ET-3010.38-5400-947-AMK-911, Rev 0, 23rd June 1997).
25 *'Safety Analysis Tables'* (DE-3010.38-5400-947-AMK-600, Rev A, 12th Sept 1997).

3.3.2 Hazardous Area Classification does not cater for 'catastrophic' releases of flammable hydrocarbons. However, in the context of the P-36 loss, it raises important issues as to a) how AMEC presented their design information and b) highlights the need for other safeguards like the provision of gas detectors, design of the ventilation system (such as provision of segregated ventilation systems and creating under-pressure for compartments) and control of ignition sources.

3.3.3 As stated in their *'Basis of Design'*, AMEC used API RP-500 for assessing the hazardous area classification and not the IEC 60079-10 standard[26]. Either was allowed by Petrobras[27], albeit the IEC standard was given a higher priority than API RP-500. However, AMEC elected to use API RP-500, which is used widely offshore and accepted worldwide. Indeed, the American Bureau of Shipping (ABS) work to API RP 500 and RINa state that whilst they work to the IEC standard, they accept the use of API RP 500. AMEC make no mention in any hazardous area classification documentation for the P-36 upgrade about their use of the IEC standard. There is an oblique reference to 'IEC' in a Safety Data Sheet, but that was prepared by AMEC in accordance with a Petrobras Data Sheet format[28].

3.3.4 AMEC prepared a *'Hazardous Area Schedule'* based on API RP-500[29], which was in error and misleading (see Figure 18). For example, the designated location of the DST system was incorrect, namely the Tank Top Level. The potential sources of release were incomplete. (There was no mention of the pump seals or drains). The extent of the Division 2 area, with a radius of 3m, did not accord with the approach given in API RP-500, first/second editions. The application of API RP-500 to Level 4 in the aft columns should have classified the whole enclosure as a Division 2 area and not just a radius of 3m around flanges and valves associated with the DST system. Further, there was an incorrect reference by AMEC to the API code section (B.6.c). This reference was to the Drains Storage Vessels being pressure vessels rather than atmospheric tanks.

3.3.5 AMEC should have applied sound engineering judgment and classified the whole of Level 4 in the aft columns as a Class 1, Division 2 area. It is not common practice to partially classify an enclosure and, therefore, if it is done it requires

26 *'Basis of Design'* (ET-3010.38-1200-941-AMK-921)
27 *'Index of Applicable Standards'* (LD-3010.38-1200-940-PPC-002).
28 *'Safety Data Sheets'*, (ET-3010.38-5400-947-AMK-602, Rev 0, 24th Sept 1997)
29 *'Hazardous Area Schedule (Complete Vessel)'* (LI-3010.38-5400-947-AMK-603, Rev 0, 22nd Dec 1997).

further study and approval. The IEC standard does not permit partial classification of areas where there are multiple release sources – as was the case with the DST system. Had the whole enclosure been classified, this would have had ramifications for Level 3 above and the ventilation system. Further, the DST vent line flange at Level 3 of the aft columns should have been included in the *'Hazardous Area Schedule'*. This was omitted by AMEC.

3.3.6 If AMEC used the IEC 60079-10 standard to limit the hazardous areas (to 3m radius) around the DST system through the use of *'dilution ventilation'*, then there should have been an explicit reference made in the AMEC documentation. There was none and, if it was AMEC's intention to use the IEC standard, this was an error on their part.

3.3.7 The *Hazardous Area Classification* Drawings prepared by AMEC[30] were in error for the DST system (see Figure 19). They show no Class 1, Division 2 radius of 3m for the DST systems in the aft column. Similarly, the inside of the DSTs has not been classified. To provide no graphic illustration of the Hazardous Areas in the aft columns for the DST system was a design error by AMEC.

3.3.8 The lack of any Hazardous Area Classification shown for the aft columns in the drawings, together with the subsequent lack of any gas detection, meant Petrobras operating personnel were not warned of the potential for gas releases within the aft columns.

3.3.9 The failure by the design team to give proper consideration to the Hazardous Area Classification for the aft columns meant there were design faults associated with the gas detection and ventilation systems for the aft columns.

3.3.10 With respect to the arguments advanced by the Classification Societies before the Maritime Tribunal, ABS stated that their role involved only the 'certification' of the P-36 whilst RINa was responsible for the 'classification'. ABS maintains the area classification of the DST system was outside their scope of work as it was not part of the topside process areas. Further, they did not have all the information on which to judge the specifications, such as ventilation systems, etc.

30 *'Hazardous Area Classification'* Drawings (DE-3010.38-5400-947-AMK-120 to 126 inclusive).

3.3.11 RINa maintain it never saw any drawings showing the old Base Oil Tanks being converted to Drains Storage Vessels and never classified the final revision of the Hazardous Area Classification drawings. There is no evidence to suggest that RINa received the final drawings. It is the responsibility of the designer to ensure that the correct drawings are made available to the Classification Society in a timely fashion. The late changes by AMEC to the DST scheme and the errors in the AMEC drawings probably were the immediate causes of this confusion.

3.3.12 RINa argue that the internal atmosphere of the DSTs could be classified as Division 2, as it would be used only for maintenance or an emergency, and therefore that would permit the area outside the DSTs at Level 4 to be classified less rigorously as 'non-classified'. This is incorrect. From consideration of the process, the DSTs were designed to contain flammable hydrocarbons. Further, it was not possible to drain fully the DSTs and, therefore, residual oil and vapours would be present continuously within a DST.

Gas Detection

3.3.13 AMEC failed to follow the recommendations of their own safety analyses and fire and gas detection philosophy in not installing gas detection within the aft column and at the ventilation air exhaust outlet (see Figure 17).

3.3.14 With gas detection installed in the column, potential ignition sources could be shutdown automatically if gas was detected and hence minimise the chance of ignition. It would also provide an essential warning for personnel that there was flammable gas within the column.

Ventilation Systems

3.3.15 The Fincantieri *'Safety Philosophy'*[31] noted the *'ventilation system for hazardous and non-hazardous areas shall not be combined. Where necessary, to prevent the ingress of gas from a hazardous area to a non-hazardous area, the latter shall be positively pressurised to a differential of at least 50 Pa'*. Similarly, the Petrobras Safety Philosophy[32] required *'closed compartments that may contain sources of*

[31] Fincantieri *'Safety Philosophy'* (SC-800-00-012), section 4.5.3. See also Fincantieri *'HVAC Philosophy'* (SC-700-77-009); section 4.1.
[32] *'Maritime Production Installation Safety Philosophy'*, (ET-3010.00-5400-947-PGT-001), Chapter 8

flammable gases or vapours shall be provided with a pressure level lower than that of the adjacent environments'. This safety measure ensured that any leak within the compartment would not migrate to adjacent, unclassified areas. The Petrobras GTS also stated[33] that rooms containing gas equipment ('classified areas') required a separate ventilation system. Similarly, '*classified rooms (zone 1 or zone 2)*' required 100% redundancy for ventilation systems. These provisions were designed to prevent the transmission of flammable gases/vapours via inter-connecting ventilation ducting. The 100% redundancy requirement was a safety feature to prevent gas accumulation and loss of a pressure differential between adjacent compartments if the ventilation shutdown.

3.3.16 The ventilation for Level 4 failed to meet the Petrobras requirements and the original Fincantieri philosophy whereby, being a classified area, the ventilation should have been segregated from non-classified areas, with 100% redundancy. Level 4 should have been maintained at a lower pressure to prevent any migration of flammable releases. Further, during the design process, consideration should have been given to the safe disposal of an accumulation of a flammable release within an aft column using the ventilation system.

3.3.17 The ventilation system provided by Fincantieri gave about 15 air changes per hour. There were no changes made to the internal column ventilation system during the upgrade project (see Figure 20). The Level 4 supply and exhausts were not designed specifically to provide 'dilution ventilation air'. Further, AMEC's internal review of the HVAC systems was based on the Hazardous Classification Drawings which did not refer to the conversion of the Base Oil Tanks into the DSTs[34].

3.4 Summary of Design Flaws causing the Loss

3.4.1 AMEC failed to consider adequately the impact that converting the Base Oil Tanks to the DSTs had on the Hazardous Area Classification in the aft columns. The Hazardous Area Classification documentation they produced for the DST system and the aft columns was in error and misleading. (See Figure 21)

3.4.2 Proper consideration of the Hazardous Area Classification in the aft columns by AMEC should have meant that gas detectors were installed to detect flammable

[33] '*General Technical Specification*', section M17.3

[34] '*HVAC Site Survey*', (ET-3010.38-5251-947-947-AMK-900; Rev A)

releases from within the column. Further, had gas been detected, known potential ignition sources could have been eliminated or shutdown.

3.4.3 Also proper consideration of the Hazardous Area Classification and the Petrobras and Fincantieri design requirements should have meant that the ventilation system minimised the accumulation and spread of hazardous gas concentrations and its ignition in the aft columns. This did not occur.

3.4.4 AMEC's Hazardous Area Classification for the DST system did not comply with the requirements of API RP 500. If, AMEC used the IEC Standard, then they failed to upgrade the ventilation system and gain approval for the changes. Either way, AMEC failed to provide adequate safeguards within the column.

3.4.5 Further, there was a lack of suitable procedures and instructions prepared by the designers in their design manuals to warn of the inherent hazards and risks of hydrocarbon leaks within the aft columns.

3.5 Comments on the Petrobras Investigation Commission Findings

3.5.1 One factor noted by the Petrobras Investigation Commission in section 6.2 of their Final Report was the malfunction of the ventilation damper actuators in not closing which allowed water to flood the lower column and pontoon below Level 4.

3.5.2 There is no direct evidence available as to the state and actions of the ventilation actuators and dampers immediately following the rupture of the DST. Water may have passed down the access shaft to the compartments below Level 4. In addition, some of the water may have passed through the ventilation system into the lower compartments. This may have been caused by the watertight dampers either being damaged or being unable to close fully due to the rupture of the DST and failure of the seawater header and rapid outflow of liquid into Level 4.

3.5.3 There were questions raised about the unreliability of the damper actuators during the P-36 upgrade project. As a result, Petrobras overhauled and tested all the dampers in the ventilation system. Whilst the system met the requirements of RINa as the Classification Society, Petrobras had planned to replace the actuators and at the time of the accident the first actuators had been delivered onboard for replacement.

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4.0 MARINE SAFETY DESIGN ISSUES

4.1 Stability Issues following the '1st Event'.

4.1.1 The rupture of the DST caused failure of the seawater header at Level 4 in the aft starboard column. This was registered by the activation of a low pressure switch in the fire ring main at 00:22:12. As a consequence, the loss of pressure in the fire ring main caused the automatic start of two seawater pumps (XA-039C and 039D) and the automatic start of two of the fire pumps (XA-401A/B/C/E) thereby putting the Platform into what was known as 'Fire Fighting Mode'. When in this mode the seachest valves would not close even if the seawater pump stopped. They remained open as the priority was to provide water for fire fighting.

4.1.2 The release from the DST as well as the water outflow from the failed seawater header filled Level 4 with liquid which overflowed to the Pump Room and the Thruster Room in the pontoon below. This caused high flooding alarms to be triggered in both rooms which were observed by the Ballast Operators shortly after their arrival in the Control Room. By this time P-36 had inclined quickly by about 2 degrees (Figure 22). The quantity of water released from the seawater header due to the operation of the seawater pumps is sufficient to account for such a list.

4.1.3 Shortly after the first event, the Ballast Operators commenced gravity ballasting of the port forward tanks to 'right' (level) the Unit as required by the Operations Manual. They continued with this exercise and almost succeeded in this task at the time of 2nd explosion.

4.1.4 A Ballast Operator also went to the starboard and aft of the Unit to see whether there was any evident breach of the hull/column, for example, by impact of a supply vessel. Subsequent investigations showed there was no breach of the hull. Another Ballast Operator checked to see whether it was possible to enter the aft starboard column.

4.1.5 The Ballast Operators noted that the seawater pump D in the starboard aft pontoon was operating but not discharging. By about 00:31 the pump had stopped. Thereafter, water continued to enter Level 4 by both gravity flow from the open seachest valves and from the seawater header which was fed by seawater pump C in the starboard forward pontoon.

4.2 Stability Issues following the '2nd Explosion'.

4.2.1 Following the 2nd explosion that occurred in the upper levels of the aft starboard column, there was a continued discharge of water from the seawater header via the open sea chest valves for seawater pump D. There was no feasible method whereby the seachest valves for pump D could be closed (see Figure 23). Also, there was a loss of the main electrical power supply which caused seawater pump C (XA-03C) to stop (00:39:58).

4.2.2 The internal flooding continued in the aft starboard pontoon, including the Ballast Tank 26S and the Stability Box 61S. (Even if 26S and 61S were closed at the time of the accident, then stability calculations predict that progressive downflooding would still have occurred, given the actions of the Ballast Operators to right the Unit by gravity feeding the port forward tanks as stated in the Operations Manual). At about 08:10 there was a sudden further loss of stability and downflooding occurred through the tank vents and damaged areas at the top of the column and the chain lockers (the design of which provided no sealing) (Figures 24 to 26). Thereafter, there was progressive flooding and the Unit was lost at 11:41 on 20th March 2001

4.3 Design Flaws Causing the Loss

Poor Design and/or Workmanship of Pontoon Stability Boxes

4.3.1 The Pontoon Stability Boxes (61P & 61S) were installed on the top of the pontoons abutting the aft column. They were designed by Noble Denton and fabricated at the Davie Shipyard during the P-36 upgrade project.

4.3.2 Cracks developed in both the port and starboard stability boxes in a top welded seam at the aft of each box. The cracks were of similar size and location in each stability box. The cracking caused ingress of seawater into each box which was disposed of to the bilge system.

4.3.3 Shortly before the accident the crack in the Port Pontoon Stability Box (61P) was repaired using an epoxy resin that was applied externally. The Starboard Pontoon Stability Box (61S) was repaired but required an internal inspection, which was scheduled for the early morning of 15th March. In order to ventilate 61S prior to the inspection, the column ventilation system was used and the hatches to Tank 26S and 61S were left open to the Access Shaft.

4.3.4 The cracking of the Pontoon Stability Boxes should not have occurred and was most probably due to poor design and/or workmanship of the boxes. (See Figure 27).

Lack of Proper Access to Pontoon Stability Boxes

4.3.5 The only access to the Pontoon Stability Boxes (61S & P) was via Tank 26 (S & P). When such access was required, the opening of Tank 26 and Stability Box 61 to the Access Shaft increased the maximum floodable volume for which the Designers provided no clear guidance. The method of access encouraged both Tank 26 and 61 to be open and this was particularly necessary to repair the cracks caused by poor design/workmanship in the Stability Boxes.

4.3.6 It was practical to provide separate internal access through Tank 26 to each new Stability Box (61), via an access trunking or cofferdam. This was a common sense design. All other hull compartments on the P-36 were provided with access trunking or similar. (See Figure 27).

Lack of a Suitable and Sufficient Design Assessment of Internal Flooding

4.3.7 The hazards and risks of internal flooding represent a foreseeable problem and it is the responsibility of an experienced designer to assess this risk and take a broad view when doing so.

4.3.8 There was no analysis of potential internal flooding scenarios conducted by Noble Denton and included in the P-36 Stability Manual. No documentary evidence has been identified that demonstrates there was any consideration given to the likelihood of internal flooding when undertaking the P-36 upgrade project. (See Figure 27).

Lack of Instructions and Warnings regarding Internal Flooding Risks

4.3.9 There was a lack of suitable and sufficient instructions and warnings regarding internal flooding of the P-36. It is the designer's responsibility to prepare a competent Operations Manual. The manual prepared by Noble Denton[35] contained no guidance on how to handle internal flooding scenarios. (See Figure 27).

4.3.10 This lack of guidance and instruction was compounded by the conflicting philosophies for the fire fighting, cooling water and ballast control systems (see below).

Inappropriate Design of Seawater Control and Isolation Systems

4.3.11 There were competing design philosophies between the fire fighting, cooling water and ballast control systems. For example, if a confirmed fire was registered by the fire detection system then the P-36 went into 'Fire Fighting Mode' and the control of the seawater pumps and sea chest valves was taken over by the fire fighting control system, which inhibited the actions from other control systems. This meant that even if the seawater pumps stopped the sea chest valves remained open (failed static).

4.3.12 The designers failed to provide a failsafe design for the seachest valves and sufficient independency in the design. There was also a lack of redundancy in the ballast control signals and alarms so that when the control system was damaged following the first and second events in the aft starboard column, there was no method whereby the seachest valves could be closed in the pontoon. (See Figure 27).

Lack of a Coherent Design Assessment of the Increased Vulnerability to Loss of Stability when Damaged

4.3.13 There was a lack of coherent design assessment of the increased vulnerability to the loss of stability when the Unit was damaged. The designers failed to take account of reasonably foreseeable events and consider the impact of realistic damage outcomes.

4.3.14 The decision by the designers during the P-36 upgrade project to subdivide tanks rather than extend the height of the fairlead boxes was not a competent design. The designers failed to ensure that the P-36 met the IMO MODU standards for

35 *'Operations Manual'* (MA-3010.38-1320-915-NBD-909, Rev A, 30th Sept 1999).

stability after damage. These decisions led to the sudden loss of stability of the Unit that was observed and the progressive flooding and its eventual loss. (See Figure 27).

Lack of Instructions and Warnings regarding the Increased Vulnerability to Loss of Stability when Damaged.

4.3.15 The designers failed to provide instructions and warnings regarding the increased vulnerability to the loss of stability when the Unit was damaged. There was a lack of guidance on the potential consequences that might arise following damage to the Unit. There was also a lack of guidance regarding the capability of equipment and what equipment could be expected to operate under damage conditions. (See Figure 27).

4.4 Comments on the Petrobras Investigation Commission Findings

4.4.1 One of the factors noted by the Petrobras Investigation Commission identified in section 6.2 of their Final Report was that the access hatch from the Access Shaft to the Tank 26S and Stability Box (void) 61S was left open thereby increasing the largest floodable volume.

4.4.2 As described above, the reason for access being required to void 61S was due to the poor workmanship/design of the stability boxes that were added as part of the P-36 upgrade project. Further, the access provided to void 61S was poor with no access trunking being provided through Tank 26S. In addition, the Operations Manual provided no guidance on the floodable volume and hazards and risks associated with internal flooding.

4.4.3 Another factor listed by the Petrobras Investigation Commission was that two of the seawater pumps were withdrawn from service for maintenance without there being a contingency plan provided. However, the question is whether the presence of a third pump would have made a difference and have prevented the loss of the Unit. The Ballast Operators followed the basic guidance given in the Operations Manual, which was to 'right' the Unit. They were in the process of achieving that goal when the second explosion occurred. That caused the loss of the ballast systems and main electrical power. Therefore, the number of seawater pumps available was not critical to the loss of the Unit.

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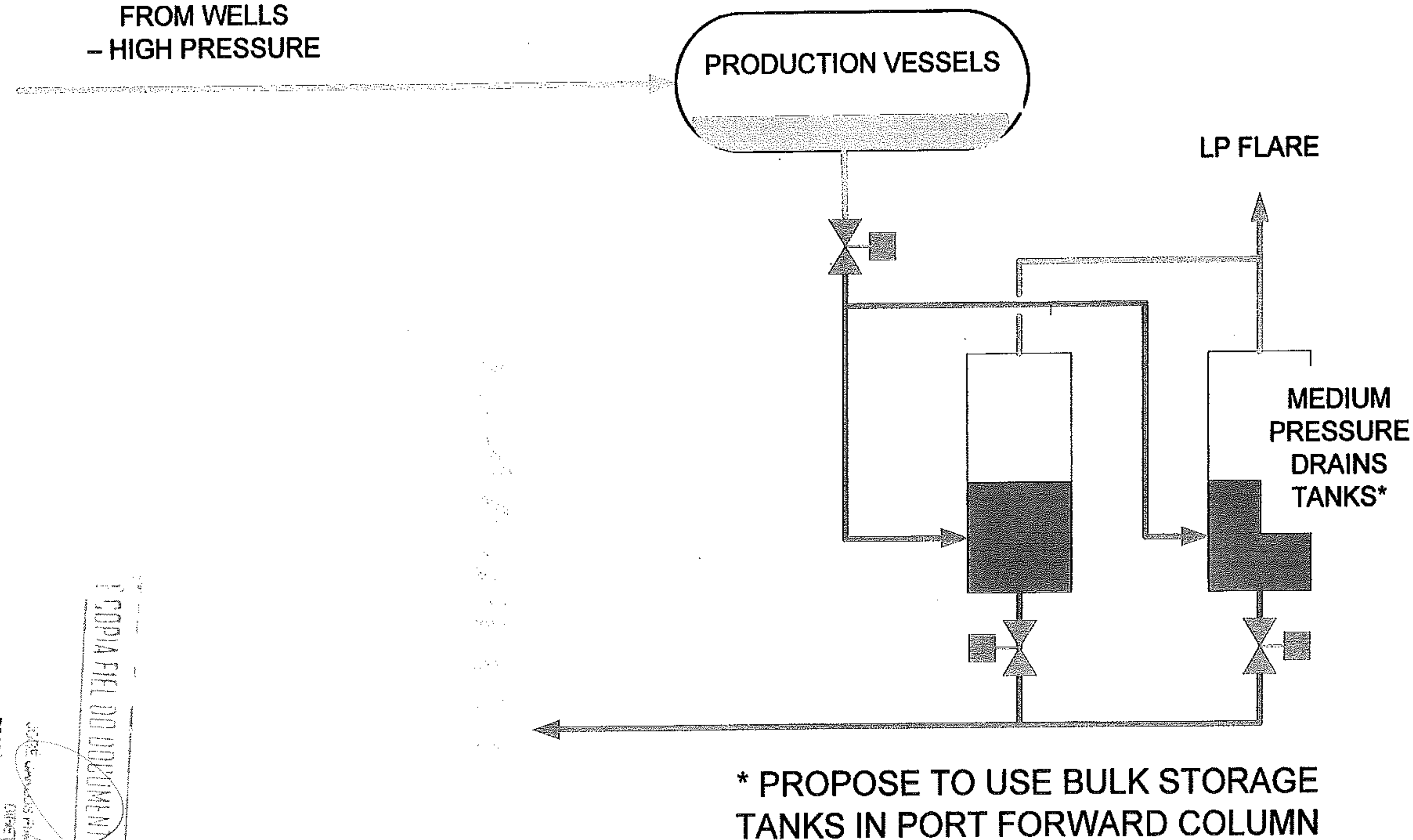
4.4.4 A further factor listed by the Petrobras Investigation Commission was the alleged lack of stability control emergency procedures and the training of Ballast Operators. Any criticism must be viewed against the 'information overload' and lack of time available in which to assess and respond to the developing problems. There were multiple alarms received in the Control Room between the 1st event and 2nd explosion. The alarm system was not designed to prioritise or present a hierarchy of critical alarms to the operators. There were complex issues to assess, with often conflicting information. Further, effort was also required to restore critical systems. There was also a lack of guidance in the design manuals as to how to assess and respond to an internal flooding condition. However, the basic guidance provided was to 'right' the Unit, which the Ballast Operators had almost achieved at the time of the 2nd explosion.



<u>FIGURE 1</u> – Initial Scheme for DST System was to use Bulk Storage Tanks in Port Forward Column

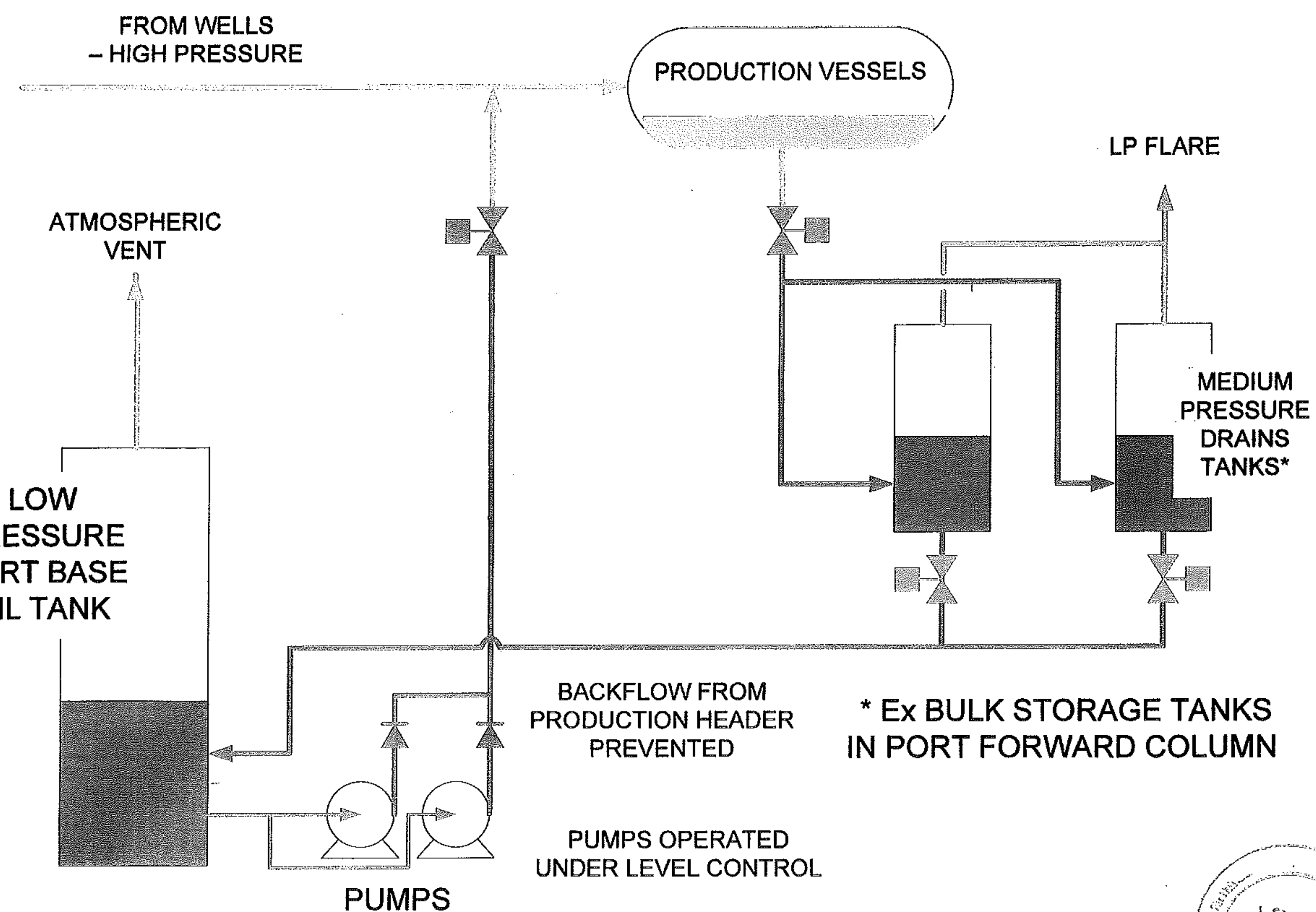
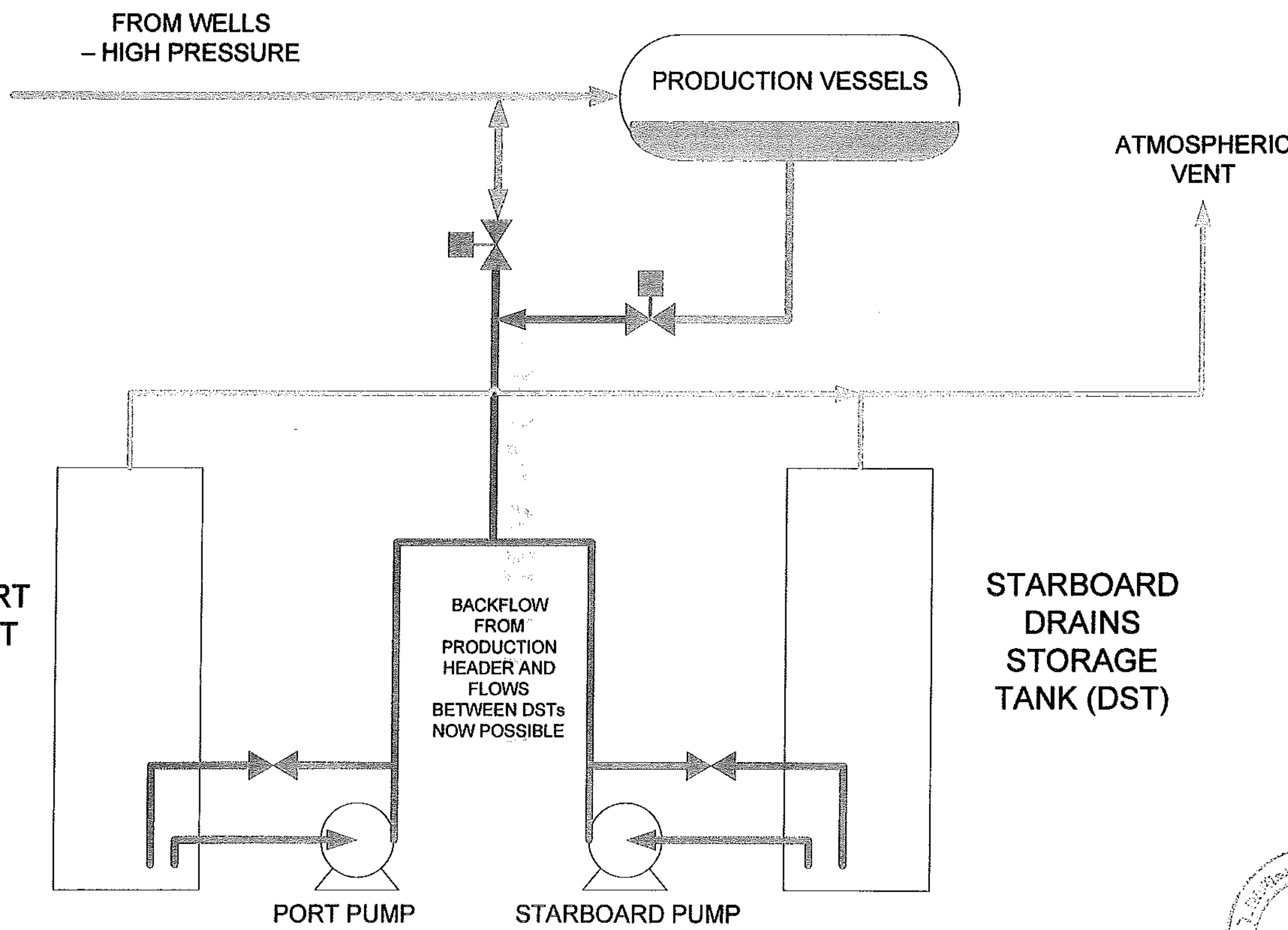


FIGURE 2 – Initial Scheme for DST System with only one Base Oil Tank



<u>FIGURE 3</u> – Final Scheme for DST System with <u>both</u> Base Oil Tanks

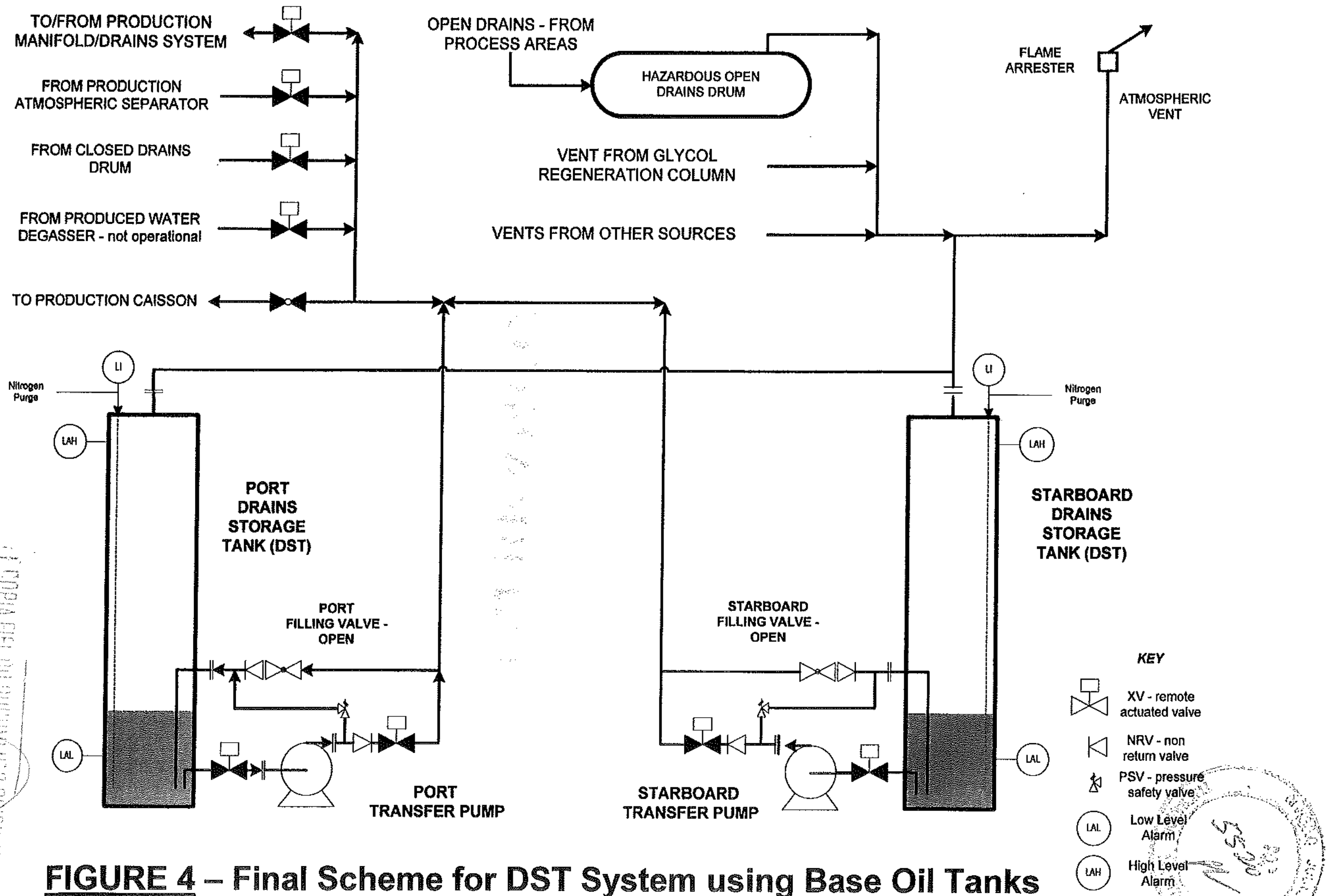


FIGURE 4 – Final Scheme for DST System using Base Oil Tanks

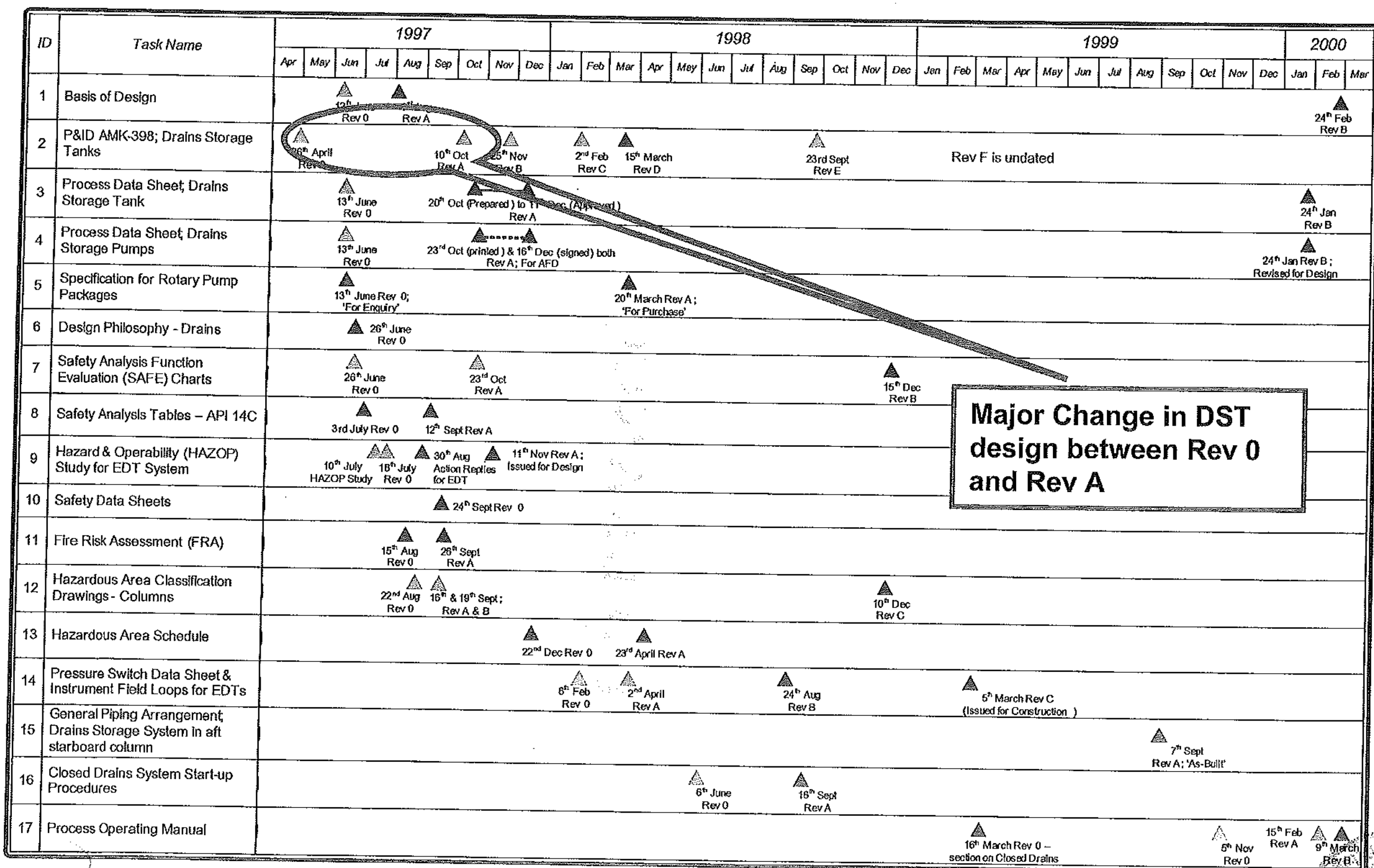


FIGURE 5 – Timeline for DST System – Document Revisions

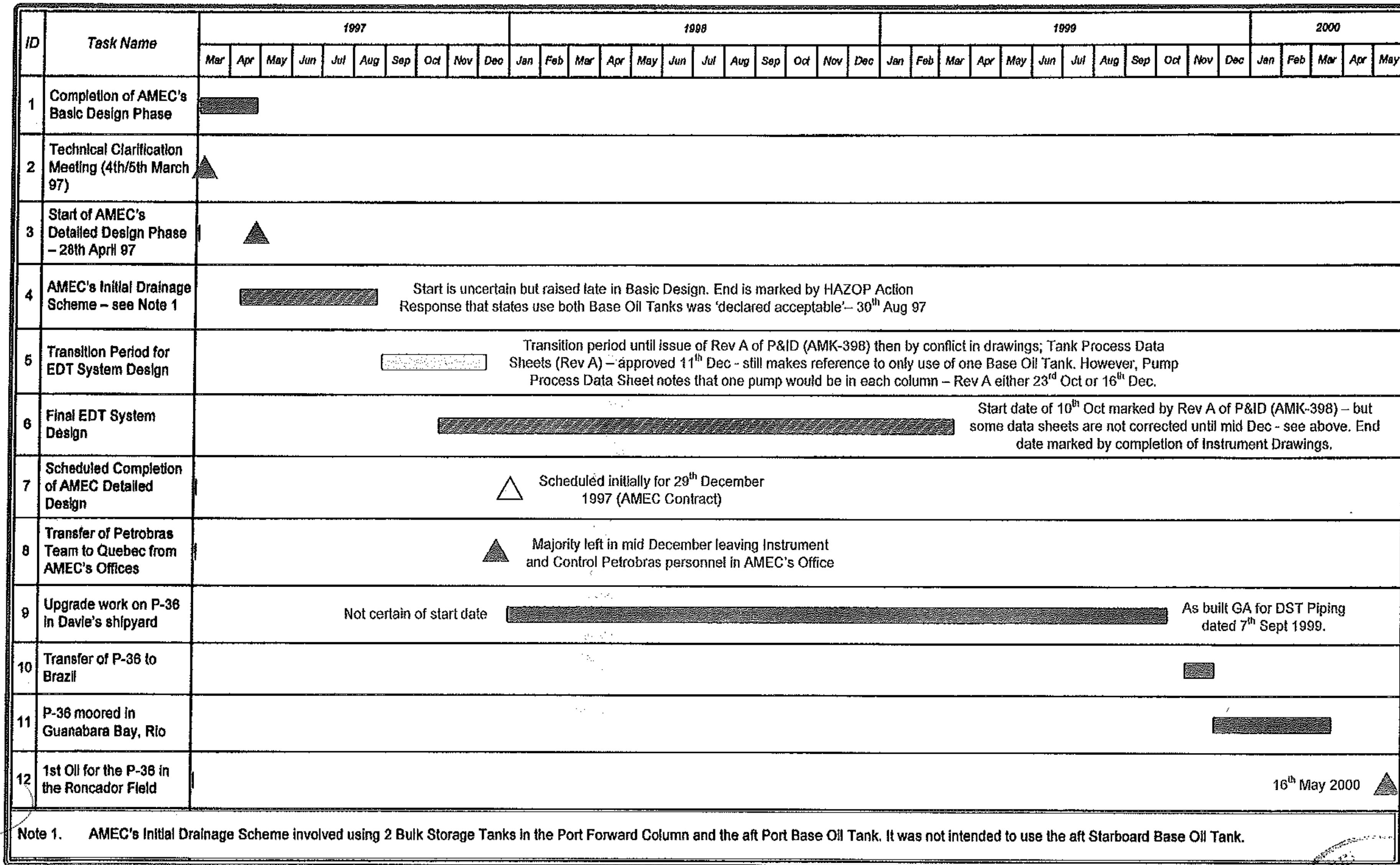
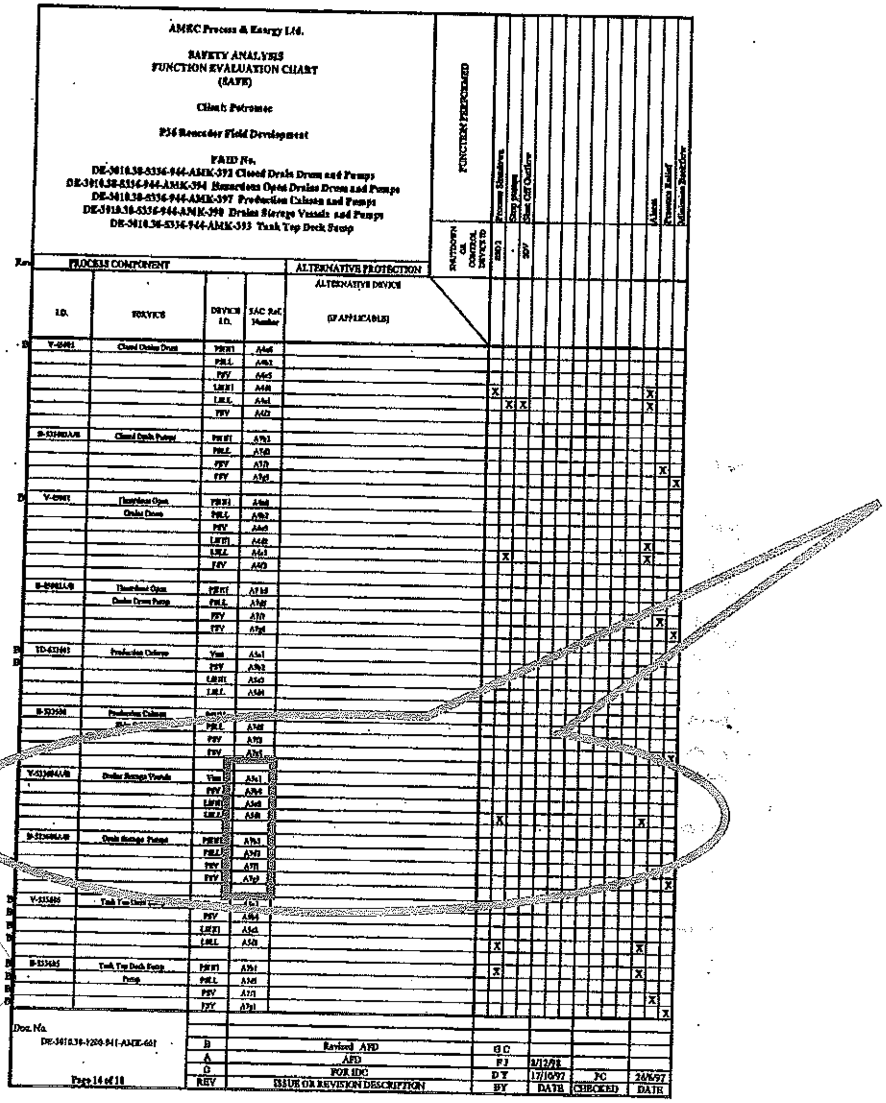


FIGURE 6 – Timeline showing DST System Design



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- Last revision (rev B - *Revised AFD*) 8th December 1998,
- Contains reasons for selecting safeguards based on API RP 14C checklist – wrong assumptions & never written into procedures

FIGURE 7 – SAFE Charts for the DST System

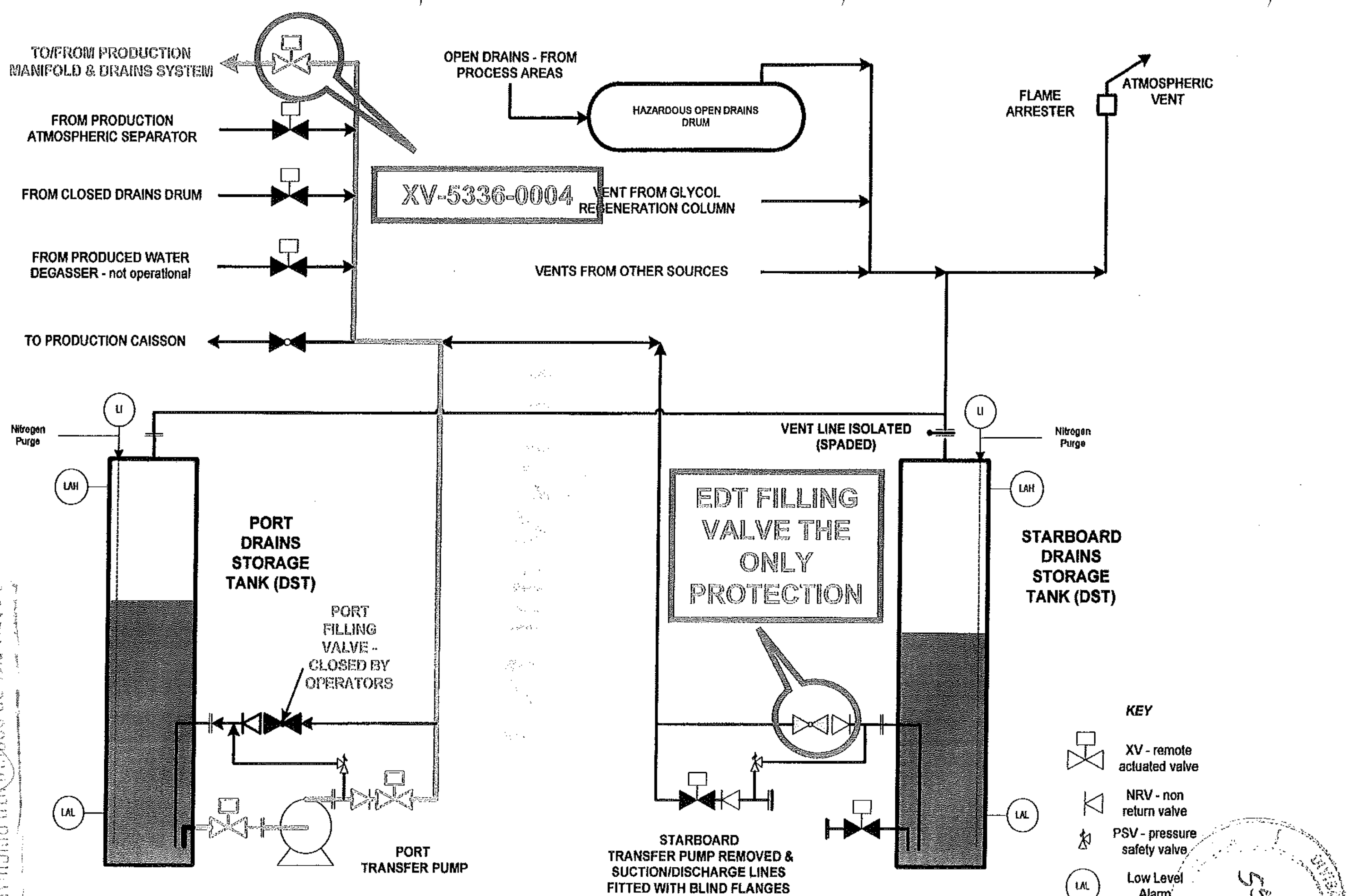


FIGURE 8 – Lack of Backflow Protection in DST System Design

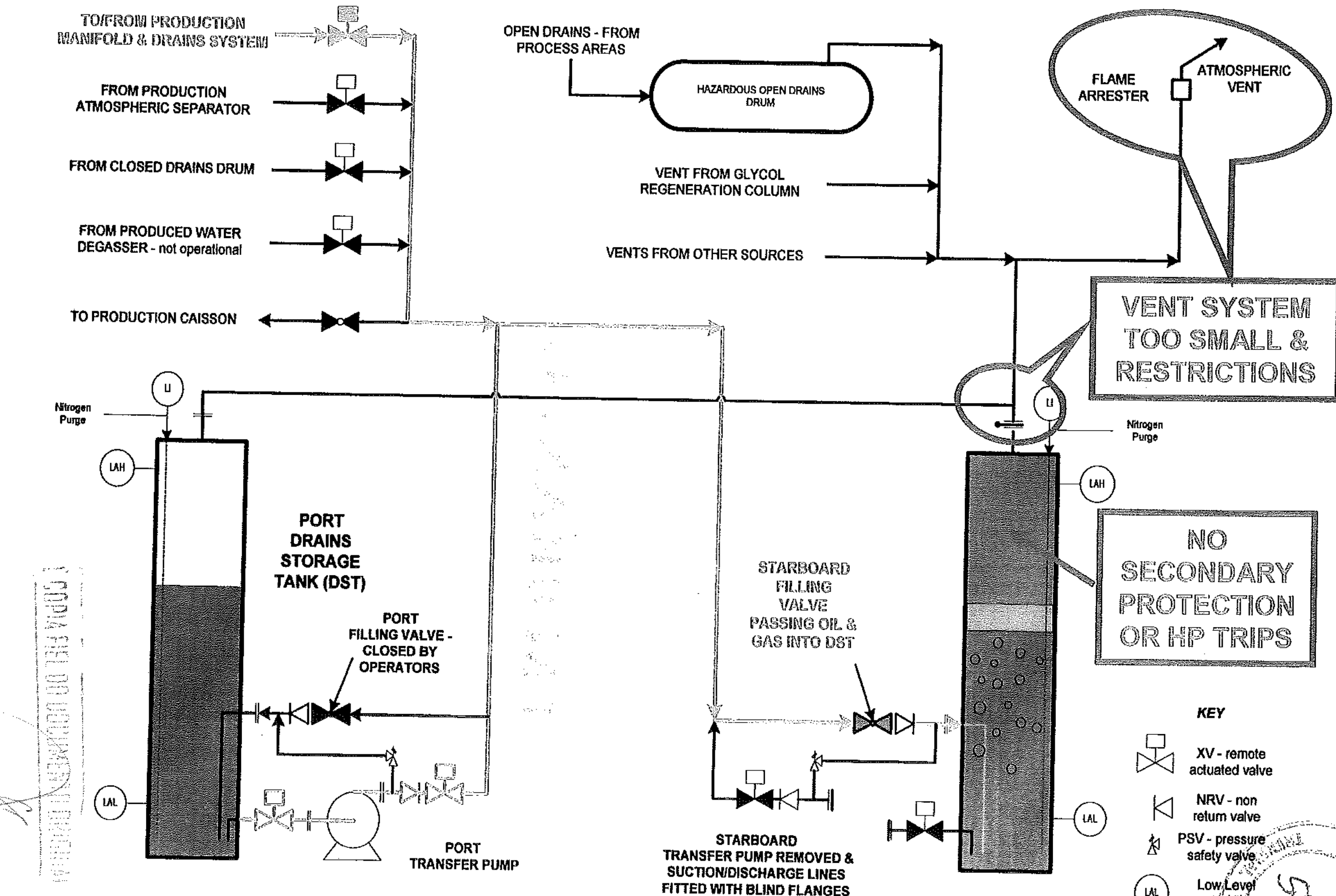


FIGURE 9 – Lack of Pressure Protection in DST System Design

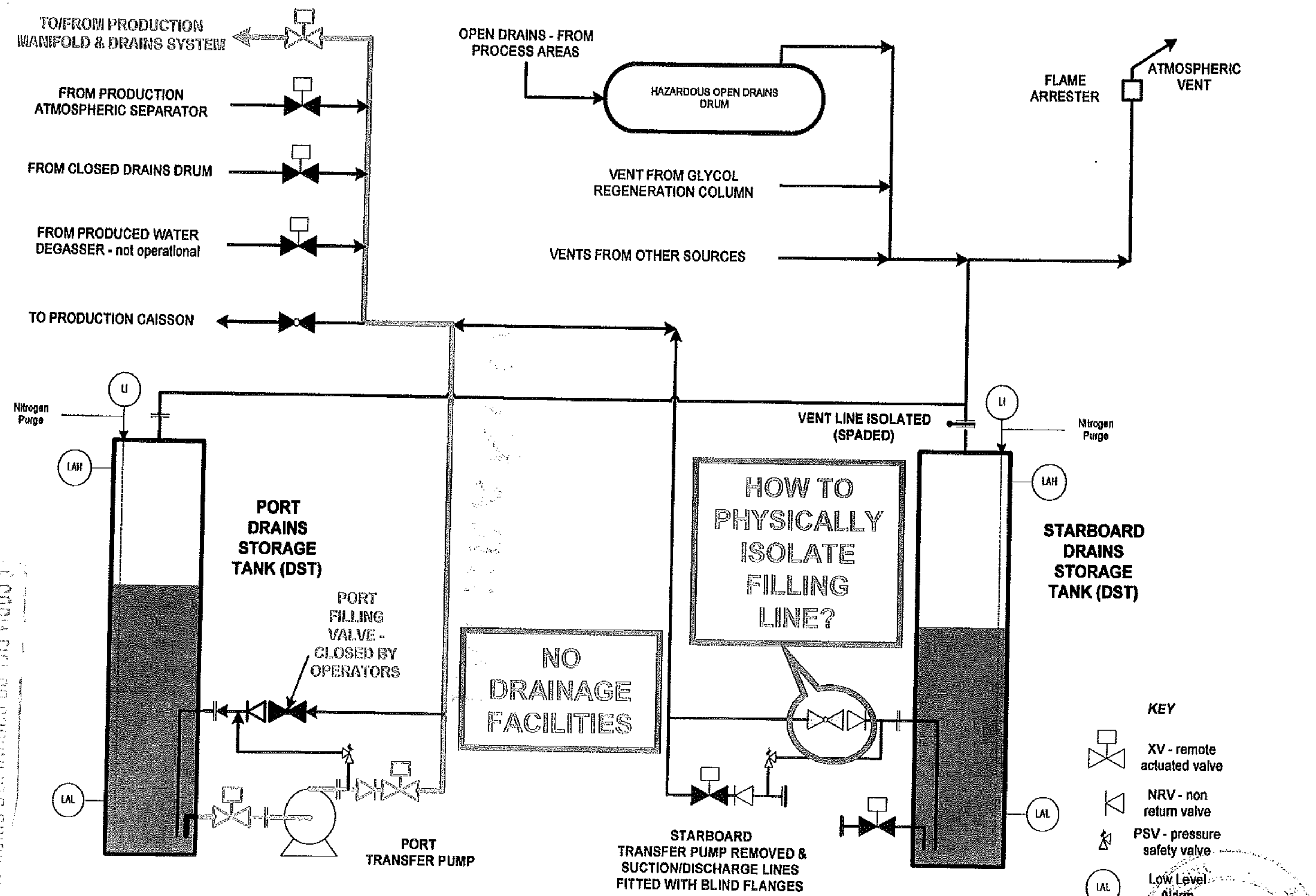


FIGURE 10 – Lack of Isolation & Maintenance in DST System Design

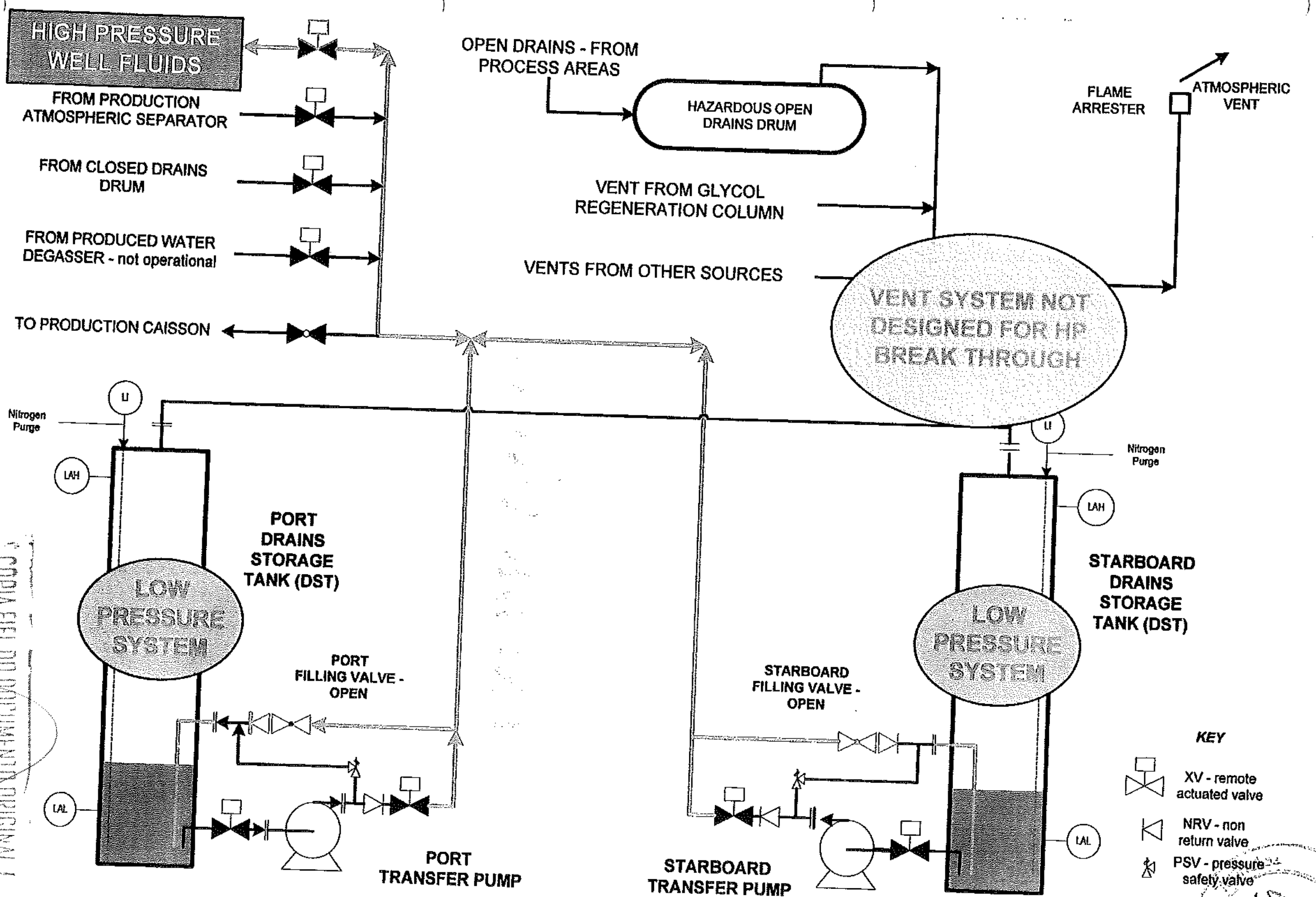


FIGURE 11 – 'An Accident waiting to Happen'

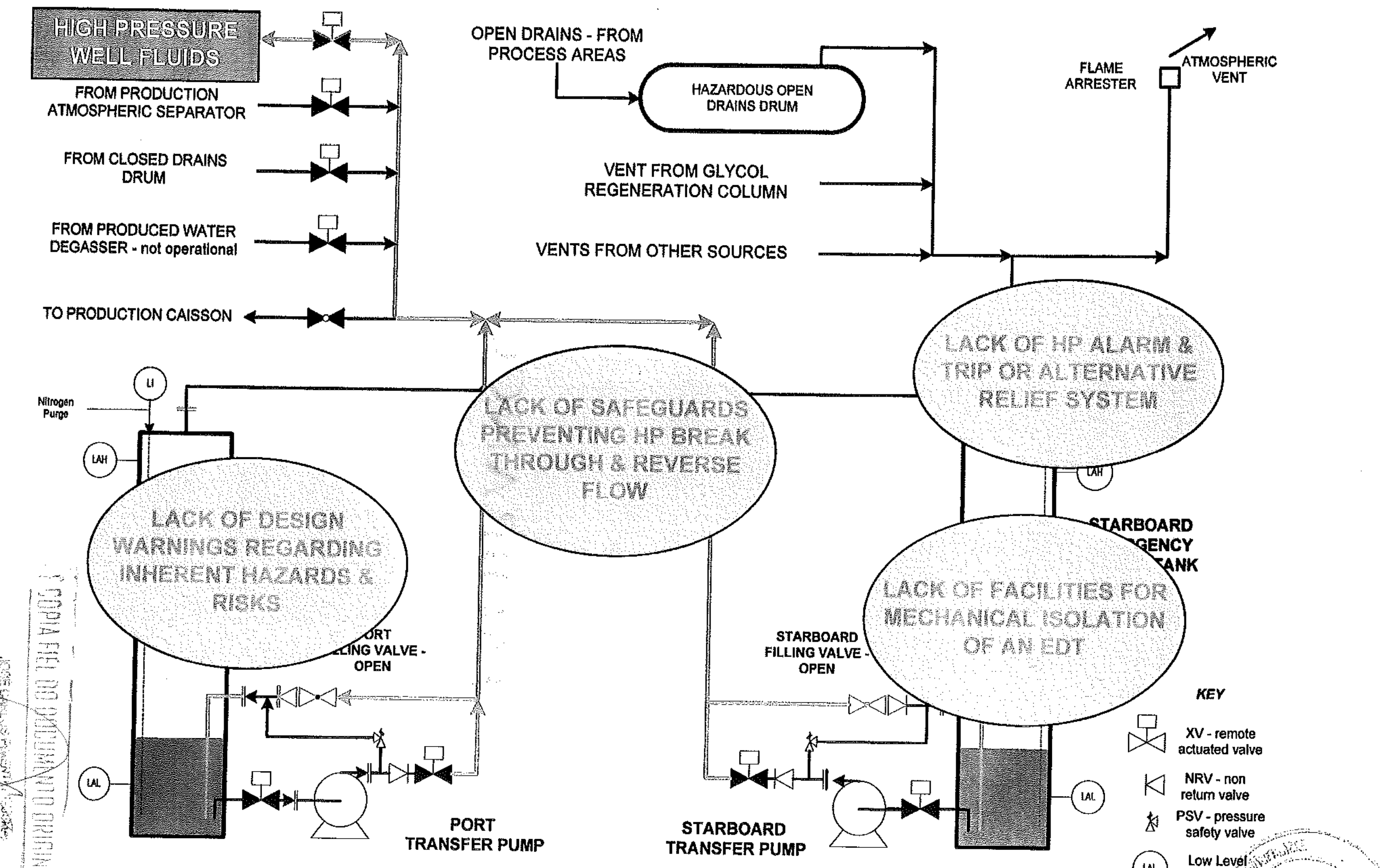


FIGURE 12 – Lack of Safeguards in DST System Design

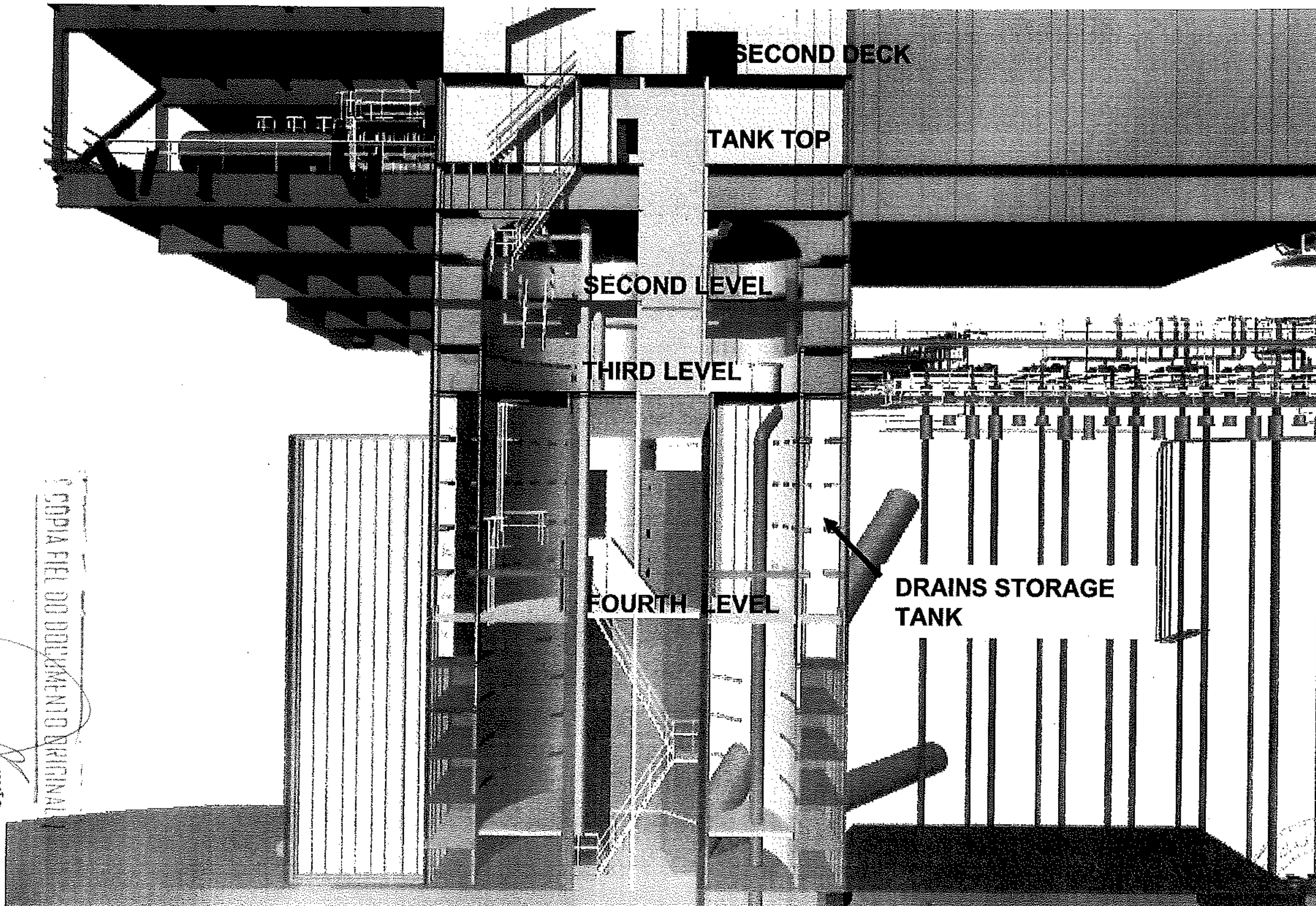


FIGURE 13 – Cross-section of the Starboard Aft Column

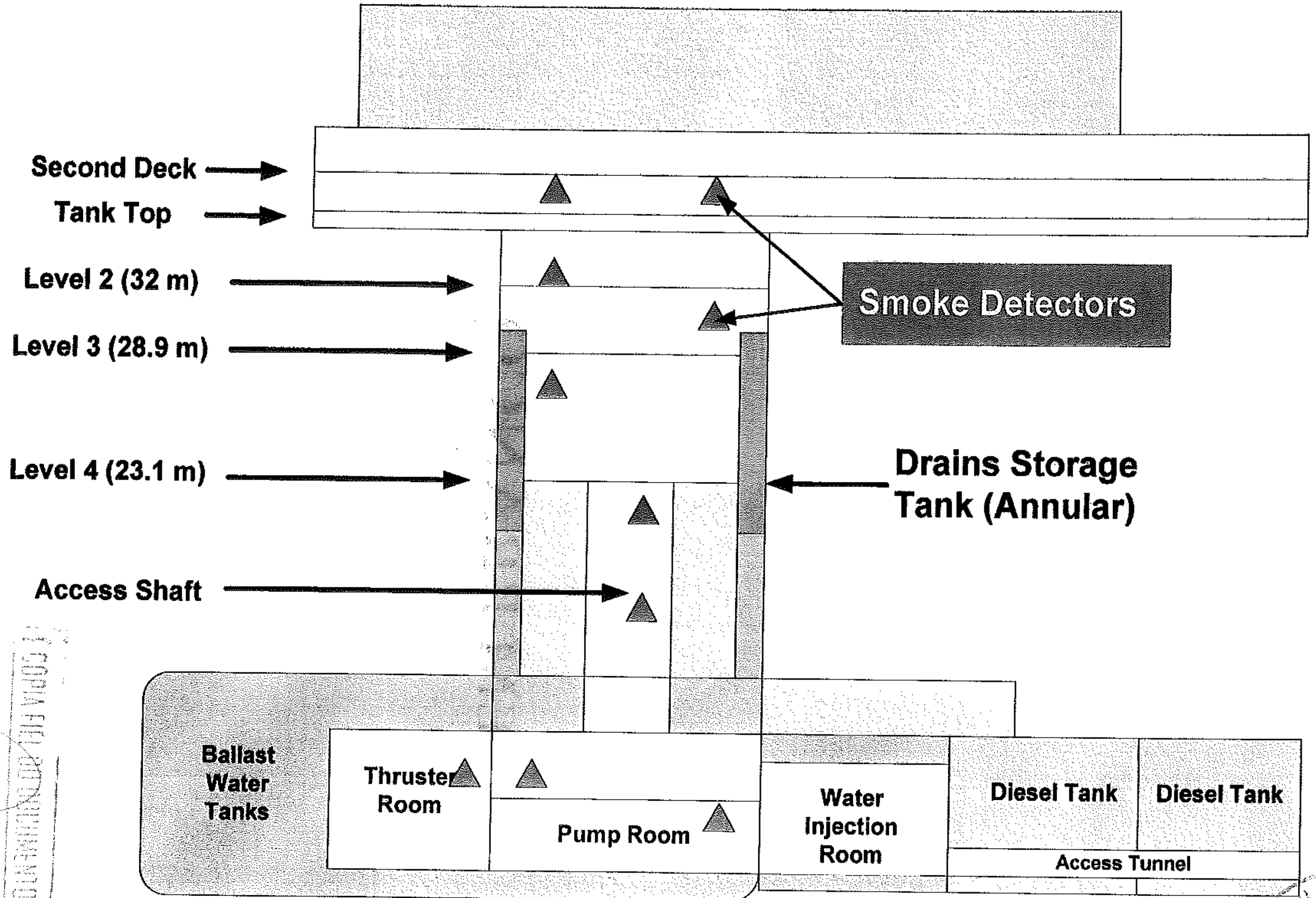


FIGURE 14 – Smoke Detectors in Aft Columns

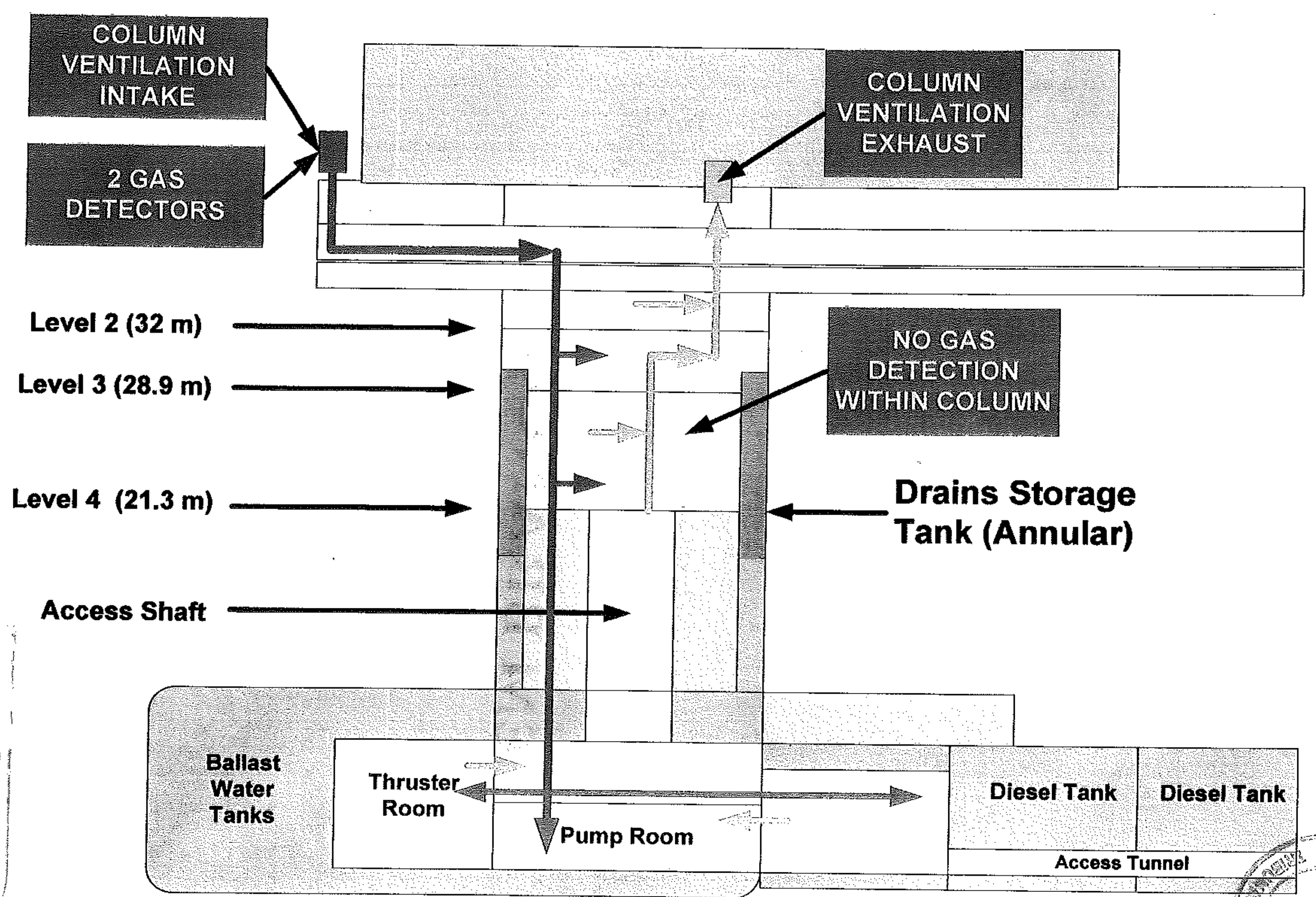


FIGURE 15 – No Gas Detection inside Aft Columns

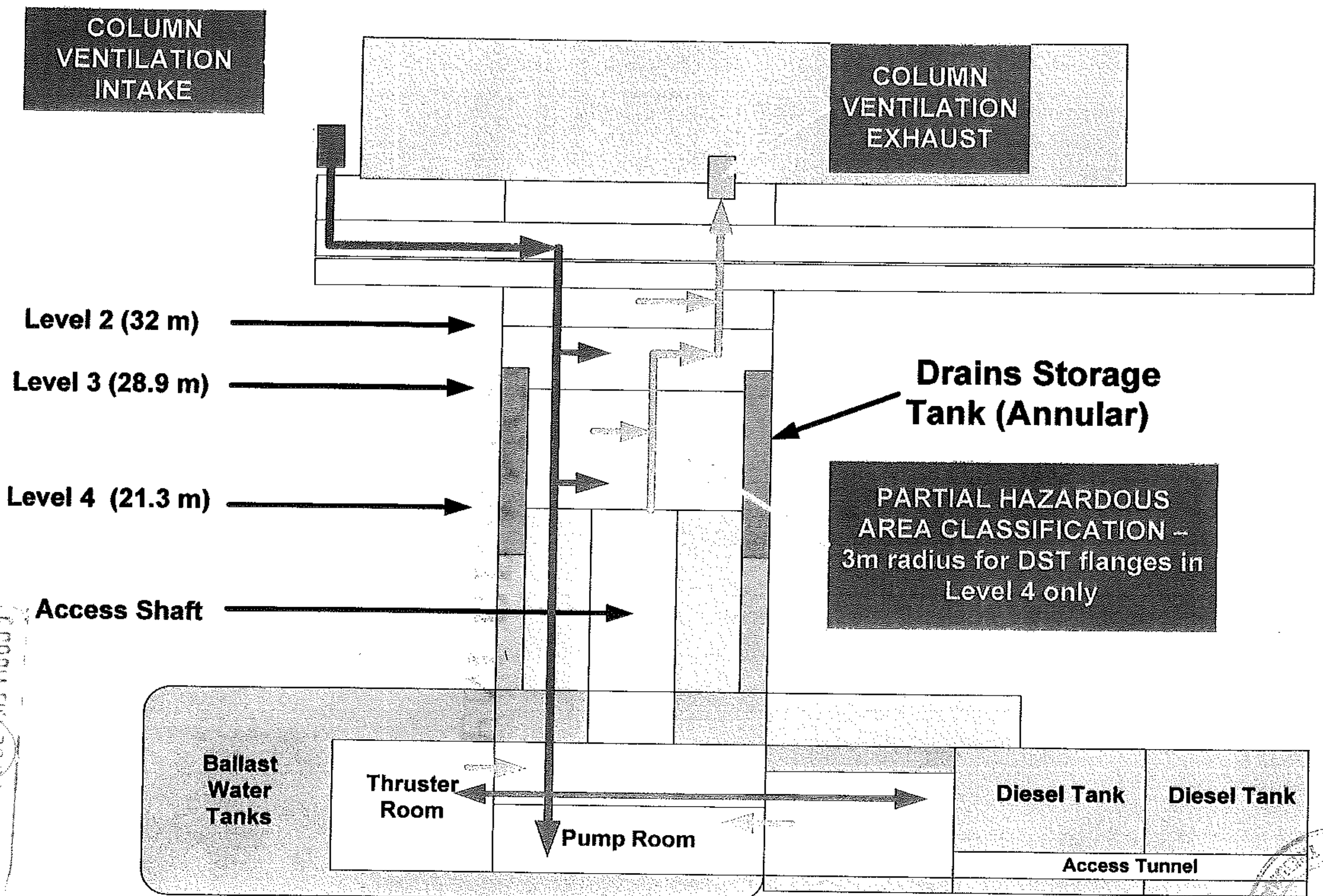


FIGURE 16 – Limited Hazardous Area Classification at Level 4

P36 RONCADOR PROJECT: SAFETY ANALYSIS TABLE [API RP 14C]

EQUIPMENT NAME AND IDENTIFIER: **Drains Storage Vessels (V-533604A/B)**
P&ID Drawing Ref: DE-3010.38-1223-944-AMK-398, Rev A

UNDESIRABLE EVENT	CAUSE	DETECTABLE ABNORMAL CONDITION AT COMPONENT	API (RP14C) PROTECTION VERSUS IN PLACE PROVISION: PRIMARY	REF	SECONDARY	REF	COMMENTS
Overpressure	Inflow exceeds outflow Thermal expansion Blocked outlet or vent	High pressure	Vent				1. Gas detection system used for leak detection. 2. There is no heat source on the vessel.
Underpressure	Withdrawals exceed inflow Thermal contraction	Low pressure	Vent				
Overflow	Liquid inflow exceeds liquid output capacity Blocked liquid outlet	High liquid level	LSHH	LAHH-HOLD 1			
Leak	Deterioration Rupture Accident	Low pressure and backflow	LSLL	LSLL-HOLD 1	ESS	Comment 1	HOLDS: 1. Tag numbers.
Excess Temperature	Excess heat input	High temperature		Comment 2			

SHEET 1	REV	DESCRIPTION OF REVISION	DRAWN BY	CHECKED BY	APPROVED: BY	DATE
	A	Issued for Design				
	0	Project review (IDC)				

P36 - RONCADOR FIELD
DRAWING TITLE: SAFETY ANALYSIS TABLE
Drains Storage Vessels V-533604A/B
DRAWING NO. DE-3010.38-5400-947-600

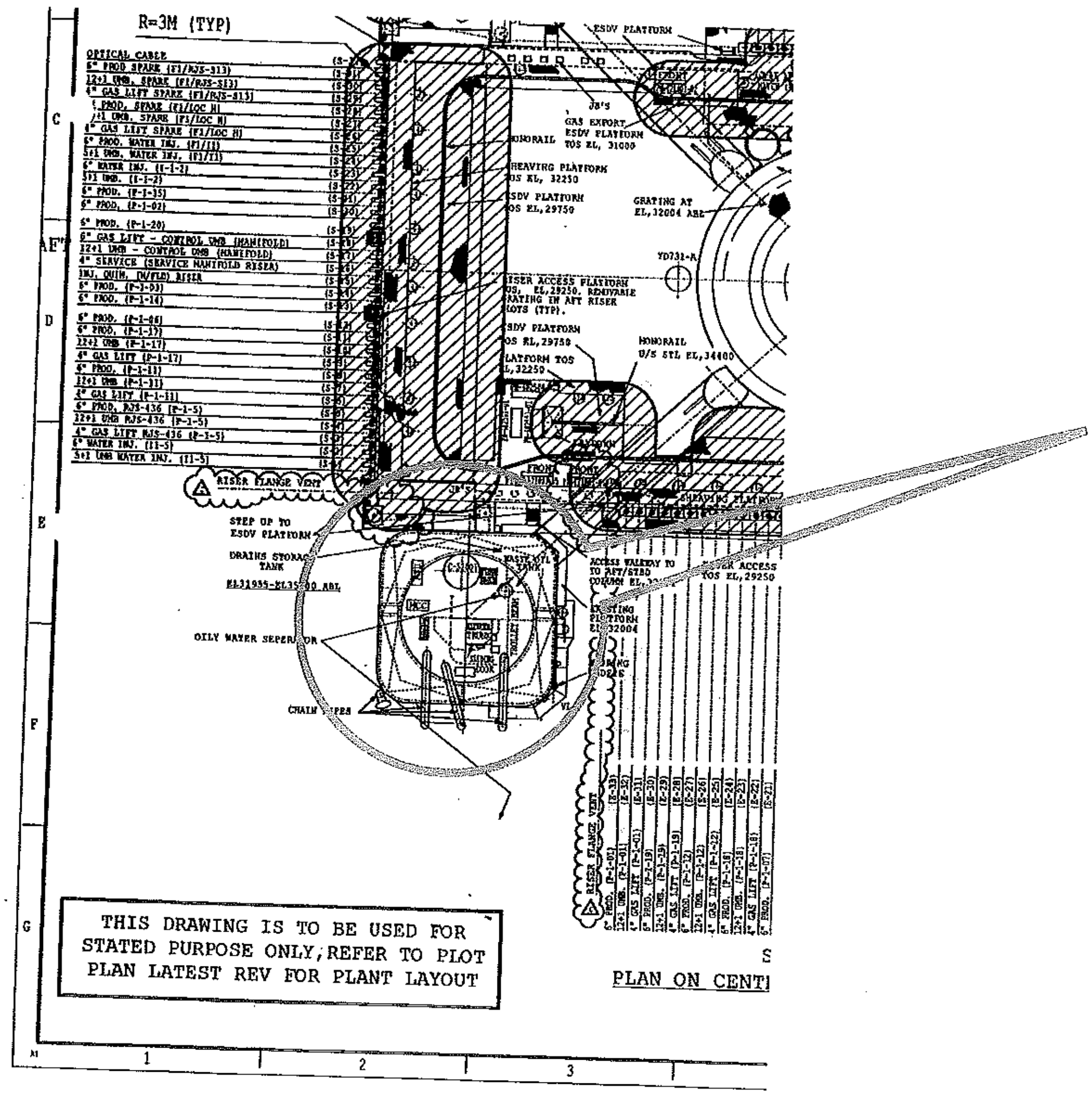
- Notes *'blocked outlet or vent'* as cause of over-pressure.
- Notes *'gas detection system used for leak detection'*.

<u>FIGURE 17</u> – Safety Analysis Tables for Drains Storage Tanks

P36 - RONCADOR PROJECT			HAZARDOUS AREA SCHEDULE									Document No: LI-3010.38-5400-947-AMK-603								Rev: A
PROCESS EQUIPMENT ITEM			FLAMMABLE MATERIAL	OPERATING CONDITIONS		L=LIGHTER THAN AIR H=HEAVIER THAN AIR	FLASH POINT °C	IGNITION TEMP. °C	BOILING POINT °C	VAPOUR PRESS. BARs	FLUID CATEGORY	DESCRIPTION OF FLAMMABLE MATERIAL CONTAINMENT	VENTILATION	SOURCE OF RELEASE			CLASSIFICATION			REMARKS
P&ID No DE-3610.38-1223-944-	DESCRIPTION	LOCATION		TEMP °C	PRESS. BARs									DESCRIPTION	PRIMARY	SECONDARY	CLASS 1 DIVISION 1	CLASS 1 DIVISION 2	UNCLASSIFIED	
AMK-394	Hazardous Open Drains Drum V-533602 Hazardous Open Drains Drum Pumps B-533602A/B	Tank Top (Aft)	Process H/C + Water	Ambient	Atmos	H/L					Flammable Liquid Class I Gas Group D	Enclosed	Adequate	Flanges Valves	—	●	—	● R = 3	—	Limits as per RP 500 Section B.6.c
AMK-397	Production Caisson	Under Tank Top (Aft)	Process H/C + Water	Ambient	Atmos	H/L					Flammable Liquid Class I Gas Group D	Enclosed	Adequate	Flanges Valves	—	●	—	● R = 3	—	Limits as per RP 500 Section B.6.c
AMK-398	Drains Storage Vessels S-533604A/B Drains Storage Vessel Pumps B-533604A/B	Tank Top (Aft)	Process H/C + Water	Ambient	Atmos	H/L					Flammable Liquid Class I Gas Group D	Enclosed	Adequate	Flanges Valves	—	●	—	● R = 3	—	Limits as per RP 500 Section B.6.c
AMK-402	HP Flare Drum V-[illegible]	Main Deck	Process H/C	Ambient -20/+70	17.00 6	H/L					Flammable Liquid	Enclosed	Adequate	Flanges [illegible]	—	●	[illegible]	● [illegible]	—	Limits as per RP [illegible] Section B.6.c

- Wrong Location – *'Tank Top'*
- Potential Sources of Release incomplete – multiple other sources
- Wrong Div 2 of 3m - <u>not</u> as per API RP 500
- Wrong Definition – Pressure Vessel

<u>FIGURE 18</u> – Hazardous Area Classification Schedule for DSTs



- **Drawings showed no Hazardous Areas in Columns – not even 3m radius.**

FIGURE 19 – **Hazardous Area Classification Drawings for Aft Columns**

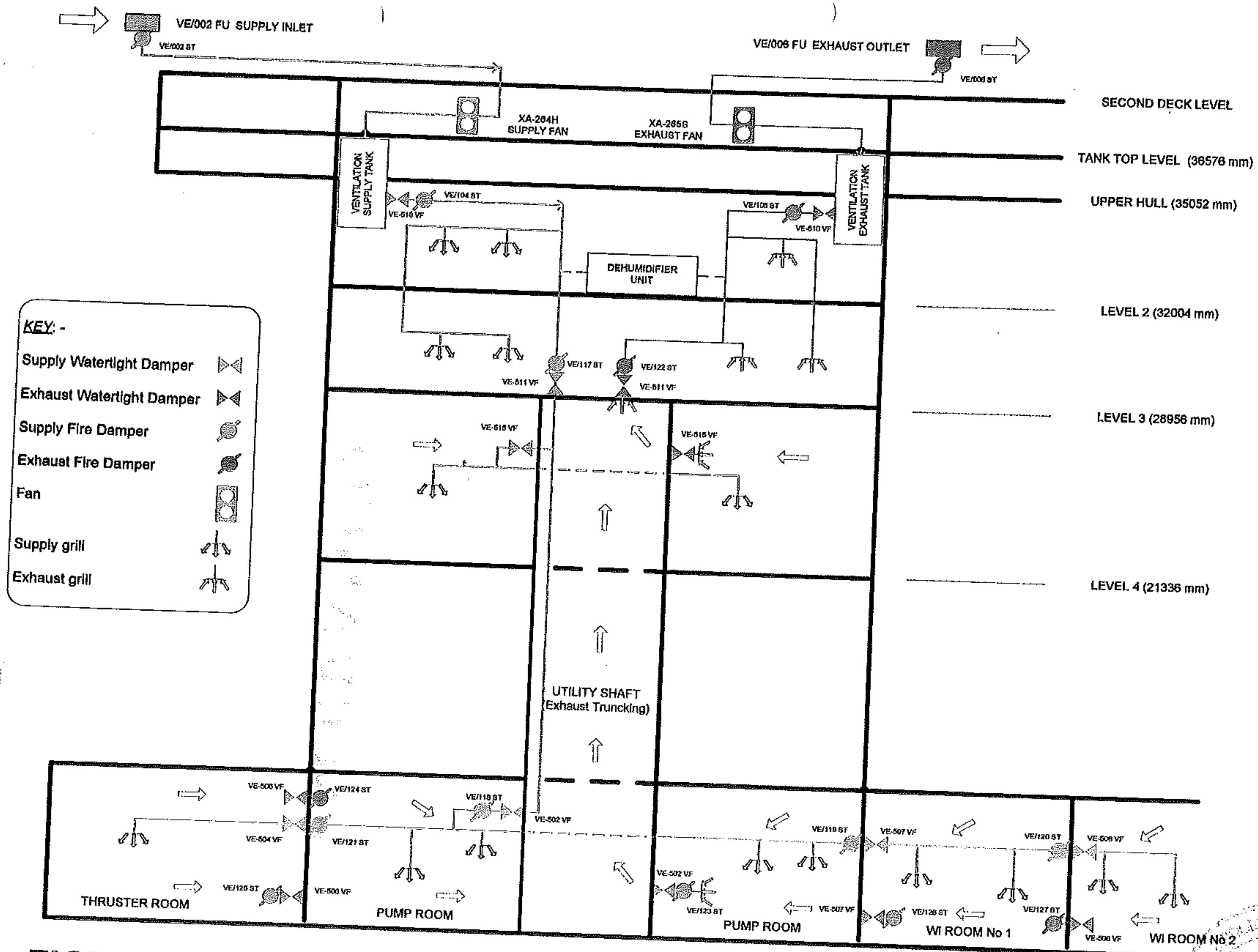


FIGURE 20 – Sketch of Ventilation System in Aft Starboard Column

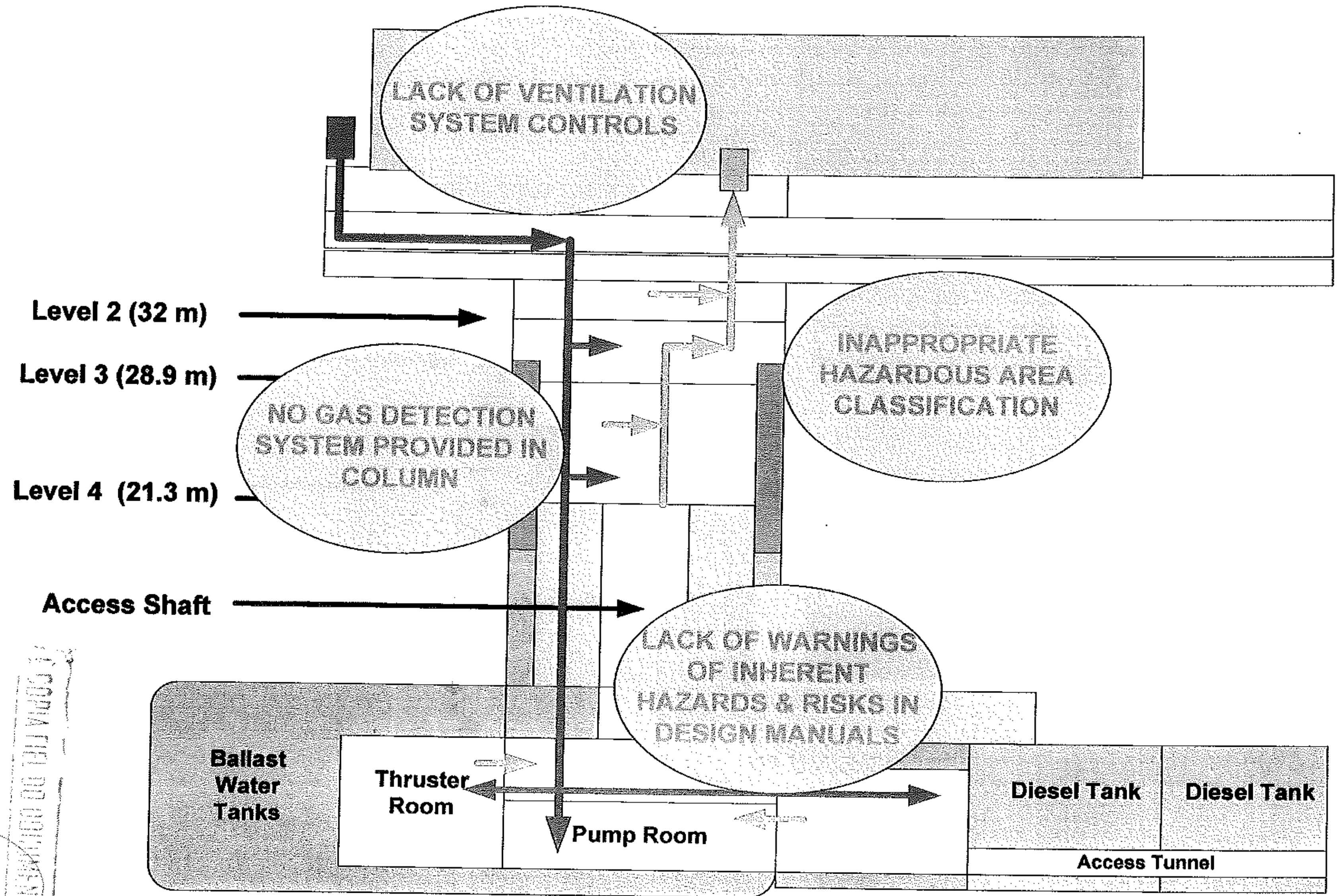


FIGURE 21 – Lack of Safeguards in Aft Column Design

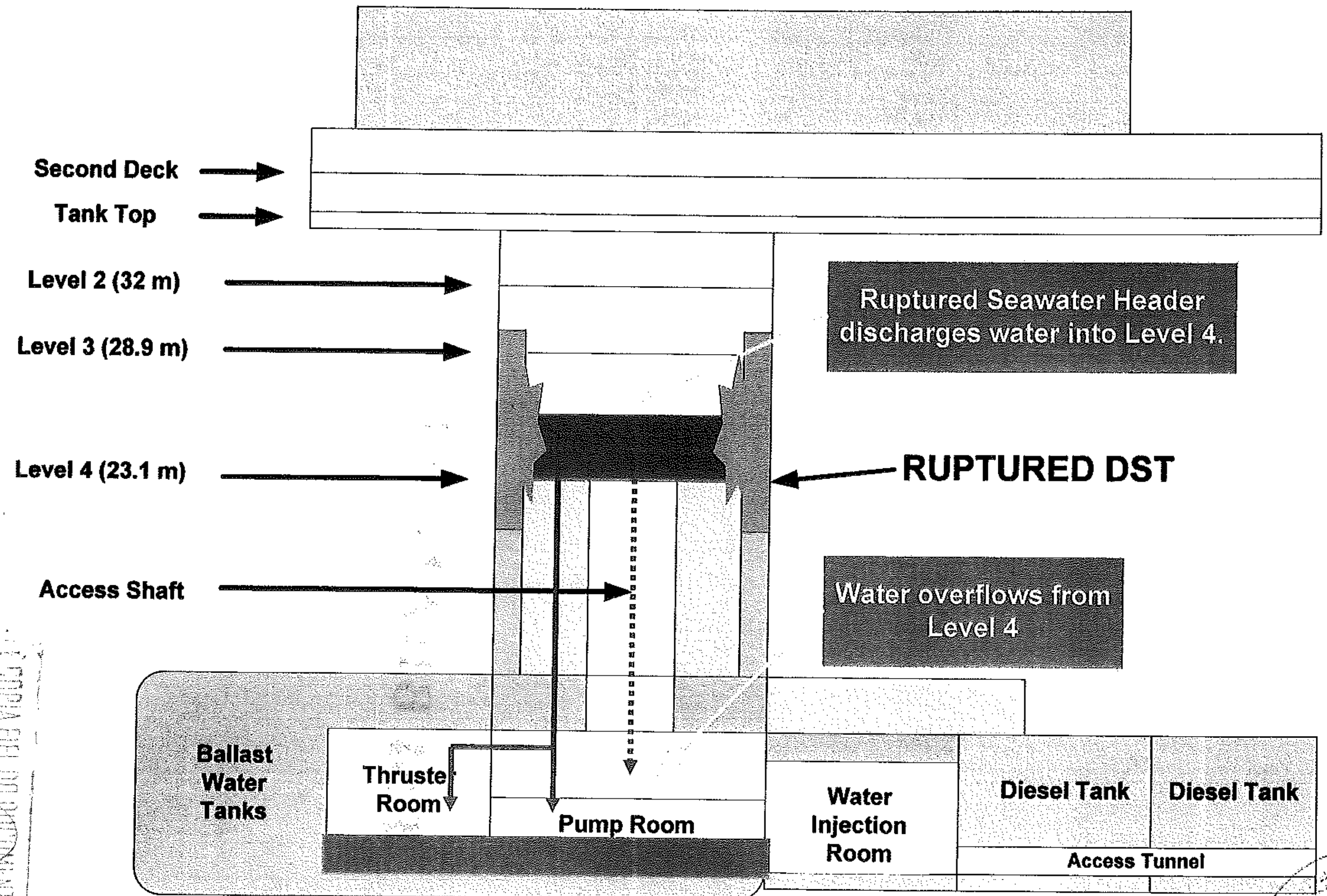


FIGURE 22 – First Event causes 2 degree Inclination

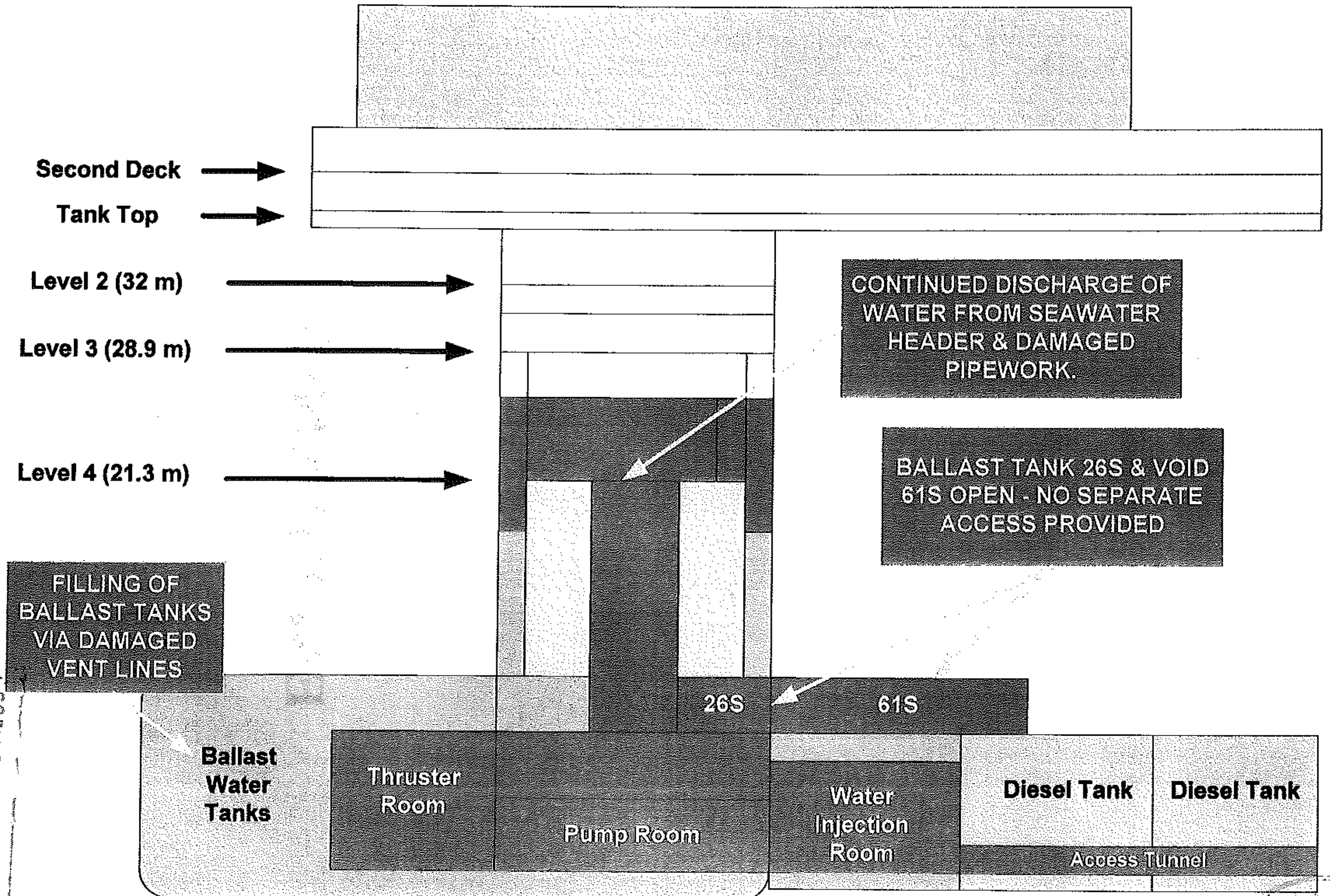
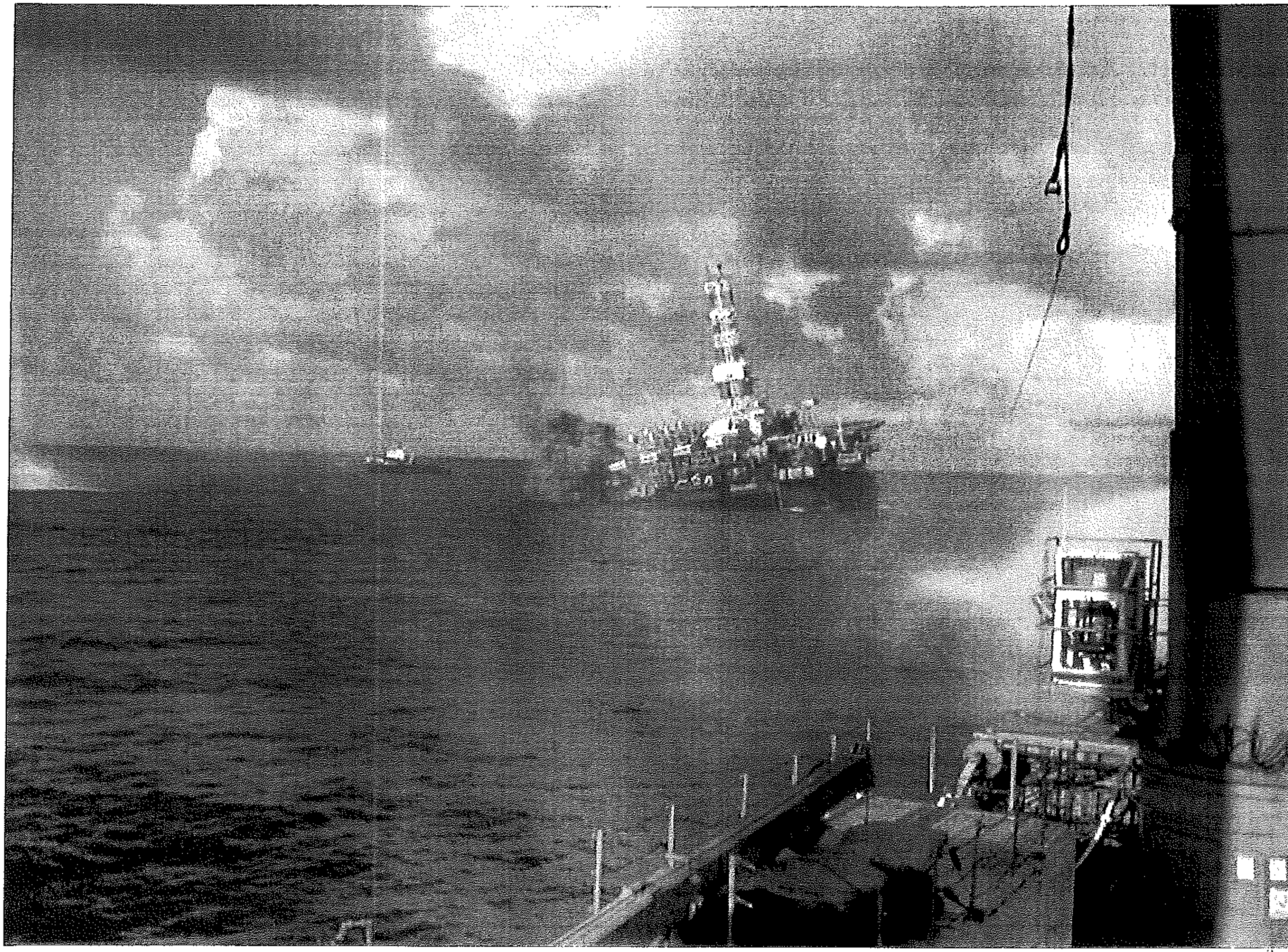


FIGURE 23 – Internal Flooding following Second Explosion



<u>FIGURE 24</u> – Sudden Loss of Stability at about 08-10

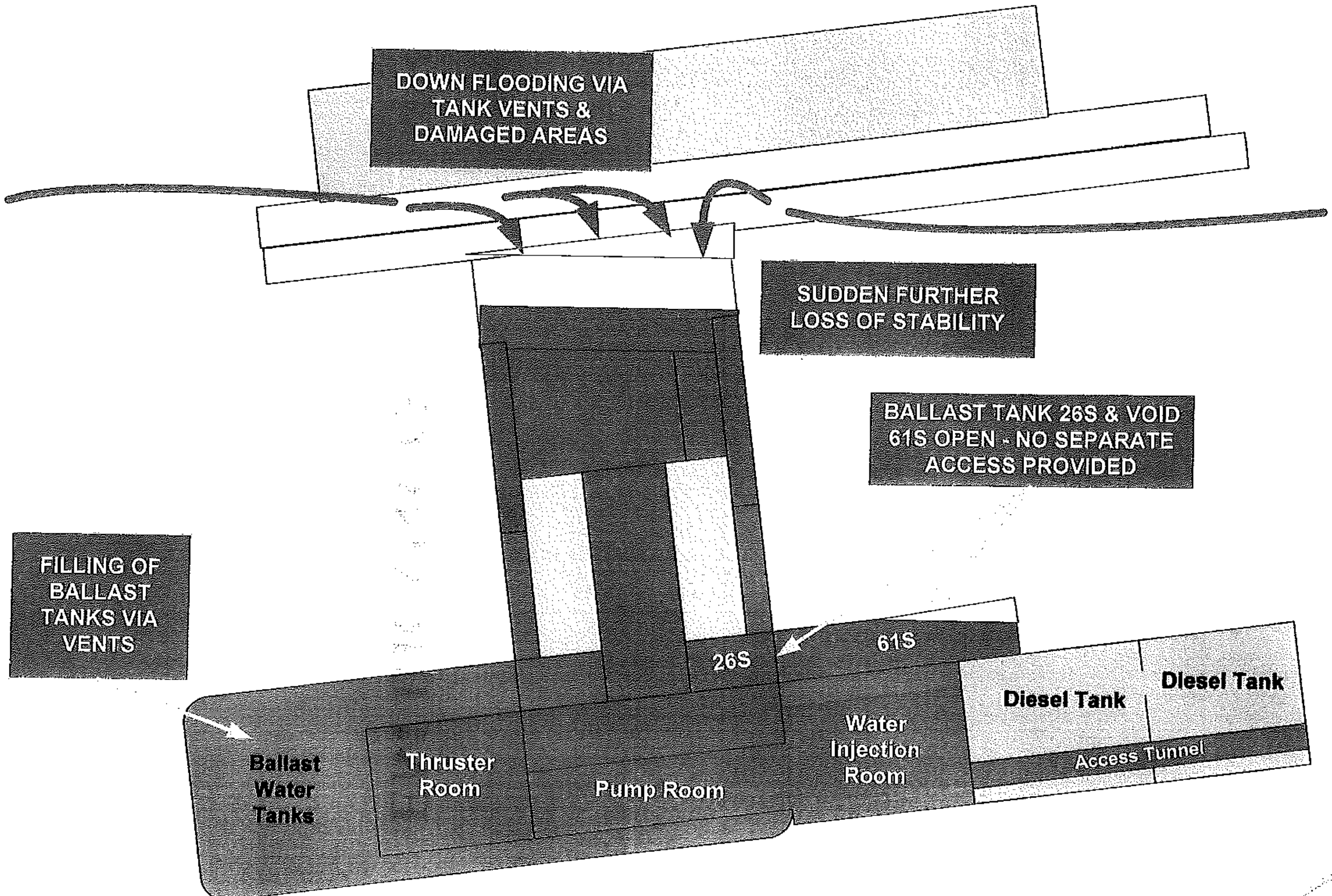


FIGURE 25 – Down Flooding of Starboard Aft Column

FIGURE 26 – **Progressive Flooding of Unit**

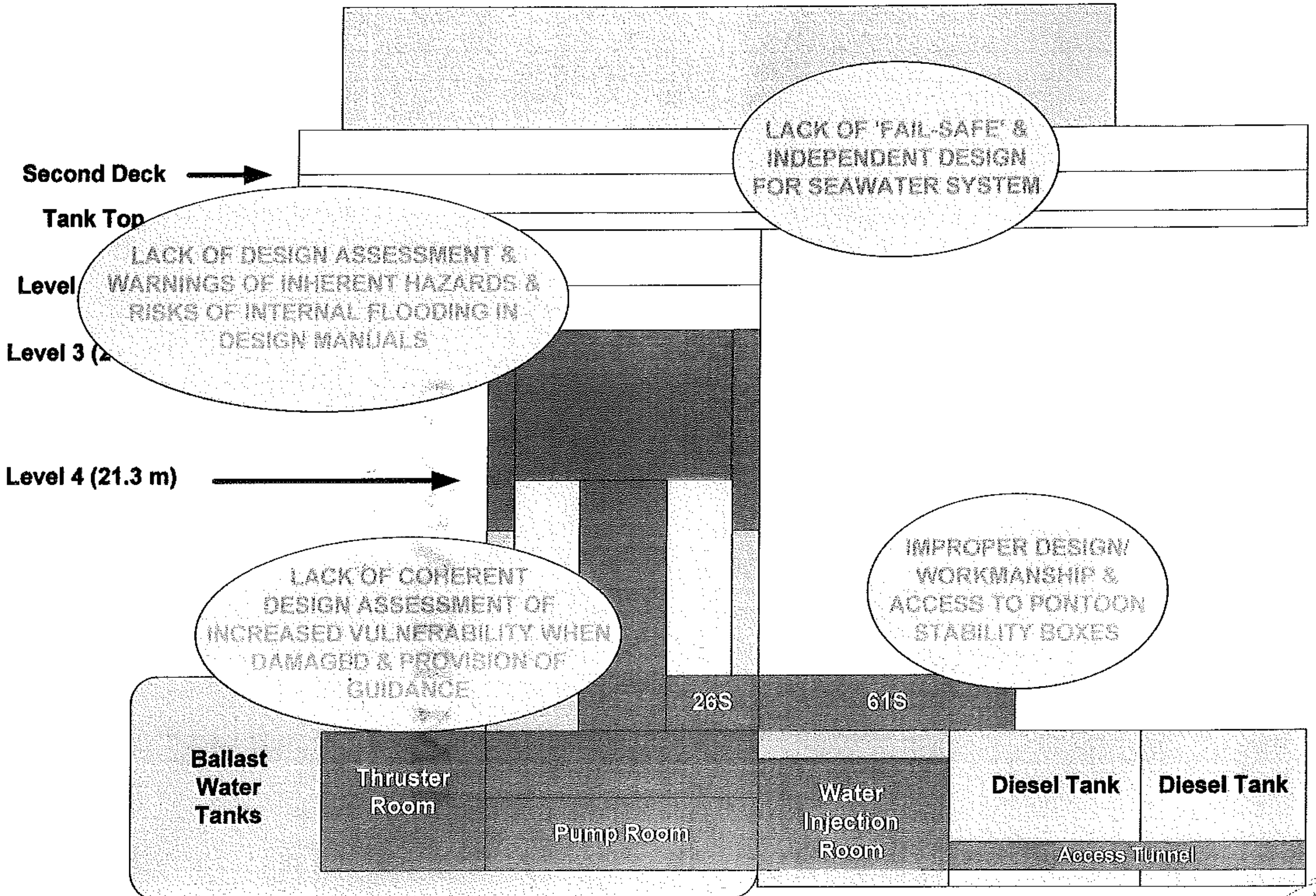


FIGURE 27 – Design Flaws & Lack of Marine Safeguards

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CERTIDÃO

CERTIFICO que nesta data foi encerrado o 24º volume do processo nº 19489/01 com suas fls. numeradas a partir do 5543-A dos autos.
O referido é verdade e dou fé.
Aos 28 de abril de 2006.

CÓPIA FIEL DO ORIGINAL

JOSÉ CARLOS PIMENTEL GUSMÃO
DIRETOR
DIVISÃO DE SERVIÇOS CARTORIAIS