Risk and Reliability Allocation Methodology for Offshore Oil Units

by

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ABSTRACT

Early approaches in engineering safety were based on deterministic concepts, according to which, safety was assured by making conservative assumptions in the design of industrial systems, as well as through the use of safety factors, based on engineering judgement.

Recent safety approaches are based on probabilistic concepts, in reliability techniques and accident consequence modelling, according to which safety is defined in terms of probabilities or frequency of failures and severity of consequences. These two items compose the basis for the evaluation of industrial risks.

Risk assessment techniques are particularly relevant for those working offshore, who are exposed full-time to several different hazards from process equipment, risers or blow-outs, ship collisions, helicopter accidents, extreme weather, etc.

At present, there are several sophisticated techniques, models and software already developed, that can be used in probabilistic risk analysis. However, general criteria for the acceptability of estimated risks have not been suitably developed, although several attempts have been made, and the question: "How safe is safe enough?" still remains without an appropriate answer.

Within this context, this Thesis presents a brief description of techniques and models presently used for risk evaluation, as well as legislation concerning risk tolerability criteria and other proposed safety targets. Regarding the establishment of global safety criteria for offshore oil units, the focus of this work will be the development of a risk and reliability allocation methodology to achieve them.

From data collected from more than thirty Brazilian offshore oil units, some of them operating for more then ten years, individual risk values for offshore employees are going to be calculated.

Based on these values, obtained for the individual risk, and on a quantitative risk assessment performed for a Brazilian Floating Production Storage Offloading vessel, a risk and reliability allocation methodology will be proposed. This methodology provides a feasible model to allocate reliability and risk criteria for the main safety functions of an offshore unit in a self-consistent manner. It provides a method for design engineers to establish minimum reliability levels for the safety systems of an industrial facility, in order to achieve safety targets previously defined for it.

The application of a risk and reliability allocation model to the problem of setting criteria for a range of hazardous scenarios presented in the operation of an offshore oil production unit is a novel approach.

It is hope that the proposed methodology can contribute to a wider discussion about the establishment of a global measure for the evaluation of safety performance of offshore oil units.

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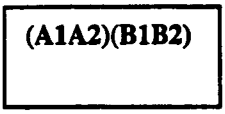
SYMBOLS AND NOTATION

FTO	Fail to operate
SO	Spurious operation
CSU	Critical safety unavailability
STR	Spurious trip rate
λ^{F}_{total}	Total rate of FTO - failure for a module (for a module of medium complexity).
C	Coverage, i.e., fraction of actual FTO-failure being detected by the built-in self-test.
c_M	Factor for module complexity.
TIF	Test-independent failure probability for FTO-failures. These are not detected by built-in self-test or manual functional testing.
$P_{k,\ k-1,2}$	Probability that "k" modules (of a specific type) fail simultaneously in a redundant configuration. This is the multiplicity distribution.
τ	Test period for manual functional testing (varies typically from one to three months for different module types).
I / O cards	Input / Output Cards
λ^{F}_{common} .	Rate of FTO- failures affecting all channels
λ^{S}_{TOTAL}	Total rate of SO-failures for a module (for a module of medium complexity).
C	Coverage, i.e. fraction of actual SO-failures being detected by the built in self-test.
LCC	Life Cycle Cost
LCA	Life Acquisition Cost
LSC	Life Support Cost
LSO	Loss due to Spurious Operation
CYR	Costs related to investments in resources for operation and maintenance of the equipment or system
CYC	Costs related to the yearly cost of operation and maintenance
CIE	Equipment cost
CIIC	Installation/commissioning cost
CIM	Management cost
Δ REL	Benefit obtained in terms of the oil and gas production saved and damage to the asset avoided due to the installation of safety systems at the facility.
Δ LL	Benefit obtained in terms of averted fatalities due to the installation of safety systems at the facility
CIEH	Component cost (hardware)
CIEA	Cost of necessary additional equipment
CIM	Management cost
CIMV	Vendor management and engineering cost
CIMC	Contractor management and engineering cost

CIIC	Installation/commissioning cost
CIR	Cost of investments in resources for operation and maintenance
CIRS	Cost of initial spare part stock
CIRT	Training cost
LUC	Critical unavailability
LL_{year}	Expected Loss of Lives per year
REL_{year}	Expected Residual Loss per year
fevent	Event frequency of an accidental event
Cevent	Expected Consequence of an accidental event
ΔNPV	NPV loss due to n months of delay of the enterprise as a whole
NPV_0	Original NPV of the enterprise with no delay
$(1+r)^{n/12}$	Discount factor
n	Number of months of delay
LSO_{year}	Expected loss per year due to spurious operation or unintended production shut-down
f_{spur}	Frequency of spurious failures
$Cost_{spu}$	Cost of spurious failures
SIL	Safety Integrity Level
FPSO	Floating Production Storage Offloading
PLC	Programmable logic controllers
xf	Fire detection system availability
xf'	Fire detection system unavailability
xg	Gas detection system availability
xg'	Gas detection system availability
pi	Pressure sensors system availability
pi'	Pressure sensors system unavailability
vi	Actuation system availability
vi'	Actuation system unavailability
c	CPU availability
c'	CPU unavailability
FAR	Fatal Accident Rate
AIR	Average Individual Risk
TSR	Temporary Safety Refuge
AIR	Average Individual Risk expression
ITSR	Frequency of Impairment to TSR
IER	Frequency of Impairment to Escape Routes

Single failure in module A

Multiple (double) failure in modules A and B. Failure events in which both modules fail simultaneously



Multiple failure: Second order dependence. Failure events in which four modules fail simultaneously. The two first modules are physically separated from the other two modules.

Detect SO

Double, detectable SO-failure in modules A and B

1. INTRODUCTION

Life is full of uncertainties and the simple fact that we are alive submits us to different types of risk during our daily activities.

As Benjamin Franklin has pointed out (letters 1789, Reid[1]): *'In this world nothing can be said to be certain, except death and taxes'.*

The acceptance of risks is a part of 'common sense' as is the rejection of unacceptable risks. However, the general principles that guide the acceptance of risks are a complex matter, which is being researched in different areas like engineering, psychology, sociology, toxicology, etc. In the same way, the determination of acceptable risks is a controversy task. Some risks are clearly 'accepted without a deeper knowledge about them, some known risks are accepted because it is believed that they can not be reduced or avoided, while other risks are 'accepted' or 'tolerated' because of their perceived benefits.

Therefore, it is possible to have an idea of the complexity and range of the matter we are going to discuss.

In order to provide a general view of the context, in which the acceptability of risks is inserted, we are going to present briefly, some current trends related to the subject, which are possible to be distinguished in the present scenario.

Mitchell[2], mentions that the first school of thought (Starr[3] is one of its members) sees the acceptance of risks as a technical decision, in which the comparison of the expected number of fatalities per year, for different industrial activities, provides the basis for the decision about the acceptability of risks by society, and for the establishment of priorities in decision-making processes. The basic principles and methods, which guide the development of such comparisons and decision bases, include 'revealed preferences'; risk comparison tables and risk decision analyses, which are usually composed by cost-benefit analyses. This approach aims to establish acceptable levels of risk that could be quantified, taking into consideration a series of different hazards and local features.

Other schools of thought (Fishhoff et al.[4], Kahneman et al.[5], Slovic et al.[6]) see the acceptability of risk as a problem of decision making, which involves technical and psychological dimensions. One of these lines is based on heuristics, in psychometric studies of individuals among different groups, in order to establish differences in the perception of risks, through qualitative dimensions. Mitchell[2] mentions that other schools (Ruckeshaus 1984, Thomas, 1986) expanded this concept, inserting in the acceptability risk approach, new topics like confidence, equality and social justice, in order to define the acceptable risk as a societal-political confronts between options, in which risk to health is only one of the items that should be considered.

Unfortunately, the basic principles that should be followed for risk assessment studies are difficult to identify and there is no simple way to ensure that a decision based on risk assessment is 'correct' (Reid[1]). This had partially led to a lack of confidence in decisions concerning risks, on the part of decision-makers and on the part of those affected by the decision.

Several industrial activities involve risks, including risks to life, risks of unserviciability, risks to environment and financial risks.

Many of those risks can be reduced through the use of suitable design procedures, safe work practices and operating procedures, but some residual risks still remain and sometimes can not be avoided.

There is a wide range of engineering standards that establish procedures to be followed in the design and operation of industrial installations, in order to assure acceptable levels of risk to workers, to general public and to industrial owners. These standards were introduced to provide a basis for dealing with a multitude of tasks and hazards, and often it is necessary to analyse them carefully before applying them without restrictions.

Present regulations usually prescribe procedures for the design, construction and operation of industrial installations based on past experience. Engineers have had a lot of success in establishing standards that were well accepted by the community and they became responsible for ensuring that those standards will be improved or refined, in order to follow technological evolution. Many engineers and scientists have been dedicating their efforts to the development of models that can describe the behaviour of physical systems and releases of toxic or flammable chemical materials. This has contributed a lot to the improvement of risk assessment techniques.

At the moment there is an increasingly demand toward the use of formal safety assessment as part of the effort to improve the level of safety for industrial workers and to reduce the costs involved on major industrial accidents.

Also due to a wider awareness of environmental problems, there is a special interest in the improvement and use of risk assessment techniques, as well as in the establishment of explicit acceptability criteria, that can contribute to safety of industrial installations and to decision- making processes related to risk.

Recently published offshore legislation in several countries (including Great Britain, Norway, Netherlands) requires the use of quantitative risk assessment (QRA) techniques.

Early approaches to engineering safety were based on deterministic concepts, according to which safety was assured by making some conservative assumptions in the design of industrial systems, as well as through the use of safety factors, based on engineering judgement. Recent safety approaches are based on probabilistic concepts, in reliability techniques and consequence modelling, according to which safety is defined in terms of acceptable probabilities or frequencies of failures and severity of consequences. These two items will form the basis for the evaluation of industrial risks.

AIChE[7] defines risk analysis as: *The development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining* *estimates of incident consequences and frequencies'.* Therefore, risk assessment techniques are based in the presumption that risks can be represented in terms of probabilities of failure and the seriousness of possible outcomes of risk producing processes.

Techniques for safety assessment are particular relevant for those working offshore, once they are exposed full-time to several different hazards, as for example releases of hydrocarbons from process equipment, risers or blow-outs, ship collisions, helicopters' accidents, falling objects, extreme weather, etc.

The quantitative risk assessment technique is today in widespread use in the offshore industry, as well as in nuclear and chemical industries, being applied to fundamental questions of conceptual design and detailed engineering design. It also subsides decisions concerning layouts and locations of industrial installations.

Quantitative risk assessment provides a tool for the engineer to quantify risk and analyse risk reduction strategies. Individual contributors to the overall risk can be identified and prioritised. A range of risk reduction measures can be applied to the major hazards and assessed, using cost-benefit analysis.

The recognition of quantitative risk assessment as an important decision-support technique in offshore industry has developed over a considerable length of time. The publication of 'Guidelines for Safety Evaluation of Platform Conceptual Design', in 1981 by Norwegian Petroleum Directorate[8], has introduced the use of quantitative risk assessment in offshore installations. The publication of this methodology had a major impact on the design concepts in Norwegian sector of North Sea and has strongly influenced the performance of quantitative risk assessment studies and offshore legislation in other countries.

At present, there is a trend in offshore safety legislation to adopt the setting of safety objectives as the prime means of regulation and corporate safety management, rather than the prescription of the means of achievement. This radical change in safety regulations is in the line with the philosophy of the Health and Safety Executive of

UK that places a strong emphasis on operators to reduce risk to a level that is 'as low as reasonable practicable' (ALARP).

Quantitative risk assessment techniques can be used as a part of a safety management program providing a logical structure within which design and operation decisions can be taken as well as performance measures.

Therefore, there are several sophisticated techniques, models and softwares already developed that can be used in probabilistic risk analysis. However, the establishment of general criteria that contributes to the acceptability of estimated risks has not been suitably developed, although several attempts have been made, and the question: 'How safe is safe enough?' still remains without an appropriate answer (today there is currents that ask: 'How fair is safe enough?').

Reid[1] mentions that the societal acceptance of technological risks is a very important task in decision-making processes. This subject has widely been researched and there is a lot of literature already available about it, which evolution has been very fast.

There was a stimulus for the development of research in this area due to controversies associated with the employment of complex technologies, including the determination of the location of nuclear industries, deposit of dangerous waste, the use of chemical toxic materials, etc. Such controversies have highlighted the urgent need of governmental measures to face the problem, despite the uncertainties associated with the available scientific methods, and the difficulties to obtain an agreement in public opinion within democratic decision-making processes.

As Reid[1] remarks, the establishment of clear acceptability criteria can be useful to governmental authorities, as they could verify the methods and results obtained from risk assessment studies. It would also provide a satisfactory way to control risks, in a societal point of view, without undue regulatory complications. Engineers would also be happy to count with a well and clearly established acceptability criteria, so that they could take 'correct' decisions and demonstrate compliance with regulatory requirements. The society as a whole body would have benefits, as it could have a wider control, based on the established criteria, over the risks to which it is submitted, as well as it could require the execution of the suitable legislation.

The technology of determination of risks is controversy in itself, and there is a great need of the establishment of acceptable references, as a basis for the use of probabilistic risk assessment methods, in order to subside risk management and engineering regulations.

From a technological point of view, the existent quantitative methods of risk assessment and acceptability criteria might appear to be sufficient for the purposes of risk assessment and regulations. The determination of acceptable risks, however, depends also on the judgement of values by society, which can not be standardised.

In the UK, the use of acceptable risks as a guiding principle was criticised by Lord Layfield, who chaired the public inquiry into the Sizewell B nuclear plant (Pidgeon et al.[9]). He suggested that the phrase tolerable risk would better reflect the seriousness of the task. Health and Safety Executive produced a report, as a result of Sir Layfield inquiry, where the concept of 'tolerability' or 'tolerable' risk is defined as following (Pidgeon et al.[9]):

***Tolerability** does not mean **acceptability**. It refers to the willingness to live with a risk to secure some benefits and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce still further if and as we can'. (HSE 1988a, p.1).*

Therefore, according to this approach, risks should be monitored, the benefits should be balanced and the risks should be, wherever possible, reduced to a level 'as low as reasonably practicable' (ALARP principle).

This approach emphasises the need of safety measures to face residual risks, as well as potential accidents that could be detected during the design of industrial installations.

It also emphasises the importance of the communication of risks, regarding public tolerability to certain technologies.

Anyway, we can conclude that the acceptability or tolerability of risks should not be a variable previously determined, to be imposed to public or workers in decision-making processes, but the product of these processes. Risks should be continuously controlled by different societal actors (public, industry, environmental authorities) in a dynamic process, in order to have the industrial activity systematically evaluated (or re-evaluated) against several criteria or methods.

Quantitative risk assessment techniques provide a powerful tool for the engineer to evaluate risks and analyse risk reduction strategies. It provides safety insights and the identification of the vulnerabilities of any industrial facility. Individual contributors to the overall risk can be identified and prioritised.

1.1 Objective of the Thesis

This Thesis presents a methodology for allocating risk and reliability between various safety functions of an offshore oil production unit. It intends to contribute to risk and safety decision making processes, establishing reference values or safety criteria (in terms of individual risk to workers and maximum tolerable frequency of impairment to Temporary Safety Refuge) to safety functions existent in any offshore unit, based on quantitative risk assessments previously performed.

It will be of interest for design engineers and maybe for policy makers, for insurance purposes or for any other parties involved with risk and reliability.

The methodology presented in this Thesis provides a way of evaluating the global safety of an industrial facility. It provides a method for design engineers to establish minimum reliability levels for safety functions of an industrial facility, in order to achieve safety targets previously defined. It is a tool for evaluating how much will be gained in terms of individual or societal risk, or in terms of other safety targets (as for example, the maximum frequency of impairment of accidental events to a specific place in the facility) when improving the availability of safety functions. As a consequence, it allows the analyst to evaluate the feasibility of achieving these proposed safety targets.

The methodology proposed in this work provides a wider insight through the unit's safety that is not usually obtained with common risk assessment approaches.

Quantitative risk assessment is a fundamental element for the allocation model presented in this work. The cost element is another essential component, one it also plays a fundamental role in the whole picture involved in risk decision-making processes. It will be carefully taken into account in the methodology proposed here.

This Thesis is also an attempt to explore others aspects of the potential role that risk assessment may play as a safety or management tool. The presented methodology requires that the analyst go through the very nature of quantitative risk assessment, through the process of delineating and quantifying all accident sequences and computing availability and risk indices toward the target lines.

On the basis of this context, this Thesis is going to present the current 'state of art' in terms of the evaluation of risks of offshore oil platforms, regarding legislation, techniques and models presently used for that.

It will present individual risk criteria for offshore employees, based on data collected from more than thirty Brazilian offshore oil units.

Based on a quantitative risk assessment performed for a Brazilian Floating Production Oil Storage Offloading vessel and using the allocation model proposed, unavailability values are going to be calculated for the vessel's main safety systems, in other to achieve the best global safety levels for the installation, considering costs and safety targets previously defined.

It is hope that these reference values and the proposed methodology can contribute to a wider discussion about the establishment of a global measure for the evaluation of the safety performance of offshore oil facilities, as well as about the way for the achievement of the safety targets defined.

1.2. Thesis Organisation

This Thesis will present in its second chapter an overview of the offshore legislation concerning risk assessment, frequencies of impairment to safety functions and the establishment of safety goals, applied or recommended in countries like Great Britain, Norway and Netherlands. Different risk acceptability or tolerability criteria adopted in different countries will be described in this chapter.

In the third chapter we will present the main topics, which compose the methodology for the evaluation of risks of offshore oil units, based on techniques and models currently used in quantitative risk assessment studies.

In chapter four we will describe the model proposed for the allocation of risk and reliability in detail, which comprises the presentation of the expressions of the average societal risk and of the average individual risk as a function of safety systems' availability or unavailability variables, as well as a reliability prediction model and a lifecycle cost model.

In chapter five we will present the allocation model application, as well as the results obtained from it in terms of unavailability or availability values for the FPSO's safety systems, regarding the optimisation of individual risk and cost expression. This chapter includes the presentation of Fatal Accident Rates (FAR values) and individual risk values for offshore oil Brazilian's workers. Therefore, data collected from more than thirty offshore oil facilities, which operate in Campos Basin (Brazil) will be presented.

In chapter six, an analysis of the main conclusions derived from the model application will be performed and a discussion about the results will be presented.

2. Offshore Legislation Concerning Risk Assessment

2.1 General

The history of occurrence of major accidents and the publicity associated with them has shown that they are a fundamental contributor factor to the evolution process of standards and regulations, as well as to the implementation of new requisitions or revision of old ones. They also constitute a strong appeal to a wider commitment from governmental authorities and society.

The occurrence of some major accidents in Europe during the 1970s, like the one which took place in Seveso, Italy, in 1976, where a release of dioxin resulted in an unwanted and widespread contamination, led to a recognition of differing standards of control over industrial activities within the European Community (EC). This led the EC Commission to prepare a Directive on major industrial accident hazards.

Since the publication of Seveso Directive, in 1982, several laws were issued concerning to risk management in process industry and quantitative risk criteria were proposed in several European countries.

Therefore, in the 80's decade, there was an increasingly trend for the introduction of risk assessment techniques in a more systematic way.

In the USA, several hazard identification techniques have been being employed, specially HAZOP, and also some quantitative risk techniques. Some American states have already stated regulations, which require the use of quantitative risk analysis from their process industry.

Table 3.1 illustrates some "current national practices" requested when a new enterprise is trying to obtain an operation licence (for non-nuclear onshore installations).

In this section, we will present a brief description of the most significant aspects of the current offshore legislation applied in countries like Great Britain, Norway and Netherlands.

2.2 Offshore Current Legislation

2.2.1 Norway

The Norwegian document named "Guidelines for Safety Evaluation of Platform Design", issued in 1981, by Norwegian Petroleum Directorate[7], and had introduced several concepts for the implementation of risk analysis, which have formed the basis for performing risk analysis in Norwegian petroleum activities and also in other countries.

These guidelines were extensively discussed and applied in offshore industry. They were only applied for safety evaluation and analysis of a completed platform in the operational phase (Oslad[13]).

The NPD Guidelines presented several concepts that were followed by industry when performing offshore risk assessment studies. Therefore, the main concepts used in this document are going to be described below, as they played a significant role in offshore risk assessment area and also to provide a better understanding about the causes that led them to be later reviewed and replaced by a new regulation issued by NPD[14] in 1991, based on the experience acquired after the implementation of them in 1981.

Definitions (NPD[7]):

"Accident: an unwanted incident or condition which is not assumed to occur during normal operation, and which can cause significant damage unless it is taken into consideration during design."

Country	Installation Classification	Hazard Identification	Partial Quantification	Probabilistic Evaluation	Quantified Objectives
Belgium	Yes	Mandatory	Sometimes	No	No
Canada*	No	No	Rare	Some	No
Denmark	Yes	Mandatory	Rare	Some	Some cases
Finland	Yes	Mandatory	Sometimes	Some	Some cases
France	Yes	Mandatory	Frequent	Rare	Occasional
Germany	Yes	Mandatory	Sometimes	No	Occasional
Greece	Yes	Mandatory	Uncommon	No	No
Italy	Yes	Mandatory	Uncommon	No	No
Japan	Yes	Mandatory	Rare	Rare	No
Luxembourg	Yes	Mandatory	Uncommon	No	No
Netherlands	Yes	Mandatory	Frequent	Yes	Yes
NSW	Yes	Yes	Yes	Yes	Yes
New Zealand	Yes	Uncommon	Uncommon	Some	No
Norway	Yes	Mandatory	Sometimes	Some	Some cases
Sweden	Yes	Mandatory	Uncommon	No	No
Swiss	Yes	Mandatory	Sometimes	Some	Some cases
Great Britain	Yes	Mandatory	Frequent	Some	Some cases
USA	Yes	Yes	Yes	Some	No

Table 2.2.1.1- Current National Practices (Cassidy[12])

*National level

Accidental event: an accident in combination with other conditions (e.g., weather conditions) which can affect the accidental effect.

Design accidental event (DAE's): accidental event, which is the basis for the design evaluation to satisfy the acceptance criteria, outlined in chapter 5 (of the NPD Guidelines)

Design accidental effect: effect of the design accidental event expressed in terms of heat flux, impact force and energy, acceleration etc., which is the basis for safety evaluations".

In the section 4.1.2 of the NPD Guidelines[7] we find:

"The aim of the safety evaluation is to establish acceptable safety in compliance with given criteria. The intention is not to include calculation of residual risk (RAE's) (i.e. probability and consequences of accidents which still may occur)".

Regarding the type of event that should be considered, the same document presents a list of them, that should be taken into consideration where relevant (NPD[7], section 4.1.3.):

"

- *Blow-out*
- *Fire*
- *Explosion and similar incidents*
- *Falling objects*
- *Ship and helicopter collisions*
- *Earthquakes*
- *Other possible relevant types of accidents*
- *Extreme weather conditions*
- *Relevant combinations of these accidents".*

In its section 4.1.4.:

"The accidents mentioned in section 4.1.3 may follow from primary failures, for example: blow-outs, fracture in riser pipes, etc. These primary failures do not require individual consideration as long as the resulting effect is accounted for an accident under section 4.1.3.".

And in section 4.2.1:

"For the section that are relevant to the acceptance criteria outlined in chapter 5, the licensee should specify a set of design accidental events, In principle, the design accidental events shall be the most unfavourable situations relative to the acceptance criteria".

Regarding the acceptance criteria NPD Guidelines presents the following figure (section 4.2.2):

"In practical terms, it may be considered necessary to exclude the most improbable accidental events from the analysis. However, ***the total probability of occurrence of each type of excluded situation should not by best available estimate exceed 10^{-4} per year for any of the main functions*** *specified in 5.2, 5.5 and 5.6."*

In sections 5.1.5.2, 5.5 and 5.6, the Guidelines presents the **acceptance criteria** described below:

5.1. *"The platform design must be such that a design accidental event does not impose a danger to personnel outside the immediate vicinity of the accident".*

5.2. *"Section 5.1. Can be considered satisfied by complying with the following criteria:*

a) At least one escape way from central positions which may be subjected to an accident, shall normally be intact for at least one hour during a design accidental event;

b) Shelter areas shall be intact during a calculated accidental event until safe evacuation is possible;

c) Depending on the platform type, function and location, when exposed to the design accidental event, the main support structure must maintain its load carrying capacity for a specified time".

As we have mentioned, after the experience acquired with the implementation of these guidelines, NPD[14] have revised and replaced them for the new regulations, named "The Regulations concerning implementation and use of risk analysis in petroleum activities with guidelines", which entered into force in 1991. These new regulations are applicable to all phases of an offshore enterprise and also for planning, implementation, use and updating of risk analysis.

A key point in the new Regulations is that the operators shall establish safety objectives for their activities. As mentioned by Olstad[13]: *"The safety objective is meant to be ideal goals, which ensure a dynamic safety evolution and promotion".*

The new Regulations also requires that the operator define risk acceptance criteria for the activities, where the risk is related to loss of human life, personnel injury, damage to environment and loss of assets and financial interests. In its chapter IV, section 11 the NPD regulation[14] states:

"The operator shall define acceptance criteria for risk in the activities. The acceptance criteria shall be defined before a risk analysis is carried out."

The results of risk analysis studies should then be compared with the acceptance criteria that has been previously established, in order to decide if the calculated risk level is deemed acceptable or whether risk reducing measures should be implemented, following the ALARP criteria.

The new NPD Regulations are based on the new principles of safety management that uses overall goals to be achieved, using risk assessment studies and defining an acceptability criterion. The safety objectives to be established define long and short-term goals for safety, while the acceptance criterion is used to define the limits of acceptability for risks at a defined moment (Osltad[13]).

Some of the definitions used in the 1981 NPD Guidelines were replaced by others in new regulations. Some of them are described below, as they also have changed "the approach" of offshore risk assessment studies.

As we can observe in the definitions presented in NPD Guidelines of 1981, the concepts of Design Accidental Events (DAE's) and Residual Accidental Events

(RAE's) formed the bases for many risk assessment methodologies presented to authorities as safety cases, These terms have been replaced by one single term in the new NPD Regulations[14], which is named *"Dimensioning Accidental Event"*. Its definition is given below (NPD):

"An accidental event which according to defined acceptance criteria represents an unacceptable risk, and which consequently serves as a basis for the design and operation of installations and otherwise for the implementation of the activities"

The NPD new Regulations[14] also states in its chapter IV, section 16, named "Risk reducing measures" the following:

"Risk reducing measures shall be implemented for each defined dimensioning accidental event so that:
a) Personnel outside the immediate vicinity of the accident are not injured,
b) Evacuation, on and from the installation can be carried out in a safe and organised manner,
c) Personnel can remain safe in one or more areas on or in conjunction with the installation, until safety evacuation is expected to be carried out,
d) Control rooms and any other areas of importance to combat an accidental event remain operative until safety evacuation is expected to be carried out,
e) External assistance can be received and carried out effectively,
f) Damage to the environment as a result of oil spillage is avoided".

And in the same section:

"Probability reducing measures shall, to extent as possible, be given priority over consequences reducing measures."

There are other aspects in NPD Regulations[14] concerning acceptability criteria that may be pointed out (section 11):

"The acceptance criteria express the level of risk deemed acceptable by the operator for a given period or phase of the activities. The need for risk reducing measures is assessed

With reference to the acceptance criteria, which must consequently be defined before the implementation of a risk analysis"

And in item Til 12: *"The acceptance criteria may be defined both in quantitative or qualitative terms, depending inter alia on the mode of expression of risk". "...When quantitative acceptance criteria are used, clearly define limits for their application must be stipulated". "...When qualitative acceptance criteria are used, the condition for their application should be similarly defined".*

Regarding the presentation of qualitative criteria, Olstad[13] presents the following example shown in figure 3.1. This example shows a matrix, which grades qualitatively, probabilities and consequences in order to obtain a ranking of risks.

What it is possible to observe, from different uses of the terms published by NPD Guidelines[7], is that there was an effort by industry, to interpret or to adapt the definitions employed in these Guidelines, in order to use them in risk assessment studies that should be presented to authorities. As the definitions of the terms were not clear in this document, there were different interpretations of the concepts proposed, all over the industry.

In Great Britain and Netherlands, the present legislation concerning offshore risk assessment is strongly influenced by Norwegian regulations, as we will show in the next sections.

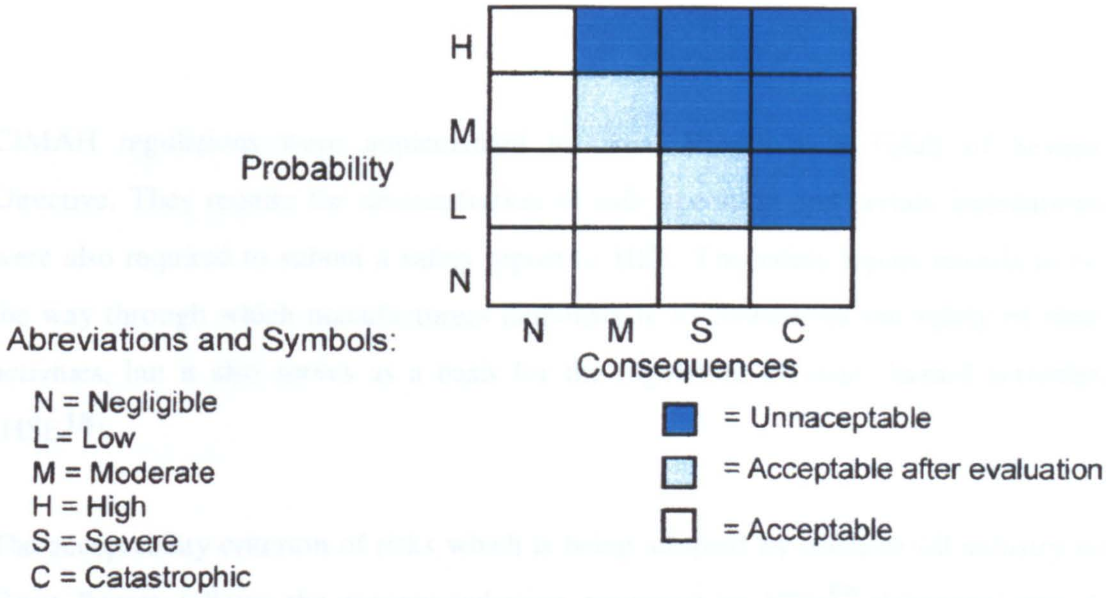


Figure 2.2.2.1. - Acceptance Criteria in Risk Analysis (Olstad)

It is also worth mentioning, that there is a recent standard named NS-5814, published by Norsk Standard[15] in 1991, which intends to be a guideline for the planning, execution and use of risk analysis.

2.2.2.Great Britain

The most frequently applied techniques in the UK sector in the 1980's were HAZOP and Fault Tree Analysis, which were employed to specific isolated cases. Prior to the Piper Alpha disaster, it was not common to find full risk analysis performed in UK platform sector (Cox[16]). Since this disaster, few full risk assessment studies have been performed for UK platforms, but these studies have not been published.

After the occurrence of the Piper Alpha explosion in an offshore installation in 1988, which took 167 lives, a public inquiry was established and conducted by Lord Cullen. The Lord Cullen report resulted in several recommendations which were incorporated in British offshore regulations and were consolidated in a publication, named "A Guide to the Offshore Installations (Safety Case) Regulations", issued in 1992, by Health and Safety Executive[17] (HSE). These recommendations were influenced by HSC/E's[18] experience of regulating major hazards onshore under the Control of Industrial Major Accident Hazards Regulations 1984 (CIMAH).

CIMAH regulations were implemented in Great Britain as a result of Seveso Directive. They require the demonstration of safe operation and certain installations were also required to submit a safety report to HSE. The safety report intends to be the way through which manufacturers demonstrate to themselves the safety of their activities, but it also serves as a basis for the regulation of major hazard activities (HSE[18]).

The acceptability criterion of risks which is being adopted by offshore oil industry in Great Britain follows the recommendations proposed by HSE[19] document named "The tolerability of risk from nuclear power stations", which describes the framework on which risk control is based. This framework reflects long established approaches, not only in UK practises but also more generally expressed views such as those of the International Commission on Radiological protection (ICRP) in 1977 and the report of the Royal Society Working Group on Risk Assessment[20]. These documents state that having assessed or estimated a risk, it is necessary to determine:

(a) Whether a given risk is so great or the outcome so unacceptable that it must be refused altogether, or

(b) Whether the risk is, or has been made, so small that no further precaution is necessary,

(c) If a risk falls between these two states, that it has been reduced to the lowest level practicable, bearing in mind the benefits flowing from its acceptance, and taking into account the costs of any further reduction. The injunction laid down in safety law is that risk must be reduced so far as reasonably practicable, or to a level which is "as low as reasonably practicable" (the ALARP principle).

Figure 2.2.2.1 illustrates the ALARP principle.

The HSE Guidelines[17] in the section *'Risk assessment: broad objectives and methodology' states* the main elements of demonstration required in a safety case:

"

(a) A description of hazards identified as having the potential to cause a major accident (including reference to actions taken to eliminate or minimise such hazards);

(b) Evaluation of the likelihood that the major hazards will be realised, and of the potential consequences (including references to preventive measures in place and their assessed effectiveness);

(c) Evaluation of the risks to persons from the consequences of major accidents (including reference to protective measures and their assessed effectiveness);

(d) In the light of previous stages, confirmation that the risk to persons described under (c) is as low as is reasonably practicable; or a description and evaluation of proposed additional preventive and protective measures which will reduce risks to required level;

(e) Description of time scales for implementing any such remedial measures, and of temporary safeguards to be applied in the interim".

The HSE Guidelines[17] in its paragraph 109, item b the following:

" *Design events: The duty holder should show that the design events on which the demonstration is based would not cause the loss of integrity of any of the following:*

(i) the passability of at least one access route to temporary refuge from each potentially manned location on the installation;

(ii) A minimum complement of embarkation points and TEMPSC specified for personnel taking temporary refuge; and

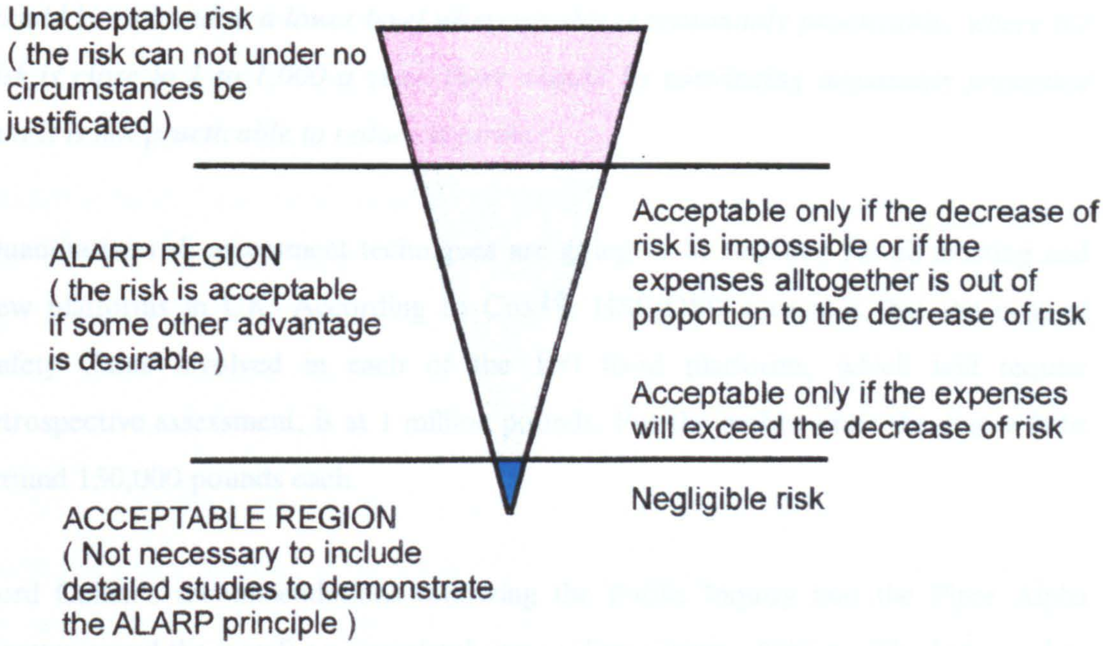


Figure 2.2.2.1 - Risk Level and ALARP Principle (OLF)

(iii) The passability of at least one evacuation route to each of these embarkation points".

Taking into consideration the results of quantitative risk assessment (QRA), this document requires a demonstration in the safety case, that the performance standards established for temporary refuge, etc., will reduce risks to person to as low as reasonably practicable, regarding the measures adopted to prevent and reduce the effects of major accidents. According to HSE Guidelines[17], paragraph 116:

"This requires estimation by QRA of the frequency of 'extreme events' together with those 'design events' where (e.g. because of unanticipated component failure or human error) the Temporary Safety Refuge (TSR) system fails to maintain its integrity for the full period assumed in the design;

And in its paragraph 117: *"In keeping with the concept of maximum tolerable risk, HSE will look for a demonstration that the frequency with which accidental events will result in loss of integrity of temporary refuge, within the minimum endurance time stated in the safety case, does not exceed the order of 1 in 1,000 a year. Risk* *should be reduced to a lower level wherever this is reasonably practicable; where the risk is close to 1 to 1,000 a year, there should be convincing arguments presented that it is not practicable to reduce it further".*

Quantitative risk assessment techniques are going to be required for all existing and new platforms in UK. According to Cox[16], HSE/OSD estimates that the cost of Safety Cases involved in each of the 100 fixed platforms, which will require retrospective assessment, is at 1 million pounds. For the mobile units the cost will be around 150,000 pounds each.

Lord Cullen's recommendations following the Public Inquiry into the Piper Alpha disaster paved the way for a completely new safety regime offshore. The Industry has implemented all his recommendations. The Health and Safety Executive (HSE) has replaced the old prescriptive regulations with new goal-setting regulations that set objectives. The duty holder determines the most appropriate safety measures to reduce risks to as low as reasonably practicable.

The cornerstone of the new regime is the Safety Case for each installation that the Duty Holder must prepare and have accepted by the HSE. An essential ingredient of the Safety Case is the involvement of the workforce. Operators have made great progress in tapping this valuable resource for experience, knowledge and ideas and has created a comprehensive system of Safety Committees covering every installation.

The Industry view is that goal-setting Regulations should be supported by non-mandatory guidance preferably created by the Industry itself through its associations such as UKOOA. These assist Operators when setting their own standards of performance that, provided they followed the guideline, would be based on "good practice" as defined by the Industry. This approach is entirely consistent with Lord Cullen's recommendations.

Where Industry Guidelines are in place and serving their intended purpose there should be no need for the HSE to issue its own Technical Guidance in support of the Regulations.

The influence of Lord Cullen's recommendations has spread beyond the UK. A meeting of the International Labour Organisation in Geneva in 1993 concluded that the first priority of the ILO was "*to promote the adoption on a world-wide basis of the principle of Self-regulation based on Safety Management Systems within a framework of goal-setting regulations, and full workforce involvement at national and company level in safety matters in the Offshore Petroleum Industry*".

The benefits of these dramatic changes are now being realised. The risk of another major accident is lower, probably by as much as an order of magnitude. This was confirmed by the Interim Evaluation of the Safety Case Regulations carried out by HSE in 1995, which concluded that there is evidence of a substantial reduction in risk.

There has been a steady fall in the frequency of reported injuries. In 1994/95 injuries resulting in three or more days off work fell to less than half of the level in 1989/90, the year after Piper Alpha. The frequency of serious injuries has been more resistant to improvement but did fall significantly in the year 1993/94 and 1994/95 to a level 40% lower than in 1989.

In conclusion, the Industry is improving safety offshore. The Safety Case philosophy is working. The new goal-setting Regulations will consolidate the regime and encourage Operators to achieve their aims for continuous improvement. Lord Cullen, in his painstaking analysis of the evidence given to him, made recommendations that are exerting a powerful influence throughout the world. The Offshore Industry has implemented his recommendations and is beginning to experience real and tangible improvements in safety offshore. "Good safety is good business" is more than a slogan, it is a fact.

The Motivation for Change

In his report published in November 1990, Lord Cullen set the scene for a completely new safety regime offshore. His 106 detailed recommendations covered every aspect of offshore safety. Three of them in particular provided the motivation for the change from the old prescriptive regulations of the past to the goal-setting regulations that are in place today. Lord Cullen recommended that:

- The administration of offshore safety should be transferred from the Department of Energy (DEn) to the HSE.
- The present array of detailed prescriptive regulations should be revoked and replaced with goal-setting regulations.
- The Operator should be required by regulation to submit to the regulatory body a Safety Case in respect of each of its installations.

In making these recommendations, Lord Cullen paved the way for the Offshore Industry to be regulated according to the principles established by Lord Robens in 1971 and which were gradually being adopted by the HSE in formulating new regulations onshore. Lord Robens pointed out that it was impractical for regulations to prescribe precisely what safety precautions should be taken in any given situation and therefore safety would be enhanced if the Regulator set safety objectives, leaving the determination of the detailed precautions to the Duty Holder. Where appropriate the Regulator and/or the industry concerned would publish guidance to assist Duty Holders to achieve the goals set by the regulations.

The Old Style Regulatory Regime

To fully appreciate the change that has taken place in the Offshore Industry, it is necessary to understand the previous regime and why it did not deliver the high standard of safety that was its objective.

Under the former UK regulatory system, there was potential for confusion by Operators in dealing with the various authorities that administered the regulations. For example, the sections of the Health & Safety at Work Act (HSWA) 1974, which were applied offshore were administered by the DEn under an agency agreement granted by the Health & Safety Commission (HSC), which administered the HSWA on behalf of the Department of Employment. The regulations, made under the Mineral Workings Act, covering active fire-fighting, life saving appliances and standby vessels were administered by the Department of Transport (DoT) under an agency agreement granted by the DEn. The certification of the installation as fit-for-purpose was carried out by independent Certifying Authorities (CAs) on behalf of the DEn. Finally, DEn Inspectors carried out offshore inspections themselves.

These complex administrative relationships are illustrated in Figure 2.2.2.2.

This complex web of surveys and inspections was supported by Guidance Notes, then in their 4th Edition, which laid down quite prescriptive methods for designing and equipping offshore installations. Although these Guidance Notes were revised from time to time, they tended to inhibit duty holders from seeking innovative solutions to design, construction and operating problems.

Lord Cullen recommended that in place of this complex control of the regulatory system there should be a single regulatory body for offshore safety, and that this should be the HSE. In response to this recommendation, a new Offshore Safety Division of the HSE was formed which took over the administration of offshore safety on 1 April 1991.

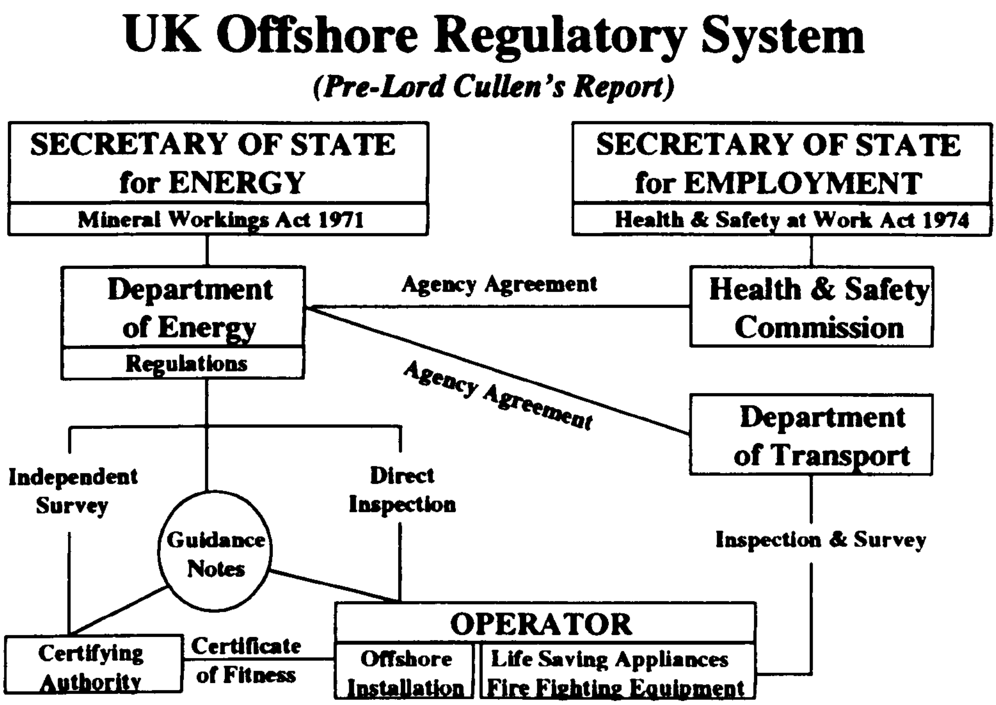


Figure 2.2.2.2 – UK – Offshore Regulatory System

Goal-Setting Regulations

Lord Cullen recommended also that the Construction & Survey Regulations, the Fire-Fighting Equipment Regulations, the Life Saving Appliances Regulations and the Emergency Procedures Regulations should be revoked and replaced by goal-setting Regulations. Operators should be encouraged to specify the standards that they will use to comply with the goals established by these new regulations. For a given installation compliance may be demonstrated by reference to such standards, the terms of guidance notes and what is shown by safety assessments.

This approach to safety regulations is completely in accord with the evidence given by UKOOA at the Piper Alpha Public Inquiry.

The New Goal-Setting Regime

The goal-setting regulations recommended by Lord Cullen are now in place and the architecture of the new regulations is illustrated in Figure 2. The contrast with the past is very evident.

- All the health and safety regulations that apply to offshore installations, pipelines and wells are made under the HSWA and are administered by the HSE; so there is no longer scope for Operators to be confused by having to deal with more than one regulatory authority.

- The Safety Case is the primary engine demonstrating that major hazards are identified and risks reduced to as low as reasonably practicable (ALARP). It is also a vehicle for demonstrating compliance with the other regulations. The Safety Management System ensures that the organisation, resources, roles and responsibilities are suitable and are documented, understood, carried out and subjected to audit.

- The Safety Case embraces every hazard that could cause a major accident. It is a holistic approach that leaves no gaps, unlike the former regime in which pipelines and risers were not subject to the independent survey for the Certificate of Fitness. The system of certification, which was carried out by the CAs appointed by the Secretary of State, has been replaced by a system of verification by independent and competent persons, appointed by the duty holder, of safety-critical elements identified by the Duty Holder using the Safety Case.

Direct inspection of particular items by Inspectors from the DEn or DoT has been replaced by comprehensive audits by HSE to ensure that the Duty Holder is operating in accordance with the systems and procedures described in the Safety Case. HSE has issued Improvement Notices to Operators who have failed to operate their installation according to their own procedures as described in the Safety Case.

This approach places the whole responsibility for safety on the duty holder where it belongs. It motivates the duty holder to focus on major hazards, on safety-critical elements and on systems and procedures that ensure that the safety goals are achieved and risks are ALARP.

It is important to recognise that the lack of prescriptive standards in the new goal-setting regulations does not mean that duty holders can adopt unsuitable safety practices. In an Industry that uses heavy equipment to produce and transport oil and gas at high pressure, there are many hazards that have to be managed safely. In a goal-setting regime, duty holders must identify these hazards, eliminate them by good design if possible; otherwise by selecting appropriate materials and procedures reduce the risk that the hazard presents to ALARP.

This is an onerous responsibility. No longer can duty holders take shelter behind a prescriptive regulation that sets a standard that may not be suitable for the particular circumstances. Instead a safety assessment must be made, taking into account all the local circumstances, and the risk reduced to ALARP. The advantage to the duty holder is that there is no restriction on the way in which the risk is reduced. This flexibility paves the way for the introduction of new technology and innovative solutions.

Workforce Involvement

An essential ingredient of the Safety Case holistic approach is the involvement of the workforce including non-technical support workers, technicians, operators, supervisors and managers. Operators have worked hard and made great progress in tapping this valuable resource for its experience, knowledge and ideas. Although some aspects of safe design such as structural integrity, which requires complex engineering analysis and quantitative risk analysis, are not easily understood or accessible to the majority of the workforce, there are many safety issues which are The identification of hazards likely to cause fire and explosion and the preparation and testing of emergency procedures are examples where the workforce on site is well placed to participate in the creation of the Safety Case.

The Offshore Industry has created a comprehensive system of safety committees. On every offshore installation, safety representatives are elected by groups of no more than 40 of their fellow workers to represent their interests and concerns. These safety representatives are automatically members of safety committees that meet regularly and discuss all aspects of safety. Safety representatives are trained to undertake their role, which includes an understanding of safety legislation, the identification of potential safety hazards and the representation of safety issues and concerns to the management and their constituents.

All these changes have brought about a cultural shift in attitudes towards safety. A safe place of work can only be created through Management Systems that ensure a partnership between good design, suitable equipment and safe operating practices carried out by a workforce that is fully aware of safety issues and understands their role. The offshore industry has made tremendous progress in introducing and encouraging safe attitudes through an increasing involvement of its workforce.

The Role of Guidance

The Industry view is that goal-setting Regulations should be supported by non-mandatory guidance preferably created by the Industry itself through its associations such as UKOOA. These assist Operators when setting their own standards of performance that, provided they followed the guideline, would be based on "good practice" as defined by the Industry. This approach is entirely consistent with Lord Cullen's recommendations.

Lord Cullen recognised the value of Guidance in supporting goal-setting Regulations. His Recommendation 17 made it clear that Guidance should give non-mandatory advice on one or more methods of achieving such objectives, without prescribing any particular method as a minimum to be taken in default of an acceptable alternative. He also supported Industry-published guidelines in, for example, Recommendation 101 where he said that drills and exercises should be carried out in accordance with UKOOA Guidelines.

UKOOA Guidelines set out what is widely held to be good practice. The current UKOOA Publications List includes over thirty guidelines on matters directly related to offshore safety. These publications play an important role in helping Operators and contractors to assess their own systems and operations and to amend them if they wish. Although they are non-mandatory, compliance with them is usually accepted by HSE Inspectors as evidence that safe working practices are being followed.

Industry Guidelines also assist Operators and contractors to comply with the goals set out in Regulations. Where Industry Guidelines are in place and serving their intended purpose there is no need for the HSE to issue its own Technical Guidance in support of the Regulations. The advantage of Industry taking responsibility for these Guidelines is twofold.

First, by "owning" the Guidelines Industry becomes more committed to their use. Second, they can be more easily and quickly updated.

The HSE is receptive to this view and has encouraged and supported the industry in its work to expand the range of "good practice" guidelines.

From the Industry point of view it is recognised that such Guidelines will have greater credibility if they are broadly based and include input from and reviews by the HSE and the workforce.

World-wide Influence of Lord Cullen's Recommendations

In 1993, in Geneva, a tripartite meeting of the International Labour Organisation (ILO) discussed safety issues relating to work on offshore petroleum installations, in particular the lessons learned from Piper Alpha and Lord Cullen's Report. Employer, Trade Union and Regulatory representatives from fifteen countries took part. The meeting concluded that the first priority of the ILO was " *to promote the adoption on* *a world-wide basis of the principle of self-regulation based on Safety Management Systems within a framework of goal-setting regulations, and full workforce involvement at national and company level in safety matters in the Offshore Petroleum Industry."*

Self-regulation by Industry means that the community, through its safety regulatory agencies, will set the safety goals. Industry will create the Safety Management Systems to achieve the goals using means, which best match, the requirements of the individual installation at its particular location.

When this important principle is followed all over the world it will help to create a working environment in which oil companies, most of which are multi-national in scope, will be able to harmonise their Safety Management Systems, thereby reducing the potential for disparity between different countries in their operations and in turn their safety performance.

This move towards the adoption of Lord Cullen's recommendations on a world-wide basis is very evident from the content of papers presented at international conferences. The theme of one of the Safety Sessions at the SPE International Conference on Health, Safety and Environment in New Orleans in June 1996, was "Sustaining Global Progress".

One of the papers presented described how the Azerbaijan International Operating Company had developed a formal health, safety and environmental management system and a structured Safety Case for a large Caspian Sea project. These procedures were adopted to ensure that risks were properly identified and controlled against a regulatory framework that is complex, fragmented and prescriptive.

The Benefits of Goal-Setting

As the Safety Case Regulations only came into effect in 1993 and the last of the goal-setting Regulations, covering the Design and Construction of Installations, came into force on 30 June 1996, it is still too early to judge the full effect of the new regime. On the other hand, Regulations only provide a framework for the Industry, they do not achieve improved safety. Only the Industry itself can do this and, since Piper Alpha, the Industry has been busy implementing safety improvements. Immediately after the disaster and before Lord Cullen's Public Inquiry was convened a number of safety improvements were initiated.

Offshore Safety Initiatives

- Central training register established
- Permit to work system improved
- Emergency shut-down valves re-located
- Subsea isolation systems installed
- Smoke hazard mitigated
- Evacuation and escape systems assessed and improved
- Formal safety assessments initiated

In every case these initiatives proved to be in tune with Lord Cullen's recommendations.

By the end of November 1993, just three years after Lord Cullen published his report, the Offshore Industry had implemented the 48 recommendations that required action by Industry. This included the submission over 200 Safety Cases to HSE.

In parallel with this huge effort, UKOOA working with the International Association of Drilling Contractors (North Sea Chapter) (IADC), The British Rig Owners Association (BROA), The British Chemical Engineering Contractors Association (BCECA), The International Marine Contractors Association (IMCA) and The Offshore Contractors Association (OCA) published new Industry Guidelines on a wide range of safety related subjects. They describe Industry good practice and also assist Operators and contractors to achieve the objectives of the new goal-setting regulations.

The Industry is committed to the principle of continuous improvement and believes the Safety Case provides the ideal vehicle to foster improvements. Nevertheless, whenever the impact of the Safety Case System is discussed a number of key questions are often raised:

- Is the Safety Case achieving the aims and aspirations of Industry - Is it working?
- Has the Safety Case significantly reduced the risk of major accidents?
- A lot of money, time and effort is being spent to improve safety - is this being reflected in fewer accidents and injuries, and therefore lower costs?

The risk of major accident is lower, probably by as much as an order of magnitude.

This was confirmed by the Interim Evaluation of the Safety Case Regulations carried out by HSE in 1995, which concluded that there is evidence of a substantial reduction in risk.

Offshore Accident and Injury statistics are published by the Offshore Safety Division of HSE.

These are illustrated in the bar chart in Figure 3 for the years 1988/89 to 1994/95.

The validity of the HSE data has been challenged by some academics who make the somewhat surprising claim that safety offshore has worsened since Piper Alpha and the implementation of Lord Cullen's recommendations. Earlier this year UKOOA commissioned a study by Environment & Resource Technology Ltd (ERT) associated with Heriot-Watt University. The objective of the study was to provide an independent view as to the credibility of published information on accident and injury statistics. In compiling these data ERT used information supplied by the HSE, and, as to numbers of employees, the Grampian Region and the Inland Revenue.

The result of the study is superimposed on the HSE published data. The two lines, which appear from years 1992/3 - 1994/5 represent differing methods of estimating the numbers employed offshore. The very close correlation between the ERT analysis and the HSE data confirms the industry's confidence in the information published by the HSE.

Since Piper Alpha in 1988, there has been a steady drop in the frequency of all reported injuries. This welcome trend is evidence that the Management Systems are working to achieve a continuous improvement in safety performance as measured by lost time injuries.

In 1994/95, there were 270 injuries that resulted in 3 days or more off work. Over half (148) of these were caused by slips, trips and falls and handling materials. A further 42 were caused by lifting and crane operations and use of hand tools. The complete breakdown is shown below:

Over the same period there has been a slower reduction in the frequency of fatalities and serious injuries, although there was a welcome drop in 1993/94 and 1994/95.

In 1994/95 there was one fatality and 41 serious injuries, the main causes of which are summarised below.

Serious injuries are potential fatalities. In other words an accident that results in serious injury could, with a change in the circumstances, have instead resulted in a fatality.

This is why they are investigated and the causes analysed carefully. It is significant that no serious injury resulted from a fire or explosion, the prevention of which is subject to intense analysis in the Safety Case.

The focus of attention on major accident prevention in the Safety Case has reduced the frequency of serious injury, but the common everyday mishaps listed above still occur. It is in this area where real progress can be made by using management systems that involve the workforce in identifying workplace hazards and assessing the risk of accidents.

Over 3-Day Injuries *April 1994-March 1995*	
Slips, trips, falls	*90*
Handling materials	*58*
Lifting and Crane operations	*22*
Use of hand tools	*20*
Use of machinery	*10*
Diving related	*5*
Loss of containment	*5*
Others	*60*
Total	***270***

Practical guidance can be extremely effective in preventing these all too common accidents and a recent initiative by the Offshore Contractors Association in publishing a new guide ("Offshore Access Scaffolding Guidance") aimed at reducing offshore scaffolding accidents will make an important contribution to improved safety.

The Offshore Industry is continually striving for continuous improvement and in this quest is often critical of its own achievements. Sometimes, however, it is instructive to take a broader view. If the safety performance of the oil and gas exploration and production sector is compared with other industries there is every reason for the Industry to take pride in its achievements.

In the 1994/95 Annual Report of the HSC, which includes injury statistics for all industries, the Offshore Oil & Gas Industry compares very well indeed.

The basis of these statistics is different to those provided by the Offshore Safety Division of HSE, in that the HSC statistics include accidents occurring to all persons involved in the Offshore Industry, i.e. those working offshore and in onshore offices of Operators in the same way as is done for other industries.

Serious Injuries ***April 1994 - March 1995***	
Slips, trips, falls	*12*
Lifting, Handling, Cranes	*10*
Handling goods and materials	*3*
Falling objects	*3*
Diving related	*3*
Use of machinery	*3*
Mooring	*3*
Sea Transport	*3*
Use of hand tool	*1*
Other	*1*
** Fatalities* ***Total***	***42***

The all-injury frequency is lower than that for coal mines railways, metal manufacturing, water supply, construction, and the onshore chemicals and oil refining sectors. A similar picture emerges from reports of fatal and major injuries.

This performance is more impressive than it seems because, offshore, every injury inside the 500m-safety zone is counted, irrespective of the employer. Boats, helicopters, divers and contractors of all disciplines are included. This is not the case for other industries.

In conclusion, it is reasonable to claim that the Industry is improving safety offshore. The Safety Case philosophy is working and the new goal-setting regulations will consolidate the regime and encourage Operators and contractors working together to achieve their aims for continuous improvement.

Lord Cullen, in his painstaking analysis of the evidence given to him, made recommendations that are exerting a powerful influence throughout the world. The Offshore Industry has implemented his recommendations and is beginning to experience real and tangible improvements in safety offshore. Good safety is good business is more than a slogan, it is a fact.

2.2.3. Netherlands

In Netherlands, there are three ministries that are responsible for major hazards:

- VROM - Ministry of Housing, Spatial Planning and Environment, responsible for environment policy and safety of people outside major hazard sites and for the overall co-ordination of policy on major hazards

- SWZ - Ministry of Social Affairs and Employment, responsible for major hazards and policy affecting the safety of people within establishments.

- BiZA - Ministry of Interior, responsible for emergency planning and response and for the general safety of citizens.

In 1992, VROM[22,23] issued two documents, which provides a guide to be used for the presentation of offshore safety cases (for new and old installations) to Dutch authorities. Some of its most important aspects are going to be described further in this section.

The documents mentioned above, provide a guide for the preparation of safety case, regarding the conceptual phase of the design, the engineering phase, where a complete quantitative risk assessment applies, and some recommendations to be followed during operational and abandonment phases of an oil platform. Concerning the conceptual phase, the document in it s chapter "Concept Safety Evaluation" presents the following:

"Based on the conceptual design, this evaluation should assess the design, layout and performance of safety critical systems. It should identify the type, likelihood and consequences of potential accident hazards, together with possible combinations of

such events. Possible interactions with other facilities or systems installed and measures to mitigate them, should also be examined".

"It should be verified, subject to a number of findings and recommendations, that these hazards have a sufficiently low probability of:

a. Loss of life
b. Loss of assets
c. Loss of production
d. Damage to the environment".

Regarding the acceptance criteria (Dutch Department of Mines[22,23]):

"Minimum acceptance criteria for major hazards should be identified during the conceptual design. Calculations should be based on an individual potential loss of life per year (8760 hrs)".

"The evaluation and "Failure mode, effect and criteria analysis" will result in the minimum acceptance criteria, e.g.:

a. At least one escape route and the available usable duration period should be given.
b. The duration period that the control room/accommodation remain intact should be given
c. The duration period that the support structure must maintain its load carrying should be given.
d. The potential accident hazard areas should be segregated to enable effective control measures.
e. Essential safety control functions are to be located within the control room".

In the same section, the Dutch document requests the operator to define the qualitative technique employed to identify hazards and to evaluate the probability of accident hazards and mitigation factors.

In the chapter named "Risk Assessment", where a complete quantitative risk assessment should be developed, the Dutch documents[22,23] describe the acceptance criteria as following:

"Different acceptance criteria are in existence. For example, the endurance of a TSR during a calamity, the availability of escape routes and life saving appliances, the availability of detection and means of control (Emergency shut-down systems (ESD's), etc.). Also more generally, risk criteria as individual risk and group risk. In first instance the acceptance criteria will be defined by the mining enterprise, and such should be stated in the safety case".

"The authorities should interpret these with certain flexibility. On the other hand, they will press the mining enterprises to use acceptance criteria which will improve the level of safety and as a result, will reduce the possibilities and consequences of major accidents".

The last document concerning quantitative risk assessment studies, issued in 1997 (Jones), establishes the following:

- That the operators require a permit to function issued by the provincial or municipal authorities. Two safety reports are required. One for on-site safety which is sent to Ministry SZW Inspectorate for assessment. The other for off-site safety is assessed by provincial and municipal staff. The off-site safety report differently from the on-site report, must give quantitative risk data, looking carefully at the requisite – risk contours.

- Emergency response is considered primarily as responsibility of the site operator, at least for the initial on-site response in the event of an emergency.

The following requirements should be presented in on-site safety report:

(a) the classification of hazards is required, using the methodology set out by a Guideline published by SZW;

(b) The hazard rating assessment is carried out by the manufacturer (or consultant acting on his behalf);

(c) There are no requirements for QRA data;

(d) Evaluation by SWZ is therefore on a qualitative basis. If assessment of some specific element in the process require a more in depth study, a QRA could be required.

The off-site safety report must contain the following:

The owner of the establishment must submit an external report covering:

(a) qualitative aspects that must include:

- description of plant and process sites;
- description of preventive measures and safety management system.

(b) quantitative data: that must give the results of the quantitative risk assessment study (QRA), expressed both as risk contours and as a graphical representation of societal risk in form of F-N curves. A quantitative assessment of risks to the aquatic environment is also requested.

The safety report must be renewed every five years.

The relevant QRA figures are the following:

<u>Individual Risk</u>

Maximum Permissible Risk	New Situations:	10^{-6}/yr
	Existing Situations:	10^{-5}/yr

<u>Societal Risk (for establishments)</u>

Directional Value	> 10 deaths	10^{-5}/yr
	> 100 deaths	10^{-7}/yr

	> 1000 deaths	10^{-9}/yr

For an Individual Risk value (IR) > 10^{-5}/yr, immediate measures are required to correct the situation.

For risks in the range of 10^{-5}/yr and 10^{-6}/yr, measures are required to reduce risks as far as possible through technical means (As Low As Reasonably Achievable - ALARA). The basis of ALARA is "best available technology". VROM interprets "reasonable", as following:

(a) The economic situation in the sector and the state of the art in that sector. The economic situation in an establishment is not a factor.

(b) Where the maximum IR value is exceeded, greater levels of control are required even though the costs may be substantial;

(c) Where the perceived risk is high, e.g. nuclear, compared with more accepted risk, e.g. LPG, the authorities will take less account of the cost of controls.

3. Current Approaches to Quantitative Risk Assessment of Offshore Units

3.1. General

As we have discussed before, risk analysis is used to predict the behaviour of a system in abnormal circumstances, estimating the probabilities associated with accidents and their consequences. It is a methodology where the experience and knowledge will be systematically utilised to this prediction, which must be based on future operation and environmental conditions. It involves a lot of uncertainty, as the operational conditions will never be known in detail with complete certainty.

As the European Federation of Chemical Engineering[24] (EFCE) mentions, risk analysis can be summarised by three questions:

1.What can go wrong?
2.What are the effects and consequences?
3.How often will it happen?

There are several different and useful qualitative techniques already developed and employed in industry, that identify and qualitatively evaluate "what can go wrong". The answer to this question may reveal some aspects of the installation that may deserve further analysis. To achieve a complete risk analysis it is necessary to answer the other two questions.

In this section we intend to outline the current techniques utilised to evaluate risks, with a special emphasis in the description of the topics involved in a methodology for evaluating risks of offshore oil platforms, taking into consideration the particular characteristics presented by offshore enterprises.

3.2. Offshore Units Description

It is usually common to refer to offshore oil units on the basis of their principal products: oil and gas. Therefore, it is possible to refer to them as units of gas or of oil and gas.

In the majority of cases, in offshore units, gas will be produced as a sub product, and in many times it will be burned in the flare.

In a gas production unit there will be suitable treatment systems, designed to dehydrate the gas, which will be recovered to be used in gas lift injection systems or recovered and sent to be processed.

There are several types of offshore units: mobile platforms, fixed platforms, vessels and Floating Production Storage Offloading vessels (FPSO), which will be the focus of the model presented in this Thesis.

Mobile units (platforms) are usually employed in drilling exploration and in advanced production. Mobile units can be classified as following:

. Jack-up platforms
. Semi-submersible platforms
. Drilling ships or drilling barges

Mobile units are usually used for drilling purposes. In Brazil several mobiles are converted to production platforms.

Fixed platforms are mainly used for production purposes and further development of oil fields.

Fires and explosions is the major contributor to the global risk of offshore units, as many studies have shown (Peterson et al.[25]). There is an unlimited set of possible sources of fires and explosions leading to different magnitudes of consequences, ranging from small pool fires to full scale blowouts.

Platforms can also be categorised in manned and unmanned platforms Risky activities usually take place on manned platforms, which are employed for drilling of new wells (production well) and for maintenance of wells (wirelining and workover).

The Floating Production Storage Offloading units have been recently adopted by PETROBRÁS and it can be described as a vessel, which processes and stores gas and oil, or in other words, it is a tank vessel, where a process plant has been installed. A brief description of the FPSO under study is provided below.

3.3.Quantified Risk Assessment Methodology for Offshore Units

The use of risk analysis in offshore oil enterprises should be a continuous and consistent process that can provide a valuable support for project safety management. As a continuous process, risk analysis can and should be employed in different phases of an offshore enterprise: in the feasibility phase, in the concept phase, in basic design (also known as pre-engineering phase) and in detailed engineering design.

The suitability of techniques to be employed in each case, and the depths of study depend on the availability of the information and documents already issued by the project team in each phase. A cost-benefit approach will certainly prove that, the best results will be obtained, when risk analysis is performed in earlier stages of a project, where the modifications to be implemented are much simpler.

Offshore oil platforms present some specific features. In this section, we will briefly list current techniques that can be used during the basic design (pre-engineering) and detailed design of an offshore oil platform.

3.3.1. Quantitative Risk Assessment Procedure

The methodology described here, to be used for offshore quantitative risk assessment is basically based on currents approaches presented by AIChE[27], by Engelhard[28], in a TNO report and by Andersen et al.[26], in a SINTEF report. The following steps are proposed:

A. QRA definition

B. System description and inventory of basic data

C. Identification of hazards

D. Inventory of protective measures employed (active and passive protection)

E. Selection of incident, incident outcomes and incident outcome cases

F. Consequence estimation

G. Frequency estimation

H. Risk evaluation

A.QRA Definition converts user requirement into study goals and objectives. Risk measures and risk presentation formats are chosen finalising a scope of work for the QRA. The depth of the study is selected based on specific objectives and resources available. The need for special studies (the evaluation of domino effects, protective system unavailability, etc.) is also considered.

B. System Description and Inventory of basic data

These two items are related to the compilation of all process/systems information needed to perform a risk analysis. So, it should require process and flow diagrams, piping and instrumentation diagrams, weather and environmental data, material data, lay out drawings, operating and maintenance procedures, etc.

For the risk analyst it is very important to have a complete survey of all material processed or produced in the installation, as well as the necessary data related to technical equipment.

C. Identification of Hazards

C.1. Identification of initiating incidents/events:

This step is fundamental for the overall quality of the analysis. Generally the initiating events of offshore platforms fall under the following types:

. Releases of hydrocarbons from process equipment
. Blow-outs
. Releases from risers
. Utility System Failures
. Failures during construction
. Dropped objects
. Helicopter accidents
. Ship collisions
. Structural Failures
. Environmental loads.

These initiating events can vary in size and intensity. Quantitative Risk Assessment analyses only the most representative effects. In carrying out a QRA, the above list of events may be expanded into a much longer and detailed list, which should be made per platform. Typically, several hundred initiating events might be found.

The capability of producing damage is mainly due to (Andersen et al.[26]):

. Thermal effects
. Over pressures (explosions)
. Fragments and missiles

C.1.1. Identification techniques

There are several techniques employed by industry for the identification of hazards, initiating events and incidents.

Some of these techniques are HAZOP, FMEA, What-If, Preliminary Hazards Analysis, Engineering Checklists, Fault Tree Analysis, etc.

Another way of obtaining a list of incidents is to consider possible leaks and major releases from fractures of all process pipelines and vessels. In this approach it is very important to include all piperwork and vessels in direct communication, since they may share a significant inventory that can not be isolated in an emergency.

Some of the most commonly used identification techniques are mentioned below and can be found in suitable literature (AIChE, Lees, etc.):

C.1.1.1. Hazard and Operability Studies (HAZOP)

C.1.1.2.Hazard indices

C.1.1.3.Accident statistics

C.1.1.4. "What If" analysis

C.1.1.5. Checklists

C.1.1.6. Preliminary Hazard Analysis (PHA)

C.1.1.7. FMEA

C.1.1.8. Fault tree analysis

C.1.1.9. Event tree

C.1.1.10.Cause-consequence analysis

D. Inventory of Protective Measures

Protective measures are very important to limit the effects of accidents. Therefore, it is necessary to obtain information about passive and active protective measures when modelling the consequences of an incident. A brief description of passive and active protective measures used in the FPSO under analysis was presented in the FPSO description's section (section 3.2.1).

E. Selection

The purpose of selection is to reduce the number of incident outcome cases to a manageable size, without neglecting any significant incidents or incident outcomes.

E.1. Selection of incidents/events

The purpose when generating a list of incidents/events is to select a minimum number that can represent the incidents that were enumerated, satisfying the requirements of the study.

The risk analyst should review the initial list and exclude the incidents that are too small for concern, producing a revised list. It is also important to group very similar or redundant incidents. Then, this list should be reduced by grouping similar incidents into subsets, and when possible, replacing each subset with a single equivalent incident. This can be achieved by considering similar inventories, compositions, discharge rates and discharge locations.

This process can be made much easier through the use of ranking techniques. AIChE[27] proposes that the selection of incidents should include contributions from each class of incidents, as described in table 3.3.1.1. Then, an allocation of these incidents into the three classes presented in this table shall be performed as a ranking technique. Further rankings can be achieved, within each of the incident classes proposed, as for example preliminary ranking criteria, based on the severity of hazards.

There are various techniques that can be used for ranking purposes. One of them is called Failure Mode, Effects and Criticality Analysis (FMECA), which is equivalent to a FMEA, but also includes a criticality analysis. It consists basically of the modes in which equipment could fail the resulting effects and of the estimation of failure probabilities.

It is very useful to construct, and it has been being used currently, a criticality matrix which provides a way of comparing each failure mode or incident with others taking into consideration the severity or severity category and the probability of occurrence.

Localised Incident

Localised effect zone, limited to a single plant area (e.g. pump fire, small toxic release)

Major Incident

Medium effect zone, limited site boundaries (e.g., major fire, small explosion)

Catastrophic Incident

Large effect zone, off site effects on the surrounding community (e.g., major explosion, large toxic release)

Table 3.3.1.1 Classes of Incidents (AIChE[27])

The Military Standard - MIL-STD-1629A[29], since 1977, has proposed the use of this type of matrix.

There are many companies that perform a FMEA/FMECA or some type of this technique, for the selection or ranking of incidents under different forms. It is common to find some columns included or excluded in the worksheets used for this purpose.

Failures or incidents that have unacceptable criticality ranking levels should be re-evaluated and are the most likely candidates for the implementation of mitigating measures.

An example of a criticality matrix to be used in risk assessment studies of offshore platforms is provided in a report issued by The Royal Norwegian Council for Scientific and Industrial Research (Jensen et al.[30]). This report presents a matrix with a risk classification, as shown in figure 3.3.1.1 and also in guide table 3.3.1.2

As another example, we can mention Engen et al.[31]., in a SINTEF report. They also propose the use of a matrix for ranking purposes, as not all failures that have been identified are equally important, as some present very low frequency or very low severity.

Consequences:	Event severity group A,B C A is the most severe	
		Return periods, years
Probabilities:	**Probable**	less than 100
	Reasonable Probable	between 100-10^4
	Remote	between 10^4-10^7
	Extremely Remote	above 10^7
Risk Orders:	Combination of consequences and probabilities, according to matrix presented in figure3.	
Risk Notations:	Human	risk to human life
	Pollution	risk to environment
	Economic	risk to property

Table 3.3.1.2 - Risk Classification (Jensen et al.[30])

The matrix proposed by Engen et al.[31] For a preliminary criticality evaluation of a well system is based on frequency grading and severity grades, as shown respectively in tables 3.3.1.3 and 3.3.1.4.

The setting of frequency numbers, as Engen et al.[31] Mention, is based on information from articles reporting equipment failures, from discussions with users and suppliers of the equipment and from technical evaluation of equipment.

As in other matrices, there will be an intermediary area, where it is not absolutely defined if a failure should be considered critical. Engen et al.[31] propose the use of a detectability grading (shown in table 3.3.1.5) and the introduction of two rules, which may be used for this intermediary area:

"

1. If the severity number is 4, the abnormal loads created will be analysed to establish whether they affect a component or subsystem, acting as a safety back up for the failed part. If so, it will be regarded as critical, and vice-versa.

2. In the rest of the cases, it is the detectability that will be used as a criterion. If the developing failure is difficult or impossible to detect it will be regarded as critical.".

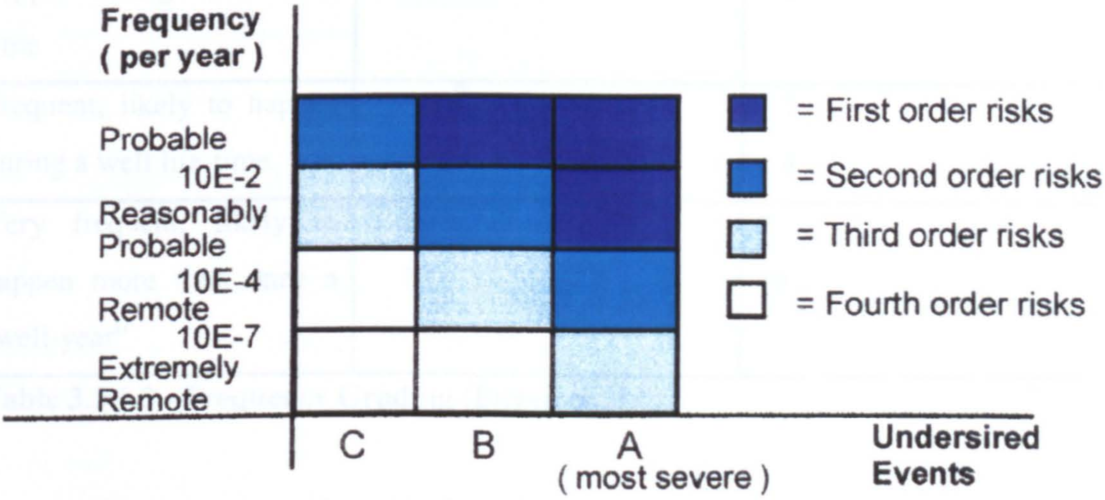


Figure 3.3.1.1 - Risk Classification (Jensen et al.)

It is also common to use a ranking technique that consists of excluding some incidents below a specified value. If we consider hole sizes for several items of process equipment, we can consider a cut-off value for loss of containment of material events, establishing an arbitrary value to analyse a smaller range of hole sizes. For example, for process pipework, we can choose a full-bore rupture and 10 % of the full-bore rupture.

A more accurate approach would request that the importance of the minimum incident size be evaluated by consequence techniques.

Practical Meaning of main groups	*Approximate absolute frequency (events/ well-year)*	*Grade*
Never known to have happened before	10^{-8} 10^{-7}	1 2
Very seldom, known happened once or twice before	10^{-6} 10^{-5}	3 4
Seldom, but likely to happen during a field life-time	10^{-4} 10^{-3}	5 6
Frequent, likely to happen during a well life-time	10^{-2} 10^{-1}	7 8
Very frequent, likely to happen more than once a "well-year"	1 10	9 10

Table 3.3.1.3 - Frequency Grading (Engen et al.[31])

Engelhard[28] presents a table (table 3.3.1.6.7) that shows a relationship between hole sizes and pipelines' diameters, which has been used by TNO in quantitative risk assessment studies of offshore platforms. According to this table, it is stated that a full bore rupture will not occur in pipelines with a diameter of more than 6 inches.

E.2. Selection of Incident Outcomes

The majority of offshore accidents are sequences of unwanted incidents (escalation of events). That is why offshore design is conceived with multiple safety functions that shall prevent accidents. However, some single incidents may also lead to accidents.

On this basis, risk analysis will, to a great extent, consist of the identification and quantification of possible sequence of incidents that may lead to damage.

Practical Meaning		*Grade*
Negligible or no effect	Calculated (known) Anticipated	1 2
Abnormal loads on other components	Designed for or calculated Not calculated	3 4
Need immediate corrective action to avoid further development of failure	Maintenance Work-over	5 6
One barrier left before loss of control	Equipment Barrier Operational Barrier	7 8
Loss of control	Minor leakage Major leakage	9 10

Table 3.3.1.4 - Severity Grading (Engen et al.[31])

The selection of possible incident outcomes should be done for each one of the incidents selected in the revised incident list, described in the previous item. The risk analyst should determine for each incident, which are the possible incident outcomes developed.

The usual technique employed to represent all the possible outcomes is the event tree. Figure 3.3.1.2 illustrates an example of event tree. It is possible to find more complex event trees used to represent the complicated and often interrelated possible incident outcomes that can result from an incident.

An event tree should be made for each module of the platform. Active and passive protection, as well as the time aspect, should be considered in the scenarios in connection with possible escalation of effects. On this basis, it is possible to make a selection of the most relevant or serious incidents. Engelhard[28] mentions that it is important to investigate whether each initiating event can take place at a number of different places in the same module, and whether this would change the incident outcome or scenario.

Practical Meaning	*Grade*
Good detection, continuously or frequent monitoring/testing	1
Difficult detection indications, may be overlooked or misinterpreted	2
No detection because methods do not exist, or methods are not approved	3
No detection because of the short developing interval compared to interval between tests	4
No detection because no warning or indication exists	5

Table 3.3.1.5- Detectability grading (Engen et al.[31])

Pipe diameter	*Hole Size (equivalent diameter)*
< 6 inches	Leak 1 inch Total rupture pipeline diameter
6-12 inches	Leak 1 inch Large leak 32% of pipeline diameter
≥ 12 inches	Leak 2 inches Large leak 32% of pipeline diameter

Table 3.3.1.6 - Hole sizes of pipelines and pipeline connections of vessels (Engelhard[28])

There are other fundamental points that should be taken into account when analysing incident outcomes, like the probability of ignition, the intensity and duration of gas cloud explosions, duration of fires, etc.

Ignition

When representing a loss-of-containment of a hazardous substance, event trees take into consideration the probabilities of an immediate or delayed ignition of the leak and also the probabilities of failure of detection, isolation and blow down systems.

Engelhard[28] describes the result of immediate and delayed ignitions, as following:

. Immediate ignition:
Type of fires: jet fire or pool fire. Jet fires can be classified as jets colliding against walls, resulting in a diffuse flame; and jet fires without collision.

. Delayed ignition:
In the case of gas releases in confined areas, a delayed ignition may cause an explosion of the gas cloud, followed by a fire. In open areas, there will be a major likelihood of the occurrence of fires, without the generation of over pressure shock waves.

Each of the outcomes resulting from an ignited leak (explosions, pool fires, and jet fires) can result in escalation within or beyond the module where the leakage occurred. The probability of a local escalation and the time delay before this occurs depend on the nature of the incident (flash-fire, deflagration, pool fire, etc.), which causes the escalation and on the effectiveness of safety protective systems provided in the module.

The probability of ignition depends also on whether the leak occurs in a classified or in an unclassified module. In classified areas we shall have smaller probabilities of ignition, as ignition sources (like open flames, electrical sparks, etc.) should not be present, although the suitable equipment used in those areas may fail, causing ignition. Possible escapes of hydrocarbon from classified areas to unclassified areas (other modules) should be considered.

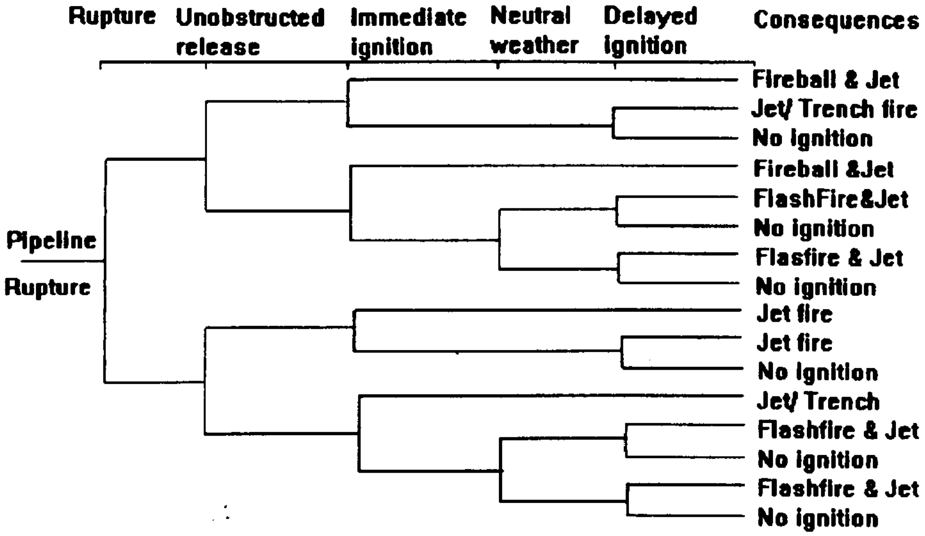


Figure 3.3.1.2 - Pipeline Risk Assessment Method: Event Tree (Crossland et al.32)

E.3. Selection of Incident Outcome Cases

As we have discussed before, each incident outcome can generate one or more incident outcome cases. In order to distinguish each case from the others it is necessary to characterise them numerically, utilising specific parameters.

One of the ways to distinguish an incident outcome case from other is the prevailing weather. Therefore it is necessary to consider several parameters as wind speed, atmospheric stability, humidity, atmospheric temperature, etc.

The risk analyst after identifying all the parameters that affect the incident outcomes should choose a range of values for each parameter and create discrete values within each range.

That is a manner of avoiding the multiplication of number of cases to be studied. It is also possible to use sensitivity methods to analyse the importance of each selected parameter, evaluating its impact on calculations.

F. Consequence Estimation

The purpose of this section will be to present a brief description of models currently available and used in consequence estimation.

The available literature related to consequence and effect models is very wide. Most of the models presented in this section are based on TNO[33] (Yellow Book), on AIChE[27] and on European Federation of Chemical Engineering[24]. AIChE[27] also mentions the following references: Lees (1980), Rinjmond Public Authority (1982), Mecklenburgh (1985), Warren Centre (1986), and Marshall (1987), and others publications from the American Institute of Chemical Engineers.

It is important to highlight that there are several available computer programs in the market, developed for consequence and effects modelling. They can provide suitable support for risk analysts. Regarding specifically the offshore area, it is important to point out that improvement of models, which are suitable to simulate hydrocarbon leakages in enclosed or partially enclosed modules, has been widely improved in the past five years. Now, it is possible to find softwares that can help the risk analyst to simulate the time-dependency of leaks and some important factors, allowing that the rate at which the leak consequence decays and the effects of protective systems (emergency shut down and blow down systems, fire and gas detection systems, ventilation systems) be considered in consequence models. Softwares like the OHRA Tool Kit (developed by DNV/Technica) and PLATO (developed by Four Elements Ltd -UK) can be very useful to offshore risk assessment studies. There are also Computational Fluid Dynamics (CFD) models, which are now being frequently used, as Phoenics (Cham), Fluent (Fluent), etc.

The primary components in consequence estimation are source and dispersion models, fire and explosion models, vulnerability models and also mitigation factors.

Source and dispersion models provide quantitative information on source rates and dispersion of vapour clouds to some concentration levels. Fire and explosion models convert this information on the cloud for flammable releases, into potential hazards, such as thermal radiation and explosion over pressures. Vulnerability models convert these incident specific results into effects on people (injury or death) and on structures.

Through the use of consequence modelling, it is also possible to determine the dimensions of the area, which is going to be affected as a result of the occurrence of fires, caused by the ignition of gas or oil leakage's.

Additional refinement can also be obtained by the application of mitigation factors, such as sheltering or evacuation, which tend to reduce the magnitude of potential effects in real accidents.

The following physical models are considered in quantitative risk assessment studies, and their description can be found in AIChE, Lees, TNO Books, etc.:

F.1. Source and dispersion models

F.1.1. Discharge rate (or Outflow) models (See Note*)

F.1.1.1. Gas Outflow

F.1.1.2. Liquid Outflow

F.1.1.3. Two-Phase Outflow

F.1.2. Flash and Evaporation

F.1.2.1. Flash Evaporation and droplets formation

F.1.3. Dispersion Models

F.1.3.1. Momentum jets

F.1.3.2. Dense gas dispersion models

F.2. Explosions and Fires

F.2.1. Unconfined Vapour Cloud

F.2.2. Physical Explosion

F.2.3. Boiling Liquid Expanding Vapour Explosion (BLEVE) and Fire Ball

F.2.4. Confined Explosion

F. 2.5.Pool Fire and Jet Fire

Blowdown and emergency shut-down systems play a very important role in limiting the material amount (inventory) that can be released in an incident.

Usually in offshore units, there are fire and gas detectors spread all around the platform, so that they will actuate shutdown systems that will reduce the amount of gas released and duration of leaks or fires. Those detectors also activate deluge systems to fight fires and also to cool process equipment. Fire fighting and safety equipment is distributed all over the platform.

Available Computer Codes

There are several available computer codes that can be used to consequence modelling. Some of them are listed below:

CHARM (Radian Corporation); DEGADIS (US Coast Guard); EAHAP (Energy Analysts); HASTE (ERT Inc.); SLAB (Lawrence Livermore National Laboratory); TRACE (SAFER Corporation); WHAZAN (Technica International); EFFECTS (TNO); PHAST (DNV); OHRA Tool Kit; PLATO (Four Elements Ltd.); REAGAS (TNO); CLICHE (British Gas); FLACS (Christian Michael Institute); VENTEX (Shell); Phoenix (Cham); Fluent (Fluent), Flowtran (ANSIs), etc.

F.3. Vulnerability Models

As we have described in the previous section, physical models provide possible outcomes resulting from a release of a hazardous material: dispersion models provide concentration or doses of dispersed vapour; UVCE and flash fire models, physical explosion models, BLEVE and fireball models, confined explosion models, pool and jet fire models, all the estimated shock wave over pressures, fragment velocities or/and radiant flux. All of them are based in the assumption that the severity of outcome depends on the distance from the source of release.

After these estimations are performed, it is necessary to evaluate the consequences of these outcomes. Some risk assessment studies are interested in estimating the effects on physical properties (buildings, structures) and others in estimating the effects on human beings. In the case where an analysis of the consequences to physical properties is the object of study, the target will be monetary losses. In the other case, it will be the number of deaths or injuries. The majority of risk assessment studies deal with damage to structures or buildings and exposures to flammable of toxic substances leading to death or injury. In order to compare different damages, it is important to have the same comparison criteria, and it is common to use fatalities as the predominant reference for evaluating the effects of thermal radiation, toxic doses and blast over pressures.

It is possible to determine the effects on human beings or structures directly, using effect models, based on predetermined criteria, as for example, the concentration exposure of a toxic substance resulting in death. In fact, these consequences do not have a form of a discrete function, but they may fit in a probability distribution function.

The Probit method (probability unit method), which is a statistical method, provides as AIChE[27] mentions, a time-dependent correlation between any variable that has a probabilistic outcome that can be represented by a normal distribution. It is possible to assess toxic effects through the establishment of a toxic dose (concentration per unit time) and the percentage of persons affected by this toxic dose. The Probit method can also be applied to thermal and explosion effects. The Probit method is a useful method to estimate the number of deaths caused by the incident outcomes selected, which will then be compared with an acceptability target.

Effect models can be found in suitable literature (AIChE, Lees, TNO Books). The most common ones are listed below:

F.3.1. Toxic gas effects (toxic criteria currently used, are ERPG's, IDHL, EEGLs and SPEGLs, TLVs and STELs, PELs, TDXS and Probit functions)

F.2. Thermal effects (thermal criteria)

F.3.3. Explosion effects (prediction of the impact of blast over pressure and projectile on people and objects)

G. Frequency Estimation

The techniques used to calculate frequencies of failures are based on system reliability theory.

Sometimes it is possible to address a probability value to an incident, based on available historical data. For example the number of recorded incidents can be divided by the exposure period (e.g. plant-years, pipeline mile-years) in order to obtain a failure estimation.

When you deal with system failure probabilities, where a system is supposed to be composed of some components, it is necessary to utilise reliability techniques in order to obtain values for the reliability or availability of the system.

This section will present a brief description of the basic concepts involved in reliability theory and the associated techniques currently used.

G.1. Reliability analysis basic concepts

The probability of failure as a function of time can be defined by (Kapur[34])

$$P(t \le t) = F(t), \qquad t \ge 0$$

Where *t* is a random variable denoting the failure time. Then *F(t)* is the probability that the system will fail by time t. In other words, *F(t)* is the failure distribution function, also known as the unreliability function.

Reliability can be defined as: ***"the probability that a system will perform its intended function at a certain time t, under specified conditions"***. Therefore, we can write (Kapur[34]):

$$R(t) = 1 - F(t) = P(t > t)$$

Where $R(t)$ is the reliability function.

If the time to failure random variable t has a density function $f(t)$, then:

$$R(t)=1-F(t)=-\int_{0}^{t} f(\tau)\,d\tau=\int_{t}^{\infty} f(\tau)\,d\tau$$

For example, if the time to failure is described by an exponential density function, then

$$f(t)=\frac{1}{6}e^{-t/\theta}, \qquad t \geq 0, \quad \theta > 0$$

where:

θ = Expected value of the random variable commonly termed MTBF (mean time between failures)

And this will lead to a reliability function defined by:

$$R(t)=\int_{t}^{\infty}\frac{1}{\theta}\; e^{\frac{-\tau}{\theta}\,d\tau}$$

$$= e^{-(t/6)} = e^{-\lambda t}, \mathrm{t} \geq 0$$

Where:

λ = *Failure rate;* $\lambda = 1/\theta$

Or if considering a Weilbull distribution where the failure distribution is described by:

$$F(t)=1-\exp\left\{-\left(\frac{t}{\theta}\right)^{\beta}\right\} \qquad , t\geq 0, \theta > 0, \beta > 0$$

Where:

β = Weibull shape parameter or slope

Then the reliability function is:

$$R(t)=e^{-(t/\theta)^{\beta}}, \qquad t\geq 0$$

Therefore, given a particular failure density function or distribution function, the reliability function can be found directly.

Availability definition- A(t): ***"Probability that a component or system be operational in a certain time t".***

This definition is related with the concept of instantaneous availability. Another very useful concept is the one related with the average availability in a certain time interval T, which can be given by the following expression:

$$A_{avg}(T)=\frac{1}{T}\int_{0}^{T}A(t)\,dt$$

For a component or system that can present only two possible states, operating or failed, it is possible to define the unavailability $Q(t)$ as following:

$$Q(t) = 1 - A(t)$$

For repairable components with constant failure rates and repair rates, the instantaneous availability can be given by the following expression:

$$Q(t)=\frac{\lambda}{\lambda+\mu}\,[1-e^{-(\lambda+\mu)t}]$$

$$Q_M(T)=\frac{\lambda}{\lambda+\mu}-\frac{\lambda}{(\lambda+\mu)^2 T}[1-e^{-(\lambda+\mu)}]$$

And,

$$Q_\infty=\frac{\lambda}{\lambda+\mu}$$

It is possible to observe that the average availability assumes the assintotic (or limit) value as T increases. Regarding that the repair rate μ is equal to 1/average repair time (σ), we can rewrite the above equation as following:

$$Q_\infty=\frac{\lambda\sigma}{1+\lambda\sigma}$$

As usually $\lambda\sigma \ll 1$, it is possible to write:

$$Q_\infty \cong \lambda\sigma$$

Another very useful expression for Q_∞ can be written as following regarding that λ = 1/MTTF and μ = 1/MTTR, and replacing these terms in the mentioned equation:

$$Q_\infty=\frac{MTTR}{MTTF+MTTR}=\frac{Time\ out\ of\ operation}{Total\ time}$$

Table 3.3.1.7 illustrates some values of failure rates.

The most common techniques used for the evaluation of failure frequencies, which are essentially based on reliability theory and can be found in classic reliability literature, are listed below:

G.1. Fault Tree Analysis

G.2. Event Trees

G.3. Markov Processes

G.4. Common Cause Failure Analysis

G.5. Human Error Analysis

Type of equipment	*Failure mode*	*Failure frequency*	*Leakage*
Process Piping			
< 3 inch.	small leak	1 E-5/m.year	
	large leak	1 E-6/m.year	
>3inch.	small leak	1 E-6/m.year	
	large leak	1 E-7/m.year	
Pressure vessel	small leak	1 E-4/year	
	large leak	1 E-5/year	
Valve	seal failure	1 E-2/year	1 inch

Table 3.3.1.7 - Failure rates of equipment (Pietersen et al.[35])

H. Evaluation of Risks

As the Royal Society[20] defines in the Study Group Report - Risk Assessment, risk evaluation is:

" ...The complex process of determining the significance or value of the identified hazards and estimated risks to those concerned with or affected by the decision".

Therefore, risk evaluation involves the evaluation of the results of the probabilistic risk analyses with regard to the postulated risk acceptance criteria. So, it is necessary to have an acceptability criterion established, as well as a trade-off between perceived risks and perceived benefits.

In this section we will briefly describe some of the acceptability criteria currently used for the evaluation of risks.

H.1. Acceptability Criteria Currently Used

H.1.1. General

According to the document named "Guidelines for Establishing Acceptance Criteria for Risk Analysis" published in 1992, by The Norwegian Oil Industry Association[21] (OLF), the acceptance criteria can defined as following:

"Criteria used to express an acceptable risk level in the activities, e.g., a term for the limit of the risk that the operator will accept in his activities".

According to the up to date European regulations, the operator should define the acceptance risk criteria for his activities before the risk analysis is performed. Therefore, the acceptance criteria should be established according with the operator's own safety targets and then, be submitted to authorities.

Risk assessment studies can be performed in different levels of detail, as well as it can be performed in different phases of a project, so that the acceptance criteria will be defined according to the depth of the study carried out and to the level of accuracy required. Therefore, sometimes it is enough to define qualitative criteria, as for example, the matrix we have shown earlier in this work.

As we have already mentioned, as a result of Layfield inquiry, the UK Health and Safety Executive (HSE) issued a report in which tolerable risk is defined as following (Pidgeon et al.[8]):

"Tolerability does not mean acceptability. It refers to live with a risk to secure certain benefits and in the confidence that it is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore but

rather as something we need to keep under review and reduce still further if and as we can"

By introducing this definition HSE intends that the tolerability concept leads the industrial risks to be continuously monitored, evaluated against possible benefits and reduced wherever possible to a level "as low as reasonable practicable". This concept implies that individuals, group of individuals or society who must undertake risks due to industrial activities, may be granted a role in decision-making processes about risks. In this respect, as Pidgeon et al.[8] mention, HSE is correct in stating that *'the judgement on what is tolerable is not a scientific but a political matter'.*

Therefore, we can conclude that the acceptability or tolerability criteria should not be imposed to people, but should be established as a result of an interactive and democratic process between experts and the individuals or group of individuals, who should undertake the risks in question.

H.1.2. Types of acceptability criteria

The acceptability criteria can be expressed in different ways. A distinction should be made between the following types of criteria currently used:

- Risk Comparison
- Risk matrix
- Potential Loss of Life (PLL)
- Fatal Accident Rate
- Individual Risk Criteria
- Societal Risk
- Risk related to main safety functions

H.1.2.1. Risk Comparison

The risk comparison approach involves the comparison with risk levels associated with several hazards, for which risk statistics are available.

It is often assumed that the risk comparison, when used in risk evaluation should include comparison with "acceptable risk levels". Therefore, it is assumed that acceptable (or unacceptable) risk levels can be determined taking into account risk statistics for existing (accepted) risks (Reid[1]).

Typical estimates of deaths associated with numerous types of hazards are shown in table 3.3.1.8.

It is often assumed that the acceptability of risks depends on particular factors (associated benefits, etc.) only for intermediate risks (between 10^{-6}/year and 10^{-3}/year).

In order to account for the societal impact of multiple fatalities caused by a single event, the risks associated with multiple fatalities have been compared using frequency-consequence curves that will be presented later in this chapter.

Public attitudes have shown an especially strong aversion to risks associated with multiple fatalities and catastrophes. Several researchers have attempted to describe risk aversion by equating N lives lost simultaneously with N^m lives lost individually ($m > 1$).

H.1.2.2. Risk Matrix

If the risk analysis is performed to such a level that it is possible to categorise qualitatively or quantify probabilities and consequences (severity of consequences), the acceptability criteria can be presented on the basis of a matrix model, as was shown in figure 3.3.1.1.

The matrix model can be used in a qualitative way and in a quantitative way. As it is possible to observe the matrix model can be used to define a qualitative or a semi-qualitative acceptability criterion through the use of categories of frequency and consequences, such as "seldom", "great", "catastrophic".

The intermediate region of the matrix, as well as the ALARP region, where the risk should be reduced as much as reasonable practicable, is usually evaluated through the performance of a cost-effectiveness or cost- benefit analysis, techniques that are going to be presented ahead.

H.1.2.3. Potential Loss of Life (PLL)

According to OLF[21] document, the potential loss of life (PLL)is the average number of fatalities per year (or other relevant time unit). It is a long-term average number of fatalities per unit of time that takes into account the number of personnel on board the installation.

Cause	*Risk (x 10^{-6} p.a.)*
Natural hazards (US)	
hurricanes (1901-1972)	0,4
tornadoes (1953-1971)	0,4
lightning (1969)	0,5
earthquakes	2
General Accidents (US 1969)	
railway travel	4
electrocution	6
air travel	9
water transport	9
road accidents	300
Offshore oil and gas (1967-1968)	1650
Deep sea fishing (1959-1968)	2800
Sports	
cave exploration (US, 1970-1978)	45
glider flying (US, 1970-1978)	400
scuba diving (US, 1970-1978)	420

Table 3.3.1.8 - Risk Statistics for People Exposed to Various Hazards (Reid[1])

The potential loss of life (PLL) is a useful measure to compare different design options within a given platform, including the analysis of the reduction of manned levels in the installation, in order to decrease the number of employees exposed to offshore risks.

H.1.2.4. Fatal Accident Rate (FAR)

The Fatal Accident Rate (FAR) is a measure that has been used for occupational risks, originally for the chemical industry. It was previously known as Fatal Accident Frequency Rate (FAFR).

FAR is defined as following (Jones/IChemE[37]):

"Is the number of deaths that have occurred or are predicted to occur in a defined group, in a given environment, during 10^8 *hours of total exposure".*

FAR can be interpreted for workers as the number of deaths per 1000 people involved in an activity during the working lifetime of 10^5 hours (Kletz[38]). FAR can be expressed by the equation:

$$\boxed{\textbf{\textit{FAR = Number of deaths x 10}}^{8}\textbf{\textit{ / Total working hours}}}$$

For weekly paid workers in the chemical industry the FAR is about 4 (the same as the average for all activities covered by the UK Factories Act). This is composed by (Kletz[38]):

. Ordinary industrial risks (e.g., falling downstairs or getting run over): 2;
. Chemical risks (e.g., fire, toxic release or spillage of corrosive chemical): 2.

Therefore, Kletz[38] mentions that if we are sure that all chemical risks have been identified, we can say that a man doing his job in a chemical industry, should not be exposed to a FAR greater than 2. Therefore, if this is not the case, there should be an effort to reduce or eliminate, as a matter of priority, the risks in new or existing plants in order to reduce the FAR value. In Table 3.3.1.9 some figures are presented for FAR's in UK industries (Kletz[38])

Pettersen et al.[24] mention that the risk analyses performed for Statfjord platforms A, B and C concluded that FAR values for these platforms were respectively 21, 17 and 15,5 and now, they are identifying and implementing cots-effective reducing measures to meet acceptance criteria.

H.1.2.5. Individual Risk

This is one of the most widely used expressions, as well mentioned by Crossland (Crossland et al.[32]).
Individual risk can be defined as (Jones/IChemE[37]):

"The frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards".

In other words we can say that the individual risk can be defined as the likelihood that an individual, located in the vicinity of a potential hazard installation, may suffer damage during a year, resulting from the occurrence of accidents in this installation.

Individual risks have been usually expressed through curves, which connect points of equal risk levels. Those curves are called individual risk contours. Figure 5 illustrates one of those curves.

When utilising individual risk values, care should be taken to assure that these values are calculated taking into account a "typical" or "homogeneous" group of individuals, because it is possible to find a wide variation between population, depending on their habits and on the vulnerability they present to damage. The HSE/HSC[40] recommends mother with babies who spends most time at home, implying that one could assume, in a simplified approach, that she would be present 100% of the time.

It is possible to convert FAR to individual risk (or average individual risk) through a simple expression:

Individual Risk = FAR x working hours per year/10^8

Table 3.3.1.11 illustrates figures concerning to individual risk criteria adopted in some countries.

	FAR	*Risk per person per year*
Offshore oil and gas	82	165 x 10-5
Deep sea fishing	44	88 x 10-5
Coal mining	10	20 x 10-5
Construction	7,5	17,5 x 10-5
Shipbuilding and marine engineering	5,25	10,5 x 10-5
Chemical and allied industries	4,25	8,5 x 10-5
All premises covered by the Factories Act	≅ 4	≅8 x 10-5
All manufacturing industry	1,15	2,3 x 10-5
Vehicle manufacture	0,75	1,5 x 10-5
Clothing manufacture	0,25	0,5 x 10-5

Table 3.3.1.9- FAR's for Some UK Industries 1974-1978 (Kletz[38])

H.1.2.6. Societal Risk

Although we can establish an individual risk criterion, under certain circumstances, it may be necessary to evaluate societal risks.

Consider, for example, a shopping centre located near a potential hazard installation. In this case, even if an individual is exposed to risk during short periods of time, the risk of a catastrophe involving multiple deaths will always be present. That is also the case of the transport of dangerous substances, where a leak of a chemical product could result in major consequences.

Therefore, it is possible to observe that an individual could be submitted to low (or relatively low) levels of risks, but the probability of occurrence of a catastrophe would be present and should be a matter of concern to authorities.

Authority	*Intolerable Risk (per year)*	*Negligible Risk (per year)*
VROM-Netherlands (new installations)	10^{-6}	10^{-8}
VROM-Netherlands (existing installations or combined installations)	10^{-5}	10^{-8}
EPA, Australia (new installations)	10^{-5}	10^{-6}
UK, HSE (nuclear)	10^{-4}	10^{-6}
HSE/UK (new houses)	10^{-5}	10^{-6}
Hong Kong (new installations)	10^{-5}	-
NSW (new installations)	10^{-6}	

Table 3.3.1.10 - Published Risk Criteria (Cassidy[12])

HSC/HSE[40] mentions another aspect that recommends the utilisation of societal risk criteria. This aspect refers to the additional public repugnance against events that cause roughly 100 or 1,000 victims at once. This repugnance is much higher to this kind of events than to others that cause the same number of victims but during some period of time. In literature this feature is called "risk aversion" (or "differential risk aversion") and societal risks allow this feature to be taken into account. HSC/HSE[40] recommends that, in the case that risk aversion be taken into consideration, it should be shown explicitly.

The societal risk can be defined as following (Jones/IChemE[37]):

"The relationship between frequency and the number of persons suffering from a specified level of harm in a given population from the realisation of specified hazards".

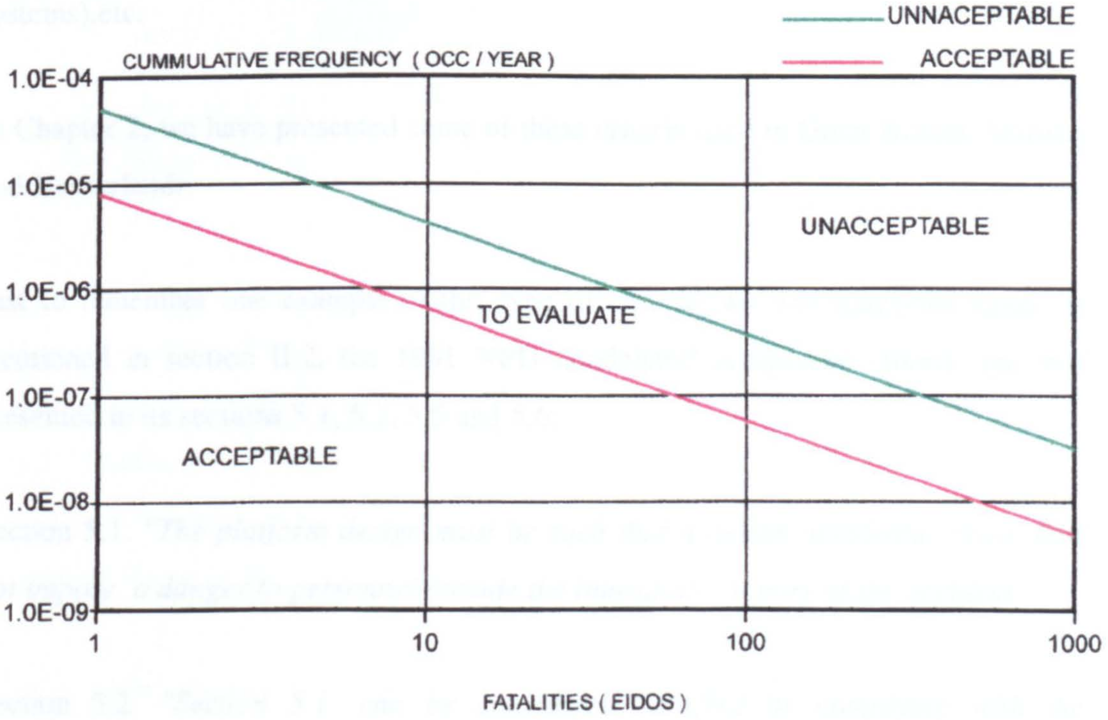


Figure 3.3.1.3 - Societal Risk -Oil & Chemical Industry
Friuli Venezia Giuli Region

At present, societal risks are represented through F-N curves, also known as "Complementary Cumulative Distribution Curve".

The F-N curves provide the expected frequency of the occurrence of accidents associated with n or more deaths. Figure 3.3.1.3 illustrates one of these curves. Figures 3.3.1.4. and 3.3.1.5 provide societal risk criteria proposed.

H.1.2.7. Risk related to main safety functions

The risk to main safety functions is related to the traditional safety concept analysis.

This approach is concerned with the integrity and ability that structures, shelter areas, escape ways and emergency systems present to withstand or survive severe accident conditions, in order to assure personnel's evacuation. Therefore, this criterion comprises, for example, the endurance of the temporary safety refuge (TSR) during a calamity, the availability of escape routes and life saving appliances, the availability of detection and means of control (emergency shut down -ESD and blowdown systems),etc.

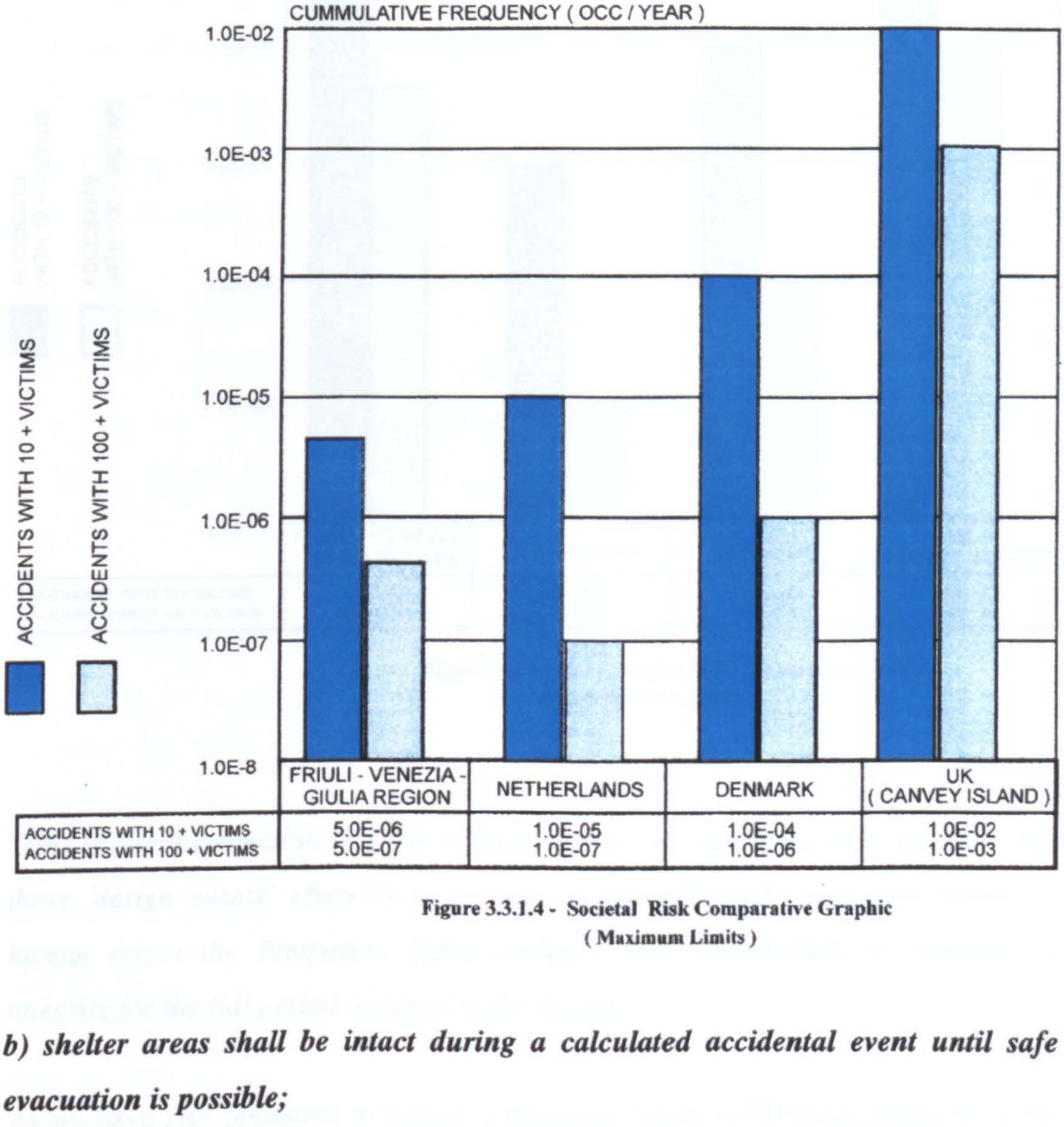
In Chapter 2, we have presented some of these criteria used in Great Britain, Norway and Netherlands.

Just to remember one example of this type of criteria, we will transcribe again, as mentioned in section II.2, the 1981 NPD Guidelines[7] acceptance criteria, the text presented in its sections 5.1, 5.2, 5.5 and 5.6:

Section 5.1. *"The platform design must be such that a design accidental event does not impose a danger to personnel outside the immediate vicinity of the accident".*

Section 5.2. *"Section 5.1. can be considered satisfied by complying with the following criteria:*

a) at least one escape way from central positions which may be subjected to an accident, shall normally be intact for at least one hour during a design accidental event;



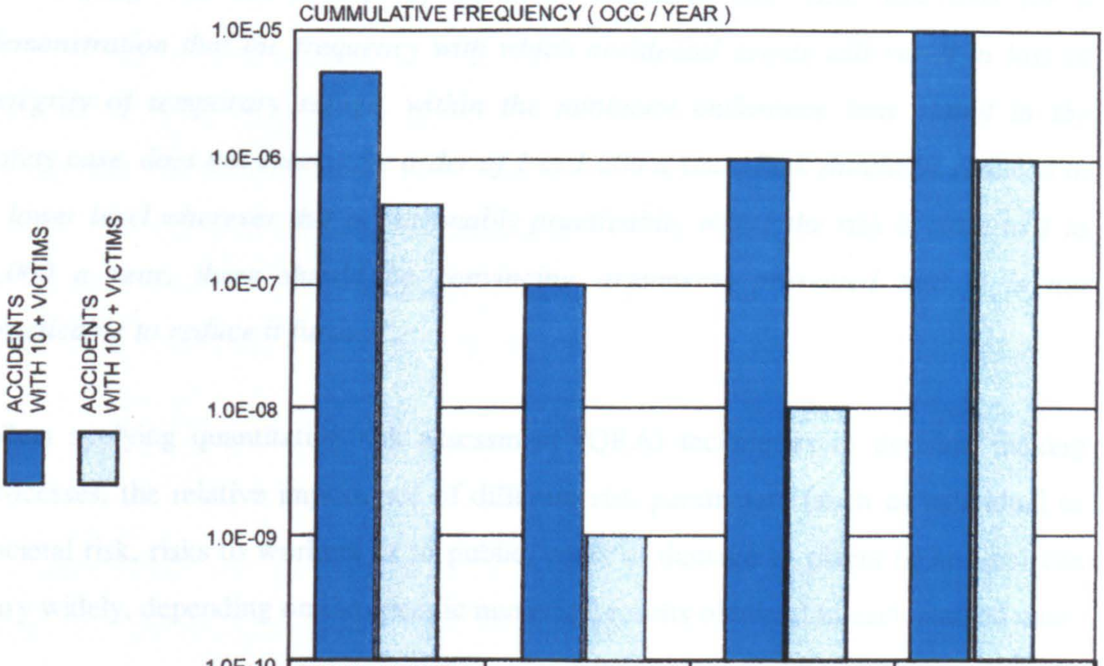
	FRIULI - VENEZIA - GIULIA REGION	NETHERLANDS	DENMARK	UK (CANVEY ISLAND)
ACCIDENTS WITH 10 + VICTIMS	5.0E-06	1.0E-05	1.0E-04	1.0E-02
ACCIDENTS WITH 100 + VICTIMS	5.0E-07	1.0E-07	1.0E-06	1.0E-03

Figure 3.3.1.4 - Societal Risk Comparative Graphic
(Maximum Limits)

b) shelter areas shall be intact during a calculated accidental event until safe evacuation is possible;

c) depending on the platform type, function and location, when exposed to the design accidental event, the main support structure must maintain its load carrying capacity for a specified time".

As another example we can mention again HSE Guidelines[17] which requires a demonstration in the safety case, that the performance standards established for temporary refuge, etc., will reduce risks to person to as low as reasonably practicable, regarding the measures adopted to prevent and reduce the effects of major accidents. According to HSE Guidelines[17], paragraph 116:



	FRIULI - VENEZIA - GIULIA REGION	NETHERLANDS	DENMARK	UK (CANVEY ISLAND)
ACCIDENTS WITH 10 + VICTIMS	5.0E-07	1.0E-07	1.0E-06	1.0E-05
ACCIDENTS WITH 100 + VICTIMS	5.0E-08	1.0E-09	1.0E-08	1.0E-06

Figure 3.3.1.5- Figure Societal Risk Comparative Graphic
(Negligible Risk Limits)

"This requires estimation by QRA of the frequency of 'extreme events' together with those 'design events' where (e.g. because of unanticipated component failure or human error) the Temporary Safety Refuge (TSR) system fails to maintain its integrity for the full period assumed in the design;

As we have also presented in before, a frequency figure of 10^{-4}/year appeared in the 1981 NPD Guidelines[7], section III.2.2, as following:

"In practical terms, it may be considered necessary to exclude the most improbable accidental events from the analysis. However, ***the total probability of occurrence of each type of excluded situation should not by best available estimate exceed*** 10^{-4} ***per year for any of the main functions*** *specified in 5.2, 5.5 and 5.6."*

HSE Guidelines[17], also presents a figure related to the maximum 'tolerable' frequency with which accidental events will result in loss of TSR's integrity, as following:

"In keeping with the concept of maximum tolerable risk, HSE will look for a demonstration that the frequency with which accidental events will result in loss of integrity of temporary refuge, within the minimum endurance time stated in the safety case, does not exceed the order of 1 in 1,000 a year. Risk should be reduced to a lower level wherever this is reasonably practicable; where the risk is close to 1 to 1,000 a year, there should be convincing arguments presented that it is not practicable to reduce it further".

When applying quantitative risk assessment (QRA) techniques to decision making processes, the relative importance of different risk parameters (such as individual or societal risk, risks to workers or to public, costs of damage to plants or houses) can vary widely, depending on the specific numerical results obtained in each studied case.

Below the "tolerable" individual risk limit and above the negligible level, it will still be necessary to demonstrate that the activity will be developed in an "optimum" safety level, so that the residual risks would be kept in a level: "as low as reasonable practicable" (ALARP). In the same way, for existing installations which are already accepted by the community, the ALARP principle should also be applied.

Inside this intermediate region, for the determination of what is really reasonable, or to decide how much should be additionally spent in safety is where some techniques are useful. A brief description of the theory concerning cost-effectiveness and cost-benefit analyses, as well as of the methods involved in the valuation of life are going to be provided below.

H.1.3. Cost-Effectiveness

Whereas the risk comparison approach is based in the assumption that the acceptability of risks depends mainly on the estimated level of risk, the cost-effectiveness approach to risk evaluation is based on the assumption that the acceptability of risks depends primarily on the cost to reduce the risk. For life threatening risks, the cost-effectiveness of risk reduction is related with the marginal cost of saving a life.

It is possible to make comparisons between the marginal costs of saving lives for several life-saving procedures, assuming that the various costs and lives saved are comparable. Such comparisons have revealed that procedures used to save particular lives (i.e. search and rescue procedures) generally involve higher marginal costs than procedures used to save statistical lives (e.g., road safety procedures) (Reid[1]). Obviously, private and public expenditure on safety is not strongly based on the cost-effectiveness of risk reduction (as assessed by methods of probabilistic risk assessment).

System analysts and economists of American federal agencies (as the American Defence Department) first developed the techniques for this type of approach.

The costs involved in damages are very difficult to evaluate specially the costs of human life therefore an alternative methodology was developed in order to avoid the use of an explicit value for human life. This approach is based on a direct comparison between the costs of control devices and the risk reduction to health, generally expressed as the number of deaths or injuries, and the associated protection level.

Therefore, the cost-effectiveness relationship is seen as a particular way for the evaluation and presentation of control devices that can be effective for reducing risks to people and environment.

The first step of the methodology consists on: 1) analysing all possible measures that can be used to protect individuals from potential hazard activities; 2) quantifying these measures in terms of total costs involved in their implementation and operation; 3) evaluating the risk reduction obtained, expressed in terms of avoided damage to health. The second step consists on choosing between several possible alternatives, the most cost-effective ones.

The last step consists on presenting the protective actions that may be taken, in order to help to identify, within a decision making process, the best possible ways to allocate resources.

Figure 3.3.1.6 shows a cost-effectiveness curve. For each particular cost, the curve shows the maximum risk reduction achieved.

The horizontal axis in figure 3.3.1.6 represents the cumulative cost. The vertical axis represents the residual cost. The level of reference, in the vertical axis corresponds to the maximum residual cost, without any special control inserted. The first measure A is the most cost-effective: the relationship cost/risk reduction C (A)/E (A) is the smaller one. The subsequent measures B, C, D are shown in an increasing order, regarding the relation cost/risk reduction.

Each point of the curve corresponds to a protection level, defined by the measures or actions associated with this point and with the precedent measures or actions in the curve. Each protection level is also economically effective, i.e., it is not either possible to find any other set of protective measures that would be more effective to the associated cumulative cost, neither find another set of protective measures that

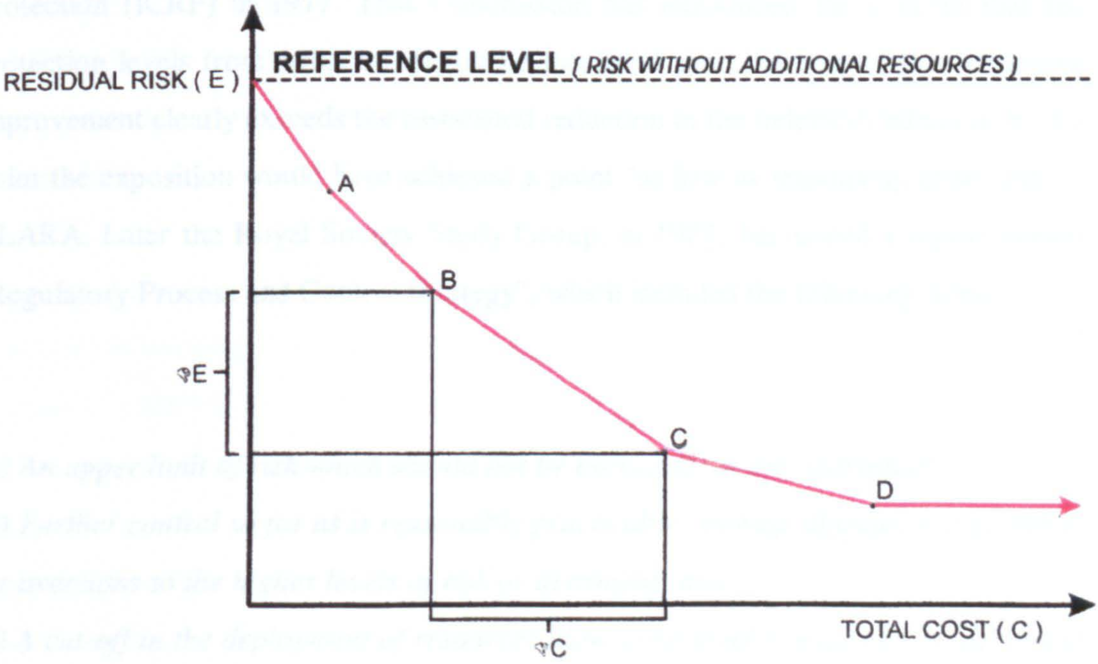


Figure 3.3.16 - Cost - Effectiveness Risk Reduction Curves.
Curves A, B, C, D are Protection Actions to Improvements Effectiveness
(INTERNATIONAL ATOMIC ENERGY AGENCY)

would involve less cost and that imply in the achievement of a better residual risk level than this.

Therefore, once all the points shown in the curve are cost-effective, it is possible to determine the most efficient set of protective measures that may be selected in a specific case, as well as the minimum amount of money that may be spent, under a certain restriction regarding the residual risk.

H.1.4. Cost-Benefit Analysis

When applying quantitative risk assessment (QRA) techniques to decision making processes, the relative importance of different risk parameters (such as individual or societal risk, risks to workers or to public, costs of damage to plants or houses) can vary widely, depending on the specific numerical results obtained in each studied case.

According to Fleishman[41] the principles nowadays employed in QRA studies are based on principles implemented by the International Commission on Radiological Protection (ICRP) in 1977. That Commission has introduced the concept that the protection levels from radiation should be increased until the cost of this additional improvement clearly exceeds the associated reduction in the inducted radiation. In this point the exposition would have achieved a point "as low as reasonably achievable" - ALARA. Later the Royal Society Study Group, in 1983, has issued a report named "Regulatory Process and Control Strategy", which included the following items:

"

(a) An upper limit of risk which should not be exceeded for any individual;
(b) Further control so far as is reasonably practicable, making allowance if possible, for aversions to the higher levels of risk or detriment; and
(c) A cut-off in the deployment of resources blow some level of exposure or detriment judged trivial".

After the publication of this report some responses have arose, related to the use of the acceptability criteria proposed, and variations of this criterion were adopted in countries like Netherlands, Great Britain and Australia.

Some authors point out that the establishment of maximum levels of individual risk is a legitimate way of restricting the exposition of certain groups of persons to industrial risks, avoiding inequalities in costs' distribution and societal benefits associated with industrial activities.

Other authors believe that it would be wrong to limit risks to society, without considering the societal benefits that a certain industry is able to generate, alleging that a rigid imposition of societal risk limits would address a disproportional weight to quantitative considerations about risks. It could neglect other important factors to decision making processes, sometimes imposing incorrect restrictions to industrial developments.

The direct extension of the principles proposed by ICRP to an acceptability criterion of risks provides a basis to the discussion about the development of new industrial enterprises, allowing the performance of a balance between new jobs and benefits to economy versus specific potential hazards, public perception of risks, etc., without disregarding the restrictions related to the calculated societal risks.

However, below the "tolerable" individual risk limit and, above the negligible level, it will still be necessary to demonstrate that the activity will be developed in an "optimum" safety level, so that the residual risks would be kept in a level: "as low as reasonable practicable" (ALARP, figure 2.2.2.1). In the same way, for existing installations, which are already accepted by the community, the ALARP principle should also be applied.

Inside this intermediate region, for the determination of what is really reasonable, or to decide how much should be additionally spent in safety, is where the cost-benefit analyses is useful and where it is increasingly being adopted.

The purpose of cost-benefit analyses is to make a balance between the implementation of additional protective measures and the associated benefits, regarding risk reduction related to economical losses and lives lost, providing a basis for the allocation of resources. However, it requires the judgement of values, including the assignment of monetary values to life, or to each "statistical fatality averted".

If the risk reduction values exceed the costs of proposed safety measures, a direct economic benefit will be achieved due to the implementation of these measures. In other cases, the residual costs will be counterpoised to the reduction obtained in societal risk levels, providing a measure to prioritise the cost-effectiveness of the presented options, in terms of the associated expenses related to "statistical fatalities averted".

In order to apply the above concepts in cost-effectiveness approaches that take into consideration the ALARP principle, it is necessary to compare risk reduction measures with appropriate monetary valuations for risk reduction, expressing them in terms of pounds (or other coin) per "statistical fatality averted".

This is the analytical frame to determine the optimum protection level that is supposed to keep the residual risks to a level "as low as reasonable practicable" (ALARP). However, it is very important to point out that cost-benefit analyses involve the judgement and assignment of complex values, which include the estimation of the value of life in monetary terms and also the evaluation of other cost components. We will briefly discuss the valuation of life in the section presented below.

H.1.5. Valuation of Life

The assignment of a monetary value to life (defined as the expenditure one might justify averting statistical fatality) is not a new task to economists. In the end of century XVII, Sir William Petty (Fleishman[41]) calculated the economic losses to England due to the war, addressing a value to the loss of lives.

Two approaches are the most commonly used: 'human capital' and 'willingness to pay'.

The 'human capital' approach assumes that the economic value of a human life, and therefore, the loss that an individual death represents to economy, consists on discounting the expected future earnings of this individual. Other calculations, that take into account the victim suffering and privations for the victim's family sometimes complement this type of calculation.

This method has been adopted by Governmental bodies in UK, including Health and Safety Executive (HSE), that utilises, as a guide line, the current value of 200,000 pounds per "statistical fatality averted".

An improvement of this method consists on discounting the losses imposed to other persons, due to the death of an individual. This method is sometimes referred as "net productivity" (in order to distinguish from the former, which is called "gross productivity").

Although the 'human capital' approach provides a basis for quantification, it does not take into account preferences of people at risk. Besides it, if we interpret this method, we can observe that what is implicit in it, is that what is important to society is just what this society wins or loses after the death of one of its members. In this point of view, the death of an individual whose contribution was negative, would bring a benefit to society, in such a manner that the lives of young and elderly or retired people, will be worthless, and this is a very perverse and absurd assumption!

In response to these imperfections, economists attempted to develop other methods, keeping the basic principles of the traditional cost-benefit analysis.

One of these methods is named "willingness to pay" and is based on the willingness to pay that an individual presents to risk decreases, or in other words, the compensation he requires risk increases.

According to HSE[40], the evaluations of values of life based on empirical studies are subjected to a wide variation, and their results are difficult to interpret. Anyway, it is usually considered that these evaluations result in higher values than the ones resulting from 'human capital' approach, and that they are of one order of magnitude higher. Therefore, this implies that the value of life would be about some millions of pounds. .

The HSE [40]mentions that the Britain societal context has led the National Radiological Protective Board, in Britain, to develop an explicit reference to be utilised in cost-benefit analyses. Recently, a multiplier factor (from 1 to 15) has been applied to the basic valuation obtained from the 'human capital' approach, implying in a range from 200,000 to 3,000,000 pounds per "statistical health effect averted", as an increasing function of individual dose (risk) levels.

It is also considered that, besides the individual aversion to risks, the society is also "risk-averse", and that it seems to react more strongly to large losses of lives, which present a low frequency of occurrence, than to frequent losses which present smaller consequences. Therefore, there are some proposals that intend to address a higher weight to low frequent events that involve major consequences, by applying a function that reflects this weight. This function will attempt to reflect that N lives that are lost simultaneously, would be N^m more important than the lost of one life, where $m > 1$. The merit of this type of approach, which attempts to enclosure public perception, is considered questionable.

Fleishman[41] concludes that monetary valuation range between 500,000 to 5,000,000 pounds, per "statistical fatality averted", would be adequately broad to encompass considerations such as economic methodologies, individual and societal aversion and gross disproportion when applying cost-benefit analysis to the interpretation of ALARP principle.

It is possible to suppose that other cost-benefits evaluations concerning to safety, could be directly accounted. However, that is not the case. For example, one of the potential consequences of major industrial accidents is the loss of a good image and reputation, especially when the industry is prosecuted and some management errors are found. This type of adverse publicity and loss of credibility have a strong impact to public, being difficult to account it quantitatively.

Other economic costs related to serious accident occurrences, such as direct repair costs, production losses due to shut-down periods, and the economic costs of protective measures, are in principle more tangible in monetary terms, although their quantification is often complex.

However, even in the case of direct costs, an accurate definition or reference basis for addressing those costs are subjected to judgements and opened to different interpretations. It is usually recommended that each case be analysed carefully, regarding its specific context.

4. Model Description

4.1. Introduction

The approach presented in this Thesis comprises the evaluation of safety systems availability, costs involved in the improvement of those systems, as well as the evaluation of the costs associated with incurred loss of lives, income and assets in an interactive way.

For standard plants and for new design concepts this methodology can be used to optimise safety and economics. For facilities that have been already operating, the reallocation of reliability and risks can be applied, regarding the following aspects (Cho et al.[42]: a) it should be done on a plant-by plant basis; b) it will present cost and physical limitations.

Cost limitations are obvious, once any suggested modification could imply in an extra capital investment and in additional operational costs. Physical limitations have also to be considered since you may have to introduce passive protection or maybe change lay-outs in order to achieve the safety levels recommended from the analysis which, depending on the enterprise design stage, can be not cost-effective.

Those points should be considered when analysing any unit. In the other hand, the presented methodology can be useful to have a "safety overview" of the installation, once it provides an evaluation of how far the installation is, in terms of risk levels or safety levels, from the established safety targets. It can also be useful to evaluate operational practices.

The result of the proposed approach is presented in terms of information related to costs, risk and maximum tolerable frequencies of impairment to the main safety functions of a particular unit design. It is presented as a function of the availability of its safety systems, components and structure. Additionally, the methodology presented in this Thesis provides information about alternative design configurations and operational practices.

This work confirms the technical feasibility of allocating reliability and risk in a self-consistent way. It addresses values of availability to safety systems like fire and gas detection systems, pressure sensors and blockage systems (actuation valves).

4.2. Objective

The objective of the model to be developed in this Thesis is (Cho et al.[42]):

(1) To propose a feasible model to allocate reliability and risk criteria for the main safety functions of an offshore unit in a self-consistent manner. This model will provide a method for evaluating the global safety of an industrial facility regarding aspects as safety design configurations (passive and active protection) and operation procedures (test and maintenance). It will provide a method for design engineers to establish minimum reliability levels for safety functions in order to achieve safety targets previously defined.

(2) To apply the proposed methodology, through numerical examples.

(3) To evaluate the generated results, identifying the vulnerabilities and performing a sensitive analysis, with the variation of the goal setting values.

(4) To demonstrate if it is possible or not to achieve the proposed criteria for the specific installation, providing a detailed look of the unit design in terms of the reliability of safety functions and the adequacy of active and passive protection.

The model is flexible, in such a way that it allows the analyst to include other variables that were not included in this study, such as the probability of a successful or unsuccessful sheltering, probability of a successful or unsuccessful evacuation, etc., as it will be presented ahead.

This model allows the analyst to propose his own safety goals and evaluate if it is feasible to reach them, based on design or operational targets. The fact that you can achieve other goal levels, e.g. availability goals for the safety functions, from top level goals (individual risk criterion) is an important task, once it provides a better understanding of the safety importance of each one of the various safety systems and the respective cost-effectiveness improvements.

The approach presented in this Thesis will then be a problem of determining the optimum design configuration for safety functions of an offshore unit, considering simultaneously the risk measures and costs.

In essence, the approach will be to determine the "optimum design" of the plant in terms of safety, considering simultaneously the established global measure and the costs to achieve it.

The optimum design will be the one that presents the best result considering the achievement of different reliability levels for the safety systems, which in our case will be given be in terms of different Safety Integrity Levels (ISA), together with the satisfaction of the constraints of the problem and a cost balance.

The essential elements of the analysis presented here are (Cho et al.[42]):

(1) the establishment of a global measure of unit's safety performance (top level safety indices, which in our case will be the individual risk to offshore workers and the maximum tolerable frequency of impairment to the main safety functions of the FPSO) and "objective functions" (that will be the cost function which is going to be minimised);

(2) a model for relating the global measure of plant's safety performance to specific set of measures of plant performance (the availability of safety systems, which will compose the "decision variables");

(3) a method for allocating values to these specific measures of the unit safety performance (availability of safety functions) in order to optimise the plant design and satisfy the global measures established.

In this work, the first element mentioned above will consist of a set of two components: a proposed individual risk criterion for Brazilian offshore workers, which will be calculated based on data collected in Brazilian Oil Company (Petrobras), which as a monopolist company (until the data of calculation) is far representative of the Brazilian offshore oil production "universe"; and of the maximum tolerable frequency of impairment to the main safety functions, which value is based on NPD and HSE Guidelines, as mentioned on chapter 2.

Therefore, the first step of the analysis will be to collect data related to fatalities occurred in oil platforms (including workers from PETROBRÁS and from others companies, who work for PETROBRÁS). After obtaining this data, it is possible to calculate the associated "Fatal Accident Rate" (FAR) and the Average Individual Risk (AIR).

It is important to highlight that the values presented in this work should not be regarded as prescriptive safety criteria or prescriptive safety goals. They may be taken as proposed reference values to be studied, compared and traded-off by decision-makers. The individual risk was calculated for the specific case of Brazilian offshore units, although the values obtained are very compatible with other values presented world wide for individual risks.

We suppose that the reference values proposed here can be perfectly understood by policy-level decision makers and we hope that they can serve as a contribution to a wider debate in risk assessment arena.

4.3. Methodology Development

4.3.1. General

The first step in a decision making process is to establish the objectives that should be satisfied and to define an attribute or measure of effectiveness. An attribute provides a quantitative measurement of the degree to which the corresponding objective has been achieved. In this Thesis the following attributes are considered:

1. Cost
2. Individual Risk
3. Frequency of Impairment to main safety functions (impairment to the Temporary Safety Refuge (TSR), escape routes and to structure)

The second and third attributes represent the "safety goals" to be achieved. The discussion about figures related to individual risks and the frequency of impairment to main safety functions, as well as new policies concerning risk assessment were described in chapter 2.

The first attribute included is also essential, once it is not possible to forget the cost effectiveness of the choices we have to make. As mentioned earlier in this work, precluding the economic dimension involved in this task would reduce our problem to a vague problem that is the classic one expressed by the question: How safe is safe enough? Lacking the economic dimension to try to answer this question would lead to decisions that neglect practical considerations, and are not supported by a consistent basis, once the whole frame of the losses incurred due to failures would not be considered. Besides this, if there is no constraints to achieve the various reliability levels we would choose "perfect systems", with the maximum availability and lowest related consequences in case of failure. Obviously there are constraints, since for each reliability or risk level improvement you would have a respective additional expenditure of resources, as well as technological limitations to achieve a 100% system availability or a zero industrial residual risk.

Therefore, the element cost appears as a mediator, as an element to promote a reasonable balance between mathematical and technological solutions and what is really feasible to achieve. The cost function presented in this work will also include several economic loss components included in an accident scenario. They are going to be described in section 4.3.7.

4.3.2. Facility's Model

Quantitative risk assessment models can provide a comprehensive description of the relationship between the unavailability of the unit's safety systems and the associated undesirable consequences.

Event trees methodology is the one utilised in quantitative risk assessments to model the sequence of events that occurs in any accident, with the corresponding unavailability values of safety systems, failure probabilities and probabilities associated with weather conditions, wind direction, etc.

The methodology proposed in this Thesis has to be developed based on a quantitative risk assessment study previously performed for the industrial unit under analysis.

In typical quantitative risk assessment studies, for each identified scenario (selected after the performance of a detailed preliminary risk analysis (PHA)), event trees are traced in order to determine the accident scenarios to be analysed. Then, the related consequences are modelled, and the physical effects/ vulnerability are evaluated. Finally, the average societal and individual risks are calculated.

As it is possible to observe from examples shown in Appendix 1 – figures A.1.1 to A.1.32, for each initiator event, there is a related event tree. For each one of the initiator events, there are several related accident scenarios identified by the code ID in the event tree.

We can observe from these figures (as from other event trees), availability/unavailability values are addressed to protection systems (PSL's and valves, for example), to gas and fire detection systems, as it could be to any other safety system (as for example, blow-down systems, etc.) that should be taken into account, in order to suitably simulate the sequence of events that leads to accident scenarios.

For each one of the identified accident scenarios shown in Appendix 1- figures A.1.1 to A.1.32, we will still have, what we will call from now on in this Thesis, the associated ***phenomenological event tree***. This ***phenomenological event tree*** will comprise different ignition probabilities (different ignition points), different wind velocities, different jet directions, etc. Figure figures A.1.33 in Appendix 1 provides an example of an event tree traced for the quantitative risk assessment, where the weather conditions and others probabilities are shown.

Ordinary softwares make all the mentioned calculations and generate the results. They include the probability of fatalities, the average population which is in each specific position (area), the associated average societal risk, and then the total (the sum) average societal risk associated with this specific scenario.

The model presented in this Thesis considers that the unit's safety consists of the interconnection of a number of "elements" characterised by a certain reliability level. In fact they will address availability or unavailability values to safety systems and could also be used to address probability values to failures of active and passive components, to failures of components to attend when demanded, to human errors, to operation and evacuation procedures, etc.

Therefore, utilising the quantitative risk assessment results, an expression can be produced for the societal risk and for the associated individual risk expression, imposing variables that replace the availability values addressed to safety systems. The average individual risk expression is obtained by dividing the total average societal risk of the facility (which is the sum of all average societal risk values calculated for each accident scenario) by the facility's population.

4.3.2.1. Model's Expression

According to the event tree shown in figure 4.3.2.1.1, it is possible observe that an expression for the Average Societal Risk (ASR) can be obtained as following:

$$\begin{aligned} AVSR = {} & f_1 m_{11} Ph_{11} Pb_{11} Pany_{11} + f_1 m_{12} Ph_{12} Pb_{12} Pany_{12} + f_1 m_{13} Ph_{13} Pb_{13} Pany_{13} + \ldots\ldots\ldots\ldots + \\ & f_1 m_{1k} Ph_{1k} Pb_{1k} Pany_{1k} + f_2 m_{21} Ph_{21} Pb_{21} Pany_{21} + f_2 m_{22} Ph_{22} Pb_{22} Pany_{22} + \\ & f_2 m_{23} Ph_{23} Pb_{23} Pany_{23} + \ldots\ldots\ldots\ldots\ldots\ldots + . f_2 m_{2k} Ph_{2k} Pb_{2k} Pany_{2k} + \ldots\ldots\ldots\ldots\ldots\ldots + \\ & f_i m_{i1} Ph_{i1} Pb_{i1} Pany_{i1} + \ldots\ldots\ldots + f_i m_{iK} Ph_{iK} Pb_{iK} Pany_{iK} \end{aligned}$$

Where the definitions of each one of the parameters used in the expression are defined below.

Expressing the societal risk in matrix formalism we would have:

Let $fi(i = 1,2,....I)$ denote the frequency of the ith accident initiator event. The following row vector can be defined:

$$f = [f1, f2, ..., fI]1XI \text{ vector}$$

Let mij denote functions of the unavailability of safety functions, i.e., $mij = f(x_1, x_2, ..., x_n)$. The following diagonal <u>Unavailability Matrix M</u> can be defined:

$$\boldsymbol{M} = \begin{bmatrix} m_{1j} & 0 & 0 \ldots\ldots\ldots & 0 \\ 0 & m_{2j} & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & mIj \end{bmatrix} :I \; X \; J \text{ , where } \quad j = 1,2,...,k$$

The terms mij will be composed by the product of all unavailability or availability values of safety systems represented in the event trees.

Let now suppose that given an initiator event Ii, given the unavailability of safety functions mij, we will have a probability pij, which will be called phenomenological probability. This probability will aggregate all the probabilities that appear in an event tree, as for example: probability of ignition, probability of having specific weather conditions, etc., and which will contribute to define the *jth* branch result of an event tree (the *jth* physical effect). Therefore, the following diagonal *<u>Phenomenological Matrix Ph</u>* can be defined:

$$\boldsymbol{Ph} = \begin{bmatrix} p_{1j} & 0 & 0\,\Lambda & 0 \\ 0 & p_{2j} & 0\,\Lambda & 0 \\ \mathrm{M} & \mathrm{M} & \mathrm{M} & \mathrm{M} \\ 0 & 0 & 0 & plj \end{bmatrix} : J\ X\ \ S\ matrix \text{, where}$$

Now supposing that we have a given initiator event, the unavailability of safety functions *mij*, and a phenomenological probability *pij*, we will have a certain probability of fatalities (given by Probit functions), resulting from the *jth* physical effect, obtained as a result of a branch in an event tree. Then, we can define a diagonal *<u>Probit Matrix Pb</u>*, which will be composed by probabilities *pbljs*, obtained from Probit functions, multiplied by numbers (real) *cljs*, which represents the average population present at the moment the effect is manifested, as following:

$$\boldsymbol{Pb} = \begin{bmatrix} pb1jc1j & 0 & 0 & 0 \\ 0 & pb2jc2j & 0 & 0 \\ . & . & . & . \\ . & . & . & . \\ 0 & 0 & 0 & pblclj \end{bmatrix} : S\,x\,\mathrm{Z}$$

Let now define a column vector *Pany* which represents any other probability that is desirable to add to the expression presented, as for example, the probability of an unsuccessful sheltering or the probability of a successful evacuation. This *<u>column vector Pany</u>* will be defined as following:

$$\boldsymbol{Pany} = [Pany1, Pany2, ...Panyz]^T$$

Finally, given these definitions, it can be shown that the expression for the individual risk is given by:

$$ASR = \sum_{j=1}^{k} \mathbf{f\ M\ Pb\ Pany} \qquad (4.3.2.1)$$

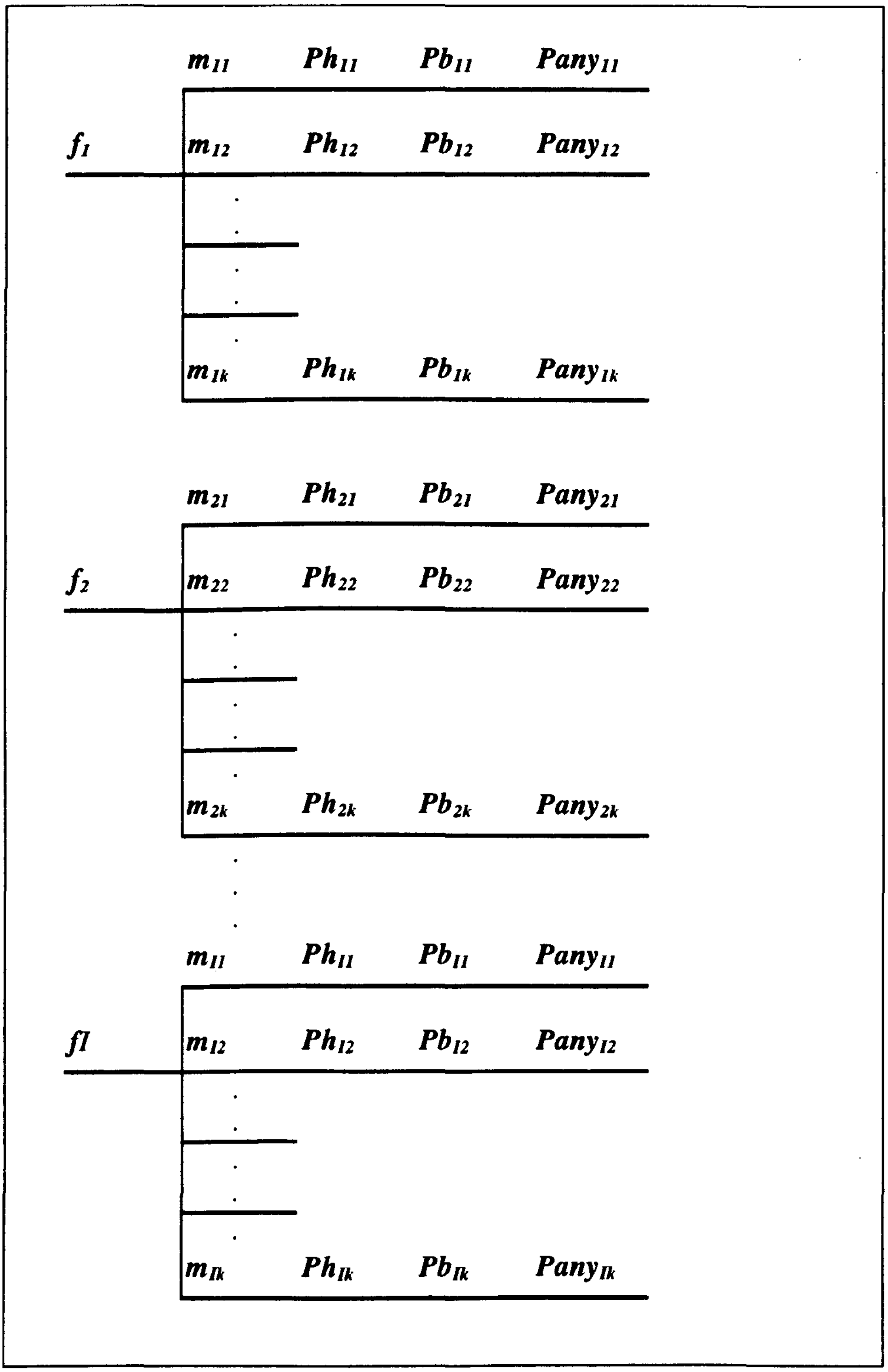


Figure 4.3.2.1.1 - Event Tree Used in the Model's Societal Risk Expression

Considering the expression given above and based in a quantitative risk assessment previously performed, the model proposed in this work will comprise the following steps:

(a) for each considered initiator event and the related societal risk calculated, variables are imposed to the availability/unavailability values associated with the safety systems considered in each branch. Therefore, the societal risk associated with the specific initiator event, the specific *mij* term (the product of the unavailability/availability variables) determined for each branch of the event tree and the related probabilities, will be expressed as a function of the safety systems' unavailability /availability variables;

(b) the sum of the terms mentioned above, associated with all the branches of all traced event trees, and expressed as a function of different unavailability/availability variables, will provide the total societal risk expression, evaluated for the facility under analysis;

(c) The total societal risk expressed in terms of safety systems' unavailability/availability variables will then be divided by the unit's population, and the individual risk expression will be obtained;

(d) The total individual risk expression (which is expressed as a function of safety systems' unavailability/availability variables) will then be optimised, considering the safety targets previously defined (in our case, the individual risk criterion and maximum frequency of impairment of accidental events to main safety systems of an offshore oil production installation) and the costs associated with the availability improvement of these safety systems.

The reliability prediction model as well as the cost model used in the methodology proposed in this work are going to be presented below.

4.3.3. Decision Space

The next step of the proposed methodology will be to define the set of all the alternatives to be evaluated – the decision space. The generation of these alternatives should be based on alternative design configurations for the safety systems to be adopted for the facility under study. For each one of the safety systems, different configurations have to be proposed and the respective availability values should be calculated. Therefore, in this work, the decision space will be composed by discrete values.

Mathematically, the decision space is the set of all technologically feasible realisations of the vector $\underline{x}$, where the dimensionality of $\underline{x}$ is equal to the number n, of the decision variables xi. Discrete design configuration unavailability values will be represented by discrete points $\underline{x}^j$, where j is the j^{th} permutation of the various discrete values of xi's.

4.3.4. Reliability Prediction Model

4.3.4.1. Introduction

When designing safety shut-down systems there is generally a conflict between *safety* and *production regularity*, in other words for several safety systems, as for example for fire and gas detection systems; there is a conflict between safety and the amount of false alarms.

When evaluating loss of safety, the failure mode *Fail To Operate (FTO)* is considered. The measure of reliability, that is used to quantify loss of safety, is *Critical Safety Unavailability (CSU)*, which can be defined as following (SINTEF[48]):

> *"The probability that the safety system is not in operation, i.e. will not automatically carry out a successful shut-down on the occurrence of an abnormal operating condition."*

When evaluating loss of production, the failure mode *Spurious Operation (SO)* is considered. The measure of reliability that is used to quantify loss of production, is *Spurious Trip Rate (STR)*, which can be defined as following (SINTEF[48]):

> " *The number of nuisance activation of the safety systems per unit time, i.e. shut-downs which are activated without the presence of an abnormal operating condition.* "

This section presents the necessary steps for calculating the Critical Safety Unavailability (CSU) and Spurious Trip Rate (STR) of various configurations of safety systems based on SINTEF Reliability Prediction Handbook (SINTEF*).

4.3.4.2. General Assumptions and Limitations

The following assumptions were considered in this work, as recommended by SINTEF handbook (SINTEF*) for reliability calculations:

- All failures occur according to the exponential model, i.e., all modules have constant failure rates;

- The unavailability of the safety shut-down systems due to repair or functional testing of system modules is not considered when quantifying loss of safety;

- Trip events that are introduced deliberately, because maintenance/test activities are to be carried out, are not included when quantifying loss of production.

- The critical safety unavailability of the system is obtained by summing the critical safety unavailability of each (set of redundant) module(s);

- Multiple failures of non-identical modules are ignored;

- The likelihood of an event causing simultaneous failures of non-identical modules is very low when compared to the likelihood of an event causing identical modules to fail simultaneously (SINTEF*).

4.3.4.2.1. Assumptions for Approximate Formulas

SINTEF handbook (SINTEF*) presents approximate reliability block diagrams and formulas to be used for reliability prediction when the assumptions listed below are valid. It is highlighted that if those assumptions do not apply, exact reliability block diagrams and formulas should be used as presented in the SINTEF appendix (SINTEF* Appendices B and C).

  - All module failure rates are less than 10^{-2} per hour.
  - At least 10% of all failures in a redundant system are multiple failures causing two or more identical modules to fail simultaneously.
  - When this assumption applies, single failures will not contribute significantly to loss of safety in redundant systems in which at least two modules must fail before the system fails to operate on a safety demand. If, for instance, 90% of the failures are single and the test period is 1 month, the single failures will contribute to system failures in the order of 1%, which is rather insignificant. Which a test period of 3 months, this contribution increases to about 3%.

- The repair time is small when compared to the interval of time between functional testing;
- The self-test period is small when compared to the interval of time between functional testing.

4.3.4.3. Safety System Configuration

4.3.4.3.1. Voting Logic

The concept related to some different types of voting logic, that can be chosen for safety shut-down systems (and will be in the chapter concerning the methodology application) are described below:

- **1001** - The single module has to give a shut-down signal for a shut-down to be activated (no redundancy - no voting);
- **1002** - Only one of the two redundant modules has to give a shut-down signal for a shut-down to be activated;
- **2001** - Both redundant modules have to give a shut-down signal for a shut-down to be activated;
- **1003** - Only one of the three redundant modules has to give a shut-down signal for a shut-down to be activated.
- **2003** - At least two of the three redundant modules have to give a shut-down signal for a shut-down to be activated.

In Table 4.3.4.1.1, various voting logic are visualised, along with the corresponding reliability block diagram for calculations of both loss of safety (CSU) and spurious trip (STR).

4.3.4.4. Loss of Safety Calculation

When designing safety shut-down systems, the main objective is to detect the hazardous condition, to shut in the process upon hazardous situations and to minimise the adverse effects of such occurrences. Failure to detect the hazardous event, or to shut in the process within a suitable period of time may lead to serious adverse effects and impose severe damage to human health, to assets or environment. Those types of events are usually denoted as undesirable events.

When quantifying loss of safety of safety shut-down systems, we are looking at the probability of occurrence of undesirable events due to failure of the safety shut-down systems (the probability that those systems will *fail to operate (FTO)*, upon a hazardous situation). This is denoted as the *critical safety unavailability (CSU)* of the safety shut-down systems (SINTEF*).

The evaluation of the loss of safety is carried out in a two step procedure (SINTEF*):

- **Qualitative evaluation**

(a) Define the undesirable event and the corresponding success criterion.

(b) Describe the module types of the system;

(c) Draw the *overall failure to operate – FTO - reliability block diagram* of system. In this step you do not need to consider the effect of dependent failures or self-test mechanisms.

(d) Draw the approximate detailed *failure to operate – FTO - reliability block diagram*. In this step you should consider the effect of dependent failures and the effect of self-test mechanisms.

- **Quantitative evaluation**

(a) Establish the necessary input data.

(b) Calculate the Critical Safety Unavailability (CSU) based on the approximate detailed *failure to operate* – FTO - reliability block diagram.

4.3.4.4.1. Qualitative Evaluation

- **Definition of the Undesirable Event and the Success Criterion**

In every reliability study, the very first step is to well define the undesirable event or to define what will be an unsuccessful mission of the system. It is important that the undesirable event gives a clear and unambiguous definition, or the analysis will mislead results. The definition should always include (SINTEF*):

- The type of event for instance fires.
- Where the hazardous situation occurs, for instance fire in area 1.
- The required action of the safety shut-down system, for instance shut-in the production of oil or gas.

A precious definition of an undesirable event is thus: *"Failure of the safety shut-down system to shut in the oil and gas production when there is a fire in area 1"*.

The corresponding "success criterion" is: " *The safety shut-down systems shuts in the oil and gas production plant when there is a fire in area 1"*.

In this work, the undesirable event for calculating critical safety unavailability values for the considered FPSO's safety systems will be:

"The safety system fail to promote the shut-down of the oil or gas production in the proper branch of the FPSO's unit, when there is the occurrence of an accidental scenario or event in the area under its protection".

In quantitative risk assessment studies the hazardous scenarios that are going to be modelled, are defined by the frequency of occurrence of a hazardous condition (leakage, for example) times the critical safety unavailability of the safety shut-down systems times the probability of other attributes (see equation 4.3.2.1 provided in section 4.3.2). Therefore, the unavailability or availability values that appear in the event trees (figures A.1.1 to A.1.32 – Appendix1) are always related to critical unavailability values (FTO).

- **Reliability Block Diagram**

In order to draw the reliability block diagrams; the different module types of the system have to be described. The description should specify (SINTEF*):

- The voting logic of the module. For sensors, it is introduced a distinction between physical voting and logical voting. The physical voting logical is the actual hardware-configured voting logical, whereas the logical voting logic refers to the degree of redundancy at a specific "measure point". Thus, when the physical voting is carried out for a large number of sensors, being spread over a wide area, all these sensors should not be considered as redundant. In this case, the analyst must himself specify how many sensors are actually intended to detect a particular abnormal operating condition. This is the number to be used in the logical voting logic.

Assume for example, that for fire detectors there is a physical 2 out of 20 voting logic. Further, that the 20 sensors are located in such a way that only 3 sensors are close enough to give a signal sufficiently fast, in the occurrence of a fire. In this case a logical 2 out of 3 voting logic should be specified. Similarly, a 1 out of 20 physical voting would be reduced to a 1 out of 3 voting.

In this work we are considering detection units, e.g., we assume that each detection unit will be the only one capable of detecting the hazardous condition in a certain point. Therefore, if that detection unit (which can present a 1oo1, 1oo2, 2oo3, 1oo3 or 2oo2 voting logic) fails to operate upon a hazardous situation, it will be considered a critical failure.

- **Drawing the Overall Failure to Operate – FTO - Reliability Block Diagram**

The next step is to draw the overall reliability block diagram based on the definition of the undesirable event, which is to be analysed.

A reliability block diagram is a logic diagram showing the combinations of module failures that may lead to specific system failures (in this case: fail to operate upon demand (FTO)). The reliability block diagram is a "success path" diagram. This means that if a path through the diagram exists (with no failed modules in the path), the system has not failed (i.e., it is able to perform its intended function).

It is always important to be aware of which failure mode or undesirable event of the system you are analysing. (In the present section, the failure mode to be analysed is "fail to operate upon demand").

We are assuming that no critical failure will occur to power modules' failures, once their failures will not incur in any fail to operate of the system, considering that a fail-safe design is used.

Some points that should be considered during the drawing of the overall failure to operate – FTO - reliability block diagram are the following (SINTEF*):

- Identify the reliability block diagram of the actuating modules by asking:

☐ *"How many of the components/modules need to operate suitably in order to have the safety shut-down system functioning properly by the occurrence of an abnormal operating situation? "*

Reliability block diagrams for the various voting logic are given in Table 4.3.4.4.1. The reliability block diagrams for the most common voting logic are described below.

- If there is a single component that must operate (must detect or must be shut) in order to have the safety shut-down system functioning properly, you have a 1oo1 voting logic. Therefore, the corresponding reliability block diagram shall be drawn as a single box in the diagram (in series).

- If there are two redundant components/modules, you have two possible voting logic, giving different reliability block diagrams for failure to operate – FTO - failures:

  - * 1oo2-voting logic: the safety shut-down system fails to carry out a proper safety action only if both components/modules present failure to operate – FTO - failures. The corresponding reliability block diagram shall be drawn as two parallel boxes.

  - * 2oo2-voting logic: the safety shut-down system fails to carry out a proper safety action if any component/module presents failure to operate - FTO - failures. The corresponding reliability block diagram shall be drawn as two serial boxes.

- The two most commonly used voting logic for triplicated modules have the following reliability block diagrams for failure to operate – FTO - failures (SINTEF[*]):

  - * 1oo3-voting logic: The safety shut-down system fails to carry out proper safety action if all three components/modules present failure to operate – FTO - failures. The corresponding reliability block diagram shall be drawn as three parallel boxes.

  - * 2oo3-voting logic: The safety shut-down system fails to carry out a proper safety action if at least two of the components/modules present failure to operate – FTO - failures. The corresponding reliability block diagram shall be drawn as three serial subsystems, each of the subsystems consisting of two modules in parallel. The first subsystem consists of module A and B, the next of module A and C, and the third of module B and C.

- Modules of the same type should be drawn below each other, so that they form a column in the diagram. These columns of modules are in this work denoted as the module subsets of the system. The module subsets are visualised in the overall reliability block diagram of the example cases.

The overall and approximate detailed Failure To Operate (FTO) block diagrams are provided on Table 4.3.4.4.1 and in Appendix 2.

- **Approximated Detailed Failure to Operate - FTO - Reliability Block Diagram for the Studied Cases**

The purpose of the detailed reliability block diagram is to model in detail the failure mechanisms of the system. When drawing the detailed reliability block diagram, the failure categories of the modules, and the operation and maintenance philosophy of the system have to be closely examined.

The failure categories to be examined are (SINTEF*):

- Fail to operate upon demand (FTO-failure) versus spurious operation failure (SO-failure);
- Single versus multiple failure;
- Undetectable versus detectable failure (by self-test).

Special notation is used to take into account these types of failure, as presented in the list of symbols and notations of this Thesis.

The detailed failure to operate – FTO - reliability block diagram is drawn, considering the module subsets. Note that each of the module subsets forms a cut set of the reliability block diagram, i.e., if none of the module in a subset functions, the system fails.

Table 4.3.4.4.1 and Appendix 2 present the detailed failure to operate – FTO - reliability block diagrams for different voting logic. They also gives the critical safety unavailability formulas for these reliability block diagrams. The reliability block diagrams given in table 4.3.4.4.1 are not exact, but when the limitations given in section 4.3.4.4.2.1 apply, it is sufficient to use these approximate reliability block diagrams. Full detailed reliability block diagrams can be found in SINTEF* - Appendix B.

4.3.4.4.2. Quantitative evaluation (quantification of the Critical Safety Unavailability (CSU)

- **Necessary Input Data**

For each module, the following input data are required for calculation of the critical safety unavailability (SINTEF*):

λ^{F}_{total} Total rate of FTO - failure for a module (for a module of medium complexity).

C	Coverage, i.e., fraction of actual FTO - failure being detected by the built-in self-test.
c_M	Factor for module complexity.
TIF	Test-independent failure probability for FTO - failures. These are not detected by built-in self-test or manual functional testing.
$P_{k,\ k=1,2}$	Probability that k modules (of a specific type) fail simultaneously in a redundant configuration. This is the multiplicity distribution.
τ	Test period for manual functional testing (varies typically from one to three months for different module types).

The rate of undetectable FTO-failure is given by:

$\lambda^F = \lambda^F_{TOTAL} \ . \ c \ . \ c_M$

That expression represents the module failure rate that should be inserted into the formulas shown in table 4.3.4.4.1.1, during the application of the methodology (Chapter 5).

Additional comments and definitions related to the input parameters used in the formulas utilised for Module complexity factor applies only for the logic control modules, and is typically related to the coverage, C, of the built-in self-test reliability calculations are given below.

Built-in self-tests are constructed to detect physical failures in the logic control modules and field cabling automatically. However, only a fraction of all failures occurring during operation will be detected by self-test (e.g., coverage), and thereby, prevented from causing systems failures. This fraction may be different for failures causing loss of safety and failures causing loss of production.

Modules complexity factor, c_m

Module complexity factor applies only for the logic control modules, and it is typically related to the coverage, C, of the built-in self-test of the module. If built-in self-test is added to a "standard" module, the module failure rate will increase. In fact, due to increased complexity, it is not certain that a higher *coverage* actually gives a higher degree of protection against failures causing loss of safety.

The module complexity factor is introduced to include also the negative aspects of built-in self-test, which is increased complexity.

For modules of "medium" complexity (e.g. coverage of CPU module – 90%) the complexity factor equals c_m – 1.0. However, if the applied module is more complex (e.g. with a coverage factor, C – 99%), them the complexity factor should be greater than 1.0 (e.g. c_m – 1.v). For very simple modules (C – O), the complexity factor should be less than 1.0.

Test-independent failure probability, TIF

Test-independent failure (TIF) probability is the constant probability that the safety system will fail to respond properly to a hazardous situation. The TIF probability represents the effect of all failures that are not eliminated by testing. Generally, design and engineering failures that have not been removed prior to system operation (inherent by the delivery of the module) will not be detected by testing. Actually TIF equals the value of CSU, immediately after a functional testing of the module has been performed. Examples of contributors to the TIF probability are:

- Failure to operate – FTO - software-failures (CPU).
- Failure to operate – FTO - failures caused by improper location of sensors (fire and gas detectors).
- Failure to operate – FTO - failures caused by lack of selectivity of a sensor (e.g. fire detector not responding to "smoke fire").

The multiplicity distribution, p_k

The multiplicity distribution allows the reliability analyst to consider the effect of dependent failures on system reliability.

Field experience shows that the effect of redundancy on system reliability is relatively. Hardware redundancy is very effective against natural ageing failures (inherent failures), but the technique is not very effective against failures due to excessive environmental stresses and human-induced failures during engineering and operation. These failures are denoted *dependent* failures, because they may affect two or more modules in a redundant configuration simultaneously (common cause failures).

For a duplicated set of modules (A and B), there are actually three possibility by the occurrence of a failure (see figure 4.3.4.4.1):

- Module A fails only.

- Module B fails only
- Both module A and B fail (simultaneously).

The probability p_1 is the relative proportion of all failures where there is a single failure only (either A or B). Similarly p_2 is the relative proportion of all failures where both A and B fail. The interpretation of p_1, p_2 and p_3 for a triplicated system is quite analogous.

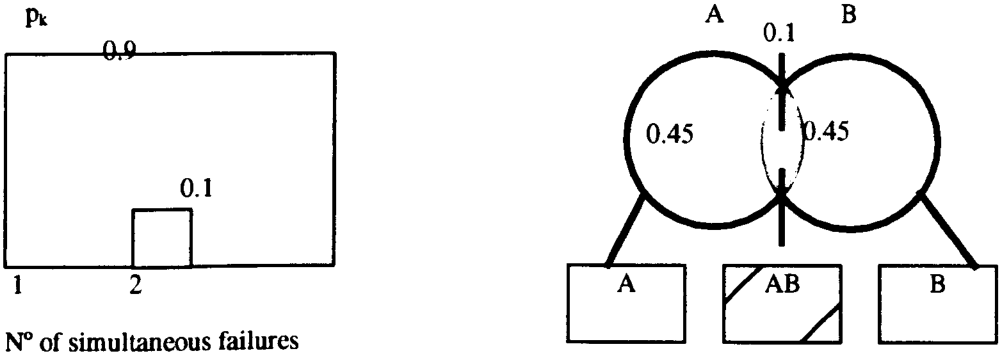


Figure 4.3.4.4.1 - Multiplicity distribution for duplicated modules.

Figure 4.3.4.4.1 shows example numbers for the multiplicity distribution of duplicated modules (SINTEF estimates). The distribution may be quite different for various module types. If, for instance, extra precautions are taken to prevent common cause failure, p_1 will be very close to 1 (e.g. greater than 0.99).

Figure 4.3.4.4.1 also shows the relationship between the multiplicity distribution and the notation used in the reliability block diagrams.

Modelling of diverse redundancy of double modules is done by specifying a new multiplicity distribution for the two modules, p_k^{AB}. This distribution replaces the p^k· s in all critical safety unavailability formulas (see table 4.3.4.4.1.1).

Input / Output Cards (I / O cards)

For I / O cards, the following information is required:

- Rate of FTO - failures affecting all channels (i.e., the common part of the I / O card, λ^F_{common}
- Rate of FTO - failures affecting one channels only, $\lambda^F_{one\,channel}$

- Number of relevant channels (#channels used). This number of channels is related to the given success criterion. Very often a single channel only is relevant for an input card. However, for output the number is often higher (if several valves are to be shut in, and are all connected to the same output card).

From this information, λ^F_{total} is obtained from the formula:

$$\lambda^F_{total} = \lambda^F_{common} + \{ (\#channels\ used) \ . \ \lambda^F_{one\ channel} \}$$

- ***Calculation***

Calculation of the CSU is done on the basis of the approximate detailed failure to operate (FTO) reliability block diagram, using the formulas given earlier in table 4.3.4.4.1.1 and in Appendix 2.

The calculation is done in steps, by calculating the critical safety unavailability for one module subset of the approximate detailed failure to operate (FTO) reliability block diagram at the time. For each module subset, the corresponding module (voting logic) in Table 4.3.4.4.1.1 is identified, and the given formula is used. The final calculation of the system critical safety unavailability is simply done by adding the critical safety unavailability values of the modules.

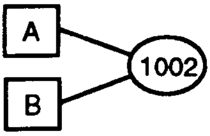
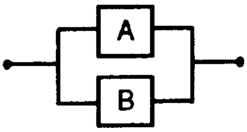
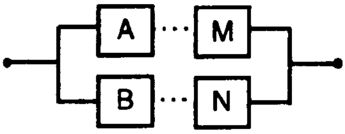
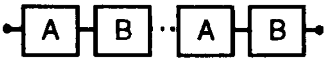
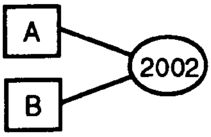
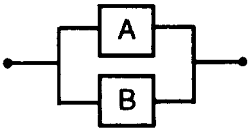
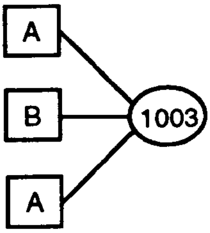
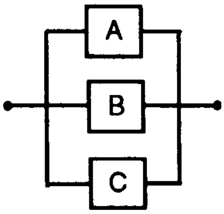
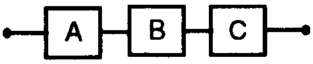
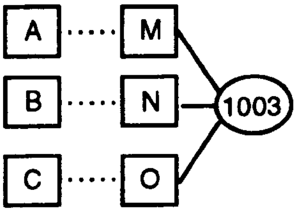
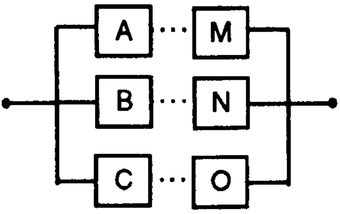
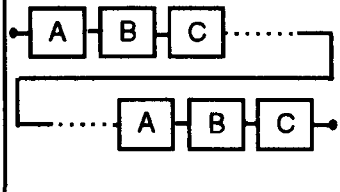
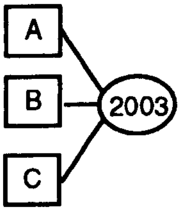
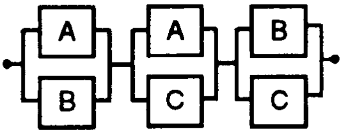
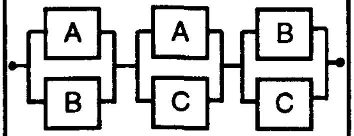
Voting logic	Reability block diagram	
	Fail-To-Operate on demand	Spurious Operation
		
		
		
		
		
		
		

Table 4.3.4.4.1 – Reliability Block Diagrams for Different Voting Logic

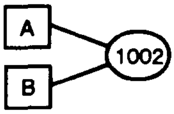
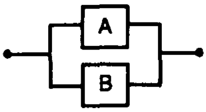
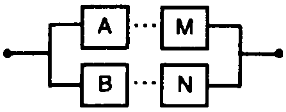
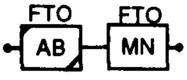
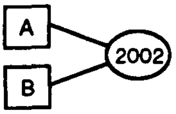
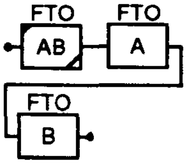
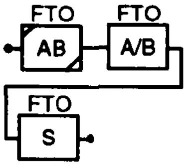
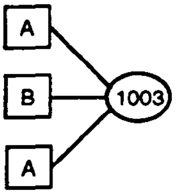
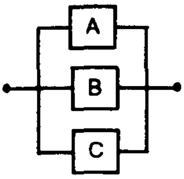
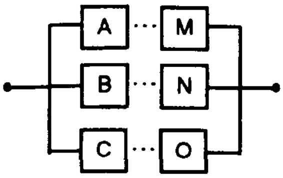
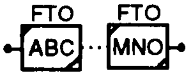
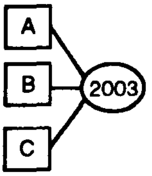
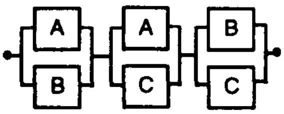
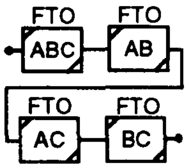
Voting logic	Overall FTO reliability block diagram	Aproximate detailed FTO reliability block diagram	Aproximate critical safety unavailability CSU
			$\left(\lambda^F \frac{\tau}{2} + TIF\right)$
			$\frac{2\rho_2}{\rho_1+2\rho_2}\left(\lambda^F \frac{\tau}{2} + TIF\right)$
			$\frac{2\rho_2}{\rho_1+2\rho_2}\left(\lambda^F \frac{\tau}{2} + TIF\right)+\Lambda$ $\Lambda+\frac{2\rho_2}{\rho_1+2\rho_2}\left(\lambda^F \frac{\tau}{2} + TIF\right)$
			$\frac{2}{\rho_1+2\rho_2}\left(\lambda^F \frac{\tau}{2} + TIF\right)$
			$\left(\lambda^F+\lambda_S^F\right)\frac{\tau}{2}+TIF$
			$\frac{3\rho_3}{\rho_1+2\rho_2+3\rho_3}\left(\lambda^F \frac{\tau}{2} + TIF\right)$
			$\frac{3\rho_3}{\rho_1+2\rho_2+3\rho_3}\left(\lambda^F \frac{\tau}{2} + TIF\right)+\Lambda$ $\Lambda+\frac{3\rho_3}{\rho_1+2\rho_2+3\rho_3}\left(\lambda^F \frac{\tau}{2} + TIF\right)$
			$\frac{3(\rho_2+\rho_3)}{\rho_1+2\rho_2+3\rho_3}\left(\lambda^F \frac{\tau}{2} + TIF\right)$

Table 4.3.4.4.1.1 – Overall and Approximate Detailed FTO Reliability Block Diagrams and Formulas for Different Voting Logic

The adding of the critical safety unavailability values for the module subsets is a first order approximation, valid for low probabilities. Details can be found in SINTEF* and in references /1/ and /2/.

4.3.4.5. Loss of Production Calculation

Failures of safety shut-down systems modules may cause spurious shut down the production. This event is denoted *spurious trip event* in this work. When quantifying loss of production, we are looking at the rate of such events, the spurious trip rate (STR).

Calculating the spurious trip rate (STR) is carried out in a two step procedure, and should be performed in parallel with the calculation of the critical safety unavailability:

- **Qualitative evaluation**

(a) Define the spurious trip event and the corresponding success criterion;
(b) Describe the module types the system consists of;
(c) Draw the overall spurious operation - SO - reliability block diagram. In this step you do not need to consider the effect of dependent failures or self-test mechanisms;

(d) Draw the approximate detailed spurious operation - SO - reliability block diagram. In this step you should consider the effect of dependent failures and the effect of self-test mechanisms.

- **Quantitative evaluation (quantification of the spurious trip rate - STR)**

(a) Establish the necessary input data;
(b) Calculate the spurious trip rate (STR) based on the approximate detailed spurious operation - SO - reliability block diagram.

4.3.4.5.1. Qualitative evaluation

- **Definition of the Spurious Trip Event and the Success Criterion**

When calculating the loss of production, the very first step is to define the spurious trip event, which is to be analysed, in such a way that it is possible to obtain a clear and unambiguous definition. If it is not done, the analysis will often be of limited value. The definition should always include:

- The undesired action of the safety shut-down systems modules upon spurious operation

The definition of the spurious trip event that is going to be considered for any safety shut-down system in this work is thus:

"The oil and gas production is shut-in unintentionally due to a failure of any component or module of the safety shut-down system".

In our case, that failure could derive from the sensor, from the input/ output devices, from the CPU or from the valves.

The corresponding "success criterion" is: *"No oil and gas production is shut-in unintentionally due to a failure of any component or module of the safety shut-down system".*

- **Reliability Block Diagram**

For the purpose of drawing the reliability block diagrams, different module types have to be described. The description should specify the following:

- The voting logic of the module;

- Whether the module has built-in self-tests for automatic detection of failures;

- The action upon loss of power, i.e., whether the module will give a spurious operation - SO or a failure to operate - FTO - failure upon loss of power.

- **Drawing the Overall Spurious Operation (SO) Reliability Block Diagram**

The next step is to draw the overall reliability block diagram based on the definition of the spurious trip event.

A reliability block diagram is a logic diagram showing the combinations of module failures that may lead to a specific system failure (here, the spurious activation). The reliability block diagram is a "success path" diagram. This means that if a path through the diagram exists (no failed modules exists in the path), the system as such has not failed (i.e., it is able to perform its intended function).

When drawing the overall spurious operation - SO - reliability block diagram, some points should be considered as described below:

- Identify the voting logic of the actuating components/modules by asking: "How many of the modules need to function properly in order to cause safety shut-down system to shut down the production by the occurrence of an abnormal operating condition?"

The reliability block diagram for the various voting logics are given in table 4.3.4.4.1. The most common voting logics are further discussed below.

- If there is only one component / module to shut in the production, you have a 1001 voting logic. The corresponding reliability block diagram shall be drawn as a single box in the diagram (in series).

- If there are two redundant components / modules, you have two possible voting logics, giving different reliability block diagrams for spurious operation - SO - failures:
  - 1002-voting logic: The safety shut-down systems will carry out safety actions unintentionally if any component / module experiences spurious operation - SO-failures. The corresponding reliability block diagram is drawn as two serial boxes.
  - 2002-voting logic: The safety shut-down systems will carry out safety actions unintentionally if both components / modules experiences a spurious operation – SO - failure. The corresponding reliability block diagram is drawn as two parallel boxes.
- The two most commonly used voting logics for triplicated modules present the following reliability block diagrams for spurious operation - SO-failure:
  - 1003-voting logic: The safety shut-down systems will carry out safety actions unintentionally if any component / module experiences a spurious operation - SO - failure. The corresponding reliability block diagram is drawn as three serial boxes.
  - 2003-voting logic: The safety shut-down systems will carry out safety actions unintentionally if at least two of the components / modules experience a spurious operation - SO - failure. The corresponding reliability block diagram is drawn as three serial sub-systems, each of the sub-systems consisting of two modules in parallel. The first sub-system consists of module A and B, the next of module A and C, and the third of module B and C.

- Modules of the same type should be drawn after (or above) each other, so that they form a subset in the diagram. These subsets are in this work denoted as module subsets of the system. The partitioning into subsets is done because when the detailed spurious operation - SO - reliability block diagram is to be drawn, dependent failures between components / modules of the same type are to be considered.

- A separate block diagram for power modules should be drawn in series with the overall spurious operation - SO - reliability block diagram of the other modules (this is an approximation valid under the limitations given before). However, this is done only if at least one of the control logic modules gives spurious operation - SO - failure upon loss of power; (if this is not the case, there will be no contribution from power module failures to STR). In this work, we are not considering the contribution of power module failures to the spurious trip rate.

The overall and the approximate reliability block diagrams are provided in Table 4.3.4.5.1.1 and in Appendix 2.

4.3.4.5.2. Quantitative evaluation (quantification of the spurious trip rate - STR)

- <u>**Necessary Input Data**</u>

For each module, the following input data are required for calculation of the spurious trip rate (STR):

$\lambda^{S}{}_{TOTAL}$	Total rate of SO-failures for a module (for a module of medium complexity).
C	Coverage, i.e. fraction of actual SO-failures being detected by the built-in self-test.
c_m	Factor for module complexity.

$P_{k,\ k=1,2}$ Probability that "k" modules (of a specific type) fail simultaneously in a redundant configuration. This is the multiplicity distribution.

The rate of undetectable SO-failures is given by:

$$\lambda^S = \lambda^S_{TOTAL}\, C.\ c_M$$

This is the module failure rate that should be inserted into the formulas provided in table 4.3.4.5.1.1 and in Appendix 2.

Coverage of built-in self-test, C

Built-in self-tests are constructed to detect physical failures in the logic control modules and field cabling automatically. However, only a fraction of all failures occurring during operation will be detected by self-test (i.e. coverage), and thereby prevented from causing system failures. This fraction may be different for failures causing loss of safety and failures causing loss of production.

Tests on input channels without a validity test will only detect failures causing loss of safety. A validity test is a self-test run either continuously or immediately after a shutdown command is detected. Failures causing loss of production will not give any prewarning that can be detected using periodic testing only. With an additional validity test, after the detection of a shutdown command, it is possible to mask out module failures causing loss of production.

A non-redundant output configuration can only detect module failures causing loss of production, but not prevent them form giving a system trip. The coverage for the failures causing loss of production is therefore negligible. Adding redundant hardware and employing a 2002 voting configuration makes it possible to detect and mask these types of failures.

It should be stressed that self-tests do not reveal design weaknesses or software failures. In particular, software failures are relevant for the logic control modules.

Module complexity factor, c_m

Module complexity factor applies only for the logic control modules, and it is typically related to the coverage, C, of the built-in self-test of the module. If a built-in self-test is added to a "standard" module, the module failure rate will increase.

In fact, due to increased complexity, it is not certain that a higher *coverage* actually gives a higher degree of protection against failures causing loss of production.

The module complexity factor is introduced to include the negative aspects of built-in self-test, which has an increased complexity.

For modules of "medium" complexity (e.g. coverage of CPU module – 90%) the complexity factor equals c_m – 1.0. However, if the applied module is more complex (e.g. with a coverage factor, C – 99%), then the complexity factor should be greater than 1.0 (e.g. c_m – 1.v). For very simple module (C – O), the complexity factor should be less than 1.0.

The multiplicity distribution allows the reliability analyst to consider the effect of dependent failures on system reliability.

Field experience shows that the effect of redundancy on system reliability is relatively moderate. Hardware redundancy is very effective against natural ageing failures (inherent failures), but the technique is not very effective against failures due to excessive environmental stressed and human-induced failures during engineering and operation. These failures are denoted *dependent * failures, because they may affect two or more modules in a redundant configuration simultaneously (common cause failures).

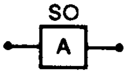
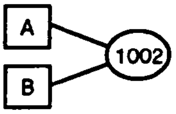
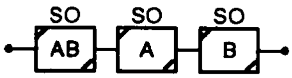
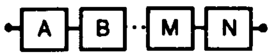
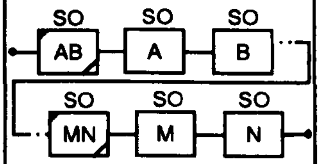
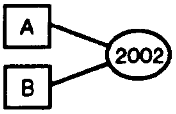
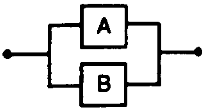
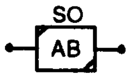
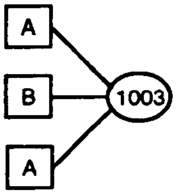
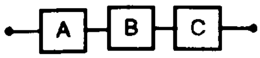
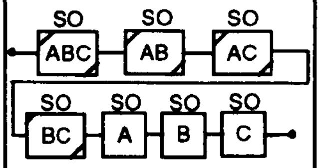
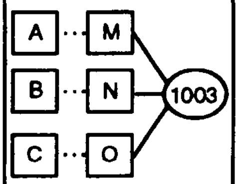
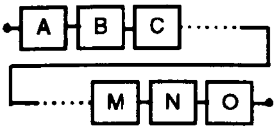
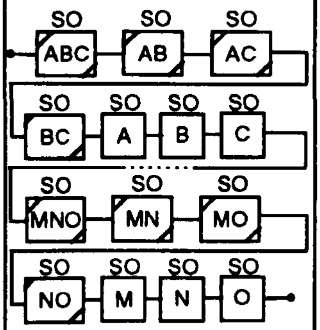
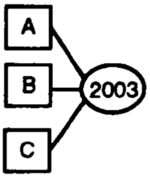
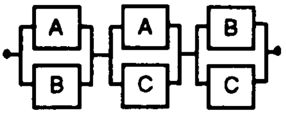
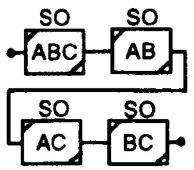
Voting logic	Overall FTO reliability block diagram	Aproximate detailed SO reliability block diagram	Aproximate rate of spurious trips STR
			λ^s
			$\frac{2}{\rho_1+2\rho_2}\lambda^s$
			$\frac{2}{\rho_1+2\rho_2}\lambda^s+\Lambda$ $\Lambda+\frac{2}{\rho_1+2\rho_2}\lambda^s$
			$\frac{2\rho_2}{\rho_1+2\rho_2}\lambda^s$
			$\frac{3}{\rho_1+2\rho_2+3\rho_3}\lambda^s$
			$\frac{3}{\rho_1+2\rho_2+3\rho_3}\lambda^s+\Lambda$ $\Lambda+\frac{3}{\rho_1+2\rho_2+3\rho_3}\lambda^s$
			$\frac{3(\rho_2+\rho_3)}{\rho_1+2\rho_2+3\rho_3}\lambda^s$

Table 4.3.4.5.2.1 – Overall and Approximate Detailed SO Reliability Block Diagrams and Formulas for Different Voting Logic

For a duplicated set of modules (A and B), there are actually three possibilities by the occurrence of a failure (see figure 4.3.4.4.1):

- Module A fails only.
- Module B fails only.
- Both module A and B fail (simultaneously)

The probability p_1 is the relative proportion of all failures where there is a single failure only (either A or B). Similarly p_2 is the relative proportion of all failures where both A and B fail. The interpretation of p_1, p_2 and p_3 for a triplicated system is quite analogous.

Figure 4.3.4.4.1 shows example numbers for the multiplicity distribution of duplicated modules (SINTEF* estimates). The distribution may be quite different for various module types. If, for instance, extra precautions are taken to prevent common cause failures, p_1 will be very close to 1 (e.g. greater than 0.99).

Figure 4.3.4.4.1 also shows the relationship between the multiplicity distribution and the notation used in the reliability block diagrams.

Modelling of diverse redundancy of double modules is done by specifying a new multiplicity distribution for the two modules, p_k^{AB}. This distribution replaces the p^k's in all STR formulas (see table 4.3.4.5.1.1).

Input / Output cards- I / O cards

For Input / Output cards - I / O cards, the following information is required (SINTEF*):

- Rate of SO-failures affecting all channels (i.e., the common part of the I / O card), λ^{S} common;
- Rate of SO-failures affecting one channel only, λ^{S} one channel;
- Number of relevant channels (#channels used). This number of channels is related to the given success criterion. Very often a single channel only is relevant for an input card. However, for output cards the number is often higher (if several valves are to be shut in, and are all connected to the same output card).

From this information, $\lambda^{S}{}_{total}$ is obtained from the formula:

$$\lambda^{S}_{Total} = \lambda^{S}_{common} + \left(\#\, channels\, used\ *\ \lambda^{S}_{one\ channel}\right)$$

- **Calculation**

Calculation of the spurious trip rate (STR) is done on the basis of the approximate detailed spurious operation - SO - reliability block diagram, using the formulas given in table 4.3.4.5.1.1.

The calculation should be done in steps, by calculating the spurious trip rate (STR) for one module subset of the approximate detailed spurious operation – SO - reliability block diagram at the time. For each module subset the corresponding module (voting logic) in table 4.3.4.5.1.1 is identified, and the given formula is used. The final calculation of the system's spurious trip rate (STR) is simply done by adding the spurious trip rates for the components / modules.

4.3.5. Cost Functions

4.3.5.1. General

The purpose of this Thesis is to present a model for allocating safety criteria, or in other words, for identifying the "best" way to improve the reliability or availability of safety systems to satisfy the established safety criteria. Therefore, the accountability of all the costs incurred due to the unavailability of these systems is very important, once it will add other elements that should be considered in order to obtain a whole picture of the cost-effectiveness of the improvement to be proposed.

The elements that constitute the cost functions considered in this work are described below. The concept of life cycle cost usually utilised in reliability analysis were expanded in this work, in other to include, besides the cost of investment and spurious actuation, other elements such as loss to lives, assets and oil and gas production.

4.3.5.2. Presentation of Life Cycle Cost Model

Life Cycle Cost is usually modelled as following:

Where,

$$LCC = LCA + LSC + LSO \qquad (4.3.5.1)$$

LCC = Life Cycle Cost
LCA = Life Acquisition Cost
LSC = Life Support Cost
LSO = Loss due to Spurious Operation

The Life Support Cost (*LCC*) is composed by two terms: the first parcel (*CYR*) is related to investments in resources for operation and maintenance of the equipment or system; the second parcel (*CYC*) is related to the yearly cost of operation and maintenance of those equipment or systems. Hence the total Life Cycle Cost can be written as (SINTEF[69]):

$$LCC = LCA + CIR + CYC + LSO \qquad (4.3.5.2)$$

Where, the terms *LCA* and *CIR* are the costs of (primary) investments of the system or equipment.

Three parcels compose the LCA term: the equipment cost (CIE), the installation/commissioning cost (CIIC) and the management cost (CIM).

In this work we are going to expand the concept usually used for life cycle cost in order to take into account the benefits achieved due to the installation of the safety systems at the unit. Therefore, the life cycle cost will be expressed by the following equation:

$$LCC = LCA + CIR + CYC + LSO + \Delta REL + \Delta LL \qquad (4.3.5.3)$$

Where:

ΔREL = represents the benefit obtained in terms of the oil and gas production saved and damage to the asset avoided due to the installation of safety systems at the facility.

ΔLL = represents the benefit obtained in terms of averted fatalities due to the installation of safety systems at the facility.

All those terms are going to be described in detail below.

4.3.5.2.1. Primary Investments Calculation

We are considering that the primary investments are composed by seven elements, as expressed bellow:

$$\textbf{\textit{Total Primary Investment}} = CIE + CIM + CIIC + CIR \qquad (4.3.5.4)$$

or as:

$$\textbf{\textit{Total Primary Investment}} = CIEH + CIEA + CIMV + CIMC + CIIC + CIRS + CIRT \qquad (4.3.5.5)$$

Where:

CIE = Equipment cost
$CIEH$ = Component cost (hardware)
$CIEA$ = Cost of necessary additional equipment
CIM = Management cost
$CIMV$ = Vendor management and engineering cost
$CIMC$ = Contractor management and engineering cost
$CIIC$ = Installation/commissioning cost
CIR = Cost of investments in resources for operation and maintenance
$CIRS$ = Cost of initial spare part stock
$CIRT$ = Training cost

In order to easy cost calculations, the safety shut-down systems were divided into the following parts:

Detection system: Composed by detectors (fire or gas and input devices to CPU or by pressure sensors more the input device to CPU; field cabling, including junction boxes and cubicles.

CPU: Composed by CPU

Actuation system: Composed by blockage valves and output devices from CPU.

Definitions of each one of the cost components are described below.

Component Cost (CIEH)

The component cost includes the direct component cost (detector, sensor, CPU, valve, etc.)

Cost of Necessary Additional Equipment (CIEA)

SINTEF“” considers that for logic units the “footprint cost” should be included here. That means that the indirect cost for the Oil Company of the floor area occupied by the equipment should be considered. In this case the relevant equipment to be considered would be the cabinet for CPUs. In this work we have included the cabinet cost and all other costs related to CPUs in the component cost (*CIEH*).

Regarding others components like detectors, sensor, valves, the necessary additional equipment would be related to holders, field cabling, junction boxes and cubicles. In this work, the cost of holders were included in the component cost and the cost related to field cabling, etc. were included in the commissioning part of the investment cost (CIIC) which tales into account the installation and testing costs.

Vendor Management and Engineering Cost (CIMV)

Two parts compose this cost element. The first one comprises the management and engineering done by the field equipment (detectors, sensors, valves) vendor and the second one comprises the management and engineering done by the vendor of logic units. For both parts, this includes the following:

- Cost of management and engineering done by the vendor, including documentation;
- Cost of the application software (non-standard software);
- Cost of internal vendor acceptance tests and factory tests.

In this work as SINTEF[49] has adopted, the vendor management and engineering cost was taking into account as following:

For field equipment (detectors, pressure sensors, valves):

$$CIMV = 0.25 * CIEHfieldeq \qquad (4.3.5.6)$$

For logic control units (CPU, input and output devices):

$$CIMV = 0.4\ CIEH \qquad (4.3.5.7)$$

Installation/Commissioning Cost (CIIC)

This cost element considers all initial costs for installing and putting the equipment or system into operation. This includes the following:

Installation/mechanical completion:

- cabling
- termination
- hook-up
- certification
- etc.

Commissioning:

- loop-test
- start-up
- etc.

Oil Company/Contractor Management and Engineering Cost (CIMC)

This includes the cost of management ad engineering done by the Oil Company or contractor, including documentation. In this work this parcel is taken into account as following:

$$CIMC = 0.25 * (CIEH + CIMV + CIIC) \qquad (4.3.5.8)$$

Cost of Initial Spare Part Stock (CIRS)

This cost element comprises the initial investments in spares. It is assumed that the number of initial spare parts should be v% of the total number of components of that type, rounded up to the nearest integer.

Training Cost (CIRT)

This cost element comprises the cost of initial training of maintenance and operation personnel. Training costs were assumed to be equal for the detection system, for CPU and for the actuation system.

All those terms are going to be described in detail below.

4.3.5.2.2. Calculation of Cost for Operation and Maintenance (CYC)

There are two elements included in the parcel concerning the yearly cost of operation and maintenance, as following:

- periodic testing;
- corrective maintenance

4.3.5.2.2.1. Periodic Test Model

The periodic testing costs per year for each component type are obtained as following:

Test costs per year = (number of components) * (test frequency) * (average man-hours per test) *(cost per man-hour) (4.3.5.9)

Where:

Test frequency* = *(12 months/year) / (test period in months) (4.3.5.10)

4.3.5.2.2.2. Corrective Maintenance Model

The total cost per repair will be expressed by:

Total cost per repair *= (man-hours per repair) * (cost per man-hour)*
+ (other costs per repair) (4.3.5.11)

The last term in the expression above includes spare parts, tool consumption, etc.

Repair costs per year *= (number of components) * (failures per component per year)*
** (total cost per repair)* (4.3.5.12)

For corrective maintenance, the total rate of physical failures is used in the calculations. This value is equal to the sum of failures rates for failure to operate mode (FTO) and for spurious operation mode (SO). Sometimes for logic control units, different failure rates are used for different configurations, reflecting differing complexity between components.

4.3.5.2.3.Unavailability Cost Calculation

4.3.5.2.3.1. Overall Model

In order to evaluate life unavailability cost it is necessary to take into account the yearly costs imposed due to the critical unavailability of safety systems, as well as the yearly costs incurred due to the spurious actuation of safety systems (unintended production shut-downs).

The critical unavailability of a safety system is the unavailability derived due to a failure to operate in case of the occurrence of an accidental event, leading to consequences in terms of fatalities, damage to assets and loss of income (due to deferred production). Therefore, we will express the first parcel of the total life unavailability cost, e.g., the cost associated with the critical unavailability *(LUC)* as following:

$$LUC_{year} = LL_{year} + REL_{year} \qquad (4.3.5.13)$$

Where:

LL_{year} = Expected Loss of Lives per year
REL_{year} = Expected Residual Loss per year

- **Expected Loss of Lives**

The parcel concerning the Expected Loss of Lives per year (*LLyear*) is given by the following expression:

$$\boxed{LLyear = Number\ of\ fatalities\ per\ year * value\ of\ life * Critical\ Safety\ Unavailability \qquad (4.3.15)}$$

Then the benefit (*Δ LLi*) obtained due to the installation of the safety systems is calculated in terms of deaths averted. The value of *Δ LLi* will be obtained by the difference between the cost associated with loss of lives in case there is no safety system installed (e.g., when the safety critical unavailability is equal to 100%), and the cost associated with loss of lives related to a certain safety system configuration (a certain safety system's reliability level). The *Δ LLi* value can be obtained by the following expression:

$$\Delta LLi = \begin{bmatrix} Number\ of\ fatalities_{\ i=0} * Value\ of\ life * CSU_{\ i=0}\ - \\ Number\ of\ fatalities_{\ i=1,5} * Value\ of\ life * CSU_{\ i=1,5} \end{bmatrix} \qquad (4.3.5.15)$$

Where:

CSU = critical safety unavailability, and

$CSU_{i=0}$ = 1, critical safety unavailability value associated with no safety system installed

- **Expected Residual Loss per year**

The Expected Residual Loss per year *(REL)* is given by the following expression:

$$\boldsymbol{RELyear} = fevent * Cevent * CSU \qquad (4.3.5.16)$$

Where:

RELyear = Expected Residual Loss per year after the occurrence of an accidental event
fevent = Event frequency of an accidental event
Cevent = Expected Consequence of an accidental event
CSU = Critical Safety Unavailability

The term -Expected Residual Loss per year- includes the loss to assets plus the loss of net income per year after the occurrence of an accidental event due to the critical unavailability of safety systems.

Then the benefit (*ΔREL)* obtained due to the installation of the safety systems is calculated, in terms of avoided loss. The value of *ΔRELi* can be obtained, by the difference between the economic loss when there is no safety system installed (e.g., when the safety critical unavailability is equal to 100%), and the economic loss associated to a certain safety system configuration (a certain safety system's reliability level). The *Δ RELi* value can be obtained by the following expression:

$$\Delta RELi,_{i=1,5} = fevent * Cevent * (CSU\ Case0 - CSU\ Casei,_{i=1,5}) \qquad (4.3.5.17)$$

4.3.5.2.3.2. Loss to Assets and Loss of Income due to Total Loss or Severe Damage

- **Loss of Assets**

The calculation of the loss to assets can be performed, considering events that cause total loss or a severe damage to the unit. Therefore, it is necessary to get information about the number of occurrences related to accidental events that have caused total loss or severe damage to similar facilities.

According to WOAD[v0], it is possible to get the following figures for all units world wide, during the period of 1980 to 1993:

Number of occurrence of fires that cause total damage to the unit: 2
Number of occurrence of fires that cause severe damage to the structure: 3

Based on the numbers presented above and after estimating values for the total loss of the industrial facility or for a severe damage (which can be considered as v0 % of the value estimated for total loss), its is possible to obtain an average value estimated for loss of the asset.

It is important to consider the insurance made for the installation, the cost of this insurance and if it would cover a total loss of the unit, in case of the occurrence of a major accident.

- **Loss of income due to the occurrence of a dangerous situation**

Considering that after the occurrence of an accidental event the unit will be out of operation during a certain period of time, it is necessary to calculate the associated loss of income. In the case of oil production facilities the loss of income is expressed in terms of deferred production (oil plus gas).

We will considered that the occurrence of a major accident in the vessel will delay the enterprise as a whole for a period of time equal to n months (Pereira[55]).

The delay of n months of the enterprise as a whole will imply in a displacement of n months of all the enterprise's cash flows simultaneously. Therefore, the income loss calculation (in Net Present Value - NPV) will be simply the discount of the original NPV (NPV_0 - without delay or delay equal to zero) by the discount factor $(1 + r)^{n/12}$, where r is the annual discount rate and n is equal to number of months of delay of the enterprise as a whole.

Therefore, the income loss due to n months of delay (ΔNPV) will be given by the following expression (Pereira[55]):

$$\Delta NPV = NPV0\left(1 - \frac{1}{(1+r)^{\frac{n}{12}}}\right) \qquad (4.3.5.18)$$

Where:

ΔNPV = NPV loss due to n months of delay of the enterprise as a whole
NPV_0 = original NPV of the enterprise with no delay
$(1+ r)^{n/12}$ = discount factor
n = number of months of delay

4.3.5.2.3.3. Expected Loss per year due to Spurious Actuation

The expected loss per year due to spurious operation or unintended production shut-down (LSO_{year}) will be given by the following expression:

$$LSO_{year} = f_{spur} * Cost_{spur} \qquad (4.3.5.19)$$

Where:

f_{spur} = Frequency of spurious failures

$Cost_{spu}$ = Cost of spurious failures

The cost of spurious actuation is calculated in terms of loss of production (oil loss plus gas loss), as described below. In fact, we would have an income loss due to postponed production during the production shut-down time, which could be calculated. As this period of time is very short (equal to v0 min- estimation based on PETROBRÁS offshore experience), it is possible to simplify this calculation and just consider this parcel as loss of production during this period of time. This is the period of time estimated as the required returning time to normal production after an unintended production shutdown. Therefore, we will have the following expressions:

Oil loss due to spurious actuation (pounds) = oil production (barrels/day) * oil price (pounds /barrel) * fraction of time to return to normal production (4.3.5.20)

Gas loss due to spurious actuation (pounds) = gas production (m3/day) * gas price (pounds/day) * fraction of time to return to normal production + gas loss due to the burn of gas (pounds) (4.3.5.21)

Where:

Gas loss due to the burn of gas (pounds) = gas production (m3/day) * gas price (pounds/day) * fraction of time for plant blow-dow (4.3.5.22)

4.3.6. Optimisation Model

The optimisation model that will be used to solve the problem proposed by the allocation model is the Solver – Microsoft Office 97, an user-friendly code that is applied to linear and non linear problems.

Solver is used to solve typical optimisation problems, where it is necessary to maximise or minimise a certain function with several variables, submitting that function to some constraints.

The values that will be addressed to the safety systems' availability variables will be the ones established by ISA[v4] for Safety Integrity Levels, which definition and values are given below:

Safety availability definition (ISA[v4]): *"Fraction of time that a safety system is able to perform its designated safety service when the process is operating."*

Safety Integrity Level (SIL): *"One of three possible discrete integrity levels (SIL 1, SIL 2, SIL 3) of Safety Instrumented Systems. SILs are defined in terms of Probability of Failure on Demand (PFD)."*

Table 4.3.6 shows the three Safety Integrity Levels - SILs – proposed by ISA[v4] :

At present designed engineers are trying to achieve SIL 4 for safety instrumented systems, which corresponds to a probability of success on demand greater than 0.9999.

The constraints will be defined as a function of safety system's availability/unavailability and in terms of maximum tolerable individual risk and maximum tolerable frequency of impairment to main safety functions of the facility under analysis.

Safety Integrity Level (SIL)	**Probability of Failure on Demand**	**Probability of Success on Demand**
1	10^{-1} to 10^{-2}	0.9 to 0.99
2	10^{-2} to 10^{-3}	0.99 to 0.999
3	10^{-3} to 10^{-4}	0.999 to 0.9999

Table 4.3.6 – Safety Integrity Levels proposed by ISA[14]

The use of Solver will be presented in Chapter 5 of this Thesis, in the application of the proposed methodology for the allocation of risk and reliability.

5. Methodology Application

5.1.General

The proposed model was developed for a Floating Production Storage Offloading vessel (FPSO), which is a ship that is capable of receiving the production, processing the production through a process plant, and of storing oil in its tanks until the offloading occurs. The detailed description of the FPSO used in this work is presented below. Figures 5.1.1, 5.1.2 and 5.1.3 illustrate the FPSO's layout and the turret system.

The methodology presented here has to be based on a complete quantitative risk assessment previously performed for the facility under analysis. In our case, the quantitative risk assessment performed for one of the PETROBRÁS FPSO's was utilised as the basis for the methodology's application (Principia/ Petrobras[43,44]).

5.2. Floating Production Storage Offloading (FPSO) Description

5.2.1. Introduction

The availability of very large crude carrier (VLCC) tankers with their low cost of conversion, associated with the availability of turret and swivel technology were the main reasons to PETROBRAS decision to install FPSO's vessels since 1997. The arrangement option made for the sub-sea pipelines oil exportation was a tandem ship-to-ship system.

Area of application

In Campos Basin, PETROBRAS has been developing fields like Barracuda, Albacora, Marlim and South Marlim.

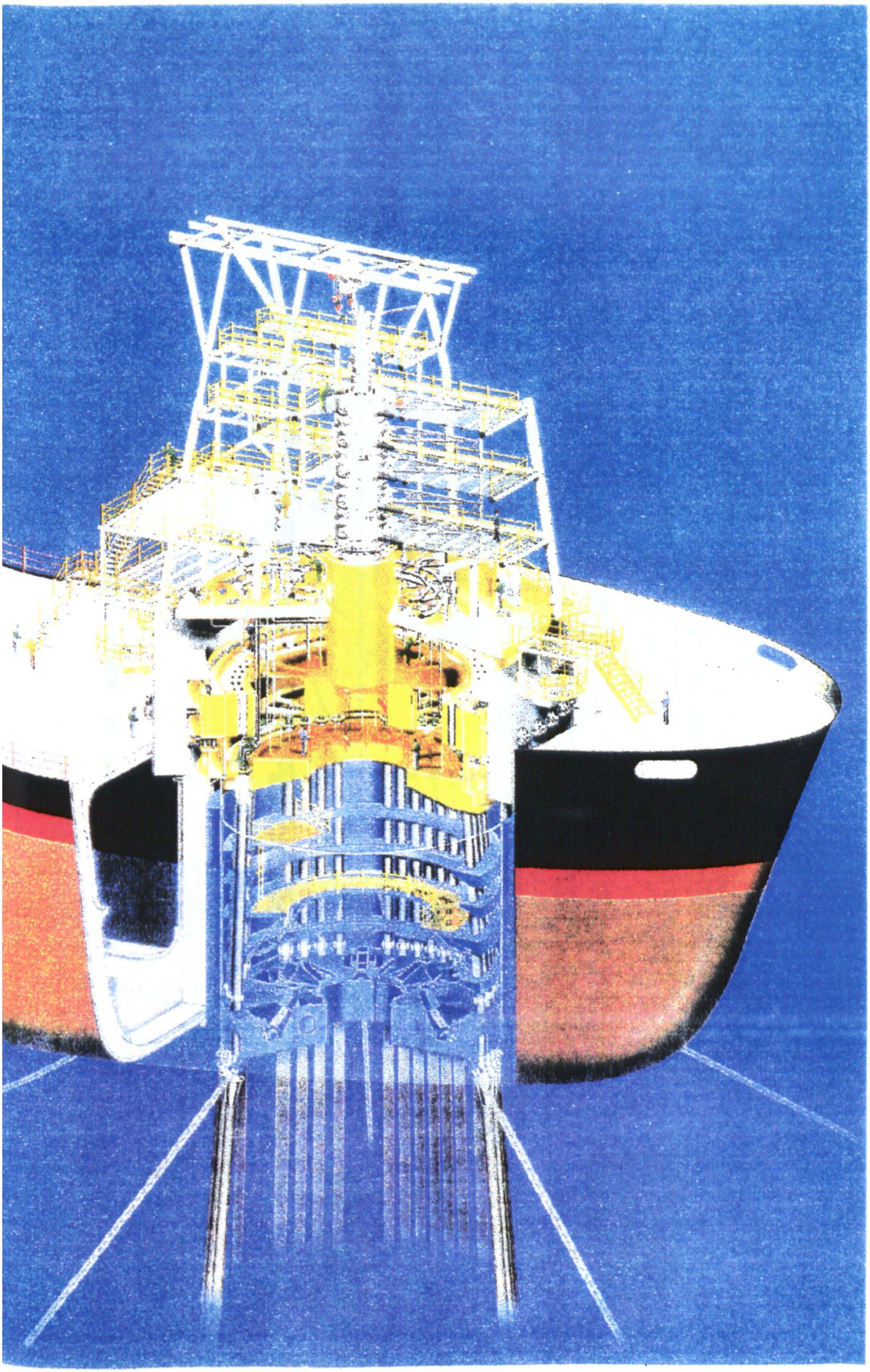


Figure 5.1.1 - Ilustration of FPSO and its turret system

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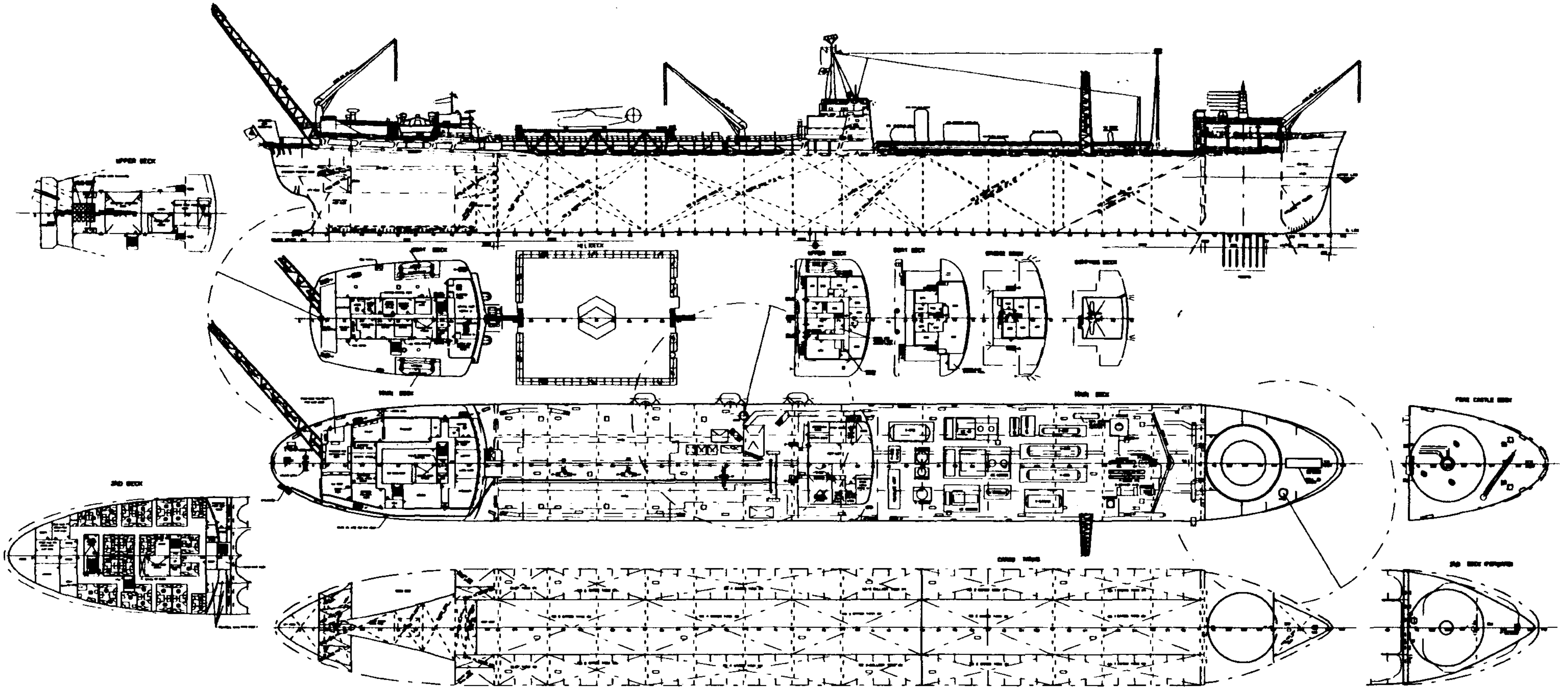
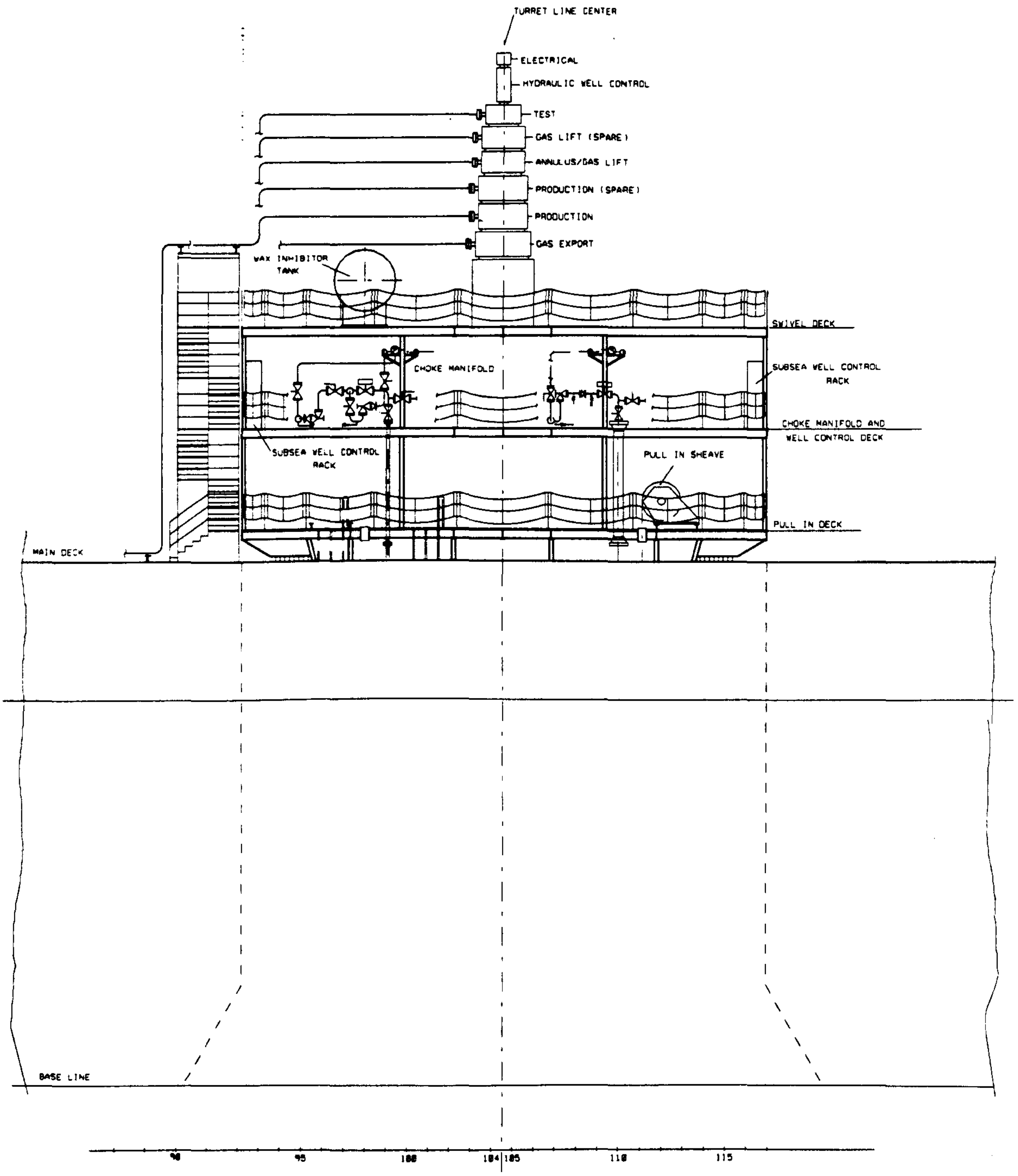


Figure 5.1.2 - Illustration of the FPSO's layout



ELEVATION

Figure 5.1.3 - Illustration of FPSO's turret system

Formerly, the successful concept adopted by PETROBRÁS was the use of floating production systems with the semi-submersible conversion and/or construction of new production units.

During the development of preliminary feasibility studies (until 1993) for the oil field mentioned above, world situation has changed a lot and PETROBRAS has decided to adopt FPSOs in Barracuda, Marlim and Albacora fields due the following reasons:

-Availability of existing tankers (VLCC) in the Company's Fleet.
-High cost of existing semi-submersible units for conversion or new construction.
-Less initial investments for tankers conversion.
-More flexibility for production transportation
-Less initial costs in comparison with pipelines and with on shore facilities.

Besides the exposed reasons, the FPSO's concept with their several alternatives of mooring has been extensively used worldwide, as in North Sea, West Africa, Indonesia, South America, etc.

5.2.2. Main Features of FPSOs

The main features of the FPSO under study will be presented below. The main characteristics of its systems, as well as the safety design and supervisory and control philosophy are going to be briefly described.

5.2.2.1. Safety Philosophy

The description of the main aspects concerning the safety philosophy adopted by PETROBRÁS for FPSO's and which are directly related to the Thesis approach are presented below. Details can be obtained in PETROBRÁS safety philosophy's technical specification[56], as mentioned in the Thesis's references.

Lifeboats

At FPSO's, lifeboats shall be installed in a number large enough for the abandonment of 100% of the population at each side of the Unit.

Lifeboats shall be installed as close as possible to sea level, preferably perpendicular to the deck and at the same level, so that there will not be a two way flow of people on the stairs during abandonment preparation. They shall be placed away and protected from the dangerous areas in positions such as to facilitate their removal from the platform preventing prevailing sea currents or wind from driving them against the legs of the platform.

Inflatable rafts

Inflatable rafts shall be specified so as to withstand a fall from the height of the facility or provision should be made for a device to lower them.

In the case of the FPSO's, there shall be installed on each side of the installation rafts in a number sufficient for the abandonment of 100% of the population (number of bunks on the living quarters).

Rescue boats

The Unit shall be outfitted with a rescue boat located close to sea level to facilitate operations of lowering and raising equipment and capable of carrying at least five seated persons and a person lying down according to SOLAS requirements.

Muster stations

There shall exist locations on the Unit, outside the processing area, that provide safety for the purposes of isolation in emergency situations and bring together the personnel not involved in the respective control operations for the transmission of specific instructions for evacuation or abandonment.

Active and Passive Fire Protection Systems

Fixed Protection Systems

- General

The location of the fire fighting resources and appliances, such as fire water main, deluge valves, hydrants, fire extinguishers, fire-fighting equipment lockers etc, shall take into consideration a qualitative/quantitative analysis of risks (fire, explosion falling load etc.) that may affect the operation of such resources. This analysis shall also evaluate the possibility of propagation of fire and its consequences considering each risk scenario.

The philosophy of protection operations in cases of fire demands, depending on the circumstances, shall action to:

- Alert the population of the Unit to any emergency conditions;
- Actuate the emergency shutdown system to shut down the wells and block the processing and utilities systems;
- Exhaust the entire stock of gas in a controlled manner at a safe point away from the Unit;
- Activate the water spray system in the area affected and /or adjacent areas in order to laminate the possibility of fire propagation;
- Flood the affected area with CO2 in order to extinguish the fire.;
- Etc.

Equipment containing, handling and/or storing flammable fluids (well area, process area, riser's connection area, turret area etc.), even when located in utilities areas, shall be protected by water spraying devices. The water mist should be applied to cool the surfaces of the equipment, thus avoiding them getting heating up to a point of collapse.

Diesel oil storage tanks, including day tanks, shall be protected by water spray, except those tanks located inside rooms protected by CO_2, those inside pontoons of Semi-submersible Platforms and those in the engine rooms of the FPSO's.

Low risk areas, such as living quarters, workshops, storage facilities etc. shall be protected by manual fire-fighting systems.

Portable fire extinguishers and hydrants shall also be adequately located as described in this chapter.

For FPSO's there shall be provided foam systems to protect the tanks storing crude oil according to classifying authorities and SOLAS requirements. Additional foam applicators shall be required if there is production equipment above the oil storage area and if the steel supporting members of the process plant can obstruct the foam system for the cargo deck.

For the FPSO's provided with "Turret", arrangements shall be made for a specific "Swivel" for water ducts to fight fire, protecting the equipment installed inside.

The helideck shall be provided with fire-fighting equipment for helicopter fuel leakage fire.

Passive Protection

Classified bulkheads and decks shall enclose high risk areas isolating them from normally serviced areas, as well as from low risk areas, as defined in IMO.

Vertical access connecting only two decks inside accommodations shall be protected in at least one of the decks by self-closing A class doors in order to avoid fire spreading from one deck to the other one. When vertical accesses connect more than two decks, they shall be enclosured by A class walls and protected by self-closing A class doors at all decks.

Bulkheads separating corridors from sleeping rooms inside accommodations shall be at leas B-15 class, extending from the floor to ceiling if the lining is not also classified as B-15 class.

Penetration

Wherever it is necessary to penetrate a classified bulkhead and deck with piping ducts, trays or cables, proper measures shall be taken to ensure the integrity, according to classification, at the penetration point. For that purpose, fireproof sealing materials properly classified shall be used to seal the penetration, and thus avoiding fire spreading.

Doors and Windows

Doors and windows shall be constructed following the integrity requirements of the type of the bulkheads in which they are located. The fire doors shall be of the self-closing type.

Windows shall not be installed in Class A-60 bulkheads.

Structural Protection

Requirements for application of passive protection on structural supports shall be defined based on studies considering the fire propagation analysis as required at this item and according to General Criteria for Petrobras Structure Installation Design.

Fire and Gas Detection Systems

These systems aim to detect the occurrence of fire and accumulation of flammable or toxic gases and vapours in dangerous concentrations. They warn the people the unit of the presence of risk conditions allowing for control actions to minimise the probability of increasing undesired effects.

Fire Detection System

General Remarks

The activated fire sensors (except those of fixed temperature type with fusible plug) shall be ready for reuse without replacement of any of their components after they have been operated.

There shall be in all Units areas hand-operated fire alarm of the "Break Glass and Push Button" type painted in the safety red colour. These push buttons shall sound a warning (indicating a confirmed outbreak of fire) in the control room and all over the Unit, except as described below:

- The hand-operated fire alarms in the living quarters shall only sound a warning in all the installation after two minutes without being acknowledged in the central control room.

Smoke and heat sensors shall be of the addressable type allowing for identification at the ECOS of the place where the detection may occur.

Selection of Sensors

In the processing and storing of flammable/fuel areas, fusible plug heat sensors shall be used with operating temperatures ranging between 70° and 77°C. Ultraviolet/Infrared sensors may also be used in these areas.

Closed areas with clean atmosphere not associated with flammable fluids, such as electric switchboard rooms, empty spaces and ceilings and false floors, batteries and battery charging rooms, telecommunication equipment rooms etc. shall be fitted with smoke sensors. Two loops of sensors are used in these areas and the activating of one sensor indicates "detected fire" and the activating of another sensor of the other loop "confirmed fire".

At points where smoke and/or dust are usually present such as: store rooms, laboratories, workshops, etc., thermovelocimetric heat sensors shall be used.

Location of Sensors

The final location of each sensor shall be established after the installation of equipment, piping, ventilation ducts etc., but the number of sensors and the respective spacing follow the recommendations on "NFPA-72E", "API-RP-14C" and manufacturers.

In all systems of detection of the type fusible plug and UV/IR in areas of confined processing , the activation of a single sensor shall be sufficient to initiate automatic safety actions such as:

- Alarm in the control and on the installation.
- Activating of ESD-3 system.
- Activating of the deluge system.
- etc.

In areas that require the actuation of 2 sensors, they shall be installed in a way that all points of the protected area are monitored by a minimum of two sensors.

Gas Detection System

Sensors

The sensors provide electrical signals corresponding to the levels of gas concentration detected in the monitored area. Warnings shall set off in the central control room whenever levels reach 20% and 60% of the LI.I. (Lower Explosive Limit) for fuel gases and 10 / 20 ppm in the air for toxic gases.

A punctual sensor type infrared shall be used for detecting combustible gases.

Location of Sensors

In order to place the sensors, a study on gas dispersion shall be elaborated taking into consideration the following aspects: gas leakage points; leakage occurrence frequency; amount and process conditions of the released gas cost x efficiency analysis.

Design Criterion:

The amount and location of the gas sensors shall be based on the utilisation of tri dimensional models for gas concentration. The air intakes for cooling machinery and air intakes for ventilation shall be monitored by gas sensors. Monitoring of exhaust outlets shall be verified case by case.

Configuration of System:

Safety actions on the Unit shall be initiated only with coincident operation of two gas sensors in the same area. To ensure that the failure of any sensors will not cause the non-operation of the system, there shall be three gas sensors (2 of 3 voting logic) on each detection location determined by the Gas Dispersion Study. The 2 of 3 voting logic criteria shall also be applied to the air intakes and outlets above described.

Detection of Combustible Gas

The operation of a single sensor indicating a concentration of 20% or 60% of the LI.I. for gas will merely set off a warning in the central control room.

Simultaneous operation of two sensors indicating a concentration of 60% of the L.I.I for gas signifies confirmed gas at a level of 60% of LI.I. and they shall start suitable control actions such as:

- A warning in the central control room;
- Disconnection of electrical equipment unsuitable for operation in the presence of gas;
- Shutdown the flow of hydrocarbons to the affected area;
- Activation of the emergency shutdown system level (ESD-3);

- etc.

Hydrogen sensors shall be installed in the exhaust ducts of the battery rooms. The activating of one sensor indicating 20% of the L I.I. shall be signalled in the control room and start up the stand-by exhausters. Detection of gas by two sensors at a level of 60% of the L.I.I. shall also inhibit the deep battery charging system.

Toxic gas (H_2S)

The activating of only one sensor indicating concentration in the air of 10ppm or above will just activate the warning in the central control room of the unit.

Simultaneous activation of two sensors indicating 10 ppm of gas concentration in the air means confirmed gas at 10 ppm and besides alarming at central control on the unit they will initiate actions such as:
- alarm all over the installation;
- start stand by ventilation (when is the case)
- etc.

Simultaneous activating of two sensors indicating 20 ppm of gas concentration in the air means confirmed gas at 20 ppm and will initiate, according to the situation, control actions such as:

- alarm at the central control room and all over the unit;
- activating the level 3 (ESD-3) system;
- interrupting the gas flow to the affected area;
- etc.

Pressure Relief and Depressurisation Systems

General Remarks

The pressure relief and depressurising systems shall be designed in accordance with "API RP 520 and API RP 521".

Depressurisation System

In principle, all pressurised equipment handling hydrocarbons shall have two independent means of relief capable of avoiding over-pressure owed to the occurrences mentioned in API RP 521 and any other specific situation not mentioned in the same norm..

The primary protection shall be provided by the emergency shutdown system and the secondary protection by a safety and pressure relief valve (PSV).

The need for installation of depressurising valves (blow down valves – BDV's) shall be analysed in all the equipment containing flammable fluids that might be set off during a fire so as to avoid a failure in the equipment due to a rise in temperature..

The depressurising system shall also be operable from the central control room or locally and automatically when activated the level 4 emergency shutdown signal (ESD-4).

Atmospheric Vent System

This system shall be used to collect all vents from equipment operating at atmospheric pressure. The gas inventory shall be dispersed safely through the "atmospheric vent". Discharge of this system may be at a point along the structure of the flare so that the exhausted gas is not ignited by the flare flame and does not form an explosive mix over the Unit.

A CO_2 snuffing system shall be provided for the flame extinction in case of ignition of exhausted gases. Provision shall be made for injecting fuel gas into the header so as to prevent the penetration of oxygen into the circuit.

Escape Ways and Routes

Escape routes have as their main purpose to provide access in a quick and safe way to the place where the lifeboats are. And they facilitate the way out for people from hazardous areas.

The following shall be considered when designing these routes:

The installation shall be fitted with primary and secondary routes and they must be free from obstacles and have the following dimensions:

- Primary route- Minimum width = 1.2 m , minimal height = 2.1 m.
- Secondary route – Minimal width = 1.0 m, minimal height = 2.1 m.

- Escape ways accessible by any area on the Unit via two different routes shall be provided. Those ways should have 1.2 m of width and 2.1 m of height.
- There must be at least two independent escape routes coming from the service areas to the living quarters or to the abandonment stations.
- Doors leading to external walkways of the Unit or other escape routes shall open outwards. Under no circumstance shall these doors obstruct the escape routes.

From any point on the installation there shall be two alternative ways leading to the escape route, except for cabins, offices, cold storage room and other rooms with less than $10m^2$ which can only have one way out.

Each access from the rooms shall have emergency lighting.

All legs of floating units located on the corners shall be provided with escape stairways leading to the sea. By each of these stairs there shall be installed a stair head two meters above sea level and large enough to accommodate two people side by side. These stairs shall be provided with emergency lighting.

The escape routes shall not be obstructed by any kind of equipment like elevators, lifting, cables etc. The escape routes floors must be painted in white and covered with anti-sliding coating.

Floors and Walkways

The walkway around the entire periphery of the Unit is a main escape route and shall not be narrower than 1.2 meters and under any circumstances, no loads shall be left there. These walkways shall be provided with railings no less than 1.1 meters high.

- The walkways on the installation premises shall, as primary escape route, have a minimal width of 1.2 meters.

Whenever necessary, the floors must have suitable protection characteristics to isolate the areas of greater risks from others of lesser risks.

For locations where the utilisation of floor railing are foreseen, they shall be of the type serrated.

The design shall foresee special spots for the " transportation basket" operation.

Emergency Shut-Down Systems

General Remarks

The emergency shutdown system shall permit an effective and safe shutdown of the process and other equipment on the Unit in order to restrict risks caused by undesired effects.

The emergency shutdown system shall be comprised of the four different levels listed below:
- Level 1: Partial shutdown of process or utilities;

- Level 2: Total shutdown of process without affecting utilities;
- Level 3: Total shutdown of process and "non essential" utilities;
- Level 4: Automatic depressurisation and preparation to abandon if necessary.

The emergency shutdown system for levels 1, 2 and 3 may be operated by hand or automatically.

The level 4 operation shall be only hand operated, except at inhabited Units where it can be operated by hand or remote control.

The pushbuttons for activating of the emergency shutdown system (ESD-2, ESD-3 and ESD-4) shall be installed at only two points, listed below in order of priority.

- Control room (through ECOS);
- Radio room;
- Unit manager's room.

ESD-2 push-buttons (adequately protected) shall also be installed at the helideck and abandonment stations.

Activities unleashed by an emergency shutdown hierarchically higher than other cover the remaining levels as well.

Safety Interlocking System

This system shall be responsible for functions such as :

- Fire/Gas Detection Fighting;
- Emergency process shutdown;
- Alarms;
- Interfacing with the Unit operation and supervisory system.

Programmable logic controllers perform all functions of the safety interlocking system where applicable.

Status warnings and signals referring to the detection and fire-fighting system and the status of the fire-fighting pumps shall be displayed on the monitor of the Central Operation and Supervisory station (ECOS).

The Electric circuits of the drive warning and signalising devices of the Unit safety systems shall have continuous monitoring arrangements to indicate open circuit, short-circuit, etc. As described in Petrobras Interlocking Technical Specification, the following equipment shall be monitored: hand-operated fire alarms, ESD and CO2 push-buttons , fusible plug and fire network pressure switch (PSL's), CO2 Master cylinders solenoid valves and directional valves, CO2 directional valves.

In case of using remote stations connected to the PLC's, they shall be installed inside protected rooms or in compartments with essential equipment.

5.2.2.2. Supervisory and Control Philosophy

The basic concept concerning this topic is to concentrate all actions related to the control and to the supervision system of the whole unit from a single control room.

Therefore, for all FPSO vessels, a supervision system based upon Digital Alpha stations was designed. From those stations, operators can interact with all the process plant, with transferring, separation and compression equipment, with navigation systems, with storage, off-loading operations, etc.

All actions related to the automatic control and interlocking of any systems are assigned to programmable logic controllers (PLCs). Those programmable logic controllers are linked to the ETHERNET network, as well as all package unit panels (used for turbo- compressor or turbo-generator, flares, booster compressor, heater panels, etc.).

There are exclusive programmable logical controllers assigned to signals from safety systems, as fire and gas detection systems, fire fighting systems, etc. There are others assigned to process interlocking, others dedicated only to process control loops, and finally there are programmable logical controllers dedicated to electrical functions (as load shedding and sharing, start-up and shutdown of electrical loads, etc). All those systems are interconnected through a local area network (LAN) in order to exchange information.

All formerly local operated ship engines were modified to allow remote operation. Consequently, the main FPSO's engine rooms, after the transformation of very large cargo carrier vessels into production units, have become unmanned rooms.

Referring to programmable logical controller units, the basic concept usually adopted is to locate the greatest possible number of remote units in the field, linked to the central room through a fully duplicated proprietary network. The purpose of that, is to avoid undesirable shutdowns, caused by electric failures.

Closed circuit TV cameras are also provided for visual information from all over the process areas to the control room (in some units there are TV cameras installed in the risers arrival's deck). Up to now this function is not integrated to the supervisory system, but studies are being carried out to provide visual information available at the workstation.

5.2.3. Vessel Characteristics

- Formerly a Very Large Crude Carrier (VLCC)
- Launched in 1974
- 337 meters length
- 54.5 meters breadth
- 21.6 meters draft
- 279,749 KT dead weight
- Main Engine: Steam Turbine

The FPSO will be installed in a water depth of 720 m and it was designed to produce oil in Marlim Field, from 6 production wells, two of them horizontal wells, 3 water injection wells, water injection facilities, gas lift compressor, oil storage, offloading and gas exportation.

The total production will be around 50,000 bbl/day of oil, 680,000 Nm3/d of gas, and 10,500 m3/d of water injection.

5.2.2.3.1. Main Systems Description

The mooring system is installed at the bow (as shown in figure 5.1.1) and it was designed to provide a safe suitable mooring facility for the FPSO in the specified conditions. It should be able to support a shuttle tanker of the same size, moored in tandem to the FPSO, while they weathervane together around the mooring, in the design's operation sea state.

Turntable Assembly

The turntable assembly is designed to permit rotational, in order to allow the FPSO weathervane. An adjustable brake mechanism is installed to apply sufficient friction, eliminating turntable motions in light weather, reducing maintenance intervention.

The main bearing is of the roller type, sealed, with lubrication (or semi-automatic lubrication). If the bearings are located above the water line, the semi-automatic lubrication is not required.

The main bearing's maintenance will be carried out without taking the FPSO out of its permanent moorings. Any bearing change-out will be performed using equipment installed on board, since positive lock/unlock devices are installed in order to allow the FPSO to operate during maintenance procedures.

Anchoring System

The anchoring system has a maximum of eight mooring lines and it was designed in such a way that the chain and wire rope have the same size, in order to minimise maintenance and spare parts. The system presents a hybrid configuration (chain, wire rope, and chain) in order to minimise the fatigue and erosion effects during operation and also to ease mooring lines handling and pull-in operations

Swivel

The swivel is designed to allow a continuous and unrestricted rotation. The unit is stackable and comprises independent paths. The swivel has two electrical brushes for power transmission and control signals. All oil paths provided in the swivel are designed to handle boiling water for wax removal purposes.

Each swivel has two internal pressure seals, one above and other below the fluid chamber.

The sealing system was designed with a barrier to eliminate seal degradation in case of fluid leakage. During all normal operation time, the pressure seal shall operate with a clean fluid. A leak detection monitor located between each pair of seals is provided and is linked with the control room. Table IV.1 shows swivel fluid characteristics. The electrical characteristics are described below.

Electrical Characteristics

440 V AC 3 phases 5 KVA
110 V Dc
Supply Ground
Ship ESD Signal
Turret ESD Signal
6 control signals (+) communication network
6 control signals (-) communication network.

Each swivel contains its own roller bearing assembly and all seals shall be made in one piece. The bearings of each path shall be provided with a self-lubrication system.

5.2.2.3.2. Main Facilities

Production Collection

The FPSO's facilities are designed to handle 50,000 bbl/day of crude oil, 1,050,000 Nm3/day of gas at 180 Bar discharge pressure, and 10,500m/day of water injection at 147 Bar.

Collection Facilities

Facilities are provided to collect the production from six wells, from the water injection manifold and from the lift gas manifold. They are installed inside the turret. In this arrangement concept, a pig/launcher receiver was included to remove wax formation.

In order to minimise the use of swivels, the turret is provided with tanks and metering pumps for chemical injection of demulsifier and anti-foam. There is also a Nitrogen Generator System (SGN) for wax removal purposes.

In order to avoid oil spills, a drainage tank is installed to collect oil leaks in the turret seals. That tank is installed in the lower deck and it is vented to the higher point of the turret's system.

Separation System

The first stage of the separation system comprises a three-phase separator, with capacity of 50,000 bbl/day and 10 minutes of residence time, considering severe foam formation. The operation pressure is 10 Bar. In parallel, there is a test separator with a capacity of 15,000 bbl/day.

The FPSO's separation plant consists of a three-stage separation system, with a desalter between the first and the second stage. In the design it was conceived the utilisation of two tanks to coalesce the production before going to the dehydration system.

The tanks present a total capacity of 32,000 metric tons that will allow a 20 hours of residence time, based on the maximum production capacity. Coalesce tanks will allow the separation of some free water and it is expected to obtain 10 % of water cut at tank outlet.

All the produced crude oil, with a 50 % maximum BSW, is heated up to 90°C, utilising water as the heating medium, which is heated with the high pressure vapour obtained from steam generator.

Offloading System

The FPSO has four transfer pumps, with 4,500 m3/h capacity, steam turbine driven, which permit a complete offloading in 24 hours.

The produced water that comes from the first stage separator, from the test separator and from the desalter, flows to the water treatment system, which consists of hydrociclones, which are installed to provide a maximum of 20 ppm of oil in water. Besides that, the effluent that comes from the hydrocyclone water flows to the FPSO's slope tank, which provides a fifteen-hour residence time to guarantee the maximum oil-water content of 20 ppm that will be then discharged into the sea.

Hydrocarbon Drainage System

A closed drainage system outside the turret is provided in order to lead hydrocarbon flows to the slope vessel, in an independent via from the tanker slope vessel.

Gas Handle System

The gas produced at the first stage of separation is scrubbed in vane type filter separators and is then compressed on turbo-compressor units (2 trains), which handle 1,050,000 Nm/day each, at a 180 Bar discharge pressure for lift gas and exportation.

The units include heat recovery systems to provide hot water for oil treatment. Check valves and subsea blockage valves were included in all gas import flow lines.

In order to prevent hydrate problems in pipelines, in the exportation and lift gas systems (chokes, lines, mandrels, etc.), one dehydration unit, which uses tri-ethylene glycol (TEG) solution, was installed at the third stage discharge compressor. Gas from the dehydration unit flows to the gas lift manifold (which is installed inside the turret), after passing through the swivel path.

The low-pressure gas from the stabilisation system is compressed in an electric driven screw compressor, and pumped to the turbo-compressor inlet.

Fuel Gas System

Low-pressure fuel gas (20 Bar) is produced in order to supply fuel gas to gas turbines, steam generators, dearator, to the gas dehydration unit and to the flare ignition system.

Flare System

In order to determine the location of the flare stack, radiation levels were considered. The flare was then positioned at the bow. Special attention has to be given to the flare's boom angle and length in order to prevent interference with the riser-launching vessel and with the anchor handling boat, during pull-in and pullout activities.

Vent System

Atmospheric relieves from the installed coalesce tanks should be collected, in order to be vented in a safe location. Tanker vent existing system uses a vacuum/relief valve, which discharges to the atmosphere. Another independent vent collection system was installed at the turret system.

Utility Systems

The FPSO utilities systems basically consist of two steam generators, air compressors, inert gas generator system, electrical system, industrial water system, cooling water system and other facilities for life supporting.

The available heat from steam generator was not enough to supply maximum crude oil heat requirements (40 MM Kcal/Hr), therefore two heat recovery units and one furnace were installed in the vessel.

In order to maximise the operational flexibility, lift water pumps were installed additionally to the existing fire pumps.

5.3. Facility's Model

The proposed model was developed for a FPSO and it was based on a complete quantitative risk assessment (Principia/ Petrobras[43,44]) previously performed for that vessel.

The description of the scenarios considered in the quantitative risk assessment is given in Appendix 3, item A.3.1.

As it is possible to observe from Appendix 3 – figures A.1.1 to A.1.32, for each initiator event, there is a related event tree. For each one of the initiator events, there are several related accident scenarios identified by the code ID in the event trees.

The availability values addressed in the quantitative risk assessment to the four protection systems (P-1, P-2, P3, P4) identified in the facility, were obtained from small fault trees (they include valve, pressure switch level (PSL) faults, etc.). The availability values addressed to gas detection and fire detection systems were obtained from previous studies (Principia/Petrobras[45,46]) that were performed for some typical Brazilian offshore platforms.

For each one of the identified accident scenarios, the associated ***phenomenological event tree***, which in our case will comprise different ignition probabilities (different ignition points - three different ignition points were considered in that study), different wind velocities, different jet directions, etc. Four different wind directions (NE, SE, NW, and SW) and five different wind velocities were considered. Figure A.1.33 in Appendix 3 provides an example of an event tree traced for the quantitative risk assessment, where the weather conditions and others probabilities are shown.

The software used for the quantitative risk assessment study makes all calculations and generates the results, which are illustrated for the initiator event named EI-11, on Table A.1.3 in Appendix 3. The results include the probability of fatalities, the average population, which is in each specific position (area), the associated average societal risk, and then the total (the sum) average societal risk associated with this specific scenario.

The proposed model considers that the units' safety can be represented as the interconnection of "elements", to which certain availability/ unavailability values or variables are addressed.

In our case those elements will be referred as xfi for fire detection systems, xgi for gas detection systems, pi for pressure sensors systems, vi for actuation systems and c for the CPU.

Therefore, utilising the quantitative risk assessment results, an expression has been produced for the societal risk and for the associated individual risk expression, imposing variables that replace the availability values addressed to four protection systems, to four different gas detection systems and also to four different fire detection systems. The average individual risk expression is obtained by dividing the total average societal risk of the facility (which is the sum of all average societal risk values calculated for each accident scenario) by the vessel's population, which in our case is equal to 26 employees.

The expressions of the total average societal and individual risk are shown in Appendix 4 - Frameworks A.4.1 and A.4.2 respectively. They were obtained using the software Microsoft Excel-97. They are equal to the sum of the two last columns of these frameworks. As it is possible to observe from them, the values of the total average societal risk, calculated in the quantitative risk assessment study for each one of the chosen scenarios, were put in the second column of the frameworks. Then, the expression of average societal risk in terms of unavailability variables was obtained.

It is important to notice that the number presented in the seventh column of the average societal risk expression is equal to the product of the values of the initiating accident frequency times the phenomenological probability value times the number of fatalities, as it was explained before.

Framework A.4.2 - Appendix 4 - shows the average individual risk expression, which is obtained by the sum of all terms presented in the two last columns.

From the mentioned frameworks, we can see seventeen different availability/unavailability variables, to which values will be allocated. They correspond to four different fire detection systems (xf1, xf2, xf3, x4), four gas detection systems (xg1, xg2, xg3, xg4), four different "pressure sensor systems" (p1, p2, p3, p4), four different blockage systems (v1, v2, v3, v4) and the CPU system(c).

The areas of the FPSO to which these variables were associated to the respective safety systems are the following:

- Turret : xg1, xf1
- Process plant: xg2, xf2
- Pump room: xg3, xf3
- Machine room: xg4, xf4

In the original quantitative risk assessment study, as it is usually done, when addressing values to the fire or gas detection system, as well as to pressure sensor systems (p1, p2, p3 and p4, the control programmable unit CPU and the actuator (valves) – are taken into account. For the purposes of this Thesis they have to be split into the sensor itself plus the CPU plus the actuator itself.

As shown in the event trees of figures A.1.1 to A.1.32 in Appendix 1, the common elements of the safety systems were represented in the beginning of the event trees, so that they would not be accounted more than once during the reliability allocation model. The calculation of the availability values calculated for each safety system studied in the original quantitative risk assessment, has taken into account the failures of the detectors or pressure sensors plus the failures in the CPU unit, plus the failures in the valves, all together. In the presented model, they will be decomposed into the CPU (referred from now on as the variable $\underline{c}$), the valve (referred from now on as the variable $\underline{vi}_{\,i=1,4}$) and the detector or pressure sensor itself. Their availability values will then be evaluated separately.

4. Decision Space

The next step will be to define the set of all the alternatives to be evaluated – the decision space. The generation of these alternatives was based on alternative design configurations for the safety systems existent in the vessel under study. For each one of the safety systems, different configurations were proposed and the respective availability values were calculated. Five different configurations were considered for each one of the safety systems studied. Figures A.5.1, A.5.1A, A.5.1B to A.5.5, A.5.5A, A.5.5B in Appendix 5 illustrate the basic configurations used for the five cases studied for the turret system. Therefore, our decision space will be composed by discrete values, calculated for these different configurations.

5.5. Reliability Calculation

Based on the basic configurations used for the five cases studied for each one of the safety systems considered in this work, as shown in Appendix 5 - figures A.5.1 to

A.5.5, on the theory and expressions given in tables 4.3.4.4.1.1 and 4.3.4.5.1.1., the critical safety unavailability (CSU) and the spurious trip rates (STR) values were calculated.

Tables A.5.1, A.5.2, A.5.3, A.5.4 in Appendix 5 present the formulas used for the critical safety unavailability and the spurious trip rate values calculations.

5.5.1. Presentation of the Safety System Configurations

The FPSO considered for the application of the methodology will comprise four fire and four gas detection areas. The basic system -1oo1 voting logic system will be considered for the fire and gas detection systems, as well as for the pressure switch levels, CPU and valves. Figure A.5.1 – Appendix 5 - illustrates the original configuration that is going to be considered as the basic one for the turret safety system. This configuration is the reference one, which is going to be optimised.

It is assumed that the response time of detectors in neighbouring areas is too long for those detectors to initiate proper safety actions.

There are of course, several ways of introducing redundancy into safety systems, as for example, promoting the duplication or triplication of each one of their components: of the sensor (gas or fire detector, or PSL), of the input and output cards, of the CPU, and of the actuator (valve).

In this work, taking the basic configuration as a reference (1oo1 voting logic -, shown in figure A.5.1 – Appendix 5), the optimisation was promoted in four more different ways for each safety system considered. They are going to be addressed as different cases (***Case 1*** to ***Case 5*** - including the original configuration), as shown in Appendix 5 - figures A.5.1, A.5.1A, A.5.1B to A.5.5, A.5.5A and A.5.5B.

The number of sensors that will be considered in each protected area of the FPSO is indicated below:

Turret: 7

Process Plant: 10

Pump room: 4

Pump machine: 8

The basic configuration shown in Appendix 5 - figure A.5.1 - is related to the FPSO turret's safety system. The difference between them and the others FPSO's safety systems is in the number of sensors/detectors. Therefore, for example, for the process plant's fire and gas detection systems, the difference in the configuration presented in figure VI.34, for Case 1, will be that instead of the 7 detectors shown, we will have 10 detectors. In Cases 2 and 5, there will be 20 detectors and in Cases 3 e 4, there will be 30 detectors. This can be extended to all safety systems studied in this work for the other FPSO's areas.

We are assuming that there are the same number of gas and fire detectors in each area considered in the analysis.

Tables Figures A.5.1, A.5.2, A.5.3 and A.5.4 in Appendix 5 show the formulas used for the calculations of the critical safety unavailability and the spurious trip rate for the five configurations (Case 1 to 5) for each one of the safety systems considered.

A single pressure switch level (1oo1) plus an input card (1oo1) will compose the basic configuration adopted for the pressure sensor system. They will be optimised considering four more cases, which adopted logical and formulas used for calculations are shown on table A.5.2.

A single CPU (1oo1) will compose the basic configuration adopted for the CPU system. They will be optimised considering four more cases, which adopted logical and formulas used for calculations are shown on table A.5.3.

A single valve (1oo1) plus an output card (1oo1) will compose the basic configuration adopted for the actuation system. They will be optimised considering four more cases, which adopted logical and formulas used for calculations are shown on table A.5.3.

Note that although there are also detectors in other areas of the FPSO, as for example, in mid-ship superstructure, in aft superstructure, in the deck and in the accommodation area, they do not appear in the quantitative risk assessment study. This is due to the fact that no accidental event that has been considered as a critical one in that study has demanded any actuation from these specific safety systems.

The description of each considered case for the safety systems under study is given below:

For fire, gas detection systems and for pressure sensor system

Case 1: No redundancy exists. The safety system is composed by components, which present a 1oo1 voting logic.

Case 2: Redundancy is introduced by doubling, in each area, the sensor and the input card only. Therefore, the sensors and the input card will present a 1oo2 voting logic.

Case 3: Redundancy is introduced by promoting a triplication, in each area, of the sensor and the input card only. Therefore, the sensors and the input card will present a 1oo3 voting logic.

Case 4: Redundancy is introduced by introducing in each area a logic of 2oo3 for the sensor and the input card only. Therefore, the sensors and the input card will present a 2oo3 voting logic.

Case 5: Redundancy is introduced by introducing, in each area, a logic of 2oo2 for the sensor and the input card only. Therefore, the sensors and the input card will present a 2oo2 voting logic.

In this context, for the fire and gas detection systems of the FPSO's turret, seven detection units, with seven detectors were considered in Case 1; seven detection units, with fourteen detectors in Cases 2 and 5; and seven detection units, with twenty one detectors in Cases 3 and 4.

For CPU:

The five cases analysed for the CPU present the same voting logic of each one of the cases described above. The considered CPU system will be composed just by the CPU itself, excluding the input and output devices. The basic case - Case 1- will be composed by a simplex CPU (1oo1 voting logic), which will be optimised utilising the redundancy with a voting logic identical to the ones of the four cases – Cases 2 to 5, described above.

For the actuation system:

The voting logic is the same described above for all five cases analysed for the fire and gas detection systems. The considered actuation system will be composed by valve (s) and by the output device (s). The basic case - Case 1- will be composed by a simplex system with a single valve and a single output device (1oo1 voting logic), which will be optimised utilising the redundancy with a voting logic identical to the ones of the four cases – Cases 2 to 5, described above.

The necessary additional assumptions are (for all example systems):

- The fail-safe principle applies (normally energised modules).
  This means, for instance, that a power failure will lead to a system SO-failure, and not to a system FTO-failure.

- Self-testing on the CPU's only.

5.5.2. Loss of Safety Calculation

When quantifying loss of safety of safety shutdown systems, we are looking at the probability of occurrence of undesirable events due to failure of the safety shutdown systems (the probability that those systems will *fail to operate (FTO)*, upon a hazardous situation). This is denoted as the *critical safety unavailability (CSU)* of the safety shutdown systems (SINTEF*).

Based on Tables Figures A.5.1, A.5.2, A.5.3, A.5.4 and on the theory presented before, the failure to operate – FTO - reliability block diagrams were made for our model.

- **Overall failure to operate – FTO – Reliability Block Diagram for the Studied Systems**

Figures A.5.1A to A.5.5A in Appendix 5 show the failure to operate – FTO - reliability block diagrams for example Cases 1 to 5 for the FPSO – turret's safety systems. These systems are the gas detection system (xg1), the fire detection system (xf1), the pressure switch level system (which includes the input cards for the CPU), the CPU and for the actuation system (valve plus output card from CPU) respectively.

Therefore, for each FPSO's area, there will be five cases analysed for each one of its safety systems. For all areas, the basic configuration (Case 1) that is going to be adopted is the simplex one – 1oo1-voting logic. Case 2 to 5 voting logics were described above.

The difference that is going to be found in critical safety unavailability values for the gas and fire detection systems for different FPSO's areas (turret, process plant, etc.) is derived only from a different number of sensors. We are assuming that the failure data and other attributes of the safety system's components included in each area were considered the same.

Therefore, for the turret's gas and fire detection systems, we have considered *seven detectors* in the basic configuration: it is addressed as ***Case 1*** (*seven detection units of 1oo1 detectors voting logic*). *Fourteen detectors* were considered in ***Case 2*** and in ***Case 5*** (*seven detection units of 1oo2 and 2oo2 detectors voting logic* respectively).

Twenty one detectors were considered in ***Cases 3*** and ***4*** (*seven detection units of 2oo3 and 1oo3 detectors voting logic* respectively). As we have discussed earlier in this work, this concept should be extended to the others FPSO's areas. It is important to keep in mind the concept of detection unit, e.g., the detection unit will be the single one responsible for detecting any hazardous condition in a certain point of the plant. Therefore, if it fails we would have a critical failure (if detectors compose the unit with a 1oo2 voting logic - two sensors will have to fail to lead to a critical fail to operate - FTO – failure).

I / O Card type (1)	**Rate of FTO failures (per 10^6 hrs)**			
	Rate of FTO failures affecting all channels (common part) (2)	Rate of FTO failures affecting one channel only (3)	Number of relevant channels (4)	Total rate of FTO failure λ^F_{Total}
Input card	0,3	0,15	1	0,45
Output card	0,3	0,15	1	0,45

Table 5.5.2.1 - Input / Output Card - Input Information (SINTEF[48])

Notes:

(1) Specify all types of I/O cards used. If the same I/O card type is used with a different number of channels (see note 4 below), repeat the I/O card type.

(2) This is the rate of failures affecting all channels of the I/O card, i.e., failure rate of the common part of the I/O card.

(3) This is the rate of failures affecting one channel of the I/O card only.

(4) Give the number of relevant channels for the success criterion defined.

(5) The total rate of FTO failures, λ^F_{total}, is the failure rat of the common part plus the failure rate affecting one channel multiplied by the number of relevant channels.

Tables A.5.1, A.5.2, A.5.3 and A.5.4 illustrate the formulas used for the critical safety unavailability calculations made for each one of the safety systems considered.

Table 5.5.2.1 provides information related with input/output cards that was used in the calculations.

- **Calculation of the Critical Safety Unavailability for the Studied Cases**

Calculation of the CSU is done on the basis of the approximate detailed failure to operate (FTO) reliability block diagram, using the formulas given earlier in table 4.3.4.4.1 and in Appendix 2.

Framework A.6.1 in Appendix 6 show the data used for critical safety unavailability calculations. Framework A.6.2 in Appendix 6 shows the critical safety unavailability values calculated for *Cases 1* to *5* for each one of the safety systems considered. The critical safety unavailability values for the gas detection, fire detection and pressure systems were obtained by the sum of the critical safety unavailability values calculated for the detector or sensor itself and the CPU's input card.

In the case of the actuator system the critical safety unavailability values were obtained by the sum of the critical safety unavailability values calculated for the valve (s) and the CPU's output card (s).

5.5.3. Loss of Production Calculation

Failures of safety shutdown systems modules may cause spurious shut down the production. This event is denoted *spurious trip event* in this work. When quantifying loss of production, we are looking at the rate of such events, the spurious trip rate (STR).

The overall and the approximate reliability block diagrams are provided in table 4.3.4.4.1 and in Appendix 2.

- **Overall spurious operation - SO - Reliability Block Diagram for the Studied Systems**

Figures A.5.1B to A.5.5B in Appendix 5 show the overall spurious operation - SO - reliability block diagrams for example *Cases 1* to *5*, which were based on the overall and the approximate reliability block diagrams provided on table 4.3.4.4.1 and in Appendix 2.

I/O Card Type (1)	**Rate of SO-failures (all rates per 10^6 hours)**			
	Rate of SO-failures affecting all channels (common part) (2)	**Rate of SO-failures affecting one channel only (3)**	**Number of relevant channels (4)**	**Total rate of critical SO-failures λ^S_{Total}**
Input card	0.3	0.15	7	1.35
Output card	0.3	0.16	1	0.45

Table 5.5.3.1 – Input/Output Card Information (SINTEF[48])

Notes:

(1) Specify all types of I/O cards used. If the same I/O card type is used with different number of channels (see note 4 below), repeat the I/O card type.

(2) This is the rate of failures affecting all channels of the I/O card, i.e., failure rate of the common part of the I/O card This is the rate of failures affecting one channel of the I/O card only.

(3) Give the number of relevant channels on each I/O card

(4) The total rate of critical SO-failures, λ^S_{Total}, is the failure rate of the common part, plus the failure rate affecting one channel only multiplied with the number of relevant channels. The total rate of critical SO-failures is used on SO tables.

Specification of input data for the I / O cards in the example is given in table 5.5.3.1.

- **Calculating the Spurious Trip Rate (STR) of the Example Systems**

Calculation of the spurious trip rate (STR) is done on the basis of the approximate detailed spurious operation - SO - reliability block diagram, using the formulas given earlier in Tables A.5.1, A.5.2, A.5.3, A.5.4 and in Appendix 5.

Framework A.6.3 in Appendix 6 shows the data used for spurious trip rates calculation. Framework A.6.4 in Appendix 6 shows the spurious trip rate values, calculated for Cases 1 to 5 for each one of the safety systems considered. The formulas and the actual spurious trip rate numbers for the different components / modules, and the total system spurious trip rate (STR) is summed up and given in the frameworks.

5.6. Cost Functions

5.6.1. Life Cycle Cost Model

Life Cycle Cost (*LCC*) is given by the following expression:

$$LCC = LCA + LSC + LSO + \Delta REL + \Delta LL \quad (4.3.5.1)$$

Where:

LCA = Life Acquisition Cost
LSC = Life Support Cost
LSO = Loss due to Spurious Operation
ΔREL = represents the benefit obtained in terms of the oil and gas production saved and damage to the asset avoided due to the installation of safety systems at the facility.
ΔLL = represents the benefit obtained in terms of averted fatalities due to the installation of safety systems at the facility.

The *LSC* part consists of two parcels, *CIR* (investments in resources for operation and maintenance), and *CYC* (yearly cost of operation and maintenance). Therefore, the expression above can be written as following:

$$LCC = LCA + CIR + CYC + LSO + \Delta REL + \Delta LL \quad (4.3.5.2)$$

Where, the terms *LCA* and *CIR* are the costs of primary investments of the system or equipment.

Three parcels compose the *LCA* term: the equipment cost *(CIE)*, the installation/commissioning cost *(CIIC)* and the management cost *(CIM)*.

5.6.1.1. Primary Investments Calculation

We are considering that the primary investments are composed by seven elements, and expressed bellow:

$$\textbf{\textit{Total Primary Investment}} = CIE + CIM + CIIC + CIR \quad (4.3.5.4)$$

or

$$\begin{aligned}\textbf{\textit{Total Primary Investment}} = {} & CIEH + CIEA + CIMV + CIMC + CIIC \\ & + CIRS + CIRT \qquad (4.3.5.5)\end{aligned}$$

Where:

CIE = Equipment cost
CIEH = Component cost (hardware)
CIEA = Cost of necessary additional equipment
CIM = Management cost
CIMV = Vendor management and engineering cost

CIMC = Contractor management and engineering cost
CIIC = Installation/commissioning cost
CIR = Cost of investments in resources for operation and maintenance
CIRS = Cost of initial spare part stock
CIRT = Training cost

In order to easy cost calculations, the safety shut-down systems were divided into the following parts:

Detection system: Composed by detectors (fire or gas and input devices to CPU or by pressure sensors more the input device to CPU; field cabling, including junction boxes and cubicles.

CPU: Composed by CPU

Actuation system: Composed by blockage valves and output devices from CPU.

Definitions of each one of the cost components are described below. Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems. The equations obtained for the Life Cycle Cost x Availability curves for each one of the safety systems considered are shown in figures A.9.1 to A.9.7 in Appendix 9.

Component Cost (CIEH)

The component cost includes the direct component cost (detector, sensor, CPU, valve, etc.). Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems.

Cost of Necessary Additional Equipment (CIEA)

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems.

Vendor Management and Engineering Cost (CIMV)

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems. Equations 4.3.5.6 and 4.3.5.7 were used for calculation.

Installation/Commissioning Cost (CIIC)

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems.

Oil Company/Contractor Management and Engineering Cost (CIMC)

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems. Equations 4.3.5.8 was used for calculation.

Cost of Initial Spare Part Stock (CIRS)

This cost element comprises the initial investments in spares. It is assumed that the number of initial spare parts should be 5% of the total number of components of that type, rounded up to the nearest integer. Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems.

Training Cost (CIRT)

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems.

5.6.1.2. Calculation of Cost for Operation and Maintenance (CYC)

There are two elements included in the parcel concerning the yearly cost of operation and maintenance, as following:

- periodic testing;
- corrective maintenance

5.6.1.2..1. Periodic Test Model

The periodic testing costs per year for each component type are obtained as follows:

Test costs per year = ***(number of components)*** ******* ***(test frequency)*** ******* ***(average man-hours per test)*** ******* ***(cost per man-hour)*** (4.3.5.9)

Where:

Test frequency = (12 months/year) / (test period in months) (4.3.5.10)

- **Average Man-hours per Test**

The average number of man-hours spent per test adopted in this work was based on the guide figures listed in table A.5.6.1.2.1. Obviously each life cycle model should consider specific values for the interval of tests, time per test and man-hour spent per test, based on the company/unit specific test philosophy and conditions.

- **Man-hours per Test for Alternative Configurations**

In all cases presented in this work, it was assumed that the time spent to test each additional detector at the same sub-area, is equal to the time spent to test the first detector at that sub-area.

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present all the costs addressed to the five different configurations of the considered safety systems.

5.6.1.2.2. Corrective Maintenance Model

The total cost per repair will be expressed by:

Total cost per repair *= (man-hours per repair) * (cost per man-hour)*
+ (other costs per repair) (4.3.5.11)

The last term in the expression above includes spare parts, tool consumption, etc.

The repair cost per year is given by:

Repair costs per year = (number of components) * (failures per component per year)
* (total cost per repair) (4.3.5.12)

The necessary spare parts for repair are supposed to be in the unit.

The cost per man-hour for maintenance personnel is assumed to be equal to 50 pounds.

As shown in frameworks A.7.1 to A.7.11.3A in Appendix 7, the yearly costs of operation and maintenance have been calculated for the five cases (Case 1, 2, 3, 4 and 5) associated to each of the safety systems considered.

Data used for periodic testing are shown on table 5.6.1.2.2.1 that displays values raised in PETROBRÁS and provided by SINTEF[49]. Note that the time spent testing each additional component is assumed to be equal to the time spent with the first component at the sub-area.

Frameworks A.7.1 to A.7.11.3A in Appendix 7, in their first pages show a column related to "others repair costs". Those costs refer to spare parts, tool consumption, etc. As a first approximation, these costs were assumed to be equal to the component acquisition costs.

Device	**Test period (months)**		**Average man-hours per test**	
	Petrobras	SINTEF	Petrobras	SINTEF
Pressure sensor	6	3	0.5	1.0
Flame detector	6	3	1.0	0.75
Heat detector	6	6	1.0	0.75
Gas detector	6	1	1.0	1.0
Valve	12	-	0.50	-

Table 5.6.1.2.2.1 - Periodic Test Data (PETROBRÁS, SINTEF[49])

5.6.1.3.Unavailability Cost Calculation

5.6.1.3.1. Overall Model

The critical unavailability of a safety system is the unavailability derived due to a failure to operate in case of the occurrence of an accidental event, leading to consequences in terms of fatalities, damage to assets and loss of income (due to deferred production). The first parcel of the total life unavailability cost, e.g., the cost associated with the critical unavailability *(LUC)* can be given in equation 4.3.5.17:

$$LUC_{year} = LL_{year} + REL_{year} \quad (4.3.5.13)$$

Where:

LL_{year} = Expected Loss of Lives per year

REL_{year} = Expected Residual Loss per year

- **Expected Loss of Lives**

The parcel concerning the Expected Loss of Lives per year (*LLyear*) is given by equation 4.3.5.14:

LLyear *= Number of fatalities per year * Value of life * Critical Safety Unavailability* (4.3.5.14)

The number of fatalities per year for each configuration is obtained from the expression of average societal risk

The value of life was assumed to be equal to 3E+06 pounds, as mentioned in Chapter 2.

The critical safety unavailability are presented on Frameworks A.7.1 to A.7.11.3A in Appendix 7 for five different configurations for each considered safety system. They also show the value *(LLyear)* associated with loss of lives for each one of these configurations. Then the benefit (*Δ LLi*), obtained due to the installation of the safety systems is calculated in terms of deaths averted. The value of *Δ LLi* will be obtained by the difference between the cost associated with loss of lives in case there is no safety system installed (e.g., when the safety critical unavailability is equal to 100%), and the cost associated with loss of lives related to a certain safety system configuration (a certain safety system's reliability level). The *Δ LLi* value can be obtained by equation 4.3.5.15:

$$\boxed{\Delta\, \boldsymbol{LLi},_{i=1,5} = \begin{bmatrix} \textit{Number of fatalities}_{i=0} * \textit{Value of life} * CSU_{i=0} - \\ \textit{Number of fatalities}_{i=1,5} * \textit{Value of life} * CSU_{i=1,5} \end{bmatrix}}$$

Where:

CSU = critical safety unavailability, and

$CSU_{i=0} = 1$, critical safety unavailability value associated with no safety system installed

- **Expected Residual Loss per year**

The Expected Residual Loss per year *(REL)* is given by equation 4.3.5.16:
the following expression:

$$\boxed{RELyear = fevent * Cevent * CSU \qquad (4.3.5.16)}$$

Where:

RELyear = Expected Residual Loss per year after the occurrence of an accidental event

fevent = Event frequency of an accidental event

Cevent = Expected Consequence of an accidental event

CSU = Critical Safety Unavailability

The Expected Residual Loss per year considers the loss to assets plus the loss of net income per year after the occurrence of an accidental event due to the critical unavailability of safety systems. It is calculated for each one of the five configurations considered for each safety system in this Thesis.

The values used for the frequency of the accidental event were obtained from WOAD, taking into account the type of the safety system considered in each case. For fire detection systems, this frequency was considered to be equal to the frequency of occurrence of fires during the period of 1980 to 1993 in North Sea, e.g., 1.849E-02 per year (WOAD[96]).

For CPU, gas detection, blockage and pressure sensor systems, the frequency of the accidental event was considered to be equal to the frequency of the occurrence of fires plus the frequency of occurrence of explosions during the period of 1980 to 1993 in North Sea, e.g., 2.412e-02 per year (WOAD**).

Regarding the evaluation of consequences in terms of residual costs, resulting from the occurrence of accidental events, like fires and explosions, the following items were considered:

(1) Loss to the asset: total loss or severe damage

(2) Loss of income: in this case we have considered that the production will not be lost, but deferred (postponed) for a period of time equivalent to the period of time to bring the same type of unit into operation. Then, the loss of income due to the occurrence of a dangerous situation associated with the unavailability of safety systems will be taken into account in the expected residual loss (*REL*) expression, as we have already mentioned above.

The loss of income due to an unintended production shutdown will be considered in the expression presented below for Loss due to spurious actuation (*LSO*).

Frameworks A.7.1 to A.7.11.3A in Appendix 7 present *REL* values obtained for five different configurations for each considered safety system. They also show the value *(REL)* associated with loss of income (due to deferred oil and gas production) and loss due to damage to assets, calculated for each one of these configurations. Then the benefit obtained (*ΔREL)* due to the installation of the safety systems is calculated, in terms of avoided loss. The value of *ΔRELi* can be obtained, by the difference between the economic loss when there is no safety system installed (e.g., when the safety critical unavailability is equal to 100%), and the economic loss associated to a certain safety system configuration (a certain safety system's reliability level). The *Δ RELi* value can be obtained by equation 4.3.5.17:

$$\boxed{\Delta RELi,_{i=1,5} = fevent * Cevent * \left(CSU_{Case\,0} - CSU_{Case\,i=1,5}\right) \quad (4.3.5.17)}$$

5.6.1.3.2. Loss to Assets and Loss of Income due to Total Loss or Severe Damage

- **Loss of Assets**

The calculation of the loss to assets was made considering events that cause total or severe damage to the unit. According to WOAD[59], it is possible to get the following figures for all units world wide, during the period of 1980 to 1993:

Number of occurrence of fires that cause total damage to the unit: 2
Number of occurrence of fires that cause severe damage to the structure: 3

It was considered that the average cost associated with a total loss of FPSO's is equal to U$ 140,000,000 (information obtained from the Insurance Department of PETROBRÁS). This value includes the cover of the cost items listed on table 5.6.1.3.2.1 below. For severe damage it was considered a value equal to 50% of the cost associated with total loss.

The insurance cost (insurance premium) is taken into account as an yearly expense of the installation during the unit operation time (20 years), which is included in the operational costs (as shown on table 5.6.1.3.2.2)

We will assume that the Oil company has made an insurance for total loss of the unit and that this insurance value will always cover the investment initially made, although Petrobras should in any case pay the deductible value of U$ 6,500,000 (PETROBRÁS Insurance Report[51]) in any case.

In our case we will consider that only the unit itself will be damaged in a total loss accident, excluding lines, wells and X trees, that would keep intact. Based on that and from table 5.6.1.3.2.2, the insured value will be the one to cover only the unit's loss, which will be equal to U$ 84,10E+06.

We will assume that after the occurrence of an accidental event, an FPSO will be out of operation during two years in case of total loss, and during one year in case of severe damage. We will also assume that the accident will occur in the first year of operation.

Therefore, we will assume that if the accident occur the related loss will be equivalent the deferred production plus the deductible insurance value that must be paid. That means that after a total or severe loss of the unit, the Oil Company will receive an amount of money equivalent to the cost of rebuilding and reinstalling the same unit (100% for total damage and 50% for a severe damage). The value of this is equal to U$ 84,10E+06 (total damage) and U$ 42,05E+06 (severe damage) respectively, as shown on tables 5.6.1.3.2.1 and 5.6.1.3.2.2, as accounted in frameworks A.8.1 to A.8.3 in Appendix 8, where Net Present Values are calculated.

Regarding the environmental damage, it was assume that the Oil Company will be covered in case of any oil spill occurrence.

All the values discussed in this section are taken into account in a specific software developed in PETROBRÁS for performing feasibility studies which provides values in terms of net revenues - Net Present Values (NPV) (as shown in Frameworks A.8.1 to A.8.3 in Appendix 8).

- **Loss of income due to the occurrence of a dangerous situation**

Considering that after the occurrence of an accidental event, the FPSO will be out of operation during two years in case of total loss, and during one year in case of severe damage, it is necessary to take into account the loss of income in terms of deferred production (oil plus gas). All that information will be put together in the software mentioned above, together with the values related to the loss of assets in order to provide the results in terms of net revenues - Net Present Values (NPV) (as shown in Frameworks A.8.1 to A.8.3A in Appendix 8. Equation 4.3.5.18 was used for calculations.

Table 5.6.1.3.2.3 provides useful information related to gas and oil production values, cost of the oil barrel, interest rates, etc, utilised for the calculations. The insurance cost (insurance premium) is taken into account as an yearly expense of the installation during the unit operation time (20 years), which is included in the operation costs.

Therefore, based on the mentioned methodology and considering the specific FPSO under study, we will get the following values for net revenues:

(1) Normal Production: 2,2701E+08 U$ (NPV) = 1,4237E+08 pounds
(2) Two years of delayed production: 1,0974E+08 U$ (NPV) = 6,8821E+07 pounds
(3) One year of delayed production: 1,5837E+08 = 9,9319E+07 pounds

Item	**Cost**
Exploration & Production Unit (E&PU)	15,00
• acquisition	20,00
• conversion	1,00
• design	7,00
• mooring	-
• turret	18,00
Subtotal	27,50
Utilities	
• basic design	0,20
• detailed engineering/building equipment	56,40
Subtotal utilities	56,60
Subtotal	
Other investments	184,60-84,10= 100,50
TOTAL	267,90

Table 5.6.1.3.2.1 - Nominal Investments (MM U$)

Item	Cost
Material	650
Personnel wages (E&P unit, Drilling)	2800
Third parties services	2000
Supervision	560
General charges	55
Equipment inspection	24
Utilities maintenance (except huge equipment)	850
Turbo machine maintenance	1094,40
Aerial transportation (PB personnel)	363,80
Aerial transportation (load)	18,40
Naval transportation (personnel)	29,10
Personnel wages (Production)	2043,90
Naval transportation (load)	547,50
Tuck boat	328,50
Diesel and lubrication fluid	489,5
Water	166,1
Insurance (E&P unit + Util.)	171,4
Subtotal	12191,6

Table 5.6.1.3.2.2 - Operational Costs (MM U$/year)
(PETROBRÁS/Campos Basin/GEDEP/GBAR)

Therefore, we would have the following figures for the loss of net income in terms of NPV:

- For Total Loss:1,4237E+08– 6,8821E+07 – 7,3544E+07 pounds
- For severe damage: 1,4237E+08 – 9,9319E+07 – 4,3046E+07 pounds

These figures will give the following average loss of net income after the occurrence of an accidental event:

Average loss of net income = (2* 7,3544E+07+ 3*4,3046E+07)/5 =
= 5,52452E+07 pounds

Therefore the consequences will be the loss of:

Cevent = 5,52452E+07 pounds (NPV)

Gas production	164000 m3/day
Oil production	13047.35 barrels/day
Gas price	0.08 U$/ m3 0.05 pounds/m3
Oil price	15.5 U$/barrel 9.72 pounds/barrel
Return average time to normal production after spurious operation	50 min
Blow-down average time due to a shut-down	15 min
Interest rate	15%
Operation time	20 years
Unit Oil Storage Capability	55000 m^3
FRP (20 years) (correction factor)	6.25933
Deductible insurance value	U$ 6.500.000
Unit Insured value	U$ 140.000.000

Table 5.6.1.3.2.3 – Data for Calculation of Economic Losses

Therefore, we will have the following expression for the Expected Loss per year due to an accidental event (REL_{year}) for each configuration considered in this Thesis:

$$\boxed{\boldsymbol{RELyear} = fevent * 5,52452E+07 * CSU}$$

Now we will have to consider the loss of income due to spurious operation or unintended production shutdowns.

5.6.1.3.3. Expected Loss per year due to Spurious Actuation

The expected loss per year due to spurious operation or unintended production shutdown (LSO_{year}) will be given by equation 4.3.5.19, as following:

$$\boxed{LSO_{year} = f_{spur} * Cost_{spur}}$$

Where:

f_{spur} = Frequency of spurious failures
$Cost_{spu}$ = Cost of spurious failures

The frequency of spurious actuation was calculated for each configuration studied in this work as shown on frameworks A.7.1 to A.7.11.3A.

The cost of spurious actuation is calculated in terms of loss of production (oil loss plus gas loss), as described below. In fact, we would have an income loss due to postponed production during the production shutdown time, which could be calculated by the same methodology described before for deferred production. As this period of time is very short (equal to 50 min- estimation based on PETROBRÁS offshore experience), we will simplify this calculation and just consider this parcel as loss of production during this period of time. This is the period of time estimated as the required returning time to normal production after an unintended production shutdown. Therefore, we will have the following expressions:

Oil loss due to spurious actuation (pounds) = oil production (barrels/day) * oil price (pounds /barrel) * fraction of time to return to normal production

Gas loss due to spurious actuation (pounds) = gas production (m3/day) * gas price (pounds/day) * fraction of time to return to normal production + gas loss due to the burn of gas (pounds)

Where:

Gas loss due to the burn of gas (pounds) = gas production (m3/day) * gas price (pounds/day) * fraction of time for plant blow-down

Therefore, we would have:

Gas loss due to spurious operation (pounds) = 164000 m3/day * 0,05 pounds/m3 * 50 min/(24*60 min) + 164000 m3/day * 0,05 pounds/m3 * 15min/(24 *60min)

5.7. Individual Risk Calculation

5.7.1. General

We have pointed out all over this work that risk assessment is one of the components to be considered in decision making processes related to industrial risks. Quantitative risk assessment came to reduce the subjectivity involved in those processes and may help all societal actors regarding questions associated with industrial safety.

Regarding this context and trying to obtain reference values for the risks involved in the operation of offshore oil facilities in Brazilian continental shelf, data collected from Campos Basin (Brazilian Oil Company – PETROBRÁS) are going to be presented. Campos Basin is the area responsible for most of Brazilian offshore oil production, where there are more than 30 platforms, some of them operating for more than 15 years. Therefore, it is assumed that it is the best area to represent Brazilian offshore oil "universe".

Based on data collected in PETROBRÁS, risk indices were calculated, and a risk tolerability criterion for individual risk for offshore oil workers proposed.

It is important to highlight that although some facilities present an acceptable societal risk level, they may impose a high-risk level to certain group of individuals. This worry about the most exposed population to risk is responsible for the requirement of individual risk assessment, which has been inserted in different international regulations.

5.7.2. Fatal Accident Rate and Individual Risk Expressions

As it was presented earlier in this work, an ordinary index used to express individual risk to workers is the Fatal Accident Rate – FAR, which is given by the following formula:

$$\boldsymbol{FAR} = \frac{Number\ of\ fatalities\ x\ 10^8}{Total\ Working - Hours}$$

The number 10^8 hours, which is used as a reference, is obtained by the following expression:

10^8 = 1000 employees working x 2500 working hours per year x 40 years

This index – FAR – can easily be converted into the individual risk using the following formula:

$$Individual\ Risk = \frac{FAR\ x\ Working - Hours\ per\ year}{108}$$

5.7.3. Collected Data and Calculations

In all Fatal Accident Rate calculations, the number of fatalities associated with PETROBRÁS employees was obtained from the PETROBRÁS/SUSEMA Report. The Fatal Accident Rate presented in this Thesis is going to be exposed for two different periods of time. The Fatal Accident Rate from 1982 to 1993 has already been calculated (Faertes[57]) and the Fatal Accident Rate during the period of 1994 to 1998 is going to be calculated in this Thesis. Data utilised for the calculation of both of them are shown below. Than, the total Fatal Accident Rate, calculated for the period of time from 1982 to 1998 is going to be presented.

In order to evaluate the term "total working hours", it was considered the average offshore unit's population, which was obtained from PETROBRÁS/ Campos Basin / NUPRO-N, NUPRO-NE, NUPRO-S, NUPRO-AB, NUPRO-MRL. We have considered that the total working-hours will be obtained by the product of this number times 24 hours (since we have assumed that an average population will be present at the offshore unit for 24 hours a day, and that those employees will be subject to risk for 24 hours per day).

For the period of 1982 –1993 it was not possible to obtain the precise operation time of all units considered, once some (few of them) have been operating in different places in Brazil and there is no sufficient registration. However for this period of time, it was possible to find most of the necessary data. For the period of time from 1994 to 1998, all the necessary data were available. Table 5.7.3.1 presents the operation time for 36 of the 41 platforms considered for the period of 1982 to 1993, as well as the unit's average population. Table 5.7.3.2 shows the operation time for the period of time from 1994 to 1998, as well as the associated unit's average population for all units considered.

From PETROBRÁS Safety Indices Report and from PETROBRÁS Injuries Resulting Accident Report (RAL), a total number of 65 fatalities was found during the period of 1982 to 1993. This number includes accidents related to PETROBRÁS employees who work in Campos Basin, for the Southwest Production Department (RPSE), for the Southwest Drilling Department, and for the Telecommunication Department (DITEL), as all of them work offshore.

From those 65 fatalities, which happened in the "platform universe" during the period of 1982 to 1993, 37 refer to the major accident (blowout) that occurred in Enchova Platform (PCE-1) in 1984. From those 37 fatalities, 27 refer to PETROBRÁS employees and 10 to third parties' employees.

From data provided in PETROBRÁS reports mentioned above, we have 3 fatalities (1 in 1987 and the other 2 in 1991) in the period of 1982 to 1993, related only to the process activity itself. The others fatalities were related to accidents associated with falls, dropped objects, helicopter falls, diving, etc. Table 5.7.3.3 describes the accidents associated to process activity that occurred during 1982 to 1993.

Using the total number of fatalities, equal to 65, as well as the number of fatalities associated with the process activity, i.e., 40 (37 from Enchova accident plus the 3 mentioned above), the total working hours, the Fatal Accident Rate for the period of 1982 to 1993 was calculated.

As it is possible to see from Table 5.7.3.1, the total working-hours value for 36 platforms is equal to 2.10 x 10^8 hours. As it was not possible to obtain suitable information for platforms PA-6, PA-13, PA-16, SS-14, SS-23 and SS-24, an average working hours value was estimated, which is equal to 0.067x 10^8 hours for each one of them. Therefore, multiplying this value by 6 platforms, we have 0.36 x 10^8 hours. This makes a total working- hours value of 2.50 x 10^8 hours.

Therefore the following Fatal Accident Rate values were obtained for the period of time from 1982 to 1993:

$$Total\ FAR_{1982-1993} = \frac{65\ x10^8}{2.5x10^8} = 26$$

$$FAR_{\text{related to process including PCE 19982 - 1993}} = \frac{40x\ 10^8}{2.5x\ 10^8} = 16$$

$$FAR_{\text{related to process, excluding PCE 1982 - 1993}} = \frac{3\ x\ 10^8}{2.5\ x 10^8} = 1.2$$

In order to calculate the Average Individual Risk (AIR) values, we have to consider the crew working offshore regime, which comprises 14 days working offshore and 21 free days. This regime corresponds to a value of 3384 working-hours per year, assuming that the average offshore population is present and exposed to risks for 24 hours per day.

Therefore, the following values were obtained for Average Individual Risk (AIR) for offshore workers, corresponding to the FAR values calculated above:

$$AIR_{1982-1993} = \frac{26 x 3384}{10^8} = 8.80\ x 10^{-4}\ per\ year$$

$$AIR_{\text{related to process including PCE 19982 - 1993}} = \frac{16 x\ 3384}{10^8} = 5.41 x 10^{-4}\ per\ year$$

$$AIR_{\text{related to process, excluding PCE 1982 - 1993}} = \frac{1.2\ x\ 3384}{10^8} = 4.06\ x\ 10^{-5}\ per\ year$$

For the period of 1994 to 1998, data were collected from different sources, as for example, from PETROBRÁS software named SISIN, complemented by datasheets comprising third parties accident data. The data of our concern is associated with accidents occurred in Campos Basin during the period of 1994 to 1998.nclude accidents related to PETROBRÁS employees who work in Campos Basin.

From these sources it was possible to find a total number of 12 fatalities during the period of 1994 to 1998. From those 12 fatalities, 2 refer to PETROBRÁS employees and 10 to third parties' employees, as shown in tables 5.7.3.4 and 5.7.3.5 below.

From data provided by PETROBRÁS, it is possible to find 1 (one) single fatality related to the process activity itself that has occurred in1997, as shown in table 5.7.3.4, related only to the process activity itself. The others fatalities were related to accidents associated with falls, dropped objects, helicopter falls, car accidents, etc.

As it is possible to see from Table 5.7.3.2, the total working-hours value for the universe of offshore units considered, which corresponds to the number of units that have been operating during the period of 1994 to 1998, is equal to 1,1644E+08 hours.

Therefore the following Fatal Accident Rate values can be obtained for the period of time from 1994 to 1998:

$$Total\ FAR_{1994-1998} = \frac{12\ x10^8}{1{,}1644x10^8} = 10{,}31$$

$$FAR_{related\ to\ process\ 1994-1998} = \frac{1x\ 10^8}{1.1644x\ 10^8} = 0.86$$

In order to calculate the Average Individual Risk (AIR) values, we have considered the same regime of 14 days working offshore and 21 free days.

Therefore, the following values were obtained for Average Individual Risk (AIR) for offshore workers, corresponding to the FAR values calculated above:

$$AIR_{1994-1998} = \frac{10.31\ x3384}{10^8} = 3.49x10^{-4}\ per\ year$$

$$AIR_{\text{related to process 1994 - 1998}} = \frac{0.86 x 3384}{10^8} = 2.91 x 10^{-5} \textit{ per year}$$

Platform	*Average Population In the Unit*	*Operating Time (hours)*
SS-05	69	96576
SS-06	78	104376
SS-08	73	96576
SS-10	110	6840
SS-11	75	78624
SS-15	80	90840
SS-17	84	95952
SS-18	135	88344
SS-19	74	87480
SS-20	104	14424
SS-28	89	48528
SS-29	138	4608
SS-33	102	13176
SS-38	54	18192
PNA-1	122	90984
PNA-2	96	87408
PCH-1	100	84576
PCH-2	143	88272
PGP-1	146	105120
PCP-1	67	43872
PCP-2	73	43992
PPG-1	150	43848
PVM-1	65	40344
PVM-2	65	43080
PVM-3	47	39912
PPM-1	181	81408
PCE-1	70	78740
SS-01	68	105120
SS-37	72	20448
SS-43	98	9984
SS-16	100	100032
SS-21	90	89448
SS-22	110	82512
SS-34	90	42384
SS-36	70	16104
PMLZ-1	27	10224
TOTAL		**2.1 x 10^8 hours**

Table 5.7.3.1 - Operating time and average population on board for units operating during the period of 1982 to 1993

Unit	*Total Average Population*	*Total Operation Time (days)*	*Total Operation Time (hours)*	*Total working Hours*
P-09	114	1672	40128	4,5746E+06
P-13	73,20	1672	40128	2,9374E+06
PCH-I	133,60	129	3096	4,1363E+05
PCH-II	91,80	1672	40128	3,6838E+06
PGP-I & SS-11	166,40	3344	80256	1,3355E+07
PNA-I	87,60	1672	40128	3,5152E+06
PNA-II	145	1672	40128	5,8186E+06
P-26	130	129	3096	4,0248E+05
P-07	128	1672	40128	5,1364E+06
P-19	190	243	5832	1,1081E+06
P-24	89	1672	40128	3,5714E+06
P-25	150	1672	40128	6,0192E+06
P-34	65	306	7344	4,7736E+05
PVM-I	70	1672	40128	2,8090E+06
PCP-I/III	55	1672	40128	2,2070E+06
PCP-II	67,60	1672	40128	2,7127E+06
P-20	114,80	1672	40128	4,6067E+06
PCE-I	114	1672	40128	4,5746E+06
FPSO-2	89	1672	40128	3,5714E+06
SS-06 (*)	90	1672	40128	3,6115E+06
PPG-1	150,60	1672	40128	6,0433E+06
PPM-1	216,40	1672	40128	8,6837E+06
PVM-II	71,60	1672	40128	2,8732E+06
PVM-III	65	1672	40128	2,6083E+06
P-15	81,64	1672	40128	3,2762E+06
P-18	116,10	1672	40128	4,6589E+06
P-12	126,40	1672	40128	5,0722E+06
P-08	102,2	1672	40128	4,1011E+06
P-21	133	1260	30240	4,0219E+06
Total				**1,1644E+08**

Table 5.7.3.2 - Operating time and average population on board for units operating during the period of 1994 to 1998

The Fatal Accident Rates associated to the period of 1982 to 1998 are provided below:

$$Total\ FAR_{1982-1998} = \frac{77\,x10^8}{(1.1644x10^8 + 2.5x10^8)} = 21.01$$

$$FAR_{\text{related to process including PCE 19982 - 1998}} = \frac{41x\ 10^8}{(1.1644\ x10^8 + 2.5x\ 10^8)} = 11.19$$

$$FAR_{\text{related to process, excluding PCE 1982 - 19938}} = \frac{4x\ 10^8}{(1.1644x10^8 + 2.5\ x10^8)} = 1.09$$

Date of Accident	*Number of Fatalities-Petrobrás Employees*	*Number of Fatalities-Third Parties Employees*	*Unit*	***Description***
1987	1		Pampo (PPM-I)	During a hot-work in a well-head, there was an oil and gas leak, followed by a fire
1991	1		Namorado-I	During a purge operation in a vessel, an explosion has occurred
1991		1	Pargo	Fire in a water and oil separator

Table 5.7.3.3 – Accident data during the period of 1982 to 1993

Year	*Total Number of Fatalities-Petrobrás Employees*	*Total Number of Fatalities- Third Parties Employees*
1998	None	2
1997	1	3
1996	1	3
1995	None	1
1994	None	1

Table 5.7.3.4 – Total number of fatalities during the period of 1994 to 1998

Therefore, the following Average Individual Risk (AIR) values corresponding to the FAR were obtained for the period of 1994-1998:

$$AIR_{\text{related to process including PCE 1994 - 1998}} = \frac{21.01x\,3384}{10^8} = 7.11x10^{-4}\ per\ year$$

Date of Accident	***Number of Fatalities- Petrobrás Employees***	***Number of Fatalities- Third Parties Employees***	*Unit*	***Description***
7 April 98		1 – Ueliton S. Moraes (LOCMAR)	P-25	Hit by marble blocks when repairing the unit's bathroom
21 March 1998		1- Renato Gomes Machado (Continental)	PCH-I	Fall in the ocean
97	1- Marco Antônio Vieira		Land transportation	Car Accident during course from Imbetiba to Imboacica
31 March 1997		1- Homero Higino (Stalt Comer)	Well RPS-232- Piraúna field	During diving operation to fix an X trees there was an accumulation of inflammable material and an explosion (the diver was cutting a piece)
17 July 1997		1- Paulo Cesar Valença Pinto (Schahin Cury)	NS-09	Hit by a crane's cable
29 August 1997		1- Manoel Rodrigues da Silva (crew)	Tug - Maersk Rider	Hit by the buoy of the anchor system during its launching
29 August 1996	1		Land transportation	Car accident
21 September 1996		1- Raul Hernandez Martinez (Java Boat)	Mire Tide vessel	Oxygen absence when trying to lift cement bags inside the silo
29 September 1996		1- Paulo Sergio S. Moraes 1- Omar Broseghini (both from Schahimn Cury)	Albacora field	Helicopter fault - going to NS-09. The first one has died during the helicopter's forced land of the on water. The second one has disappeared.
19 July 1995		1- José Dalmo Marçal (Gemat-Atlant.)	Land- in a shipyard	Hit by pipes during a piling up operation with a empilhadeira!!
8 November 1994		1- Reinaldo dos Santos Vangeler (ISA Asesessoria)	Land – Pipeline Storage Park	Fall during an Xtree repair

Table 5.7.3.5 – Accident data during the period of 1994 to 1998

Period of time and type of calculation performed	*FAR values*	*Individual Risk values per year*
Total – 1982 to 1993	26	8.80e-04
Process activity including PCE accident - 1982 to 1993	16	5.41e-04
Process activity excluding PCE accident – 1982 to 1993	1.2	4.06e-05
Total – 1994 to 1998	10.31	3.49e-04
Process activity – 1994 to1998	0.86	2.91e-05
Total – 1982 to 1998	21.01	7.11e-04
Process activity excluding PCE accident – 1982 to 1998	1.09	3.69e-05
Process activity including PCE accident – 1982 to1998	11.19	3.79e-04

Table 5.7.3.6 - Fatal Accident Rates and Average Individual Risk values obtained from data collected in PETROBRÁS

$$AIR_{\text{related to process including PCE 1994 - 1998}} = \frac{11.19\,x\,3384}{10^8} = 3.79\,x10^{-4}\ per\ year$$

$$AIR_{\text{related to process excluding PCE 1994 - 1998}} = \frac{1.09\,x\,3384}{10^8} = 3.69\,x10^{-5}\ per\ year$$

5.8. Allocation Model Application

Based on the cost equations (Life Cycle Cost x Availability) obtained for each one of the safety systems considered, on the expressions of average individual risk in terms of availability variables, and on established targets, the optimisation model and the results achieved are going to be presented in this section.

The life cycle cost equations, as a function of availability values were obtained for each one of the safety systems considered (turret's fire and gas detection systems, process plant's fire and gas detection systems, pump room's fire and gas detection systems, machine room's fire and gas detection systems, CPU system, pressure sensor systems and actuation (valve) systems). The curves with the associated equations are shown in figures A.9.1 to A.9.7 in Appendix 9. They were obtained using the software -Microsoft Excel, Microsoft Office 1997.

Frameworks A.7.1 to A.711.3A in Appendix 7 show the Life Cycle Cost calculations.

Life cycle cost equations were obtained for each one of the considered systems, as shown in figures A.9.1 to A.9.7 in Appendix 9 and in framework A.10.2. The total Life Cycle Cost equation is then obtained by the sum of all these equations.

Framework A.10.1 shows the expressions related to the accidental events that impact the Temporary Safety Refuge (TSR) and escape routes, in terms of safety system's unavailability variables. The final expressions are obtained by the sum of each term shown in framework A.10.2.

Framework A.10.2 also shows the expression of average individual risk in terms of the same availability variables presented in the total life cycle cost equation.

Regarding the establishment of safety goals to be achieved, maximum tolerable values can be specified for the expression of average individual risk and also for the equations, which express the frequency of impairment to the FPSO's main safety functions.

The maximum tolerable values specified for the average individual risk expression were based on the values obtained from data collected in PETROBRÁS, presented in section 5.7.3.

Regarding the expressions presented for the frequency of impairment to main safety functions, they were based on the quantitative risk assessment previously performed. Therefore, expressions for the frequency of impairment to the Temporary Safety Refuge (TSR) and to escape routes are presented also as a function of availability variables. The frequency of impairment to TSR expression was obtained from the initiator event EI-23 expression, as a function of availability variables. This event was identified in the quantitative risk assessment, as the single one that impacts the TSR.

The frequency of impairment to escape routes' expression was obtained from the sum of all initiator events that cause any damage to them. They are also presented as a function of availability variables.

In our case, the single scenario identified as the one that could impact the FPSO's structure was an explosion in the vessel's tanks. In this case no protection system exists to prevent this accident, therefore no expression as a function of safety variables was obtained. But the model is flexible and others expression can easily replace the ones presented in our model.

The maximum tolerable frequency of impairment value used at first in the model is the classic one utilised in several risk assessment studies, and presented for the first time by NPD regulations (as mentioned in Chapter 2).

These equations expressed as a function of availability variables are going to compose the restrictions of our optimisation problem. They are shown in Framework A.10.1 and in Framework A.10.2, together with the cost expressions.

The objective function of our optimisation problem will be the Life Cycle Cost equation expressed in terms of availability variables, which should be minimised.

It is important to highlight that the values presented in this work should not be regarded as prescriptive safety criteria or prescriptive safety goals. Any other expression obtained from quantitative risk assessment studies and for costs x reliability levels could replace the ones presented in the allocation model, as well as other desired safety goals.

Therefore, the following attributes are considered in the allocation model:

- **Objective function:**

Cost function which will be minimised

- **Restrictions or Safety goal to be achieved:**

$AIR \leq$ *any of the values presented in Chapter III*

$ITSR \leq 10^{-4}$ *per year*
$IER \leq 10^{-4}$ *per year*

Where:

AIR = Average Individual Risk expression

$ITSR$ = Frequency of Impairment to TSR

IER = Frequency of Impairment to Escape Routes

Tables A.11.1 to A.11.10 in Appendix 11 shows the results obtained for the equations shown in framework five. The values obtained for the cost function expressed by the variable FCOST, the restrictions imposed (represented by the values of *AIR*, *ITSR*, *IER*), as well as the variable values found by the optimisation software are shown in these frameworks.

It can be observed from Table 5.8.1 which presents a resume of the sensitivity analysis performed, that different Safety Integrity Level (SIL) values were addressed to the availability variables, as well as different restriction values.

The Safety Integrity Levels (SIL) with the other constraints of the model compose the safety goals to be achieved and that should be balanced in terms of costs.

Chapter 8 will provide an analysis of the results obtained for the allocation model.

Cell ***Name***	***AIR < 3.79e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.999 < x < 0.9999*** ***SIL 3***	***AIR < 3.79e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.99 < x < 0.999*** ***SIL 2***	***AIR < 3.79e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.90 < x < 0.99*** ***SIL 1***	***AIR < 3.79e-04*** ***AIR > 2.21e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.90 < x < 0.99*** ***SIL 1***	***AIR < 3.79e-04*** ***AIR > 2.19e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.99 < x < 0.999*** ***SIL 2***	***AIR < 3.79e-04*** ***AIR = 2.175e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.999 < x < 0.9999*** ***SIL 3***	***AIR < 3.79e-04*** ***AIR > 2.175e-04*** ***ITSR <10-4*** ***IER < 10-4*** ***0.999 < x < 0.9999*** ***SIL 3***
FCOST	-133072928.00	-133057504.00	194525696.00	194895200.00	-132951680.00	-133051744.00	-133086304.00
(pounds)							
AIR	2.173323E-04	2.176586E-04	2.207949E-04	2.263829E-04	2.193722E-04	2.17521603E-04	2.175217E-04
IER	7.270396E-05	7.335401E-05	8.086512E-05	1.000043E-04	7.767994E-05	7.29439760E-05	7.254659E-05
ITSR	1.099493E-16	1.095505E-14	1.067329E-12	3.368321E-12	4.394308E-14	1.20508484E-16	1.097114E-16
xf1	9.999000E-01	9.990000E-01	9.900000E-01	9.649899E-01	9.902971E-01	9.99187656E-01	9.99900000E-01
xf2	9.999000E-01	9.990000E-01	9.900000E-01	9.899445E-01	9.989985E-01	9.99899988E-01	9.99900000E-01
xf3	9.999000E-01	9.990000E-01	9.900000E-01	9.899997E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xf4	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xg1	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xg2	9.999000E-01	9.990000E-01	9.900000E-01	9.885686E-01	9.989368E-01	9.99899566E-01	9.99900000E-01
xg3	9.999000E-01	9.990000E-01	9.900000E-01	9.899997E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xg4	9.999000E-01	9.990000E-01	9.900000E-01	9.899989E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
p1	9.999000E-01	9.990000E-01	9.900000E-01	9.684451E-01	9.959523E-01	9.99890234E-01	9.99900000E-01
p2	9.999000E-01	9.990000E-01	9.900000E-01	9.886592E-01	9.988125E-01	9.99899261E-01	9.99900000E-01
p3	9.999000E-01	9.990000E-01	9.900000E-01	9.899576E-01	9.989947E-01	9.99899983E-01	9.99900000E-01
p4	9.999000E-01	9.990000E-01	9.900000E-01	9.858222E-01	9.984114E-01	9.99896292E-01	9.99900000E-01
v1	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.900020E-01	9.99161370E-01	9.99900000E-01
v2	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.989811E-01	9.99899718E-01	9.99900000E-01
v3	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.989996E-01	9.99899996E-01	9.99900000E-01
v4	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.989505E-01	9.99899525E-01	9.99900000E-01
c	9.997393E-01	9.979083E-01	9.900000E-01	9.900000E-01	9.978750E-01	9.99000018E-01	9.97575426E-01

Table 5.8.1 - Final Results Obtained for FCOST, AIR, ITSR and Safety Systems' Availabilities

Cell Name	AIR < or = 3.79e-04 AIR > or = 2.176e-04 ITSR <10-4 IER < 10-4 0.999 < x < 0.9999 SIL 3	AIR < or = 3.79e-04 ITSR <10-4 IER < 10-4 0.99 < x < 0.999 - SIL 2 - for gas detection, pressure sensor and actuation systems 0.999 < x < 0.999 9 - SIL 3 - for fire detection system 0.999 < x < 0.999 9 - SIL 3 - for CPU system	AIR < or = 3.79e-04 ITSR <10-4 IER < 10-4 0.99 < x < 0.999 - SIL 2 - for gas detection, pressure sensor and actuation systems 0.999 < x < 0.999 9 - SIL 3 - for fire detection system CPU system = 0.9999
FCOST	-132,276,064.00	-133,024,320.00	-133,029,936.00
AIR	2.176000E-04	2.174166E-04	2.174009E-04
IER	7.248158E-05	7.308563E-05	7.309841E-05
ITSR	1.096130E-16	1.098488E-14	1.098680E-14
xf1	9.999000E-01	9.999000E-01	9.999000E-01
xf2	9.999000E-01	9.999000E-01	9.999000E-01
xf3	9.999000E-01	9.999000E-01	9.999000E-01
xf4	9.999000E-01	9.999000E-01	9.999000E-01
xg1	9.999000E-01	9.990000E-01	9.990000E-01
xg2	9.999000E-01	9.990000E-01	9.990000E-01
xg3	9.999000E-01	9.990000E-01	9.990000E-01
xg4	9.999000E-01	9.990000E-01	9.990000E-01
p1	9.999000E-01	9.990000E-01	9.990000E-01
p2	9.999000E-01	9.990000E-01	9.990000E-01
p3	9.999000E-01	9.990000E-01	9.990000E-01
p4	9.999000E-01	9.990000E-01	9.990000E-01
v1	9.999000E-01	9.990000E-01	9.990000E-01
v2	9.999000E-01	9.990000E-01	9.990000E-01
v3	9.999000E-01	9.990000E-01	9.990000E-01
v4	9.999000E-01	9.990000E-01	9.990000E-01
c	9.966814E-01	9.997252E-01	9.999000E-01

Table 5.8.1 - Final Results Obtained for FCOST, AIR, ITSR and Safety Systems' Availabilities (cont.)

6. Conclusion

6.1. Analysis of Results

The attributes considered in the allocation model were:

1. Cost
2. Individual Risk
3. Frequency of Impairment to main safety functions (impairment to the Temporary Safety Refuge (TSR), escape routes and to structure)

The second and third attributes represent the "safety goals" to be achieved.

The second attribute is also essential to the analysis, since precluding the economic dimension involved in the evaluation of the industrial risks would lead to conclusions that would not be supported by a consistent basis, once the whole frame of the losses incurred due to failures would not be considered. They also constitute constraints, and once more, if there is no constraints to achieve the various reliability levels, we would choose "perfect systems", with the maximum availability and lowest related consequences in case of failure.

Therefore, the element cost appears as a mediator, as an element to promote a reasonable balance between mathematical and technological solutions and what is really feasible to achieve. In our case, the cost function is also taking into account all losses involved in an accident scenario.

Based on the cost equations (Life Cycle Cost x Availability) obtained for each one of the safety systems considered, on the expressions of average individual risk in terms of availability variables, and on established targets, the optimisation model and the results achieved are going to be analysed in this section.

The objective function of our optimisation problem, as we have already mentioned in the last section of Chapter 5 was the Life Cycle Cost equation expressed in terms of availability variables, which should be minimised.

The following attributes were considered in the allocation model:

- **Objective function:**

Cost function - to be minimised

- **Restrictions or Safety goal to be achieved:**

$AIR \leq$ *any of the values presented in Chapter* 2 *or section* 5.7.3

$ITSR \leq 10^{-4}$ *per year*
$IER \leq 10^{-4}$ *per year*

Where:

AIR = Average Individual Risk expression

ITSR = Frequency of Impairment to TSR

IER = Frequency of Impairment to Escape Routes

Tables A.11.1 to A.11.10 shows the results obtained for the equations shown in framework five. The values obtained for the cost function expressed by the variable FCOST, the restrictions imposed (represented by the values of *AIR*, *ITSR*, *IER*), as well as the variable values found, using the optimisation software are shown in these frameworks.

It can be observed from Table 5.8.1, which presents a resume of the sensitivity analysis performed, that different Safety Integrity Level (SIL) values were addressed to the availability variables, as well as different restriction values.

Cell *Name*	*AIR < 3.79e-04* *ITSR <10-4* *IER < 10-4* *0.999 < x < 0.9999* *SIL 3*	*AIR < 3.79e-04* *ITSR <10-4* *IER < 10-4* *0.99 < x < 0.999* *SIL 2*	*AIR < 3.79e-04* *ITSR <10-4* *IER < 10-4* *0.90 < x < 0.99* *SIL 1*	*AIR < 3.79e-04* *AIR > 2.21e-04* *ITSR <10-4* *IER < 10-4* *0.90 < x < 0.99* *SIL 1*	*AIR < 3.79e-04* *AIR > 2.19e-04* *ITSR <10-4* *IER < 10-4* *0.99 < x < 0.999* *SIL 2*	*AIR < 3.79e-04* *AIR = 2.175e-04* *ITSR <10-4* *IER < 10-4* *0.999 < x < 0.9999* *SIL 3*	*AIR < 3.79e-04* *AIR > 2.175e-04* *ITSR <10-4* *IER < 10-4* *0.999 < x < 0.9999* *SIL 3*
FCOST (pounds)	-133072928.00	-133057504.00	194525696.00	194895200.00	-132951680.00	-133051744.00	-133086304.00
AIR	2.173323E-04	2.176586E-04	2.207949E-04	2.263829E-04	2.193722E-04	2.17521603E-04	2.175217E-04
IER	7.270396E-05	7.335401E-05	8.086512E-05	1.000043E-04	7.767994E-05	7.29439760E-05	7.254659E-05
ITSR	1.099493E-16	1.095505E-14	1.067329E-12	3.368321E-12	4.394308E-14	1.20508484E-16	1.097114E-16
xf1	9.999000E-01	9.990000E-01	9.900000E-01	9.649899E-01	9.902971E-01	9.99187656E-01	9.99900000E-01
xf2	9.999000E-01	9.990000E-01	9.900000E-01	9.899445E-01	9.989985E-01	9.99899988E-01	9.99900000E-01
xf3	9.999000E-01	9.990000E-01	9.900000E-01	9.899997E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xf4	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xg1	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xg2	9.999000E-01	9.990000E-01	9.900000E-01	9.885686E-01	9.989368E-01	9.99899566E-01	9.99900000E-01
xg3	9.999000E-01	9.990000E-01	9.900000E-01	9.899997E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
xg4	9.999000E-01	9.990000E-01	9.900000E-01	9.899989E-01	9.990000E-01	9.99900000E-01	9.99900000E-01
p1	9.999000E-01	9.990000E-01	9.900000E-01	9.684451E-01	9.959523E-01	9.99890234E-01	9.99900000E-01
p2	9.999000E-01	9.990000E-01	9.900000E-01	9.886592E-01	9.988125E-01	9.99899261E-01	9.99900000E-01
p3	9.999000E-01	9.990000E-01	9.900000E-01	9.899576E-01	9.989947E-01	9.99899983E-01	9.99900000E-01
p4	9.999000E-01	9.990000E-01	9.900000E-01	9.858222E-01	9.984114E-01	9.99896292E-01	9.99900000E-01
v1	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.900020E-01	9.99161370E-01	9.99900000E-01
v2	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.989811E-01	9.99899718E-01	9.99900000E-01
v3	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.989996E-01	9.99899996E-01	9.99900000E-01
v4	9.999000E-01	9.990000E-01	9.900000E-01	9.900000E-01	9.989505E-01	9.99899525E-01	9.99900000E-01
c	9.997393E-01	9.979083E-01	9.900000E-01	9.900000E-01	9.978750E-01	9.99000018E-01	9.97575426E-01

Table 5.8.1 - Final Results Obtained for FCOST, AIR, ITSR and Safety Systems' Availabilities

Cell *Name*	*AIR < or = 3.79e-04* *AIR > or = 2.176e-04* *ITSR <10-4* *IER < 10-4* *0.999 < x < 0.9999* *SIL 3*	*AIR < or = 3.79e-04* *ITSR <10-4* *IER < 10-4* *0.99 < x < 0.999 - SIL 2 - for gas detection, pressure sensor and actuation systems* *0.999 < x < 0.999 9 - SIL 3 - for fire detection system* *0.999 < x < 0.999 9 - SIL 3 - for CPU system*	*AIR < or = 3.79e-04* *ITSR <10-4* *IER < 10-4* *0.99 < x < 0.999 - SIL 2 - for gas detection, pressure sensor and actuation systems* *0.999 < x < 0.999 9 - SIL 3 - for fire detection system* *CPU system = 0.9999*
FCOST	-132,276,064.00	-133,024,320.00	-133,029,936.00
AIR	2.176000E-04	2.174166E-04	2.174009E-04
IER	7.248158E-05	7.308563E-05	7.309841E-05
ITSR	1.096130E-16	1.098488E-14	1.098680E-14
xf1	9.999000E-01	9.999000E-01	9.999000E-01
xf2	9.999000E-01	9.999000E-01	9.999000E-01
xf3	9.999000E-01	9.999000E-01	9.999000E-01
xf4	9.999000E-01	9.999000E-01	9.999000E-01
xg1	9.999000E-01	9.990000E-01	9.990000E-01
xg2	9.999000E-01	9.990000E-01	9.990000E-01
xg3	9.999000E-01	9.990000E-01	9.990000E-01
xg4	9.999000E-01	9.990000E-01	9.990000E-01
p1	9.999000E-01	9.990000E-01	9.990000E-01
p2	9.999000E-01	9.990000E-01	9.990000E-01
p3	9.999000E-01	9.990000E-01	9.990000E-01
p4	9.999000E-01	9.990000E-01	9.990000E-01
v1	9.999000E-01	9.990000E-01	9.990000E-01
v2	9.999000E-01	9.990000E-01	9.990000E-01
v3	9.999000E-01	9.990000E-01	9.990000E-01
v4	9.999000E-01	9.990000E-01	9.990000E-01
c	9.966814E-01	9.997252E-01	9.999000E-01

Table 5.8.1 - Final Results Obtained for FCOST, AIR, ITSR and Safety Systems' Availabilities (cont.)

As it is possible to conclude from Table 5.8.1, it is not possible for that FPSO to achieve the average individual risk target of 2.91e-05 per year, calculated in Chapter 5, section 5.7.3 for the individual risk value associated with process activity (1994-1998). Even if we have SIL levels greater than 0.9999 or even equal to 1 (100% of availability) for all its safety systems, we would not be able to achieve this goal. The equivalent value of individual risk if we have a hypothetical availability value equal to 1 for all safety systems considered, will be equal to 2.17292E-04.

In order to achieve lower individual risk values, it would be necessary to implement several measures in the installation, to reduce the number of fatalities. We could mention the installation of additional passive and active protection measures, as well as effective sheltering and escaping procedures and resources. It may be expressed in the average societal or individual risk expressions as probabilities that would provide a lower value for scenarios frequencies or a lower number of fatalities.

We have run some examples (shown in A.11.1 to A.11.10 and in Table 5.8.1) using a maximum value for the individual risk equal to 3.79e-04, which is the value calculated in Chapter VI (table 5.7.3.6) for the individual risk associated with process activity, including PCE accident, during the period of 1992 to 1994. That value and even lower values can be achieved by the installation under analysis.

From Table 5.8.1 we can observe that the greater the value of safety system's availability, more negative is the value of the cost function obtained, meaning that the greater the achieved benefit is.

It is explained by the fact that, as we are dealing with big values involved with the loss of oil and gas, e.g., expressed in terms of loss of income due to deferred oil and gas production, as well as in terms of damage to assets in case of a major accident, any improvement in the critical safety availability will represent a significant benefit for the operator.

It can be observed that when addressing values in the range of 0.90 to 0.99, corresponding to the lowest acceptable SIL level- SIL-1, there will be no benefit, although the unit presents safety systems installed, once the losses incurred will prevail.

Then we have varied the values of the acceptable ranges for the individual risk (A 11.4 4 to A.11.8) to see how this variation impacts the final values of the function FCOST and the variable values. It can be observed that the requested critical safety availability values are loosen, but as expected, the benefit obtained is lower.

Tables A.11.9 to A.11.10 present other variations, e.g., different SIL levels are addressed to the safety systems, demonstrating that the model allows the analyst to evaluate the benefits achieved with different reliability levels addressed to any safety system considered. The analyst can also vary the restrictions expressions and target values in order to arrive to the best optimisation solution, regarding what is reasonably practicable to implement.

The model allows the analyst to vary the values of *AIR* and *ITSR* and *IER*, reliability levels (SIL levels), performing sensitivity analyses, in order to make a balance between the benefits and the reliability levels achieved. The model also allows the analyst to have a whole picture of the facility in terms of safety goals previously established. It also provides a clear view of the vulnerable points of the considered unit in terms of safety.

It is important to highlight that any other expression obtained from quantitative risk assessment studies and for costs x reliability levels could replace the ones presented in the allocation model, as well as other desired safety goals.

6.2. General Comments

As mentioned in Chapter 4, the intention of the proposed model was to provide a "safety overview" of the installation, taking into account the safety systems installed, and safety goals previously established.

As we have demonstrated, the model provides an evaluation of how far the installation is in terms of risk levels or safety levels, from the established safety targets.

The result of the proposed approach was presented in terms of information related to costs, risk and maximum tolerable frequencies of impairment to the main safety functions of a particular offshore unit design (in our case, a Floating Production Storage Offloading- FPSO). It was presented as a function of the availability of its safety systems, and components and structure. Additionally, the methodology presented in this Thesis provides information about alternative design configurations and operational practices.

Regarding the objective proposed in Chapter 4, the following comments are presented:

The objective of the model that was developed in this Thesis is:

(1) To propose a feasible model to allocate reliability and risk criteria for the main safety functions of an offshore unit in a self-consistent manner. This model would provide a method for evaluating the global safety of an industrial facility regarding aspects as safety design configurations (passive and active protection) and operation procedures (test and maintenance). It will provide a method for design engineers to establish minimum reliability levels for safety functions in order to achieve safety targets previously defined.

(2) To apply the proposed methodology, through numerical examples.

(3) To evaluate the generated results, identifying the vulnerabilities and performing a sensitive analysis, with the variation of the goal setting values.

(4) To demonstrate the if it is possible or not to achieve the proposed criteria for the specific installation, providing a detailed look of the unit design in terms of the reliability of safety functions and the adequacy of active and passive protection.

And the section still mentions that the model is flexible, in such a way that it allows the analyst to include other variables that were not included in this study, such as the probability of a successful or unsuccessful sheltering, probability of a successful or unsuccessful, etc.

The model presented has achieved all these goals.

The model presented allows the analyst to propose his own safety goals and evaluate if it is feasible to reach them, based on design or operational targets.

The fact that you can achieve other goal levels, e.g. availability goals for the safety functions, from top level goals (individual risk criterion) is an important task, once it provides a better understanding of the safety importance of each one of the various safety systems and the respective cost-effectiveness improvements.

The approach presented in this Thesis will then be a problem of determining the optimum design configuration for safety functions of an offshore unit, considering simultaneously the risk measures and costs.

In essence, the approach will be to determine the "optimum design" of the plant in terms of safety (which in our case were based on Safety Integrity Levels to be achieved for the safety systems together with the satisfaction of the proposed constraints), considering simultaneously the established global measure and the costs to achieve it.

Regarding the essential elements of the analysis presented in Chapter 4, the following comments are presented below:

1) The establishment of a global measure of unit's safety performance (top level safety indices: ***which in our case was given by the individual risk to offshore workers and the maximum tolerable frequency of impairment to the main safety functions of the FPSO;***

- In this work, the first element mentioned above has consisted of a set of two components: a proposed individual risk criterion for Brazilian offshore workers, which was calculated based on data collected in Brazilian Oil Company (Petrobras), which as a monopolist company (until the data of calculation) is far representative of the Brazilian offshore oil production "universe"; and of the maximum tolerable frequency of impairment to the main safety functions, which value is based on HSE Guidelines (HSE

- Therefore, the first step of the analysis was the collection of data related to fatalities occurred in oil platforms (including workers from PETROBRÁS and from others companies, who work for PETROBRÁS). After obtaining this data, it was possible to calculate the associated "Fatal Accident Rate" (FAR) and the Average Individual Risk (AIR), as shown in Table 5.7.3.6.

- The individual risk was calculated for the specific case of Brazilian offshore units, although the values obtained are very compatible with other values presented world wide for individual risks as shown in Table 5.7.3.6.

2) The "objective function": ***that in our case was defined as the cost function which was minimised;***

- The total life cycle cost equation, as a function of availability values was provided by the sum of the life cycle cost equations obtained for each one of the safety systems considered (turret's fire and gas detection systems, process plant's fire and gas detection systems, pump room's fire and gas detection systems, machine room's fire and gas detection systems, CPU system, pressure sensor systems and actuation (valve) systems). The curves with the associated equations were obtained using the software -Microsoft Excel, Microsoft Office 1997.

3) a model for relating the global measure of plant's safety performance to specific set of measures of plant performance: ***which was provided as average societal and individual risk expressions as a function of the availability of safety***

systems, as well as the expressions of frequency of impairment to the main safety functions, which constituted the "decision variables";

- Regarding the expressions presented for the frequency of impairment to main safety functions, they should be based on quantitative risk assessments previously performed. Therefore, expressions for the frequency of impairment to the Temporary Safety Refuge (TSR), to escape routes and to structure can be presented as a function of availability variables.

4) A method for allocating values to these specific measures of the unit safety performance (availability of safety functions) in order to optimise the plant design and satisfy the global measures established: ***the allocation model proposed.***

- In order to solve model, we have used the optimisation software named Solver, provided by Microsoft (1997), which is a very simple one. Other methods could be used to solve the equations, as genetic algorithms.

We can conclude that the proposed objective of this work was achieved and that it confirms the technical feasibility of allocating reliability and risk in a self-consistent way.

We hope that this work can be useful to purposes of evaluating the global safety of offshore oil units, and maybe can be extended to other industrial facilities.

We hope that the values presented here for the individual risk for offshore workers in Brazilian oil fields, can add a contribution to the wide debate that has been being promoted all over the world around risk targets and risk decision making processes.

7. References

1.Reid, S. G., "Acceptable Risk", Engineering Safety, McGraw-Hill, Inc., USA, 1991, pp. 138- 167

2.Mitchell, J., "The Evolution of Acceptable Risk", The Environmental Professional, Volume 12,1990, pp. 114-121

3.Starr, C., "Social Benefit versus Techhological Risk", Science .Number 165, 1969, pp.1232-1238

4.Fishhoff, B. C., Lichtenstein, S. and Slovic, P., "Acceptable Risk", Cambridge University Press, Cambridge, 1981, pp.1-10

5.Kahneman, D., Slovic, P. and Tversky, A., "Judgment under Uncertainty: Heuristic and Biases", Cambridge University Press, Cambridge, 1982, pp.1-15

6.Slovic, P., Fishhoff, B.and Lichtenstein, S., "Factors and Fears: Understanding Perceived Risk", Plenum, New York, NY, 1980, pp. 181-214, pp.1-9

7.Norwegian Petroleum Directorate, "Guidelines for Safety Evaluation of Platform Conceptual Design", Norwegian Petroleum Directorate, 1981, pp.1-7

8.Pidgeon, N. F., Hood, C., Jones, D., Turner, B. and Gibson, R., "Risk Perception", Risk: Analysis, Perception and Management, The Royal Society, London, 1993, pp. 89- 125

9.Pidgeon, N. F., "The Psychology of Risk", Engineering Safety, McGraw-Hill, Inc., USA, 1991, pp.167-201

10.Gregory, H. and Mendelsohn, F., "Perceived Risk, Dread and Benefits, Risk Analysis, Volume 13, Number 3, 1993, pp. 5

11.Eyles, T., Taylor, B., Baxter, C. and Willms, F., "The Social Construction of Risk ina Rural Community: Responses of Local Residents to the Hagersville (Ontario) Fire", Risk Analysis, Volume 13, Number 3, 1993, pp.281-282

12.Cassidy, K., "Risk Assessment: A Business Risk or a Risky Business?", Proceedings of the AIChE, International Simposium on Risk Management Procedures and Methods, Sao Francisco, California, 1993, pp. 236

13.Olstad, H. T., "Risk Assessment Approach to Offshore Safety: Part A-Norwegian Regulatory Philosophy", SPE-24774, 67th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers, Washington, DC., 1992, pp. 119-124

14. Norwegian Petroleum Directorate, "Regulations Concerning Implementation and Use of Risk Analysis in the Petroleum Activities with Guidelines", Norwegian Petroleum Directorate, 1992, pp. 1-15

15. Norsk Standard, NS 5814, Oslo, 1991, pp. 1-17

16. Cox, T., "Risk Analysis of Offshore Installations: A Decade of Experience and Prospects for the Future", IBC Technical Services Ltd, Risk Analysis in the Offshore Industry III, Aberdeen, 1992, pp. 4

17. Health and Safety Executive, "A Guide to the Offshore Installations (Safety Case) Regulations 1992", Health and Safety Executive, HMSO, London, 1992, pp. 1-84

18. Health and Safety Executive, "A Guide to the Control of Industrial Major Accident Hazards Regulations", HMSO, London, 1990, pp. 1-76

19. Health and Safety Executive, "The Tolerability of Risk from Nuclear Power Stations", Health and Safety Executive, HMSO, 1992

20. The Royal Society, Risk: Analysis, Perception & Management, the Royal Society, London, 1993, pp. 166-185

21. The Norwegian Oil Industry Association (OLF), "Guidelines for Establishing Acceptance Criteria for Risk Analysis", Stavanger, Norway, 1992, pp.1-17

22. Staatsoezicht op de Min (Department of Mines), "Guidelines for Offshore Safety Case Report Preparation- Framework for an Offshore Safety Case for New Fixed and Mobile Installations", The Netherlands, 1992, pp.10, 12, 13, 16 and 25

23. Staatsoezicht op de Min (Department of Mines), "Guidelines for Offshore Safety Case Report Preparation- Framework for an Offshore Safety Case for Existing Fixed and Mobile Installations", The Netherlands, 1992, pp. 4, 8, 16

24. European Federation of Chemical Engineering, Risk Analysis in the Process Industry, Report of the International Study Group on Risk Analysis, The Institution of Chemical Engineers, Rugby, Warks, 1993, pp. 7-30, 65-83

25. Pettersen, G. and Nygaard, M., "Statjord Field: Risk Analysis", SPE-23287, Society of Petroleum Engineers, First International Conference of Health, Safety and Environment, Hague, The Netherlands, 1991, pp. 687-690

26. Andersen, R. S., Engen G., Vinnem J. E., Pedersen, K. S., Emblem, K. and Amdahl, J., "Risk Analysis in Offshore Development Projects", SINTEF- The Foundation of Scientific and Industrial Research at the Norwegian Institute of Technology, Trondheim, 1983, pp. 1-107

27. American Institute of Chemical Engineers, Guidelines for Chemical Process Quantitative Risk Analysis, American Institute of Chemical Engineers, New York, NY, 1989, pp.1-165

28. Engelhard, W. F. J. M., "Quantitative Risk Analysis of Offshore Platforms- State of the Art- 'ARMS' Project- Advanced Risk System", TNO Institute of Environmental and Energy Technology, Apeldoorn, The Netherlands, 1991, pp. 1-34

29. Military Standard, MIL-STD-1629-A, "Procedures for Performing a Failure Mode, Effects and Criticality Analysis", Department of Defense, Washington, DC., 1977

30. Jensen, S. B., Vedeler, B., Wulff, E., "Risk Assessment - A Study of Risk Levels within Norwegian Offshore Petroleum Activities", The Royal Norwegian Council for Scientific and Industrial Research, Oslo/Trondheim, 1979, pp.119, 121

31. Engen G. and Golan, M., "Analysis of Well Completion Equipment and Techniques-Fault Analysis", SINTEF -Safety and Reliability, Trondheim, 1980, pp. 9-12

32. Crossland, B., Bennet, P. A., Ellis, A. F., Farmer, F. R., Gittus, J., Godfrey, P. S., Hambly, E. C., Kletz, T. A. and Lees, F. P., "Estimating Engineering Risk", Risk: Analysis, Perception and Management, The Royal Society, London, 1993, pp.17 and 24

33.TNO Institute of Environmental and Energy Technology, prepared under the supervision of the Committee for the Prevention of Disasters, Methods for the Calculation of Physical Effects, Voorbug, 1988, pp.

34. Kapur, K C. and Lamberson, L.R., Reliability in Engineering Design, John Wiley and Sons, Inc., USA, 1977, pp. 9 and 10

35. Pietersen, C. M. and Magnin, J. C. A., "Risk Assessment of Oil and Gas Installations- Safety Cases-The Dutch View", IRO-Seminar, 1993, pp.3

36. Ramsay, C., Bolsover A. J., Jones, R. H. and Medland, W. G., "Quantitative Risk Assessment applied to Offshore Process Installations. Challenges after Piper Alpha Disaster", Journal of Loss Prevention in the Process Industries", Volume 7, Number 4, 1994, pp. 327

37. Jones, D. A., Nomenclature for Hazard and Risk Assessment in the Process Industries, Institution of Chemical Engineers, Rugby,Warwickshire, 1992, pp. 6, 37 and 38

38. Kletz, T., HAZOP and HAZAN- Identifying and Assessing Process Industry Hazards, The Institution of Chemical Engineers, Rugby, Warwickshire, 1993, pp. 59-61

39. Health and Safety Executive, "Risk Criteria for Land-Use Planning in the Vicinity of Major Industrial Hazards", Health and Safety Executive, HMSO, Bootle, Liverpool, 1989, pp.19 and 22

40. Health and Safety Commission, "Major Hazard Aspects of the Transport of Dangerous Substances", Health and Safety Executive, Sheffield, 1992, pp. 98-106

41. Fleishmann, A.B., " The Use of Cost –Benefit Analysis in Evaluating the Acceptability of Inndustrial Risks: An Illustrative Case", Group Safety Centre, BP International Limited, London, pp.60-12- 60-16

42. Cho, N.Z., Papazoglou, I. A. and Bari, R.A., "A Methodology for Allocating Reliability And Risk", Department of Nuclear Enegy, Brookhaven National Laboratory, Upton, NY 11973, May 1986, pp. 1- 41.

43. Oliveira, L.F.S, Bardy, Mariana, Peçanha, C.E., "Avaliação Quantitativa de Riscos do Navio Presidente Prudente de Moraes", Principia, Brazil, 1997

44. Oliveira, L.F.S., Bardy, Mariana, Peçanha, C.E., "Avaliação Quantitativa de Riscos do Navio Vidal de Negreiros", Principia, Brazil, 1997

45. Oliveira, L.F.S., "Análise do Sistema de Detecção de Fogo da Plataforma de Pampo", Principia, Brazil 1993

46. Oliveira, L.F.S., "Análise do Sistema de Detecção de Gás da Plataforma dc ..", Principia, Brazil, 1994

47. Lasdon, L., Fylstra, D., Watson, J., Waren, ª, "design and Use of Microsoft Excel Solver, Microsoft, USA

48. Aaro, R., Bodsberg, L. and Hokstad, P., "Reliability Predicyion Handbook; Computer-Based Process Safety Systems", SINTEF, Norway, 1989, pp. 1-95

49. Lydersen, S. and Aaro, R., "Life Cycle Cost Prediction Handbook; Computer-Based Process Safety Systems, SINTEF, Norway, 1989, pp.1-47

50. Det Norsk Veritas Industry as DNV Technica, WOAD- World-wide Offshore Accident Data bank, Statistical Report 1994, DNV Technica Norge, Hovik, Norway, 1994, pp. 1-8.9

52.PETROBRÁS, "Riscos de Petróleo - Segurado - Endosso n^0.001.000.096, Apólice n^0. 001.000.024", PETROBRÁS, 1998, Anexo A, pp.1/4

53. Santos, J.A, "Engenharia Econômica-Matemática Financeira - Análise de Investimentos"- PETROBRÁS/SEDES/CENOR, Brazil, 1992, pp. 205

54.ISA–S84.01-1996, "Application of Safety Instrumentated Systems for the Process Industries", ISA, USA, 1996, pp.21

55. Pereira, C. A., "Procedimento para Cálculo, da Perda de VPL devido ao Atraso", PETROBRÁS, 1996. pp.1-2

56. PETROBRÁS/GETINP, "Maritime Production Installations' Safety Philosophy" - ET - 3000.00- 5400-947-PGT-001, PETROBRÁS, 1996

57. Faertes, D., "Sobre um Critério de Aceitabilidade de Riscos para Plataformas de Petróleo Offshore", MSc. Thesis, Universidade Federal do Rio de Janeiro, 1994, pp.

Appendix 1

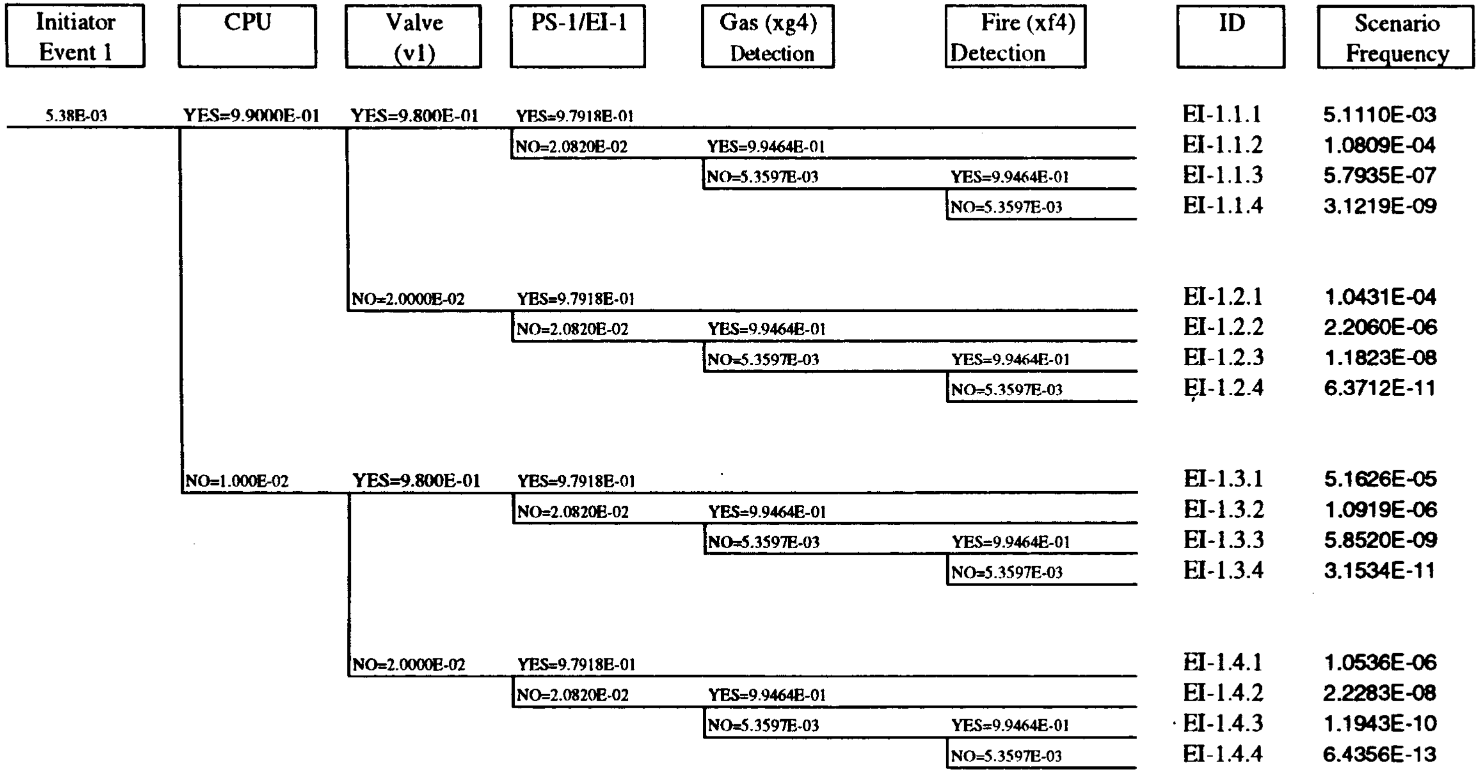


Figure A.1.1 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 1

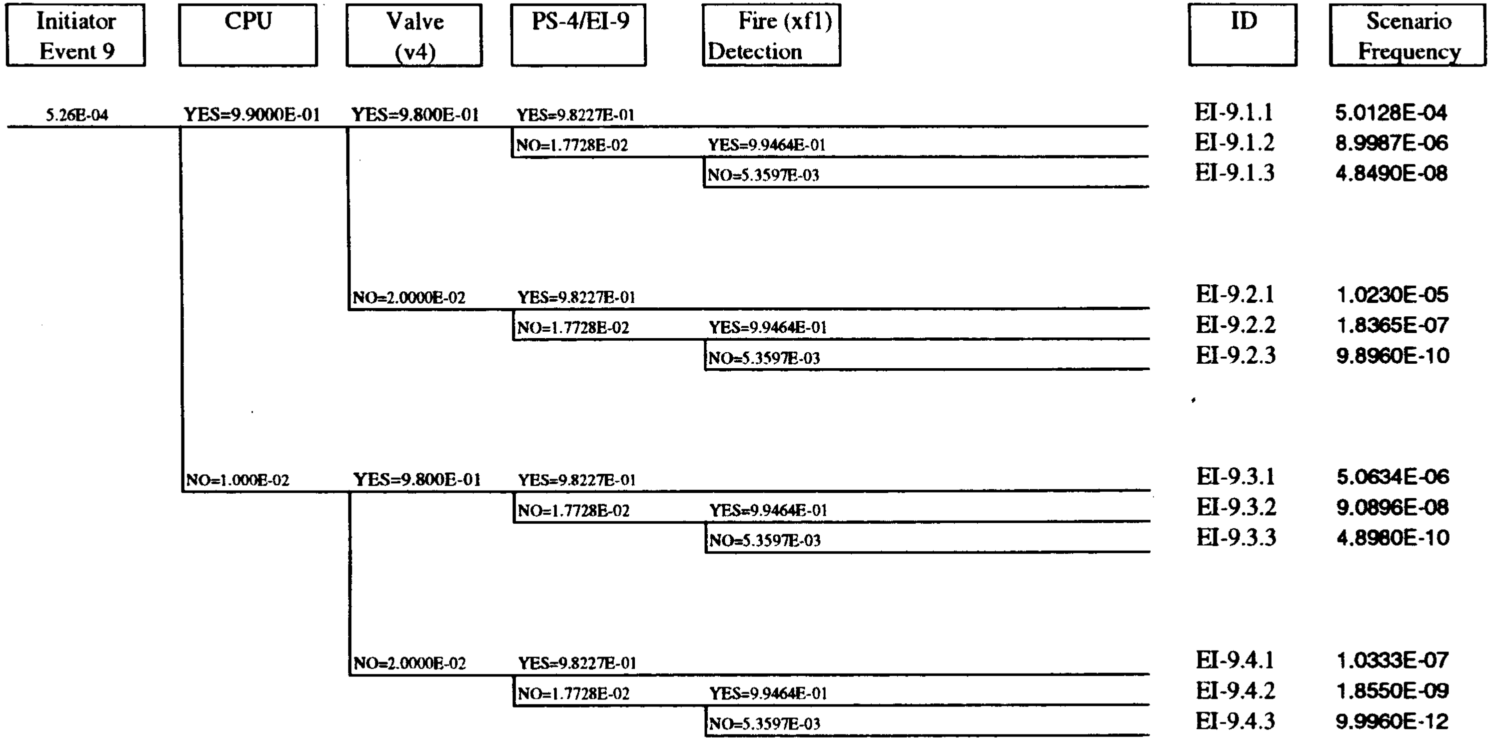


Figure A.1.2 Scenario Frequency Calculation of the Ssytemic Event Tree of the Initiator Event 9

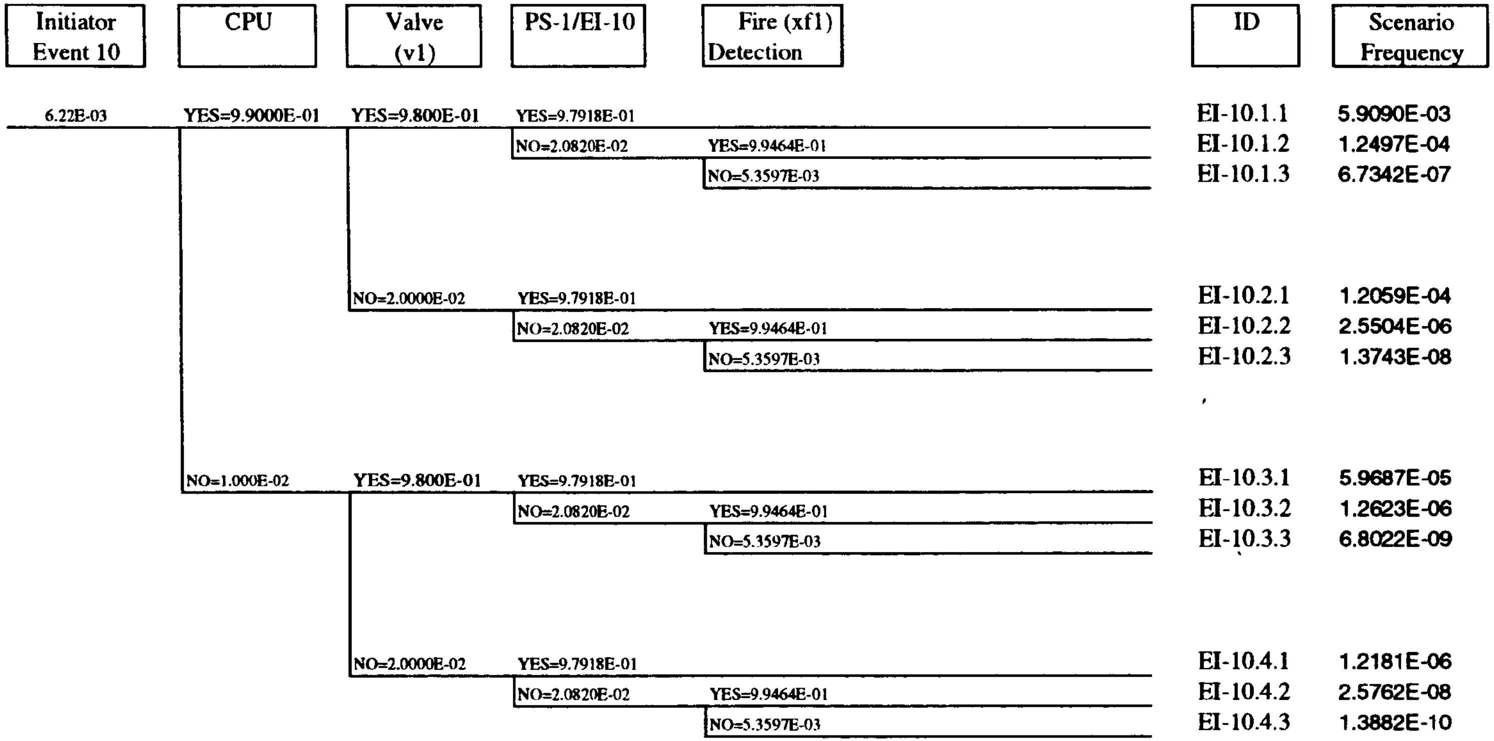


Figure A.1.3 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 1

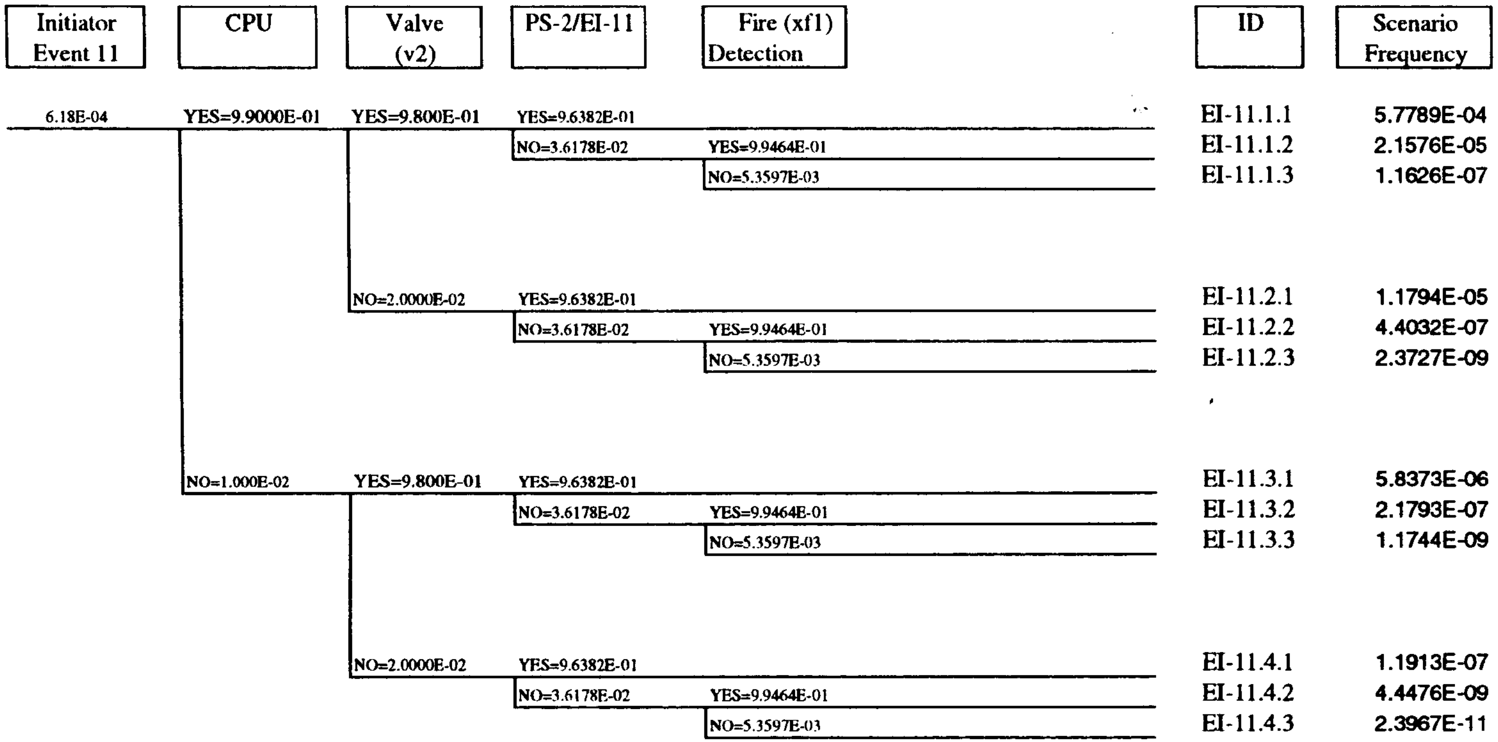


Figure A.1.4 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 11

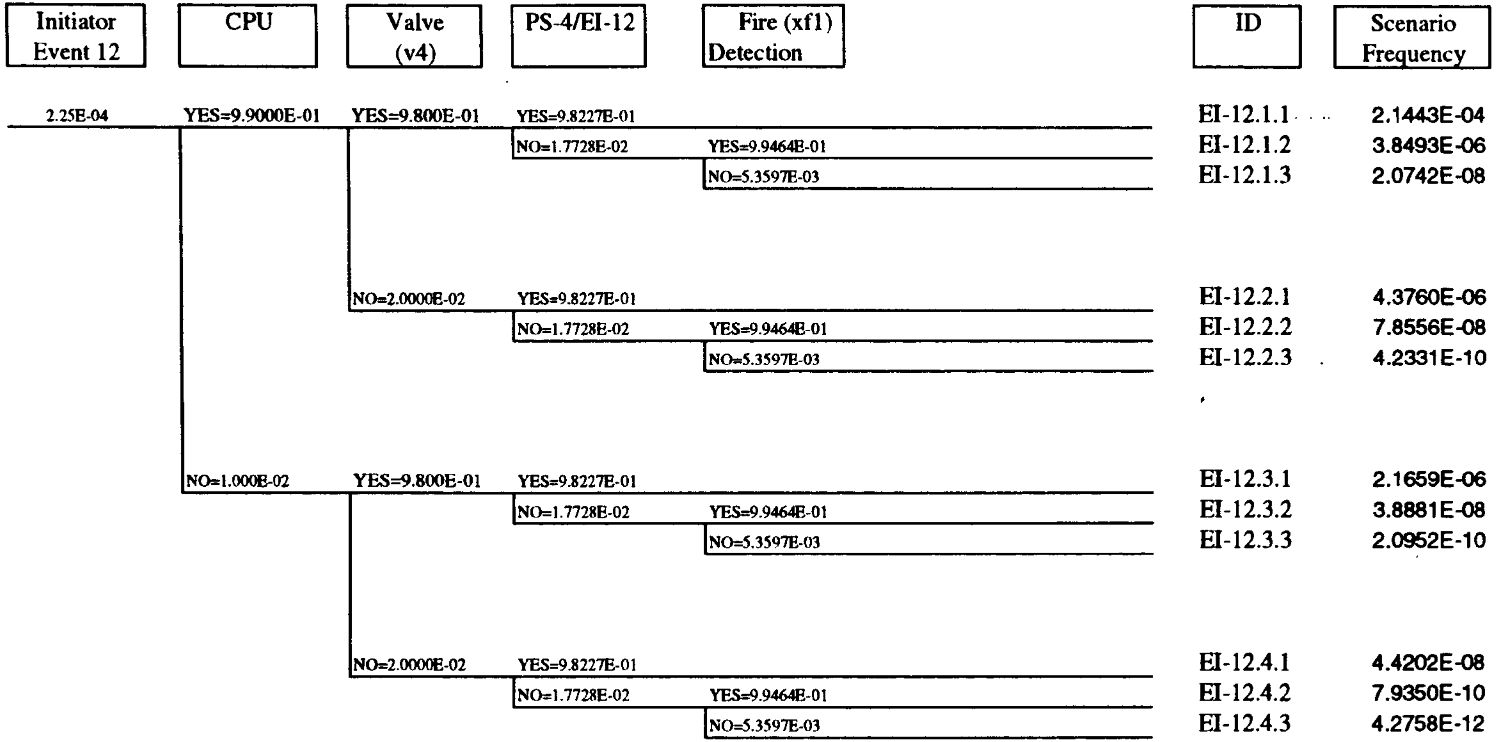


Figure A.1.5 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 12

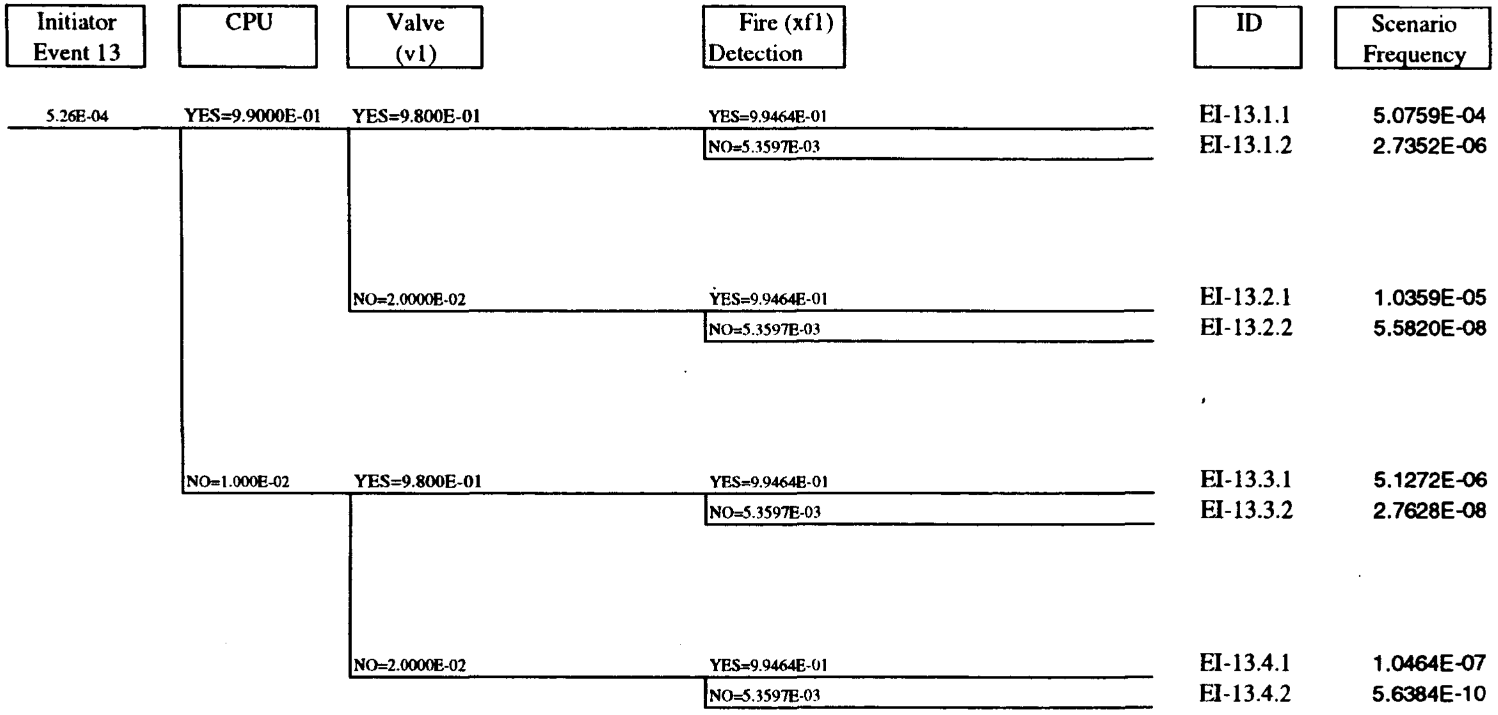


Figure A.1.6 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 1

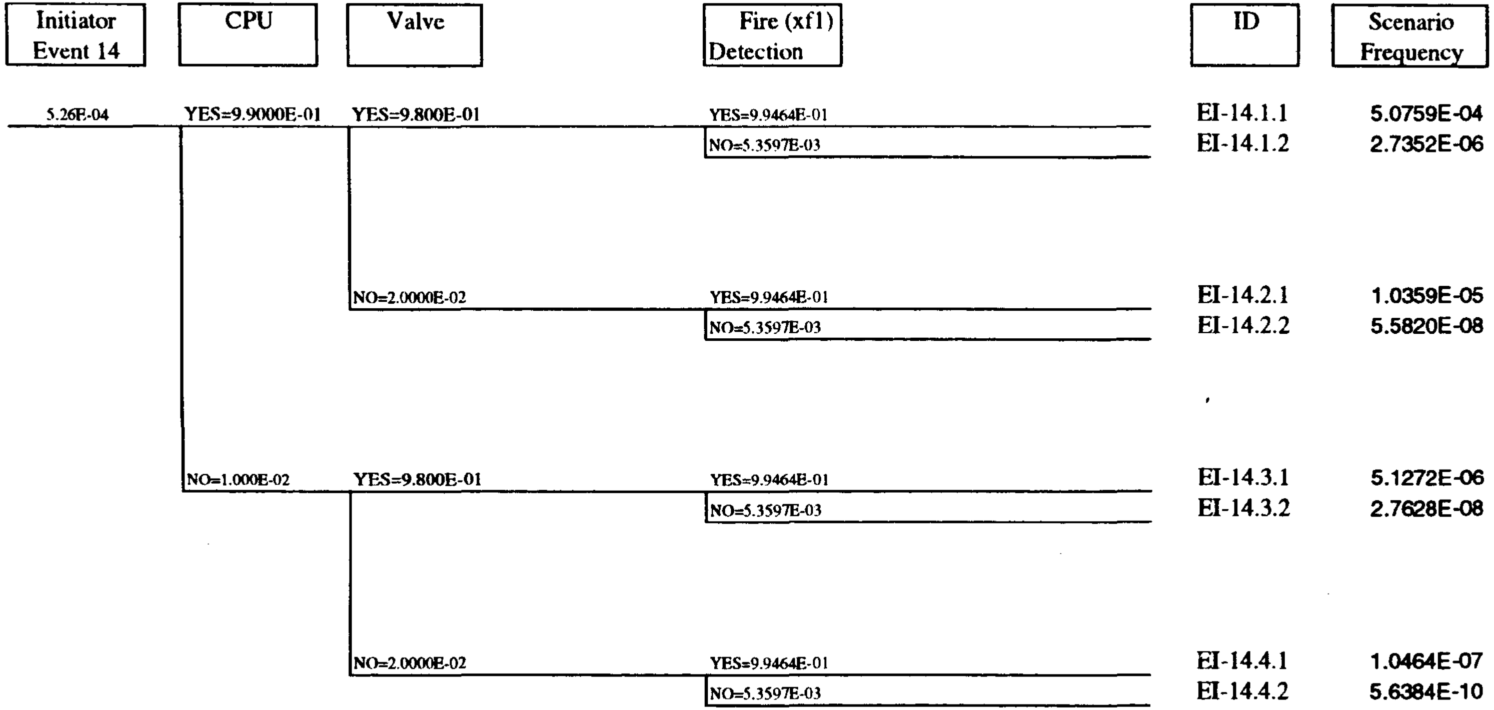


Figure A.1.7 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 1

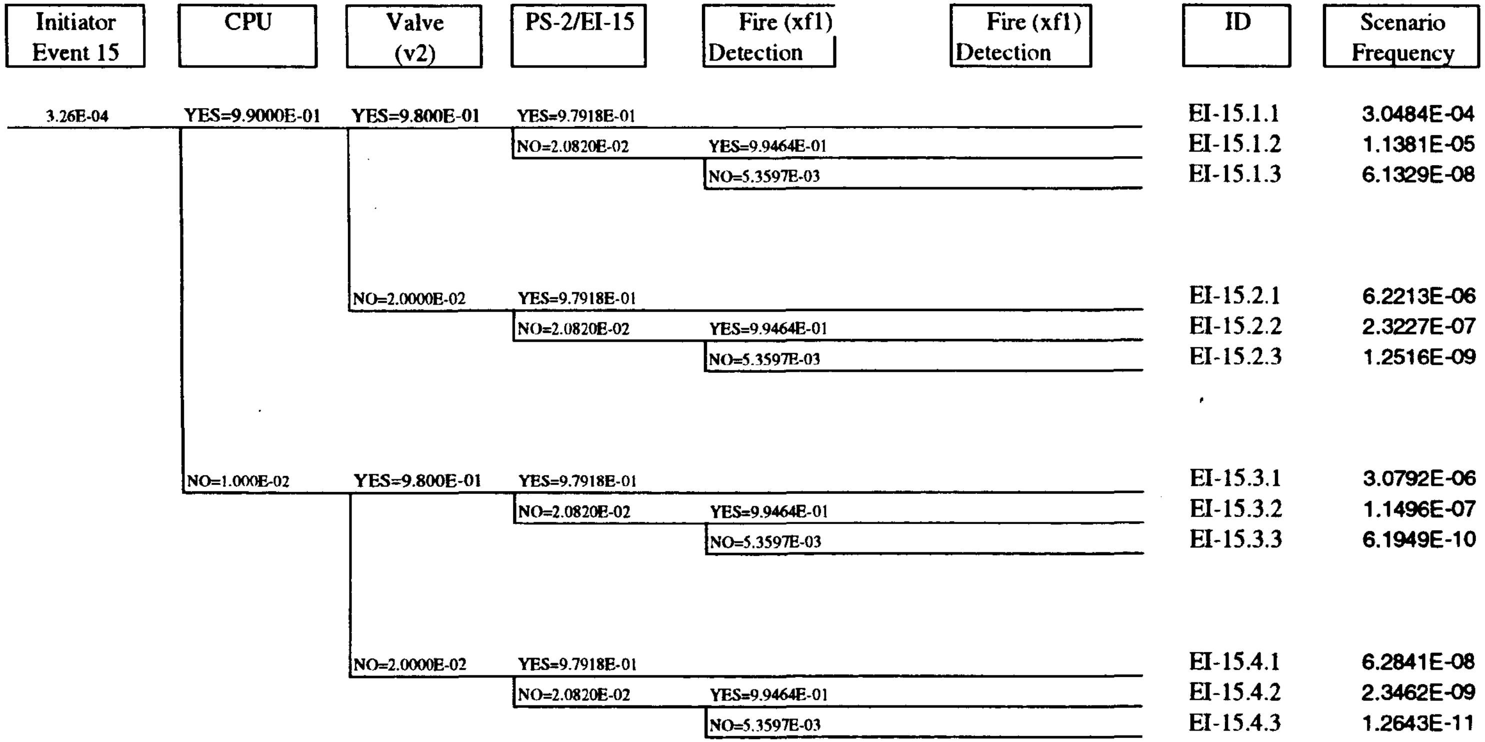


Figure A.1.8 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 15

Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 16

This event (gas stack accumulation) was not simulated due to a hole made in the stack top, incresaing the ventilation and avoiding gas accumulation

Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 17

Initiator Event 17	ID	Scenario Frequency	File Name
1.42E-03	EI-17.1	1.42E-03	EIA17RSB, EIB17RSB,

In this event no gas and fire detection systems were considered. No protection system was identified.
The frequency used in this event was equal to 1/4 of the calculated frequency (the event was calculated for 4 different release points- 1 17A, 17B, 17C and 17D)

Scenario Frequency Calculation of the Sytemic Event Tree of Initiator Event 19

Initiator Event 19	ID	Scenario Frequency	File` Name
2.16E-03	EI-19.1	2.16E-03	EIA19RSB, EIB19RSB,

In this event no gas and fire detection systems were considered. No protection system was identified.
The frequency used in this event was equal to 1/4 of the calculated frequency (the event was calculated for 4 different release points- 1 19A 19B, 19C and 19D).

Figure A.1.8A Scenario Frequency Calculation of the Systemic Event Tree of Initiator Events 16, 17, 18 and 19

Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 20

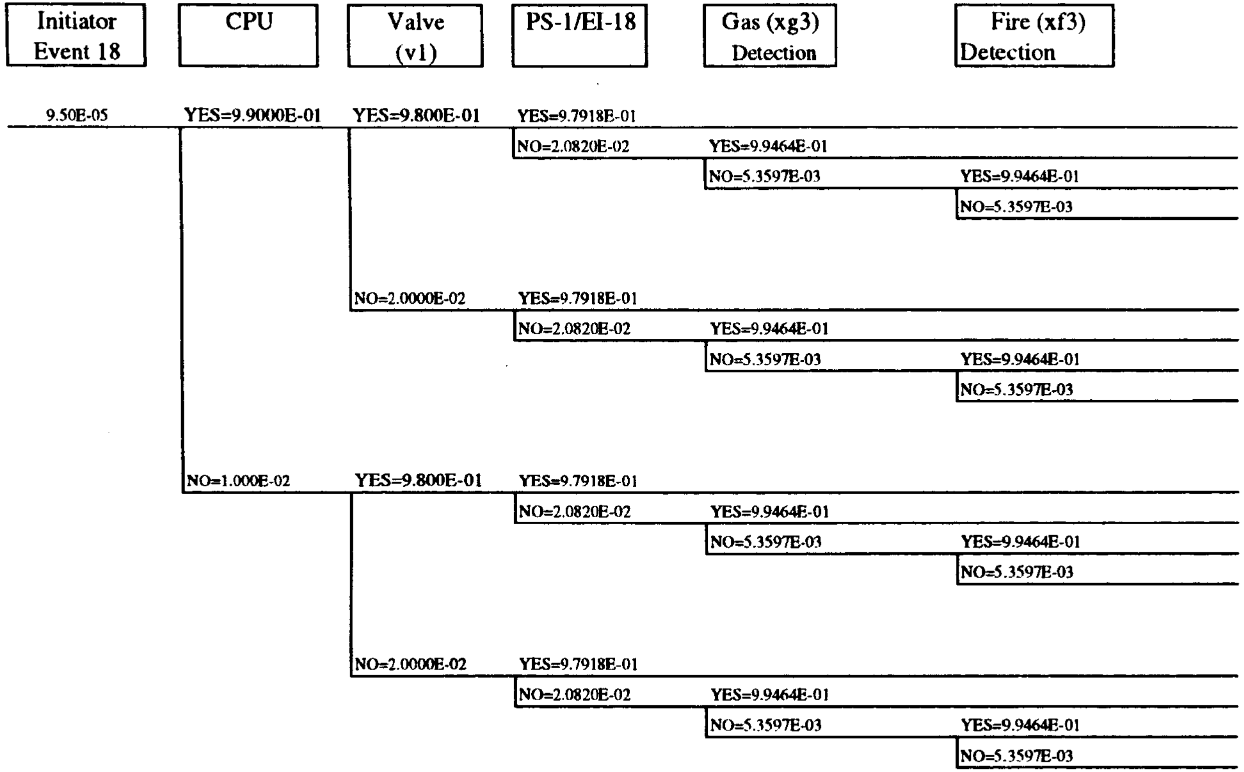
Initiator Event 20	ID	Scenario Frequency	File Name
1.02E-03	EI-20.1	1.02E-03	EIA20RSB, EIB20RSB, EIC20RSB, EID20RSB

In this event no gas and fire detection systems were considered. No protection system was identified.
The frequency used in this event was equal to 1/4 of the calculated frequency (the event was calculated for 4 different release points- 1 20A 20A, 20B, 20C and 20D).

Scenary Frequency Calculation of the Systemic Event Tree of Initiator Event 21 and 22

These events were simulated as explosions in oil storage tanks. For each one of the tanks a file exists, all of them with same frequency of occurrence addressed. The files are: EI-TQ** 1C, 1P, 1S,2C, 2P, 2S, 3C, 4C, 4P, 4S, 5C, 5P and 5S.

Figure A.1.9 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Events 20, 21 and 22



ID	Scenario Frequency
EI-18.1.1	9.0250E-05
EI-18.1.2	1.9087E-06
EI-18.1.3	1.0230E-08
EI-18.1.4	5.5126E-11
EI-18.2.1	1.8418E-06
EI-18.2.2	3.8953E-08
EI-18.2.3	2.0878E-10
EI-18.2.4	1.1250E-12
EI-18.3.1	9.1162E-07
EI-18.3.2	1.9280E-08
EI-18.3.3	1.0334E-10
EI-18.3.4	5.5683E-13
EI-18.4.1	1.8604E-08
EI-18.4.2	3.9347E-10
EI-18.4.3	2.1089E-12
EI-18.4.4	1.1364E-14

Figure A.1.10 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 18

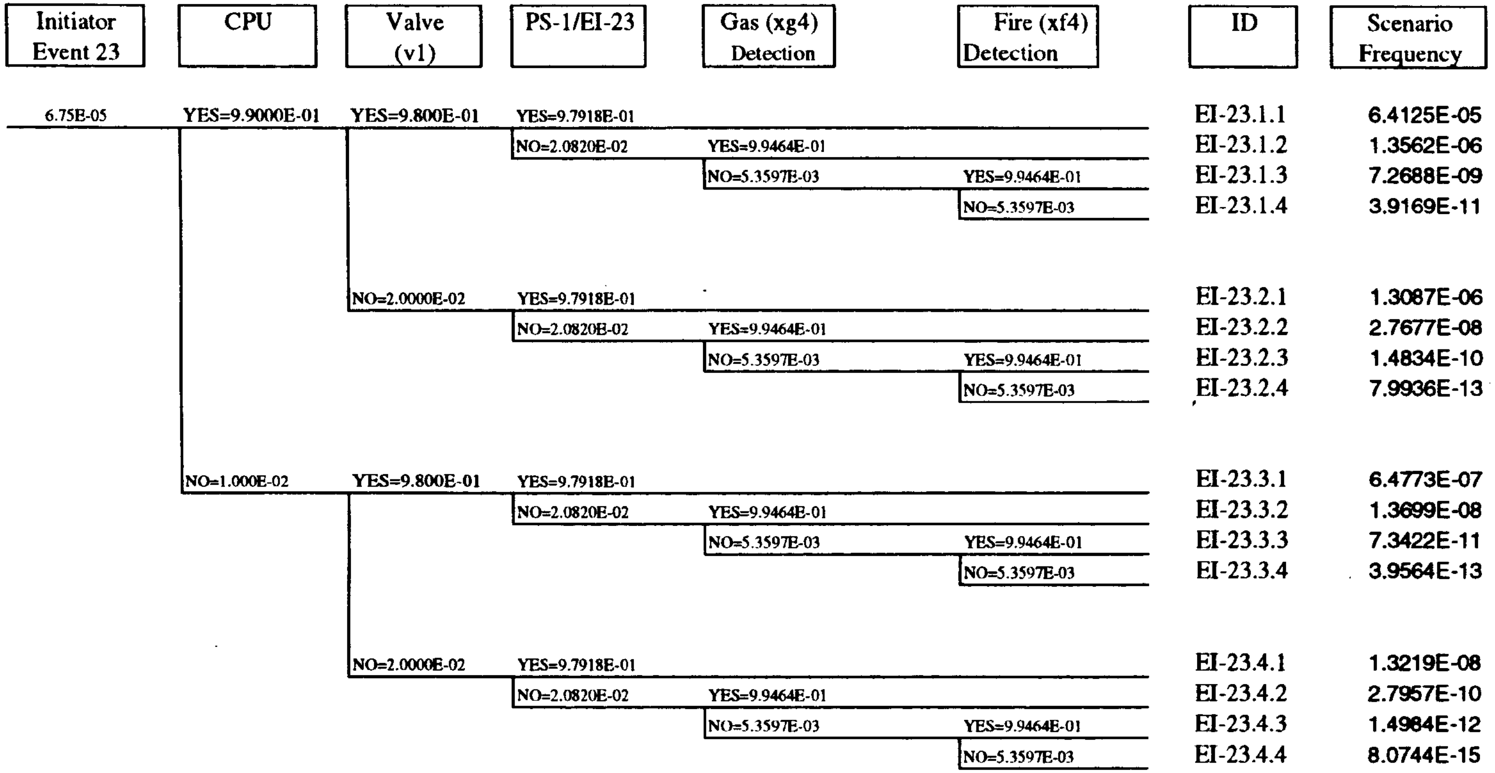


Figure A.1.11 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 23

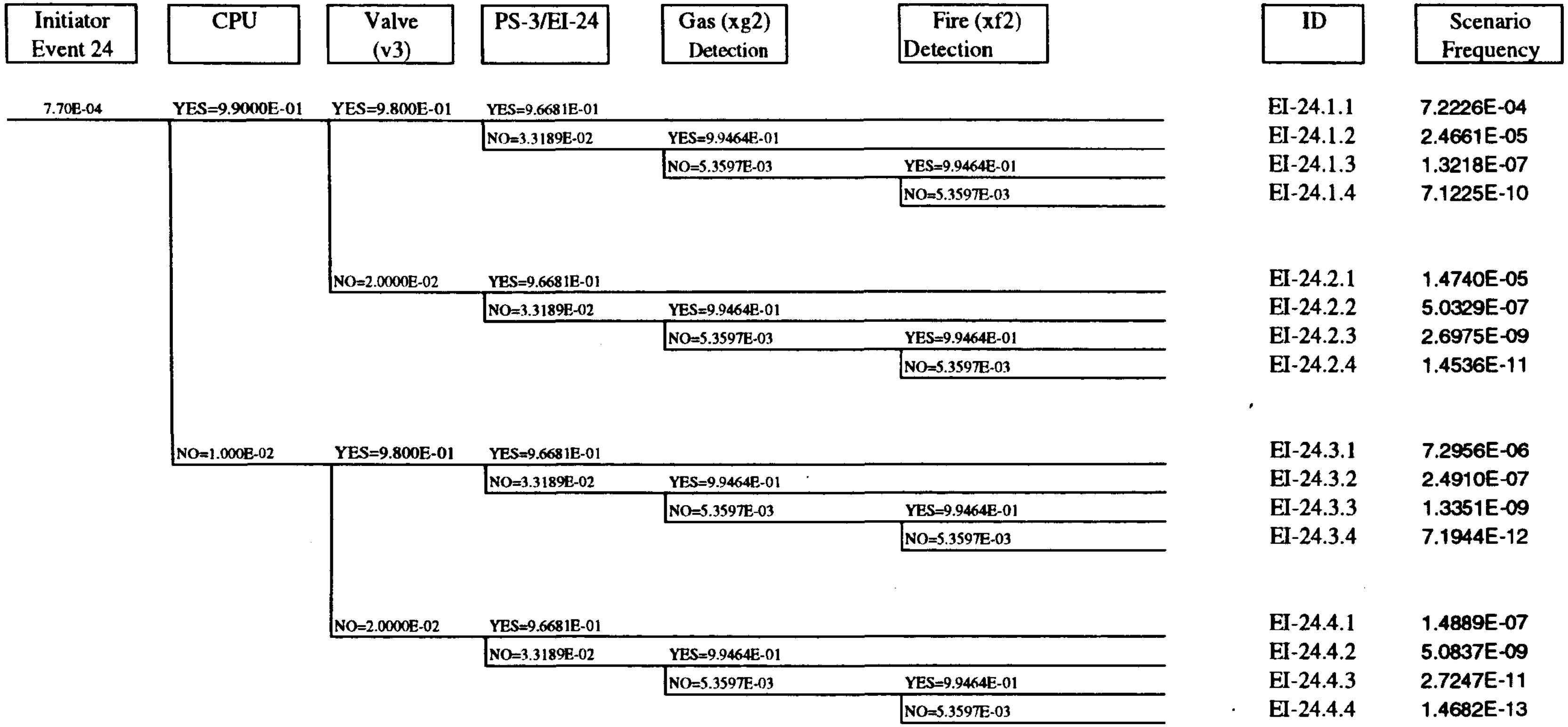


Figure A.1.12 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 24

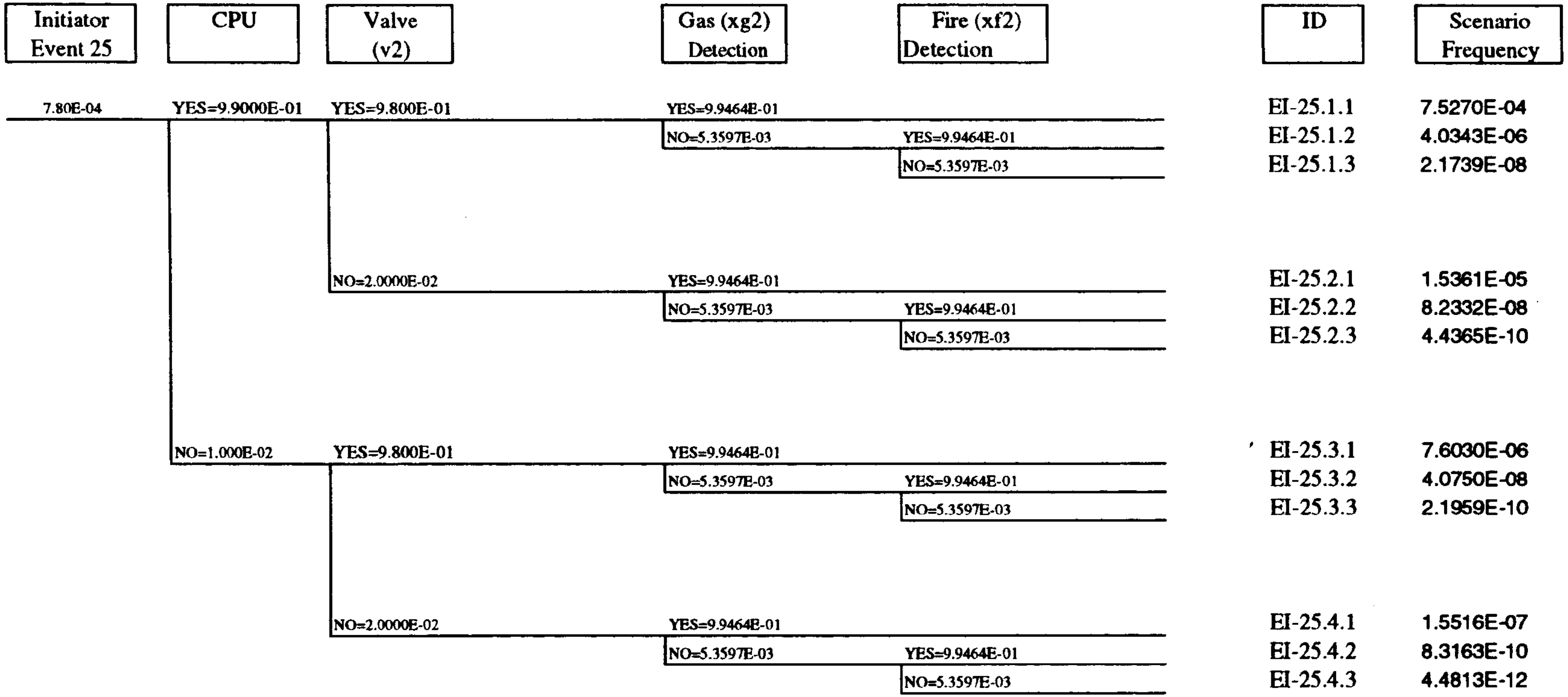


Figure A.1.13 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 25

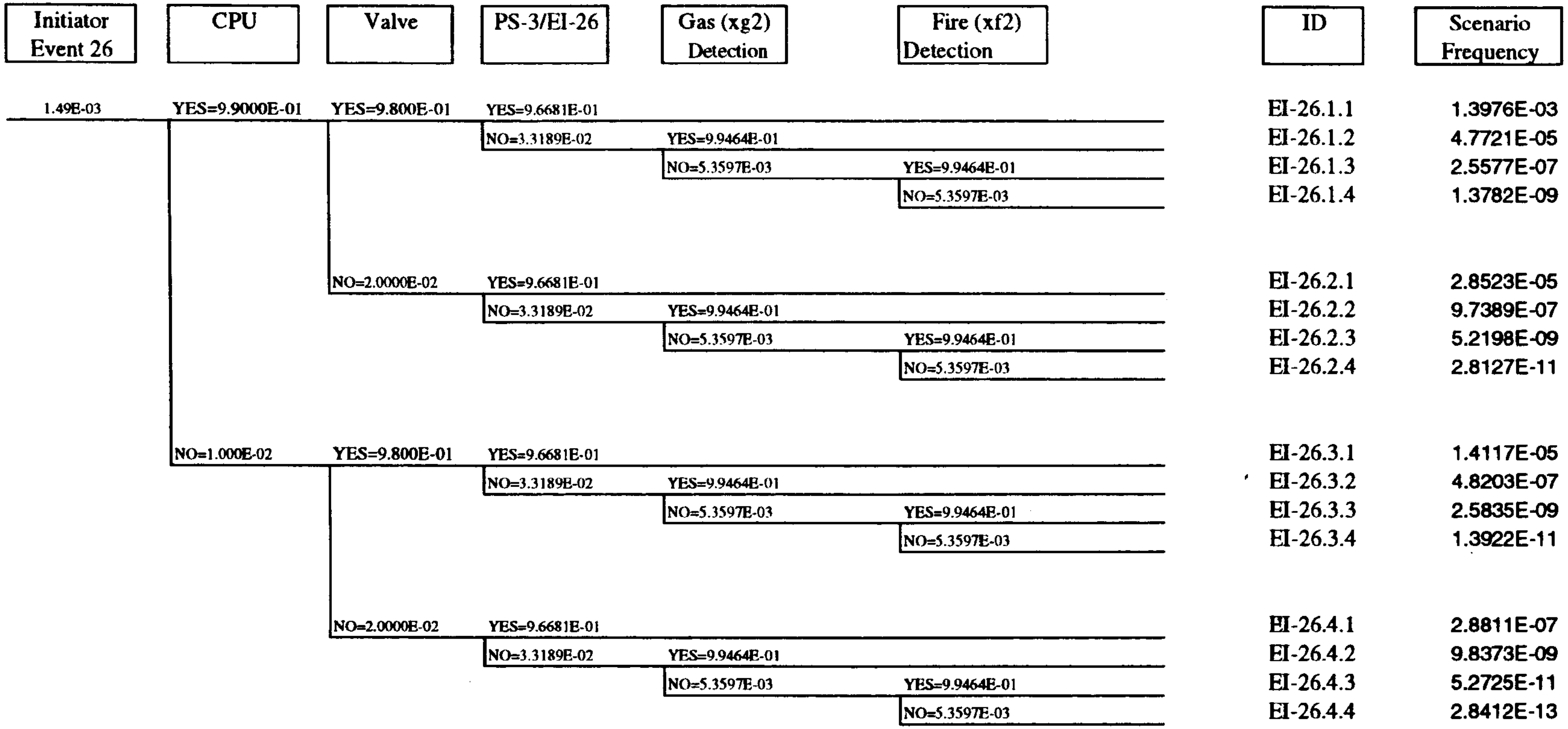


Figure A.1.14 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 26

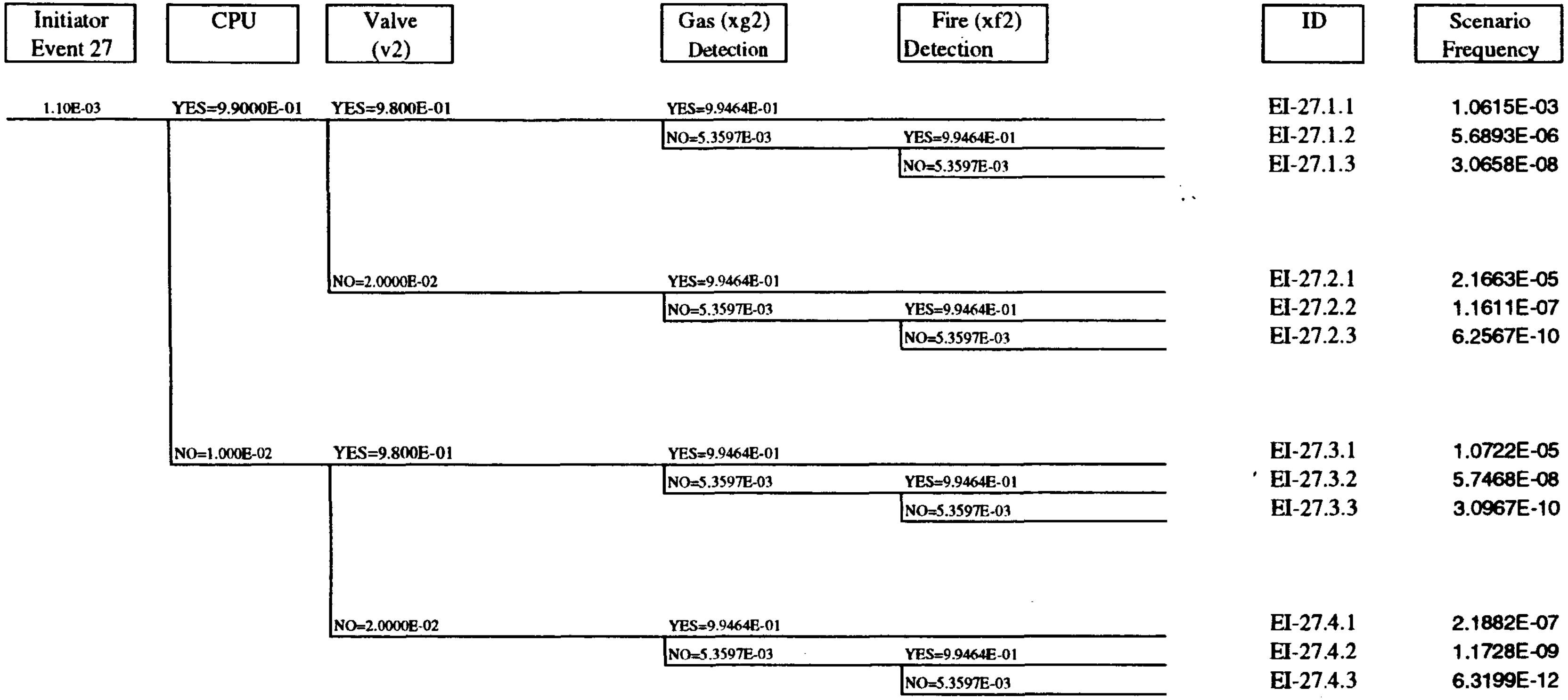


Figure A.1.15 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 27

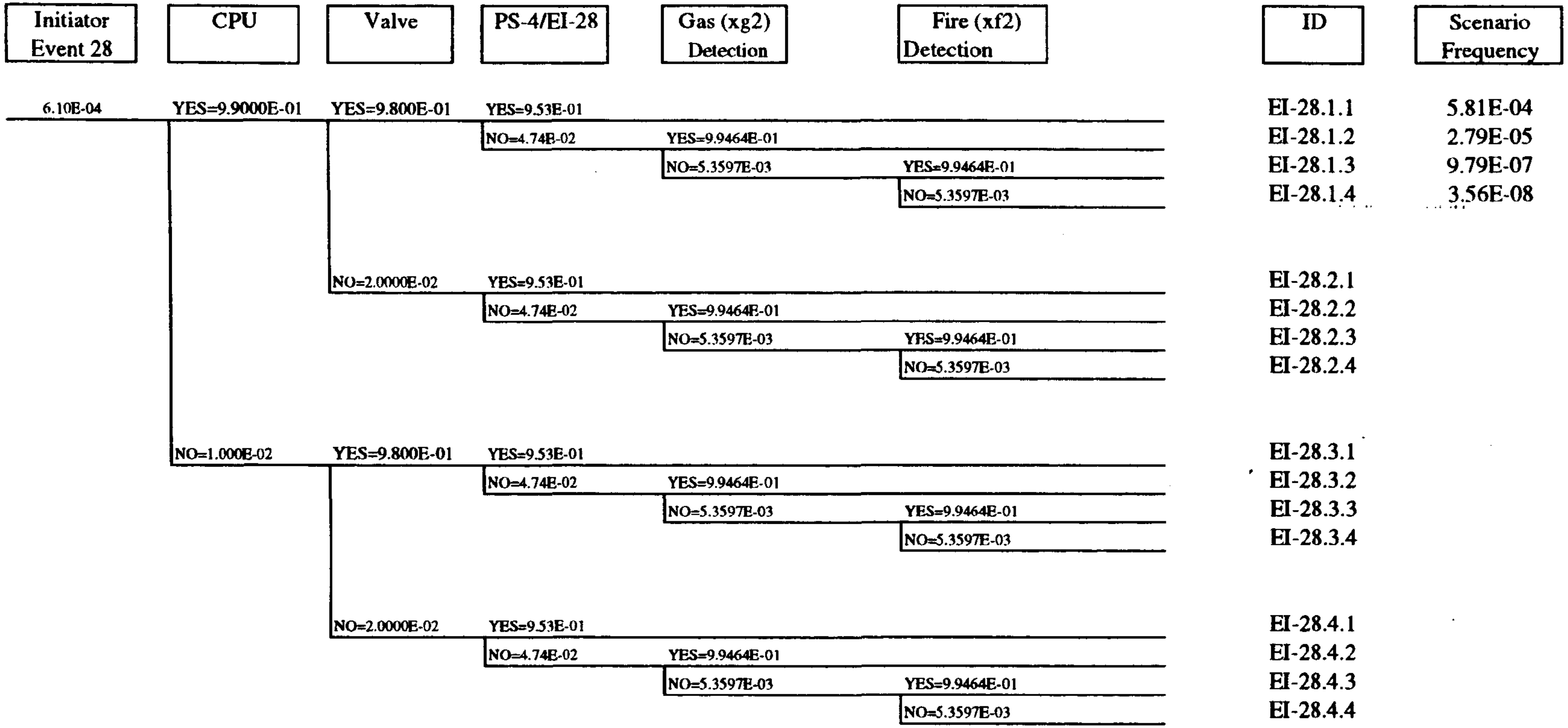


Figure A.1.16 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 28

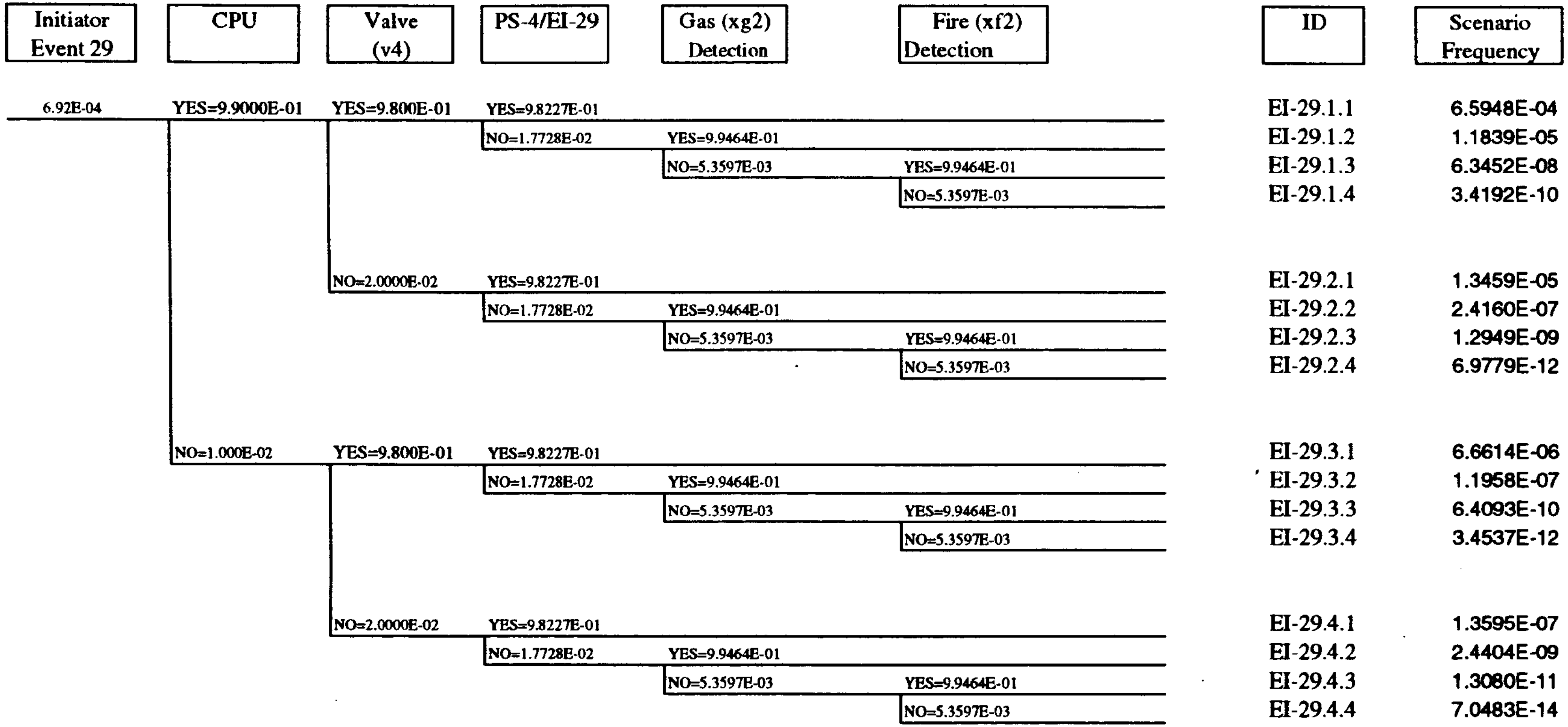
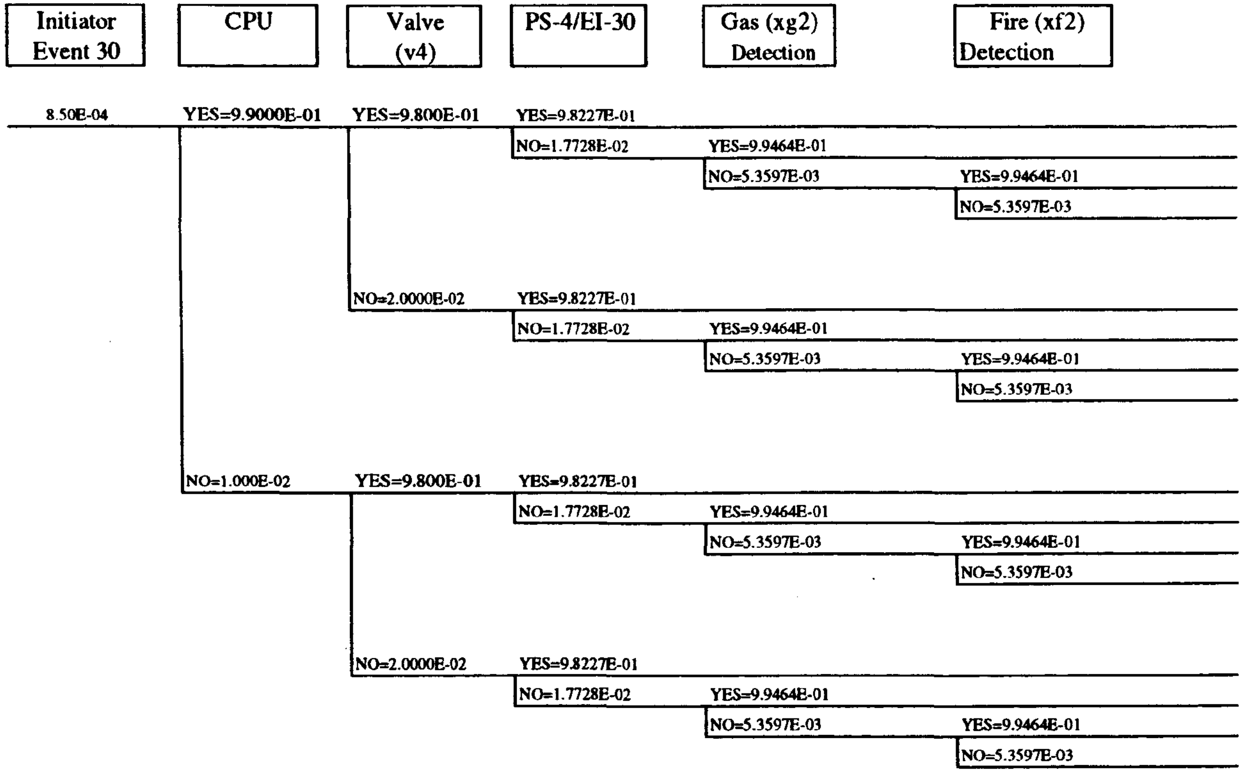
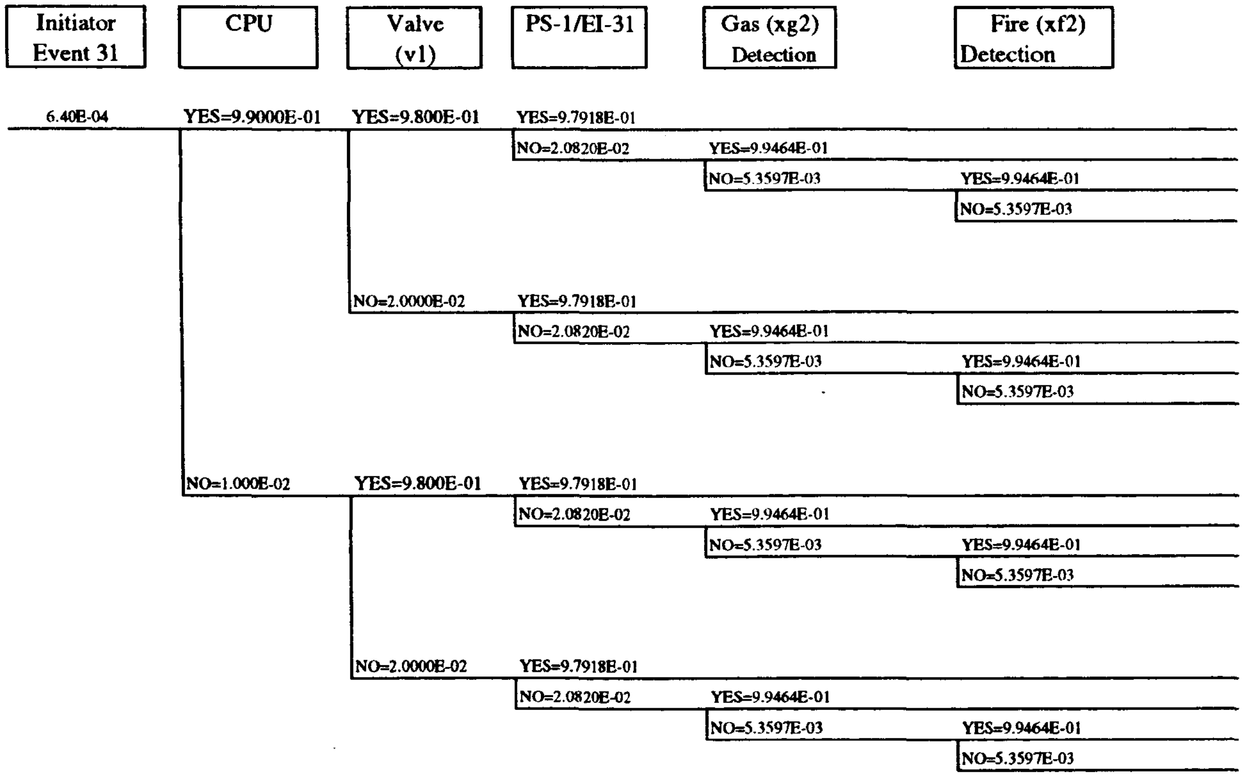


Figure A.1.17 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 29



ID	Scenario Frequency
EI-30.1.1	8.1005E-04
EI-30.1.2	1.4542E-05
EI-30.1.3	7.7939E-08
EI-30.1.4	4.1998E-10
EI-30.2.1	1.6532E-05
EI-30.2.2	2.9677E-07
EI-30.2.3	1.5906E-09
EI-30.2.4	8.5711E-12
EI-30.3.1	8.1823E-06
EI-30.3.2	1.4689E-07
EI-30.3.3	7.8726E-10
EI-30.3.4	4.2423E-12
EI-30.4.1	1.6699E-07
EI-30.4.2	2.9977E-09
EI-30.4.3	1.6067E-11
EI-30.4.4	8.6577E-14

Figure A.1.18 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 30



ID	Scenario Frequency
EI-31.1.1	6.0800E-04
EI-31.1.2	1.2859E-05
EI-31.1.3	6.8919E-08
EI-31.1.4	3.7138E-10
EI-31.2.1	1.2408E-05
EI-31.2.2	2.6242E-07
EI-31.2.3	1.4065E-09
EI-31.2.4	7.5791E-12
EI-31.3.1	6.1414E-06
EI-31.3.2	1.2989E-07
EI-31.3.3	6.9615E-10
EI-31.3.4	3.7513E-12
EI-31.4.1	1.2533E-07
EI-31.4.2	2.6507E-09
EI-31.4.3	1.4207E-11
EI-31.4.4	7.6557E-14

Figure A.1.19 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 31

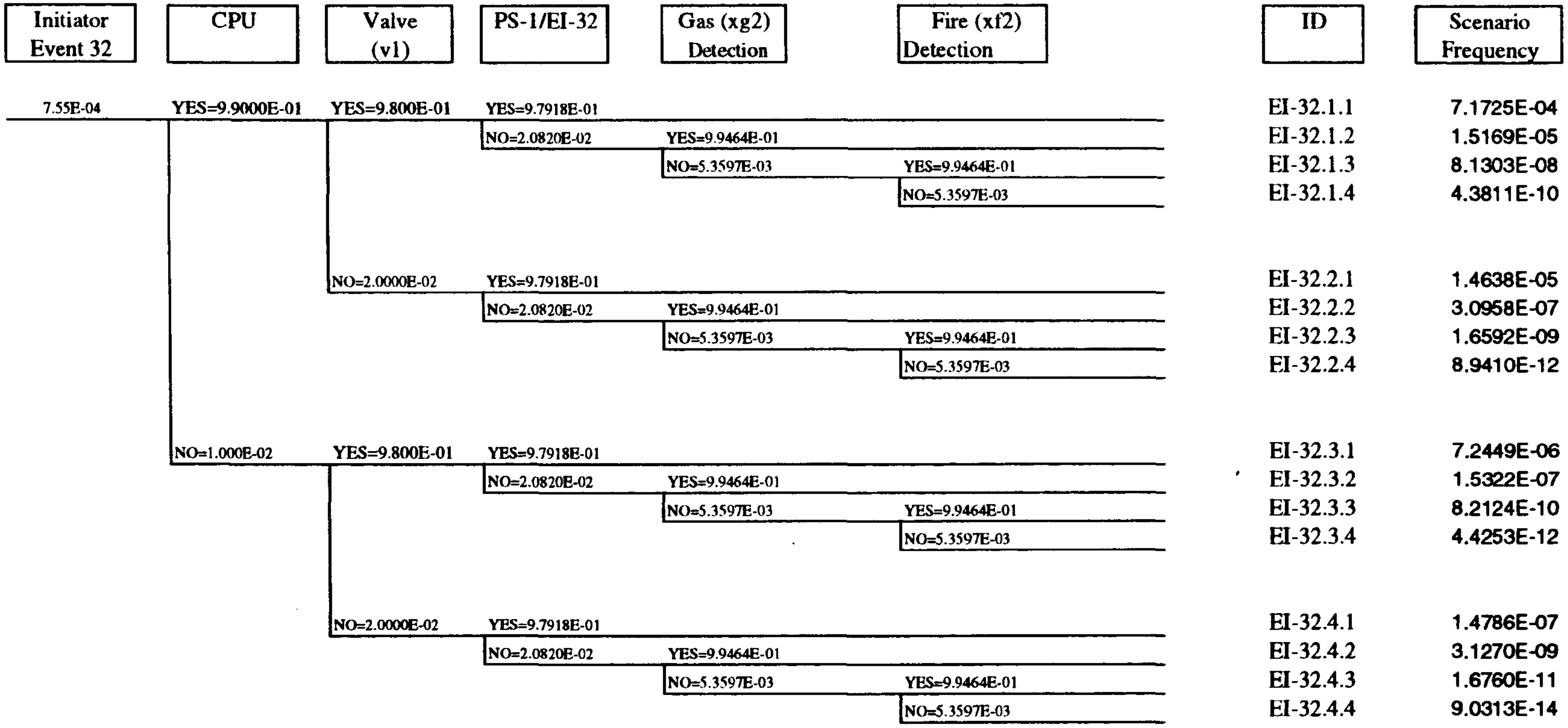


Figure A.1.20 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 32

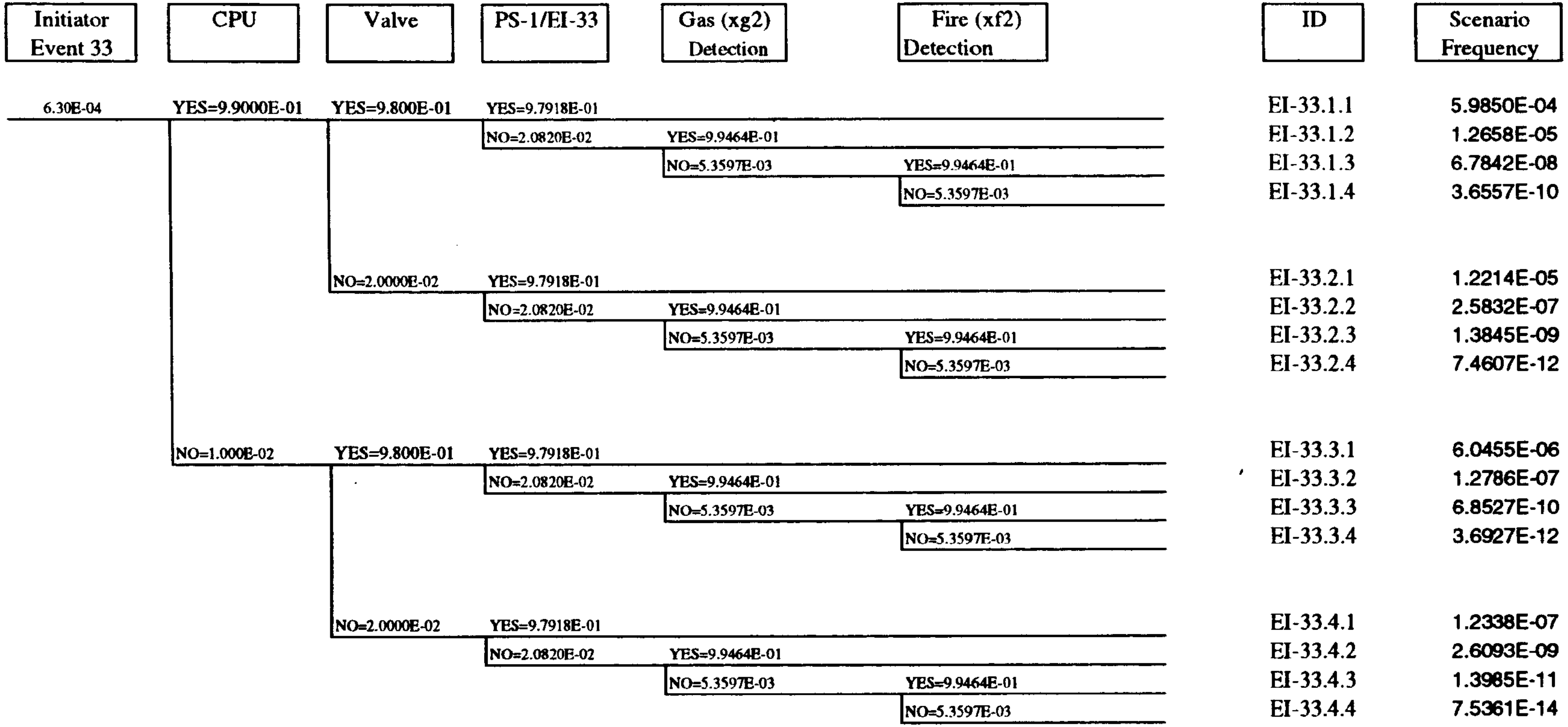


Figure A.1.21 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 33

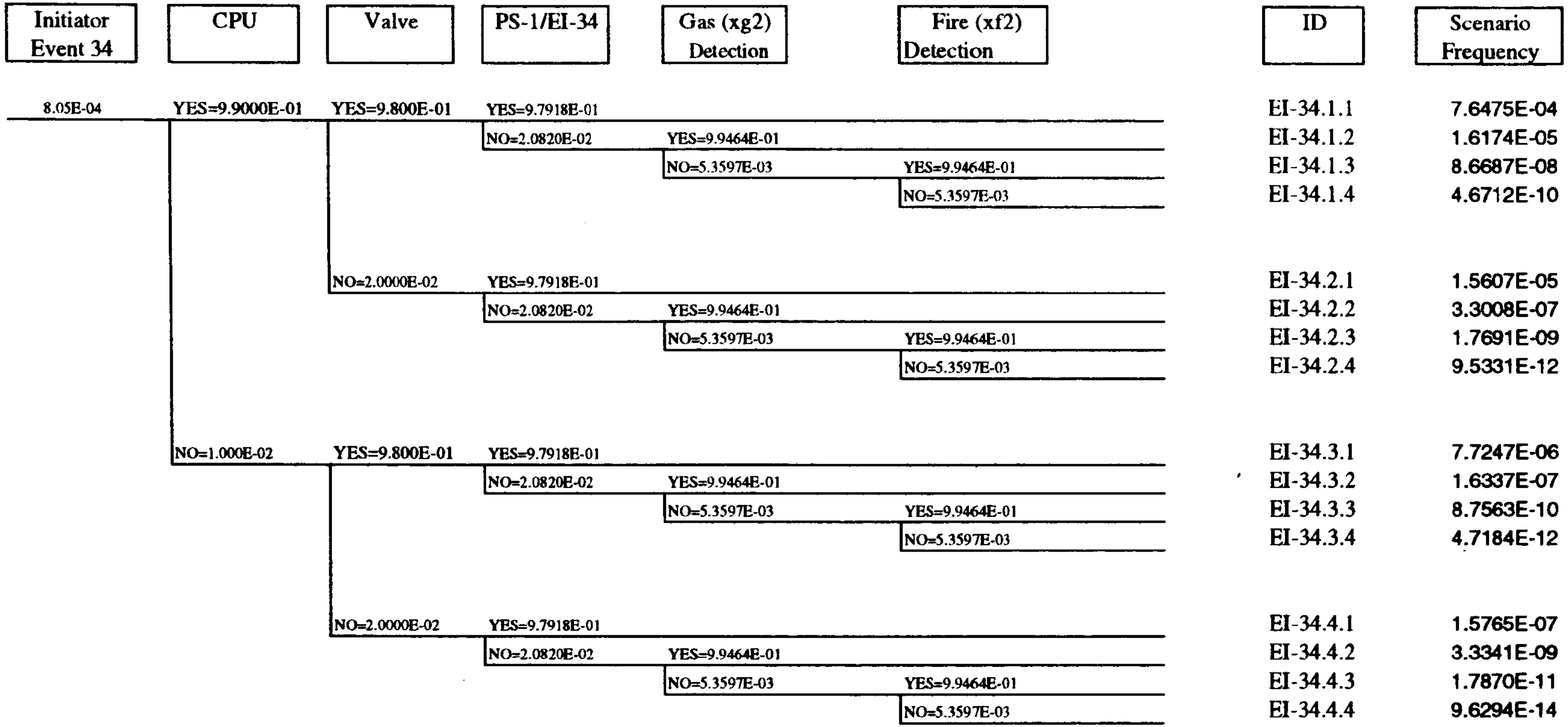


Figure A.1.22 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 34

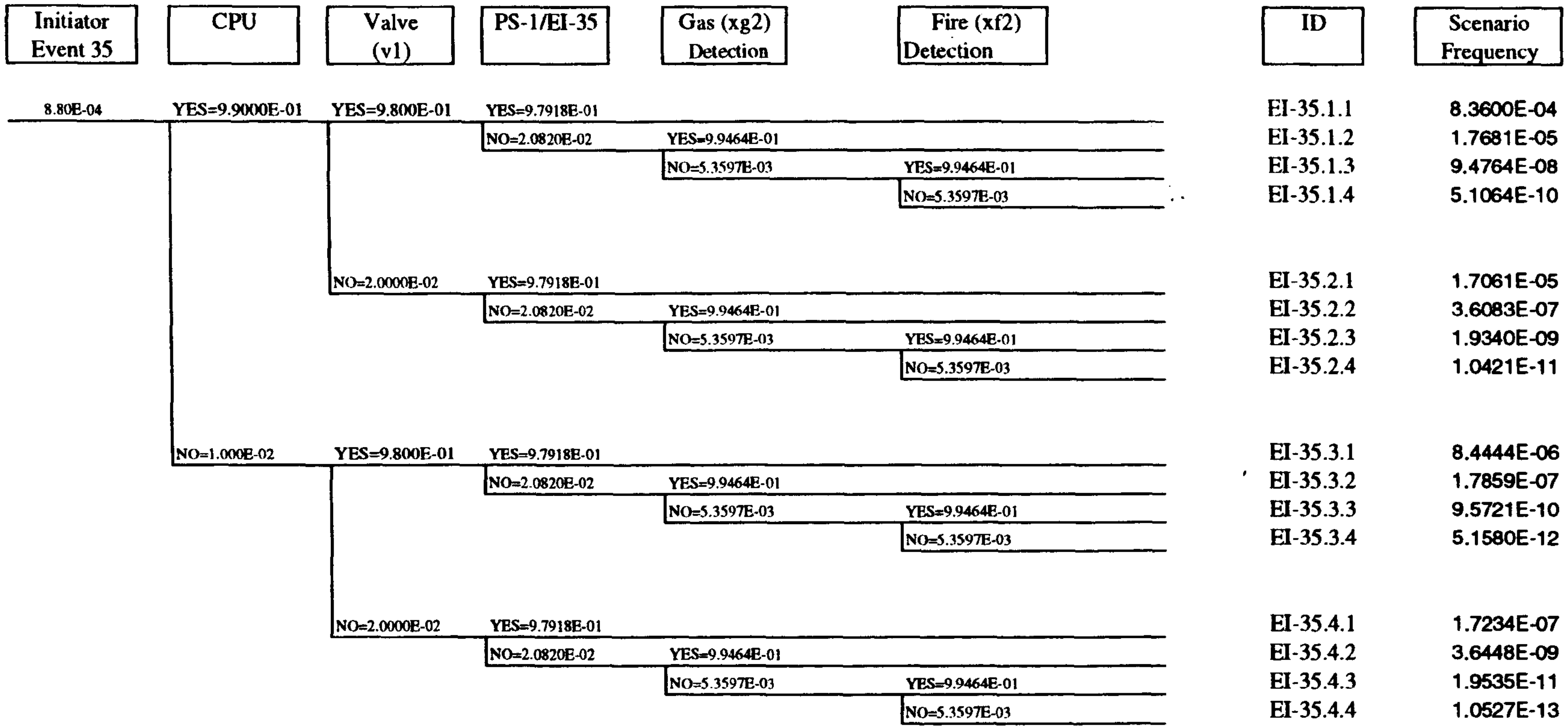


Figure A.1.23 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 35

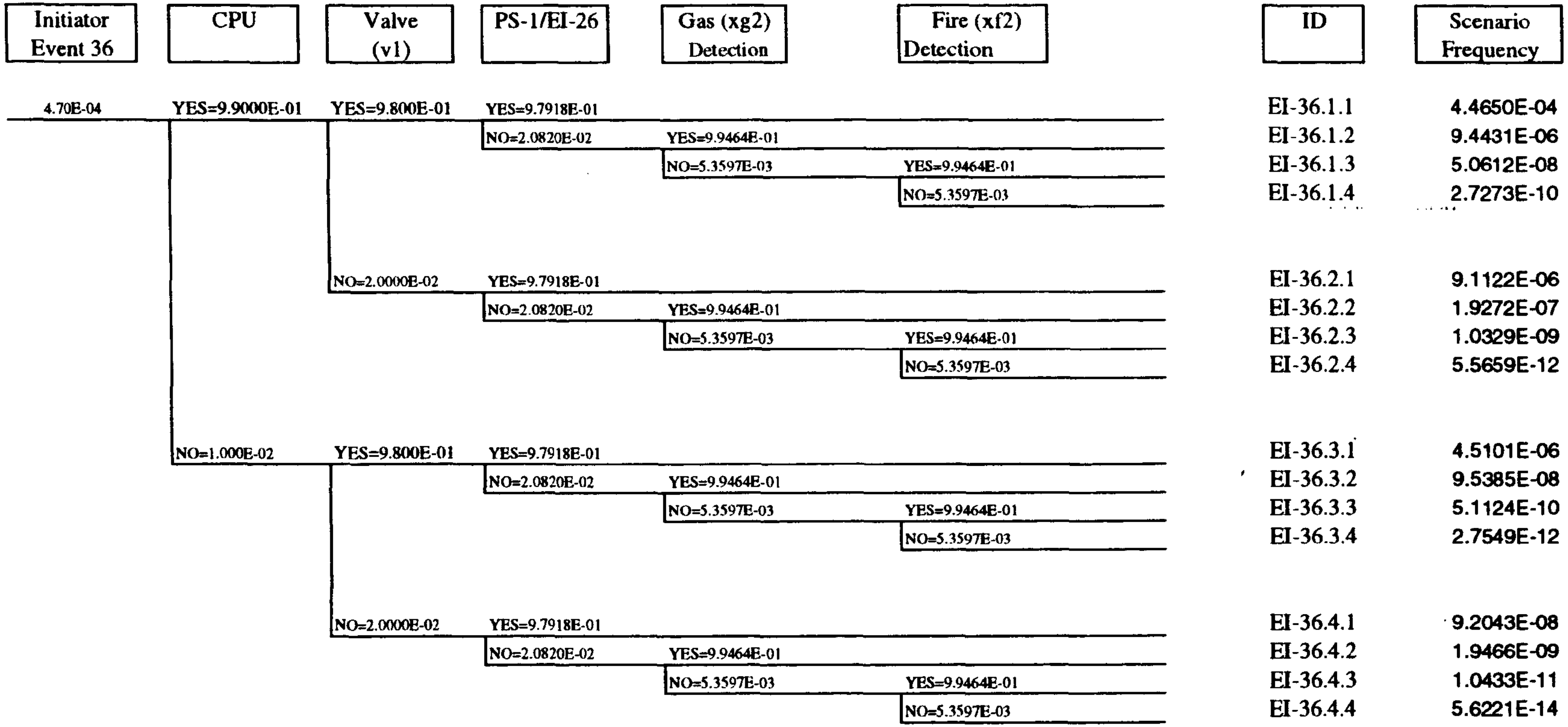


Figure A.1.24 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 36

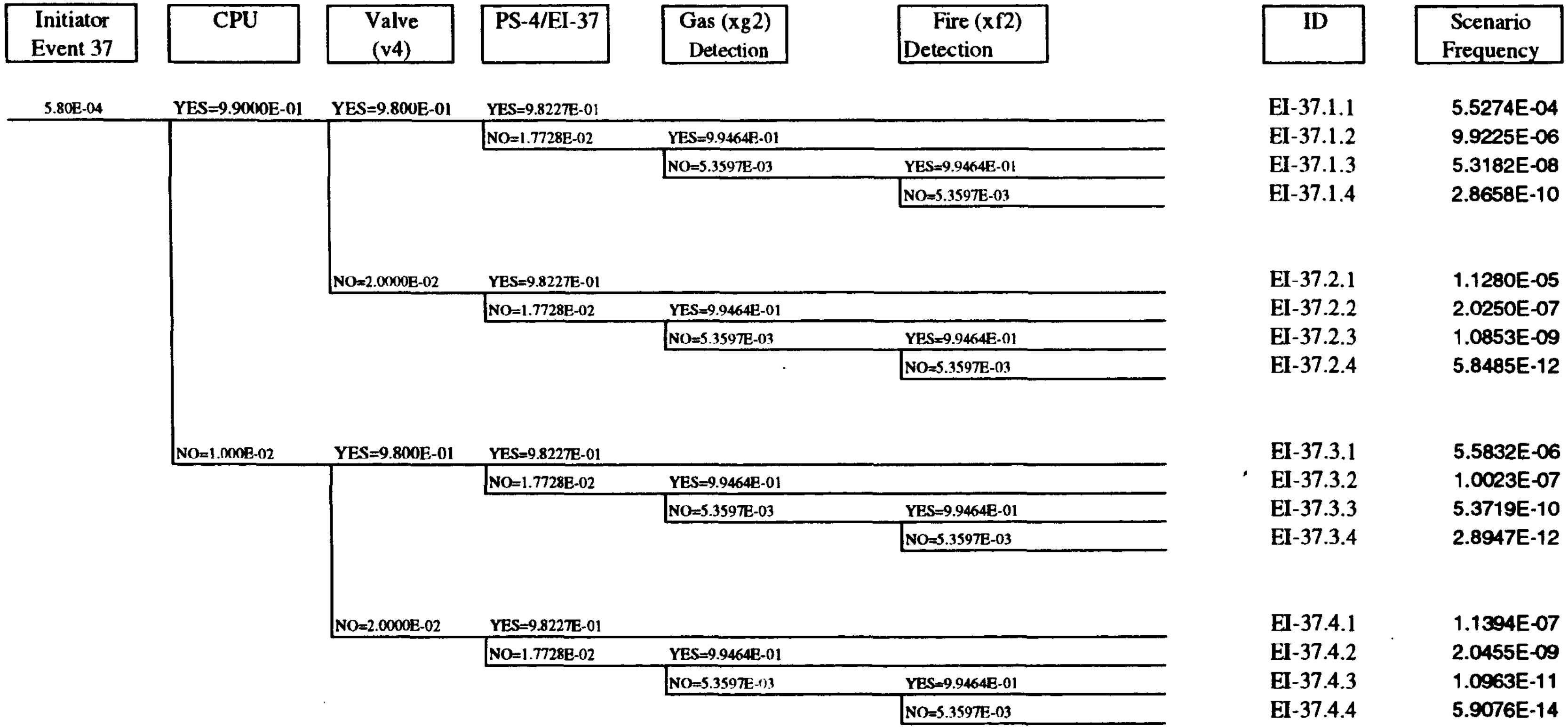


Figure A.1.25 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 37

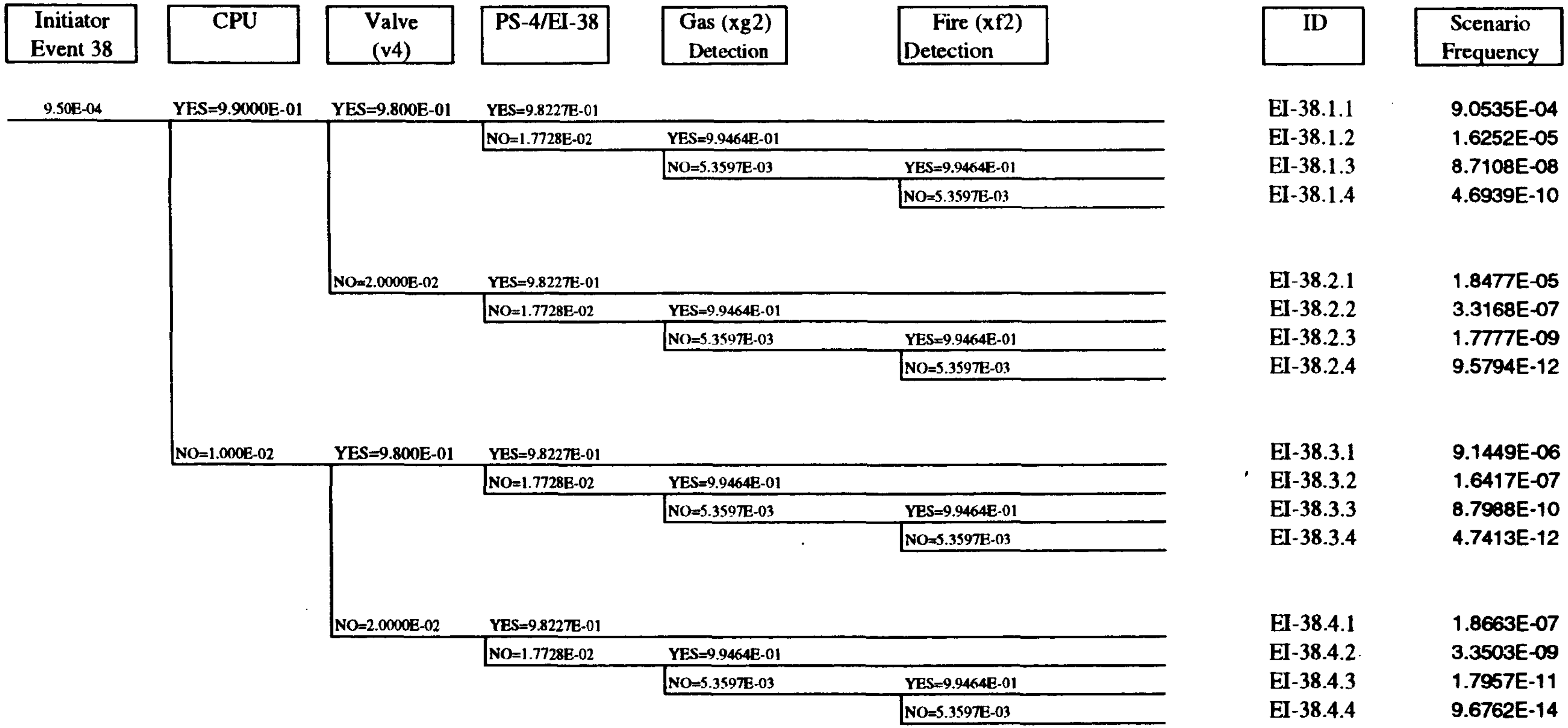


Figure A.1.26 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 38

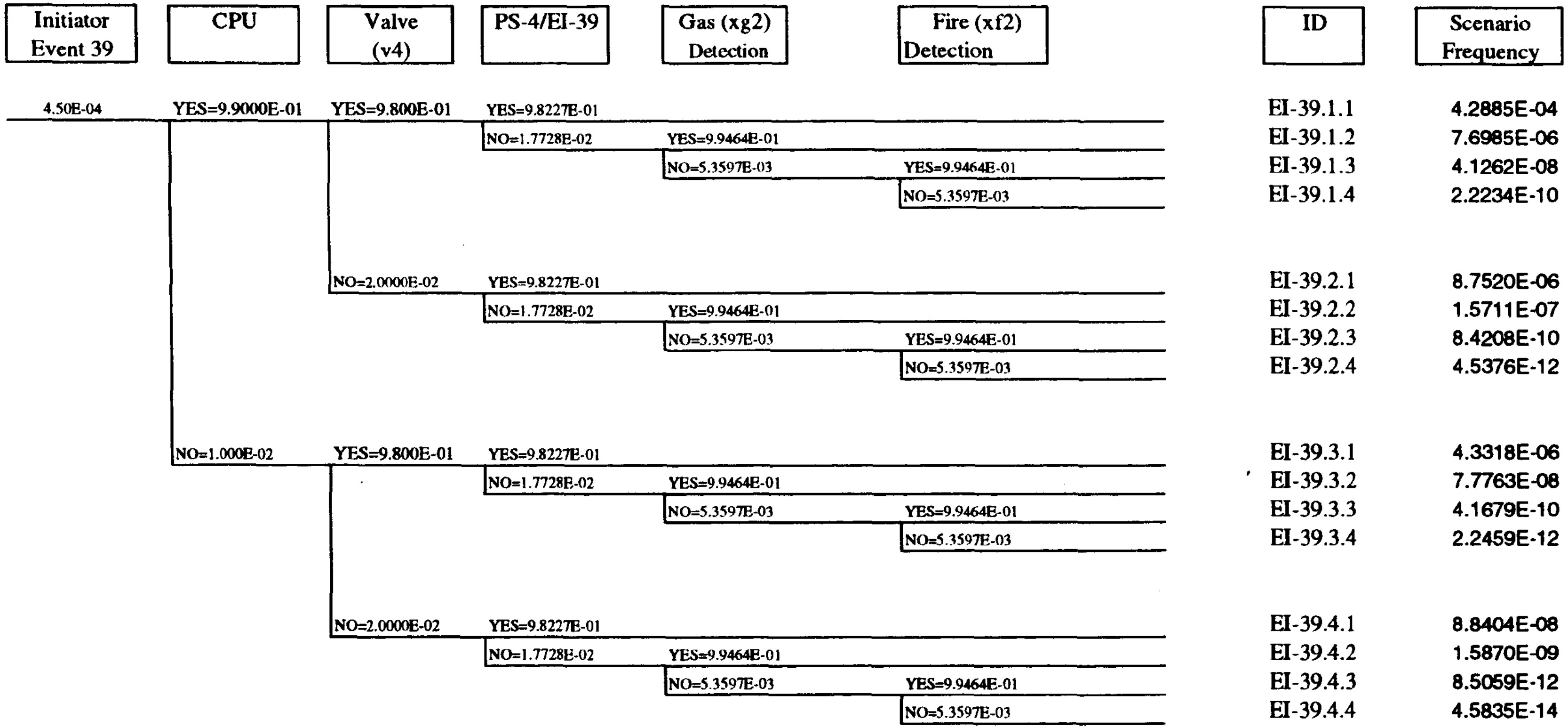


Figure A.1.27 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 39

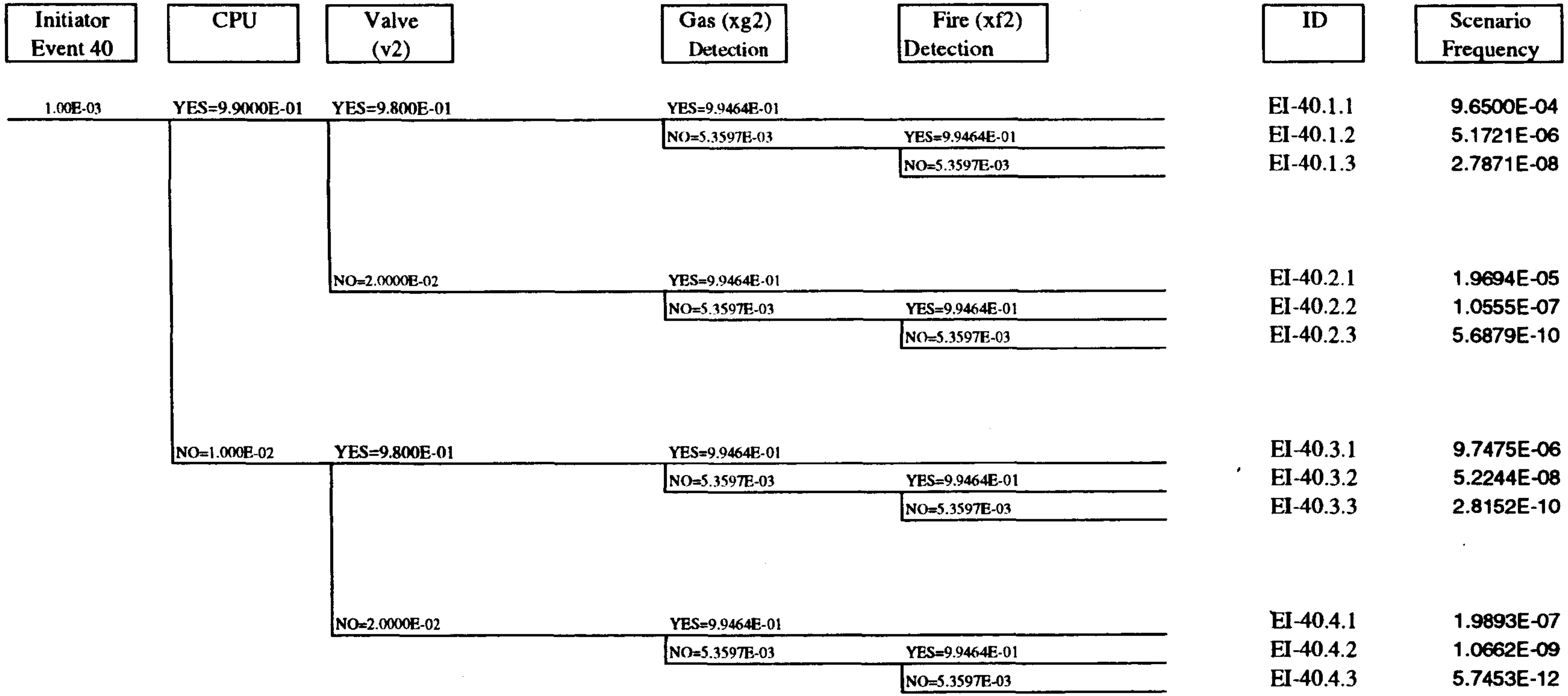


Figure A.1.28 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 40

Initiator Event 41

1.64E-03

ID	Scenario Frequency	File Name
EI-41.1	1.64E-03	EIA41RSB to EIH41RSB

In this event no gas and fire detection systems were considered. No protection system was identified.
The frequency used in this event is equal to 1/4 of the calculated frequency (the event was
8 different points: 41A, 41B, 41C,41D, 41E, 41F, 41G, 41H.

Figure A.1.29 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 41

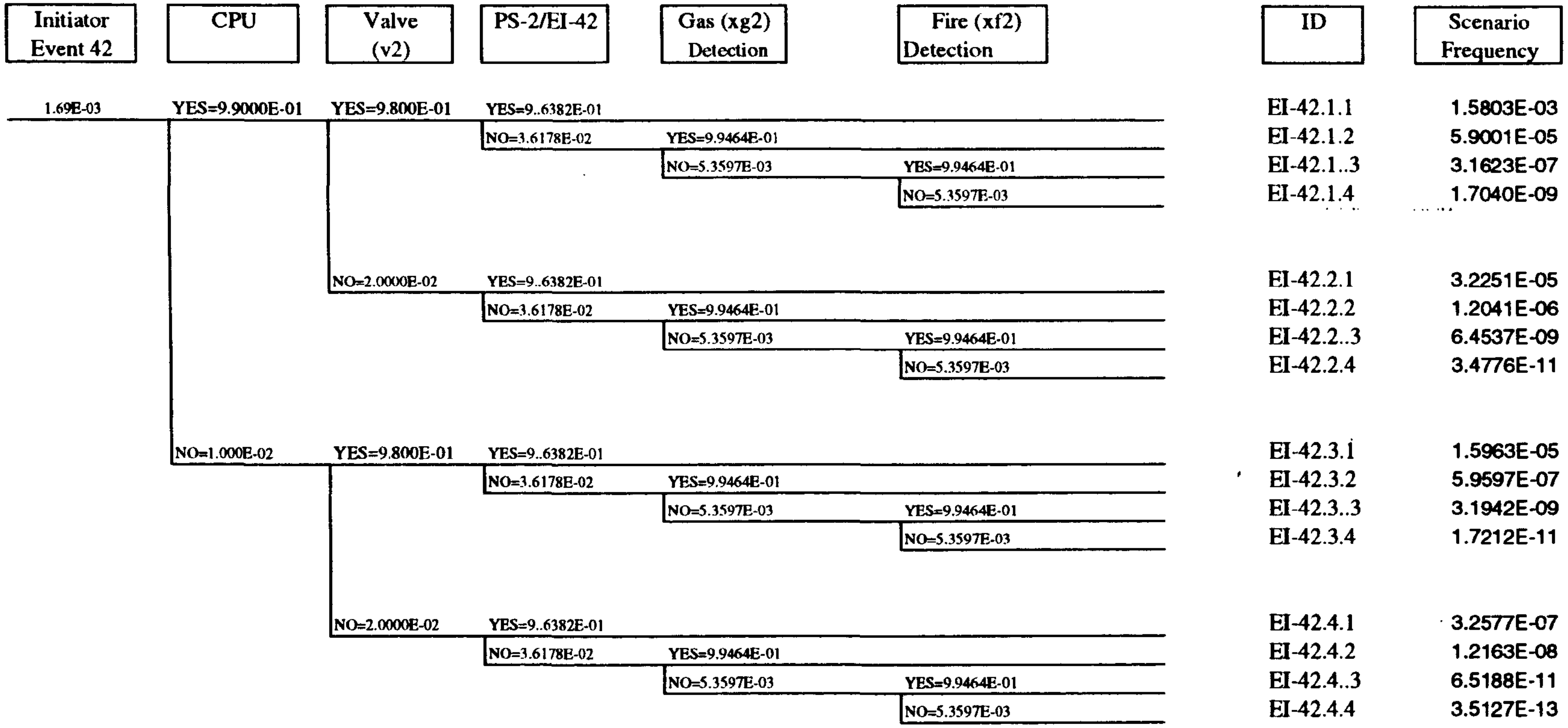


Figure A.1.30 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 42

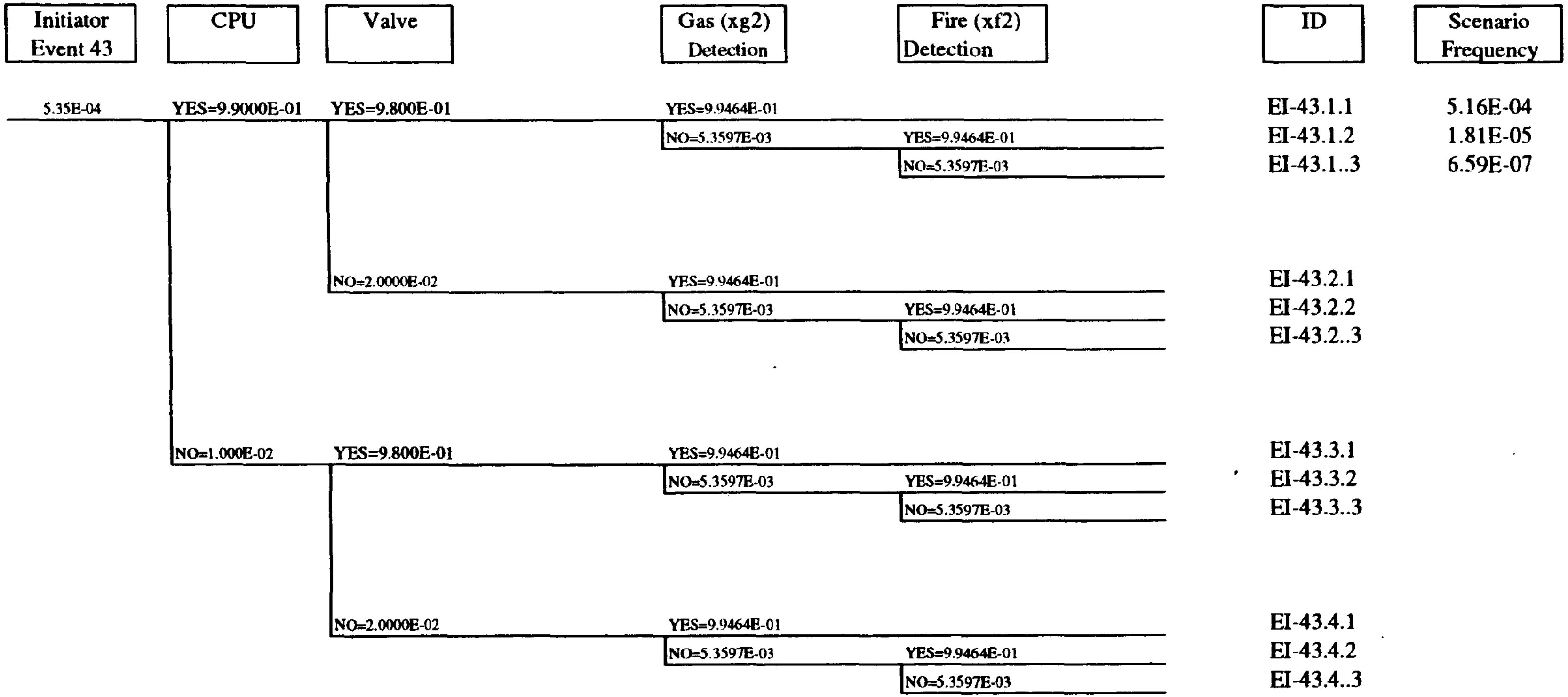


Figure A.1.31 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 43

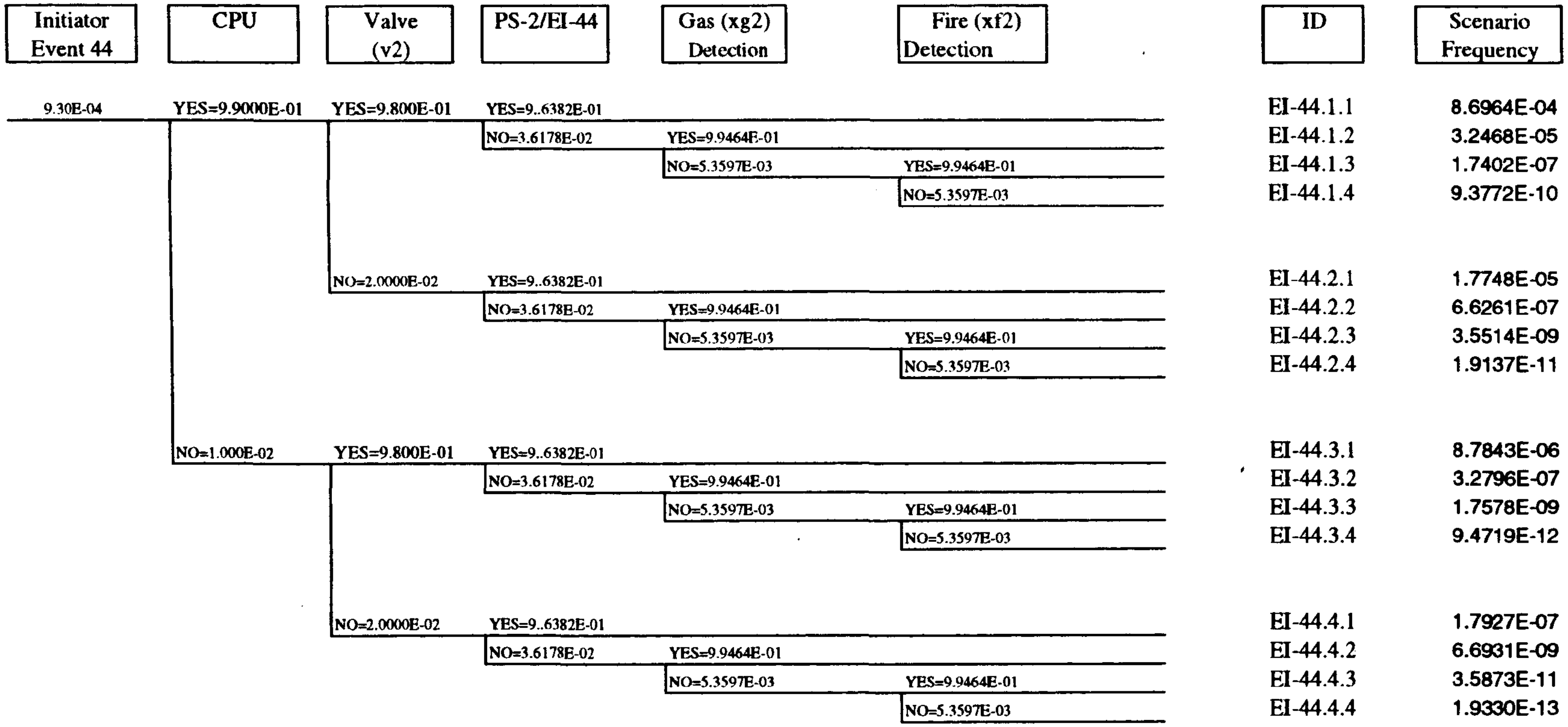
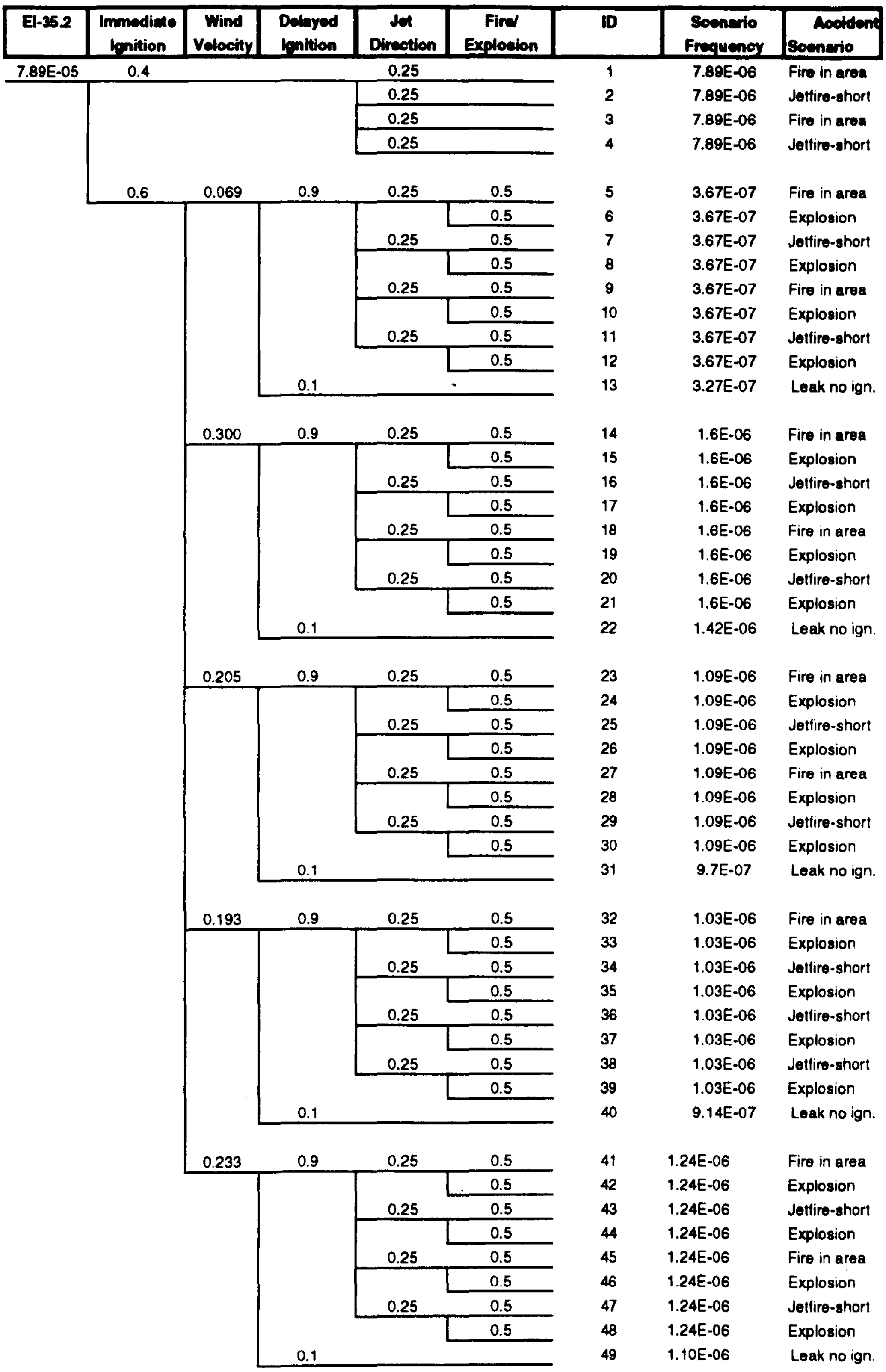


Figure A.1.32 Scenario Frequency Calculation of the Systemic Event Tree of Initiator Event 44

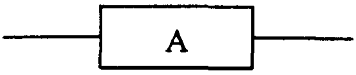


EI-35.2	Immediate Ignition	Wind Velocity	Delayed Ignition	Jet Direction	Fire/ Explosion	ID	Scenario Frequency	Accident Scenario
7.89E-05	0.4			0.25		1	7.89E-06	Fire in area
				0.25		2	7.89E-06	Jetfire-short
				0.25		3	7.89E-06	Fire in area
				0.25		4	7.89E-06	Jetfire-short
	0.6	0.069	0.9	0.25	0.5	5	3.67E-07	Fire in area
					0.5	6	3.67E-07	Explosion
				0.25	0.5	7	3.67E-07	Jetfire-short
					0.5	8	3.67E-07	Explosion
				0.25	0.5	9	3.67E-07	Fire in area
					0.5	10	3.67E-07	Explosion
				0.25	0.5	11	3.67E-07	Jetfire-short
					0.5	12	3.67E-07	Explosion
			0.1			13	3.27E-07	Leak no ign.
		0.300	0.9	0.25	0.5	14	1.6E-06	Fire in area
					0.5	15	1.6E-06	Explosion
				0.25	0.5	16	1.6E-06	Jetfire-short
					0.5	17	1.6E-06	Explosion
				0.25	0.5	18	1.6E-06	Fire in area
					0.5	19	1.6E-06	Explosion
				0.25	0.5	20	1.6E-06	Jetfire-short
					0.5	21	1.6E-06	Explosion
			0.1			22	1.42E-06	Leak no ign.
		0.205	0.9	0.25	0.5	23	1.09E-06	Fire in area
					0.5	24	1.09E-06	Explosion
				0.25	0.5	25	1.09E-06	Jetfire-short
					0.5	26	1.09E-06	Explosion
				0.25	0.5	27	1.09E-06	Fire in area
					0.5	28	1.09E-06	Explosion
				0.25	0.5	29	1.09E-06	Jetfire-short
					0.5	30	1.09E-06	Explosion
			0.1			31	9.7E-07	Leak no ign.
		0.193	0.9	0.25	0.5	32	1.03E-06	Fire in area
					0.5	33	1.03E-06	Explosion
				0.25	0.5	34	1.03E-06	Jetfire-short
					0.5	35	1.03E-06	Explosion
				0.25	0.5	36	1.03E-06	Jetfire-short
					0.5	37	1.03E-06	Explosion
				0.25	0.5	38	1.03E-06	Jetfire-short
					0.5	39	1.03E-06	Explosion
			0.1			40	9.14E-07	Leak no ign.
		0.233	0.9	0.25	0.5	41	1.24E-06	Fire in area
					0.5	42	1.24E-06	Explosion
				0.25	0.5	43	1.24E-06	Jetfire-short
					0.5	44	1.24E-06	Explosion
				0.25	0.5	45	1.24E-06	Fire in area
					0.5	46	1.24E-06	Explosion
				0.25	0.5	47	1.24E-06	Jetfire-short
					0.5	48	1.24E-06	Explosion
			0.1			49	1.10E-06	Leak no ign.

Figure A.1.33 Phenomenological Event Tree - Scenario Frequency Calculation

Appendix 2

Overall FTO Reliability Block Diagram



Detailed FTO Reliability Block Diagram

CSU:

$$\frac{1}{2}\lambda_A^F \cdot \tau$$

$$\frac{1}{2}\lambda^F \cdot \tau$$

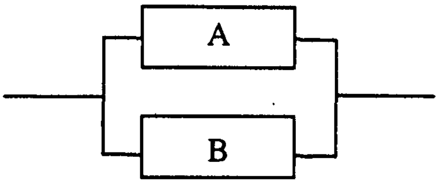
Approximate Detailed FTO Reliability Block Diagram

CSU:

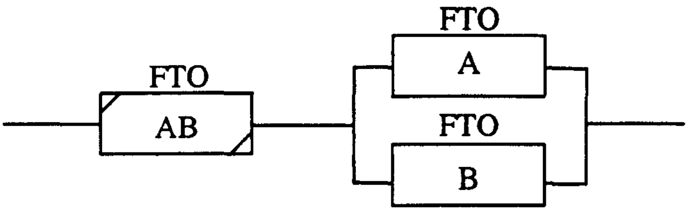
$$\frac{1}{2}\lambda^F . \tau$$

Figure A.2.1 – Overall and Approximate FTO Reliability Block Diagrams and Formulas -1001 VOTING LOGIC

Overall FTO Reliability Block Diagram



Detailed FTO reliability Block Diagram



CSU:

$$\frac{1}{2}\lambda_{AB}^{F}\cdot\tau+\frac{1}{3}\left(\lambda_{A}^{F}\cdot\tau\right)\left(\lambda_{A}^{F}\cdot\tau\right)+\lambda_{A}\,MTTR\cdot\frac{1}{2}\lambda_{A}^{F}.\tau+\lambda_{B}\,MTTR\cdot\frac{1}{2}\lambda_{A}^{F}\cdot\tau$$

$$\frac{1}{2}\frac{2\rho_2}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau+\frac{1}{3}\left(\frac{\rho_1}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau\right)^{2}+\frac{\rho_1}{\rho_1+2\rho_2}\lambda\cdot\frac{\rho_1}{\rho_1+2\rho_2}\lambda^{F}\,MTTR\cdot\tau$$

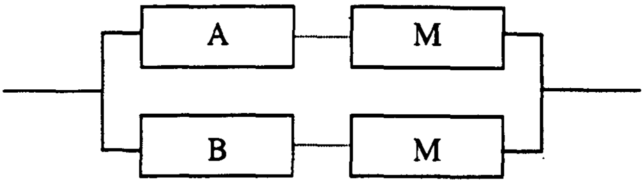
Approximate Detailed FTO Reliability Block Diagram

CSU:

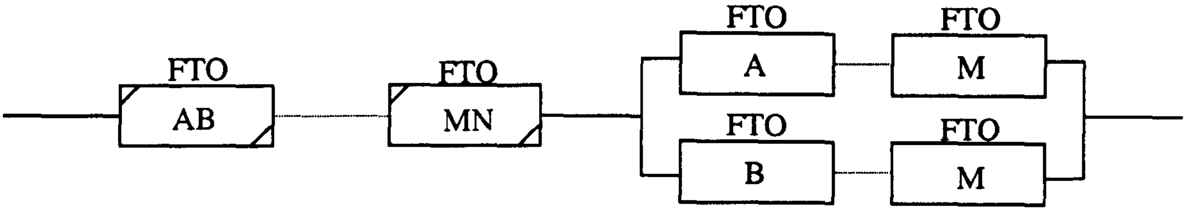
$$\frac{\rho_2}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau$$

Figure A.2.2 – Overall and Approximate FTO Reliability Block Diagrams and Formulas -1002 VOTING LOGIC

Overall FTO Reliability Block Diagram



Detailed FTO Reliability Block Diagram

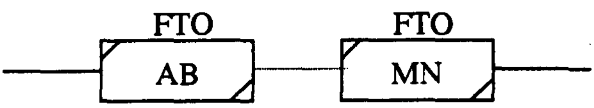


CSU:

$$\frac{1}{2}\lambda^F_{AB}\cdot\tau + \Lambda + \frac{1}{2}\lambda^F_{MN}\cdot\tau + \frac{1}{3}(\lambda^F_A\cdot\tau)(\lambda^F_B\cdot\tau) + \Lambda + \frac{1}{3}(\lambda^F_M\cdot\tau)(\lambda^F_N\cdot\tau)$$
$$+\frac{1}{2}(\lambda_A\lambda^F_B + \lambda_B\lambda^F_A)MTTR\cdot\tau + \Lambda + \frac{1}{3}(\lambda_M\lambda^F_N + \lambda_N\lambda^F_M)MTTR\cdot\tau$$

$$\frac{1}{2}\frac{2\rho_2}{\rho_1+2\rho_2}\lambda^F\cdot\tau + \Lambda + \frac{1}{2}\frac{2\rho_2}{\rho_1+2\rho_2}\lambda^F\cdot\tau + \frac{1}{3}\left(\frac{\rho_1}{\rho_1+2\rho_2}\lambda^F\cdot\tau\right)^2 + \Lambda + \frac{1}{3}\left(\frac{\rho_1}{\rho_1+2\rho_2}\lambda^F\cdot\tau\right)^2$$
$$+\frac{\rho_1}{\rho_1+2\rho_2}\lambda\cdot\frac{\rho_1}{\rho_1+2\rho_2}\lambda^F\cdot MTTR\cdot\tau + \Lambda + \frac{\rho_1}{\rho_1+2\rho_2}\lambda\cdot\frac{\rho_1}{\rho_1+2\rho_2}\lambda^F\cdot MTTR\cdot\tau$$

Approximate Detailed FTO Reliability Block Diagram



CSU:

$$\left(\frac{\rho_2}{\rho_1+2\rho_2}\lambda^F + \Lambda + \frac{\rho_2}{\rho_1+2\rho_2}\lambda^F\right)\cdot\tau$$

Figure A.2.3 – Overall and Approximate FTO Reliability Block Diagrams and Formulas -1002 VOTING LOGIC - 2 or more modules in series

Overall FTO Reliability Block Diagram

Detailed FTO Reliability Block Diagram

CSU:

$$\frac{1}{2}\lambda_{AB}^{F}\cdot\tau+\frac{1}{2}\lambda_{A}^{F}\cdot\tau+\frac{1}{2}\lambda_{B}^{F}\cdot\tau+\lambda_{A}MTTR\cdot\frac{1}{2}\lambda_{B}^{F}\cdot\tau+\lambda_{B}MTTR\cdot\frac{1}{2}\lambda_{A}^{F}\cdot\tau$$

$$\frac{1}{2}\frac{2\rho_2}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau+\frac{1}{2}\frac{\rho_1}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau+\frac{1}{2}\frac{\rho_1}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau+\frac{\rho_1}{\rho_1+2\rho_2}\lambda\frac{\rho_1}{\rho_1+2\rho_2}\lambda^{F}MTTR\cdot\tau$$

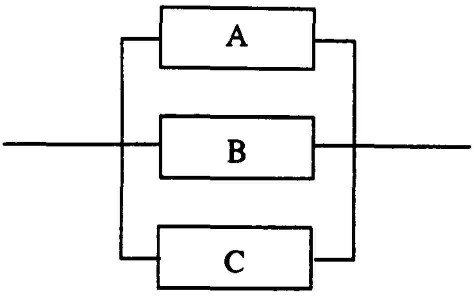
Approximate Detailed FTO Reliability Block Diagram

CSU:

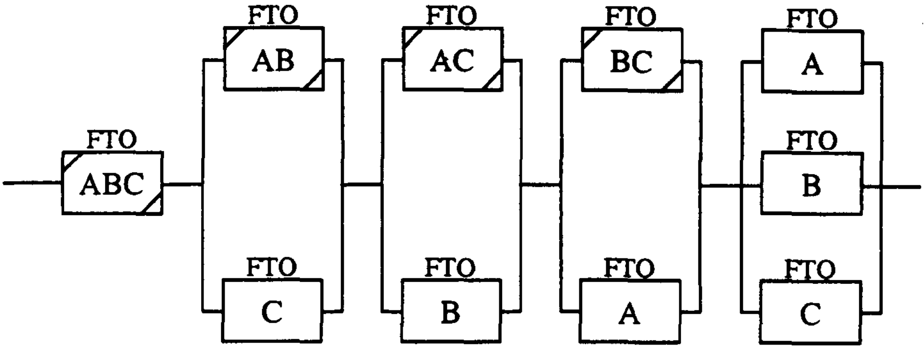
$$\frac{1}{\rho_1+2\rho_2}\lambda^{F}\cdot\tau$$

Figure A.2.4 – Overall and Approximate FTO Reliability Block Diagrams and Formulas -2002 VOTING LOGIC

Overall FTO Reliability Block Diagram



Detailed FTO Reliability Block Diagram



CSU:

$$\frac{1}{2}\lambda_{ABC}^{F}\cdot\tau+3\cdot\frac{1}{3}\left(\lambda_{AB}^{F}\cdot\tau\right)\left(\lambda_{C}^{F}\cdot\tau\right)+\frac{1}{4}\left(\lambda_{A}^{F}\cdot\tau\right)\left(\lambda_{B}^{F}\cdot\tau\right)\left(\lambda_{C}^{F}\cdot\tau\right)+3\cdot\left(\lambda_{AB}MTTR\right)$$
$$\left(\frac{1}{2}\lambda_{C}^{F}\cdot\tau\right)+3\cdot\left(\lambda_{A}MTTR\right)\left(\frac{1}{2}\lambda_{BC}^{F}\cdot\tau\right)$$

$$\frac{1}{2}\frac{3\rho_3}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\cdot\tau+\left(\frac{\rho_2}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\cdot\tau\right)\left(\frac{\rho_1}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\cdot\tau\right)$$
$$+\frac{1}{4}\left(\frac{\rho_1}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\cdot\tau\right)^{3}+\frac{1}{2}\left(\frac{3\rho_2}{\rho_1+2\rho_2+3\rho_3}\lambda\right)\left(\frac{\rho_1}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\right)MTTR\cdot\tau$$
$$+\frac{1}{2}\left(\frac{3\rho_1}{\rho_1+2\rho_2+3\rho_3}\lambda\right)\left(\frac{\rho_2}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\right)MTTR\cdot\tau$$

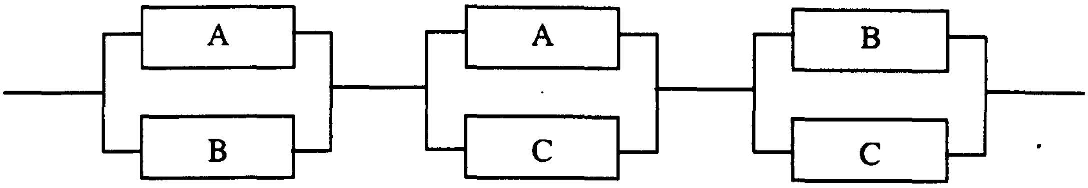
Approximate Detailed FTO Reliability Block Diagram

CSU:

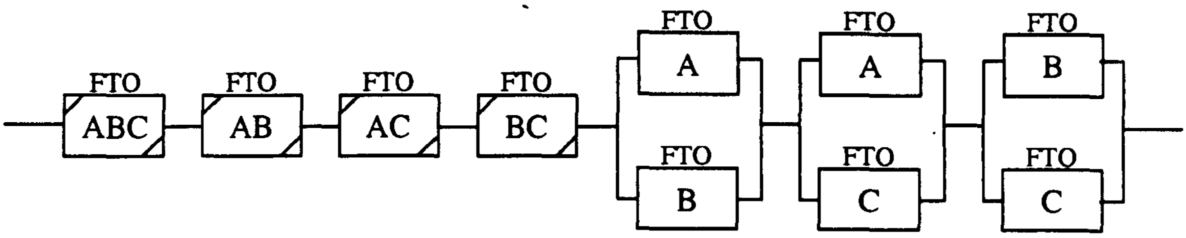
$$\frac{1}{2}\frac{3\rho_3}{\rho_1+2\rho_2+3\rho_3}\lambda^{F}\cdot\tau$$

Figure A.2.5 – Overall and Approximate FTO Reliability Block Diagrams and Formulas -1003 VOTING LOGIC

Overall FTO Reliability Block Diagram



Detailed FTO Reliability Block Diagram

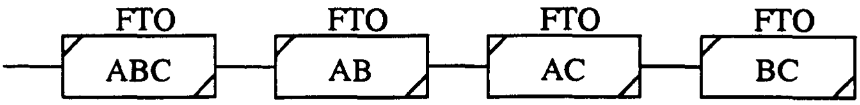


CSU:

$$\frac{1}{2}\lambda^F_{ABC}\cdot\tau+\frac{1}{2}\left(\lambda^F_{AB}+\lambda^F_{AC}+\lambda^F_{BC}\right)\cdot\tau+3\cdot\frac{1}{3}\left(\lambda^F_A\cdot\tau\right)\left(\lambda^F_B\cdot\tau\right)$$
$$+3\cdot\left(\lambda_A MTTR\right)\cdot\left(\frac{1}{2}\lambda^F_{BC}\cdot\tau\right)+3\cdot\left(\lambda_{AB} MTTR\right)\cdot\left(\frac{1}{2}\lambda^F_C\cdot\tau\right)$$

$$\frac{1}{2}\frac{3\rho_3}{\rho_1+2\rho_2+3\rho_3}\lambda^F\cdot\tau+\frac{1}{2}\frac{3\rho_2}{\rho_1+2\rho_2+3\rho_3}\lambda^F\cdot\tau+\left(\frac{\rho_1}{\rho_1+2\rho_2+3\rho_3}\lambda^F\cdot\tau\right)^2$$
$$+\frac{3\rho_1}{\rho_1+2\rho_2+3\rho_3}\lambda\cdot\frac{\rho_3}{\rho_1+2\rho_2+3\rho_3}\lambda^F\cdot MTTR\cdot\tau$$

Approximate Detailed FTO Reliability Block Diagram

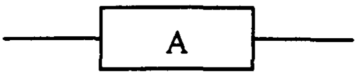


CSU:

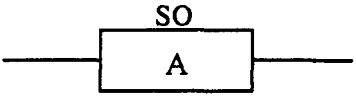
$$\frac{1}{2}\frac{3(\rho_2+\rho_3)}{\rho_1+2\rho_2+3\rho_3}\lambda^f\cdot\tau$$

Figure A.2.6 – Overall and Approximate FTO Reliability Block Diagrams and Formulas -2003 VOTING LOGIC

Overall SO Reliability Block Diagram



Detailed SO Reliability Block Diagram

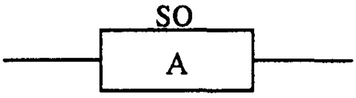


STR:

$$\lambda_A^S$$

$$\lambda^S$$

Approximate Detailed SO Reliability Block Diagram



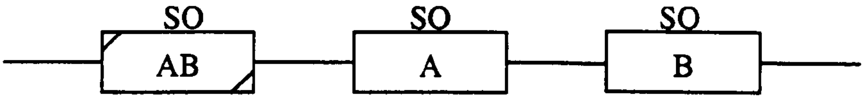
STR:

$$\lambda^S$$

Figure A.2.7 – Overall and Approximate SO Reliability Block Diagrams and Formulas -1001 VOTING LOGIC

Overall SO Reliability Block Diagram

Detailed SO Reliability Block Diagram

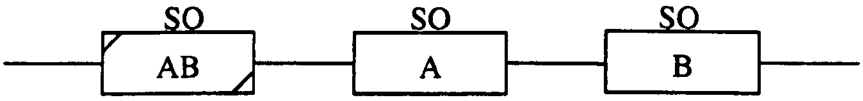


STR:

$$\lambda^S_{AB} + \lambda^S_A + \lambda^S_B + \lambda_A MTTR \cdot \lambda^S_B + \lambda_B MTTR \cdot \lambda^S_A$$

$$\frac{2\rho_2}{\rho_1 + 2\rho_2}\lambda^S + \frac{\rho_1}{\rho_1 + 2\rho_2}\lambda^S + \frac{\rho_1}{\rho_1 + 2\rho_2}\lambda^S + 2 \cdot \frac{\rho_1}{\rho_1 + 2\rho_2}\lambda\lambda^S MTTR$$

Approximate Detailed SO Reliability Block Diagram

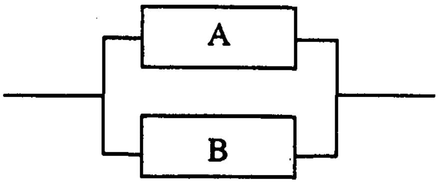


STR:

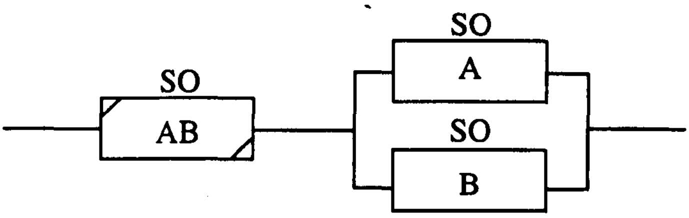
$$\frac{2}{\rho_1 + 2\rho_2}\lambda^S$$

Figure A.2.8 – Overall and Approximate SO Reliability Block Diagrams and Formulas -1002 VOTING LOGIC

Overall SO Reliability Block Diagram



Detailed SO Reliability Block Diagram

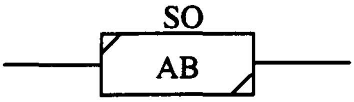


STR:

$$\lambda_{AB}^{S} + (\lambda_A MTTR)\lambda_B^{S} + (\lambda_B MTTR)\lambda_A^{S}$$

$$\frac{2\rho_2}{\rho_1 + 2\rho_2}\lambda^{S} + \frac{2\rho_1}{\rho_1 + 2\rho_2}\lambda \cdot \lambda^{S} MTTR$$

Approximate Detailed SO Reliability Block Diagram

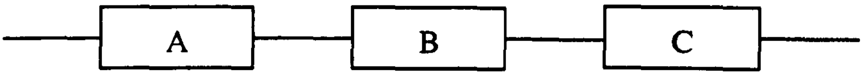


STR:

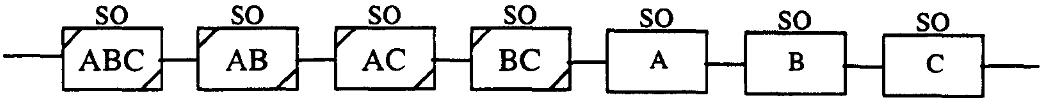
$$\frac{2\rho_2}{\rho_1 + 2\rho_2}\lambda^{S}$$

Figure A.2.9 – Overall and Approximate SO Reliability Block Diagrams and Formulas -2002 VOTING LOGIC

Overall SO Reliability Block Diagram



Detailed SO Reliability Block Diagram

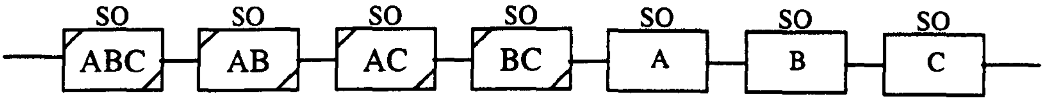


STR:

$$\lambda^S_{ABC} + \lambda^S_{AB} + \lambda^S_{AC} + \lambda^S_{BC} + \lambda^S_{A} + \lambda^S_{B} + \lambda^S_{C}$$
$$+ 3\lambda_A MTTR\left(\lambda^S_B + \lambda^S_C + \lambda^S_{BC}\right) + 3\lambda_{AB} MTTR\lambda^S_C$$

$$\frac{3\rho_3}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda^S + \frac{3\rho_2}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda^S + \frac{3\rho_1}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda^S$$
$$+ \frac{\rho_1}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda \cdot \frac{2}{\rho_1 + 2\rho_2}\lambda^S \cdot MTTR + 3 \cdot \frac{\rho_2}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda \cdot \lambda^S \cdot MTTR$$

Approximate Detailed SO Reliability Block Diagram

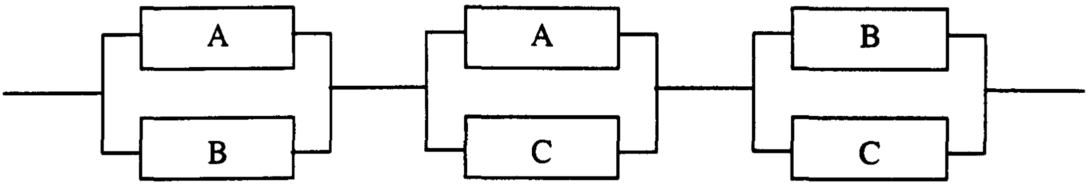


STR:

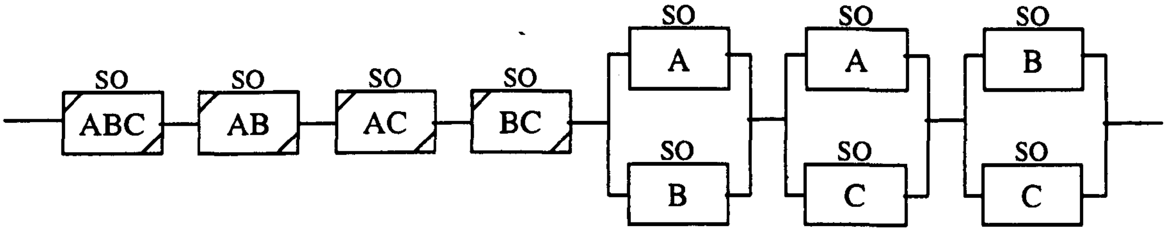
$$\frac{3}{\rho_1 + 2\rho_2 + 3\rho_3}$$

Figure A.2.10 – Overall and Approximate SO Reliability Block Diagrams and Formulas -1003 VOTING LOGIC

Overall SO Reliability Block Diagram



Detailed SO Reliability Block Diagram

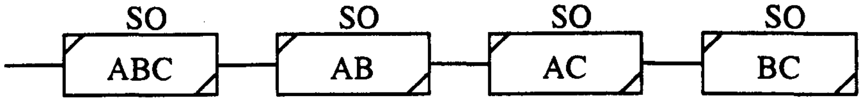


STR:

$$\lambda_{ABC}^{S} + \lambda_{AB}^{S} + \lambda_{AC}^{S} + \lambda_{BC}^{S} + 3\lambda_{A} MTTR\left(\lambda_{B}^{S} + \lambda_{C}^{S} + \lambda_{BC}^{S}\right) + 3\lambda_{AB} MTTR\lambda_{C}^{S}$$

$$\frac{3\rho_3}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda^{S} + \frac{3\rho_2}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda^{S}$$
$$+ \frac{3\rho_1}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda \frac{2}{\rho_1 + 2\rho_2}\lambda^{S} MTTR + 3\frac{\rho_2}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda\lambda^{S} MTTR$$

Approximate Detailed SO Reliability Block Diagram



STR:

$$\frac{3(\rho_2 + \rho_3)}{\rho_1 + 2\rho_2 + 3\rho_3}\lambda^{S}$$

Figure A.2.11 – Overall and Approximate SO Reliability Block Diagrams and Formulas -2003 VOTING LOGIC

Appendix 3

A.3.1. Description of the accidental events modelled in the quantitative risk assessment:

1. Event EI-01: Explosion in turret
2. Event EI-09: Large oil + natural gas release in the manifold deck, oil reception line
3. Event EI-10: Large natural gas release in the manifold deck, gas lift line
4. Event EI-11: Large natural gas release in the manifold deck, gas exportation line
5. Event EI-12: Large oil + natural gas release, after header, production line
6. Event EI-13: Large oil + natural gas release, after header, test production line, with blockage actuation
7. Event EI-14: Large oil + natural gas release, after header in the manifold deck, gas lift line
8. Event EI-15: Large natural gas release in the manifold deck, gas exportation line
9. Event EI-17: Large natural gas release in lines that cross the vessel's deck, gas exportation line
10. Event EI-18: Explosion in pump room
11. Event EI-19: Large natural gas release, in inert system gas lines
12. Event EI-20: Large natural gas release, in blow-down system
13. Event EI-23: Explosion in machine room, with detection
14. Event EI-24: Large oil + natural gas release, in line from swivel to production separators (SG-122301/V-030
15. Event EI-25: Large oil + natural gas release, in line from production separators (SG-122301/V-030) to the surge-tank (V-095)
16. Event EI-26: Large natural gas release, from production separators (SG-122301/V-030) to vessel (v-122301)
17. Event EI-27: Large natural gas release, in line from the surge-tank (V-095) to vessel (V-UC-122302-01)
18. Event EI-28: Large natural gas release, from vessel (V-UC-122302-1) to compressor C-UC-122302
19. Event EI-29: Large natural gas release, from compressor C-UC-122302 to vessel (V-UC-122302-02)
20. Event EI-30: Large natural gas release, from vessel (V-UC-122302-02) to safety vessel (V-122301)
21. Event EI-31: Large natural gas release, in line from vessel (V-UC-122301-01) to first stage of compressor C-UC-122301
22. Event EI-32: Large natural gas release, in line from first stage of compressor C-UC-122301 to vessel (V-UC-122301-02)
23. Event EI-33: Large natural gas release, in line from vessel (V-UC-122301-02) to the second stage of compressor C-UC-122301
24. Event EI-34: Large natural gas release, in line from the second stage of compressor C-UC-122301 to vessel (V-UC-122301-03)
25. Event EI-35: Large natural gas release, in line from vessel (V-UC-122301-03) to dehydration system

26. Event EI-36: Large natural gas release, in line from dehydration system, to gas-lift swivel, with blockage actuation
27. Event EI-37: Large natural gas release, in line from vessel (V-UC-122303-01) to compressor C-UC-122303
28. Event EI-38: Large natural gas release, in line from compressor C-UC-122303 to vessel V-122302
29. Event EI-39: Large natural gas release, in line from vessel V-122302 to gas exportation swivel
30. Event EI-40: Large natural gas release, in line from vessel V-122302 to combustible gas vessel
31. Event EI-41: Large natural gas release, in flare relief line actuation
32. Event EI-42: Large oil + natural gas release, in line from test swivel output to test separator V-020
33. Event EI-43: Large oil + natural gas release, in line from test separator V-020 to surge tank (V-095)
34. Event EI-44: Large oil + natural gas release, in line from test separator V-020 to safety valve
35. Event EI-TQ1C:Explosion in tank 1C
36. Event EI-TQ1S:Explosion in tank 1S
37. Event EI-TQ1P:Explosion in tank 1P
38. Event EI-TQ2C:Explosion in tank 2C
39. Event EI-TQ2S:Explosion in tank 2S
40. Event EI-TQ2P:Explosion in tank 2P
41. Event EI-TQ3C:Explosion in tank 3C
42. Event EI-TQ4C:Explosion in tank 4C
43. Event EI-TQ4S:Explosion in tank 4S
44. Event EI-TQ4P:Explosion in tank 4P
45. Event EI-TQ5C:Explosion in tank 5C
46. Event EI-TQ5S:Explosion in tank 5S
47. Event EI-TQ5P:Explosion in tank 5P

A.3.2. OUTPUT FILE – Software VULNER PLUS – Version 1.0

For each one of the events shown several scenarios were considered regarding different weather conditions and different points of ignition. Therefore, for example for the event EI-11, we would have the following related scenarios:

Initiator event EI-11.1: Large natural gas release in the manifold deck, gas exportation line

Frequency : 0.000578

Derived Scenarios:

Scenario 1: Large natural gas release in the manifold deck, gas exportation line, with
blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI16 – Furnace, 18 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.79469E-05
Consequences: 0.0455466
Average societal risk: 8.17421E-07

Scenario 2: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI17 – Process Plant, 28 seconds after release, resulting in a fire and cloud explosion.

Frequency: 5.9823E-07
Consequences: 1.46792
Average societal risk: 8.78156E-07

Scenario 3: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI13 – Process Plant, 38 seconds after release, resulting in a fire and cloud explosion.

Frequency: 4.18761E-07
Consequences: 2.2794
Average societal risk: 9.54525E-07

Scenario 4: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI14– Process Plant, 43 seconds after release, resulting in a fire and cloud explosion.

Frequency: 2.93133E-07
Consequences: 2.4847
Average societal risk: 7.28347E-07

Scenario 5: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI10- Process Plant, 59 seconds after release, resulting in a fire and cloud explosion.

Frequency: 2.05193E-07
Consequences: 2.20103
Average societal risk: 4.51636E-07

Scenario 6: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI11 – Process Plant, 61 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.43635E-06
Consequences: 2.26326
Average societal risk: 3.25084E-07

Scenario 7: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI07 – Helideck, 122 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.00545E-07
Consequences: 1.85128
Average societal risk: 1.86136E-07

Scenario 8: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI08 – Helideck, 124 seconds after release, resulting in a fire and cloud explosion.

Frequency: 7.03812E-08
Consequences: 0
Average societal risk: 0

Scenario 9: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI04– Helideck, 138 seconds after release, resulting in a fire and cloud explosion.

Frequency: 9.2668E-08
Consequences: 0
Average societal risk: 0

Scenario 10: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI05 – Helideck, 141 seconds after release, resulting in a fire and cloud explosion

Frequency: 3.44868E-08
Consequences: 0
Average societal risk: 0

Scenario 11: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI01 – Helideck, 156 seconds after release, resulting in a fire and cloud explosion.

Frequency: 2.41407E-08
Consequences: 0
Average societal risk: 0

Scenario 12: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 0 to 2 m/s, with ignition in point PI02 –Helideck, 159 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.68985E-08
Consequences: 0
Average societal risk: 0

Scenario 13: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 2 to 4 m/s, with ignition in point PI16 – Furnace, 6 seconds after release, resulting in a fire and cloud explosion.

Frequency: 7.803E-05
Consequences: 0.0455466
Average societal risk: 3.554E-06

Scenario 14: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 2 to 4 m/s, with ignition in point PI13 – Process Plant, 14 seconds after release, resulting in a fire and cloud explosion.

Frequency: 2.601E-06
Consequences: 1.97566
Average societal risk: 5.13869E-06

Scenario 15: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 2 to 4 m/s, with ignition in point PI14 – Process Plant, 16 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.8207E-06
Consequences: 2.3047
Average societal risk: 4.19617E-06

Scenario 16: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 2 to 4 m/s, with ignition in point PI10 – Process Plant, 21 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.27449E-06
Consequences: 2.64946
Average societal risk: 3.37671E-06

Scenario 17: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 2 to 4 m/s, with ignition in point PI11 - Process Plant, 23 seconds after release, resulting in a fire and cloud explosion.

Frequency: 8.92143E-07
Consequences: 2.87741
Average societal risk: 2.56706E-06

Scenario 18: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 2 to 4 m/s, with ignition in point PI07 – Helideck, 49 seconds after release, resulting in a fire and cloud explosion.

Frequency: 6.245E-07
Consequences: 1.35973
Average societal risk: 8.49152E-07

Scenario 19: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 4 to 6 m/s, with ignition in point PI16 – Furnace, 4 seconds after release, resulting in a fire and cloud explosion.

Frequency: 5.33205E-05
Consequences: 0.0227733
Average societal risk: 1.21428E-06

Scenario 20: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 4 to 6 m/s, with ignition in point PI13 - Process Plant, 9 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.77735E-06
Consequences: 1.93566
Average societal risk: 3.44034E-06

Scenario 21: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 4 to 6 m/s, with ignition in point PI10 - Process Plant, 13 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.24415E-06
Consequences: 2.60883
Average societal risk: 3.24577E-06

Scenario 22: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 6 to 8 m/s, with ignition in point PI16 – Furnace, 3 seconds after release, resulting in a fire and cloud explosion.

Frequency: 5.01993E-05
Consequences: 0.0860324

Average societal risk: 4.31877E-06

Scenario 23: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 6 to 8 m/s, with ignition in point PI13 - Process Plant, 6 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.67331E-06
Consequences: 1.67275
Average societal risk: 2.79903E-06

Scenario 24: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, with 6 to 8 m/s, with ignition in point PI10 - Process Plant, 10 seconds after release, resulting in a fire and cloud explosion.

Frequency: 1.17132E-06
Consequences: 2.30776
Average societal risk: 2.70312E-06

Scenario 25: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, beyond 8 m/s, with ignition in point PI16 – Furnace, 2 seconds after release, resulting in a fire and cloud explosion.

Frequency: 6.06033E-05
Consequences: 0.0860324
Average societal risk: 5.21385E-06

Scenario 26: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation, delayed ignition, beyond 8 m/s, with ignition in point PI13 - Process Plant, 5 seconds after release, resulting in a fire and cloud explosion.

Frequency: 2.02011E-06
Consequences: 1.50835
Average societal risk: 3.04704E-06

Combined results for event EI-11.1: Large natural gas release in the manifold deck, gas exportation line, with blockage actuation

Total Average societal risk: 5.0011E-05

F-N Curve

Fatalities Number	Frequency
1	1.68586E-05
2	7.46352E-06
3	0
4	0
5	0
6	0
7	0

Scenario Number	*Frequency*	*CPU (c)*	*Valve (v2)*	*Pressure sensor (p2)*	*Scenario Frequency*	*Phenomenological Probability*	*Consequences*	*Average Societal Risk*	*Average Societal in terms safety*	*Risk of variables*
1	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	3.1056E-02	4.5547E-02	8.1742E-07	8.7415E-07	c.v2.p2
2	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	1.0352E-03	1.4679E+00	8.7815E-07	9.3910E-07	c.v2.p2
3	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	7.2464E-04	2.2794E+00	9.5452E-07	1.0208E-06	c.v2.p2
4	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	5.0725E-04	2.4847E+00	7.2835E-07	7.7890E-07	c.v2.p2
5	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	3.5507E-04	2.2010E+00	4.5164E-07	4.8298E-07	c.v2.p2
6	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	2.4855E-04	2.2633E+00	3.2508E-07	3.4765E-07	c.v2.p2
7	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	1.7399E-04	1.8513E+00	1.8614E-07	1.9906E-07	c.v2.p2
13	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	1.3503E-01	4.5547E-02	3.5540E-06	3.8007E-06	c.v2.p2
14	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	4.5009E-03	1.9757E+00	5.1387E-06	5.4953E-06	c.v2.p2
15	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	3.1506E-03	2.3047E+00	4.1962E-06	4.4874E-06	c.v2.p2
16	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	2.2054E-03	2.6495E+00	3.3767E-06	3.6111E-06	c.v2.p2
17	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	1.5438E-03	2.8774E+00	2.5671E-06	2.7452E-06	c.v2.p2
18	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	1.0807E-03	1.3597E+00	8.4915E-07	9.0809E-07	c.v2.p2
19	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	9.2267E-02	2.2773E-02	1.2143E-06	1.2986E-06	c.v2.p2
20	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	3.0756E-03	1.9357E+00	3.4403E-06	3.6791E-06	c.v2.p2
21	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	2.1529E-03	2.6088E+00	3.2458E-06	3.4711E-06	c.v2.p2
22	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	8.6866E-02	8.6032E-02	4.3188E-06	4.6185E-06	c.v2.p2
23	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	2.8955E-03	1.6728E+00	2.7990E-06	2.9933E-06	c.v2.p2
24	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	2.0269E-03	2.3078E+00	2.7031E-06	2.8907E-06	c.v2.p2
25	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	1.0487E-01	8.6032E-02	5.2138E-06	5.5757E-06	c.v2.p2
26	6.1800E-04	9.9000E-01	9.8000E-01	9.6382E-01	5.7789E-04	3.4957E-03	1.5112E+00	3.0527E-06	3.2646E-06	c.v2.p2
Total								*5.0011E-05*	*5.3482E-05*	*c.v2.p2*
ASR										

Tabela A.3.1 - Scenarios Associated with Initiator Event EI-11.1.1

Appendix 4

The Average Societal Risk Expression as a function of availability variables will be given by the sum of the terms presented in the last column in Italic characters

Risk	Assessment	Original	Values		Variables	Values	Utilised		
sp1	9.50000E-01	**sp1'**	5.0000E-02		**sp1**	9.7918E-01	**sp1'**	2.0820E-02	
sp2	9.35100E-01	**sp2'**	6.4900E-02		**sp2**	9.6382E-01	**sp2'**	3.6178E-02	
sp3	9.38000E-01	**sp3'**	6.2000E-02		**sp3**	9.6681E-01	**sp3'**	3.3189E-02	
sp4	9.53000E-01	**sp4'**	4.7000E-02		**sp4**	9.8227E-01	**sp4'**	1.7728E-02	
XG=XF=	9.65000E-01	**xg'= xf'=**	3.5000E-02		**xg'= xf'=**	9.9464E-01	**xg'= xf'=**	5.3597E-03	
scenario	**average societal risk**	**CPU**	**protection actuator**	**blockage system**	**gas detection system**	**fire detection system**	**societal unavailability var**	**risk variables**	**in terms of variables**
EI-1.1.1	5.4085E-06	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***5.6932E-06***	*cpu.v1*	*sp1*
EI-1.1.2	1.1457E-07	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***5.7023E-06***	*cpu.v1*	*sp1'xg1*
EI-1.1.3	6.1454E-10	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***5.7068E-06***	*cpu.v1*	*sp1'xg1'xf1*
EI-1.1.4	3.3115E-12	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***5.7068E-06***	*cpu.v1*	*sp1'xg1'xf1'*
EI-1.2.1	1.1055E-07	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***5.7023E-06***	*'cpu.v1'*	*sp1*
EI-1.2.2	2.3400E-09	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***5.7068E-06***	*cpu.v1'*	*sp1'xg1*
EI-1.2.3	1.2542E-11	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***5.7068E-06***	*cpu.v1'*	*sp1'xg1'xf1*
EI-1.2.4	6.7582E-14	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***5.7068E-06***	*cpu.v1'*	*sp1'xg1'xf1'*
EI-1.3.1	5.4719E-08	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***5.7023E-06***	*cpu'.v1*	*sp1*
EI-1.3.2	1.1582E-09	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***5.7068E-06***	*cpu'.v1*	*sp1'xg1*
EI-1.3.3	6.2075E-12	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***5.7068E-06***	*cpu'.v1*	*sp1'xg1'xf1*
EI-1.3.4	3.3450E-14	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***5.7068E-06***	*cpu'.v1*	*sp1'xg1'xf1'*
EI-1.4.1	1.1167E-09	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***5.7023E-06***	*cpu'.v1'*	*sp1*
EI-1.4.2	2.3636E-11	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***5.7068E-06***	*cpu'.v1'*	*sp1'xg1*
EI-1.4.3	1.2668E-13	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***5.7068E-06***	*cpu'.v1'*	*sp1'xg1'xf1*
EI-1.4.4	6.8265E-16	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***5.7068E-06***	*cpu'.v1'*	*sp1'xg1'xf1'*

Framework A.4.1 Average Societal Risk in Terms of Unavilability/Availability Variables

	5.6937E-06	**5.6934E-06**							
EI-9.1.1	4.9529E-05	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***5.1972E-05***	***cpu.v4***	***sp4***
EI-9.1.2	8.8913E-07	9.9000E-01	9.8000E-01	1.7728E-02	1.0000E+00	9.9464E-01	***5.1972E-05***	***cpu.v4***	***sp4'xf1***
EI-9.1.3	7.9880E-07	9.9000E-01	9.8000E-01	1.7728E-02	1.0000E+00	5.3597E-03	***8.6650E-03***	***cpu.v4***	***sp4'xf1'***
EI-9.2.1	1.0108E-06	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***5.1972E-05***	***cpu.v4'***	***sp4***
EI-9.2.2	3.0253E-06	9.9000E-01	2.0000E-02	1.7728E-02	1.0000E+00	9.9464E-01	***8.6650E-03***	***cpu.v4'***	***sp4'xf1***
EI-9.2.3	1.6302E-08	9.9000E-01	2.0000E-02	1.7728E-02	1.0000E+00	5.3597E-03	***8.6650E-03***	***cpu.v4'***	***sp4'xf1'***
EI-9.3.1	5.0030E-07	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***5.1972E-05***	***cpu'.v4***	***sp4***
EI-9.3.2	1.4974E-06	1.0000E-02	9.8000E-01	1.7728E-02	1.0000E+00	9.9464E-01	***8.6650E-03***	***cpu'.v4***	***sp4'xf1***
EI-9.3.3	8.0687E-09	1.0000E-02	9.8000E-01	1.7728E-02	1.0000E+00	5.3597E-03	***8.6650E-03***	***cpu'.v4***	***sp4'xf1'***
EI-9.4.1	1.0210E-08	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***5.1972E-05***	***'cpu'.v4'***	***sp4***
EI-9.4.2	3.0558E-08	1.0000E-02	2.0000E-02	1.7728E-02	1.0000E+00	9.9464E-01	***8.6650E-03***	***cpu'.v4'***	***sp4'xf1***
EI-9.4.3	1.6467E-10	1.0000E-02	2.0000E-02	1.7728E-02	1.0000E+00	5.3597E-03	***8.6650E-03***	***cpu'.v4'***	***sp4'xf1'***
	5.7316E-05	**6.6323E-05**							
EI-10.1.1	5.9534E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***6.2667E-04***	***cpu.v1***	***sp1***
EI-10.1.2	1.2591E-05	9.9000E-01	9.8000E-01	2.0820E-02	1.0000E+00	9.9464E-01	***6.2667E-04***	***cpu.v1***	***sp1'xf1***
EI-10.1.3	6.0607E-06	9.9000E-01	9.8000E-01	2.0820E-02	1.0000E+00	5.3597E-03	***5.5980E-02***	***cpu.v1***	***sp1'xf1'***
EI-10.2.1	1.2150E-05	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***6.2667E-04***	***cpu.v1'***	***sp1***
EI-10.2.2	2.2954E-05	9.9000E-01	2.0000E-02	2.0820E-02	1.0000E+00	9.9464E-01	***5.5980E-02***	***cpu.v1'***	***sp1'xf1***
EI-10.2.3	1.2369E-07	9.9000E-01	2.0000E-02	2.0820E-02	1.0000E+00	5.3597E-03	***5.5980E-02***	***cpu.v1'***	***sp1'xf1'***
EI-10.3.1	6.0135E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***6.2667E-04***	***cpu'.v1***	***sp1***
EI-10.3.2	1.1361E-05	1.0000E-02	9.8000E-01	2.0820E-02	1.0000E+00	9.9464E-01	***5.5980E-02***	***cpu'.v1***	***sp1'xf1***
EI-10.3.3	6.1220E-08	1.0000E-02	9.8000E-01	2.0820E-02	1.0000E+00	5.3597E-03	***5.5980E-02***	***cpu'.v1***	***sp1'xf1'***

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EI-10.4.1	1.2272E-07	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***6.2667E-04***	***cpu'.v1'***	***sp1***
EI-10.4.2	2.3186E-07	1.0000E-02	2.0000E-02	2.0820E-02	1.0000E+00	9.9464E-01	***5.5980E-02***	***cpu'.v1'***	***sp1'xf1***
EI-10.4.3	1.2494E-09	1.0000E-02	2.0000E-02	2.0820E-02	1.0000E+00	5.3597E-03	***5.5980E-02***	***cpu'.v1'***	***sp1'xf1'***
	6.6701E-04	**7.2408E-04**							
EI-11.1.1	5.0011E-05	9.9000E-01	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***5.3482E-05***	***cpu.v2***	***sp2***
EI-11.1.2	1.8672E-06	9.9000E-01	9.8000E-01	3.6178E-02	1.0000E+00	9.9464E-01	***5.3482E-05***	***cpu.v2***	***sp2'xf1***
EI-11.1.3	7.6594E-07	9.9000E-01	9.8000E-01	3.6178E-02	1.0000E+00	5.3597E-03	***4.0714E-03***	***cpu.v2***	***sp2'xf1'***
EI-11.2.1	1.0206E-06	9.9000E-01	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***5.3482E-05***	***cpu.v2'***	***sp2***
EI-11.2.2	2.9008E-06	9.9000E-01	2.0000E-02	3.6178E-02	1.0000E+00	9.9464E-01	***4.0714E-03***	***cpu.v2'***	***sp2'xf1***
EI-11.2.3	1.5631E-08	9.9000E-01	2.0000E-02	3.6178E-02	1.0000E+00	5.3597E-03	***4.0714E-03***	***cpu.v2'***	***sp2'xf1'***
EI-11.3.1	5.0516E-07	1.0000E-02	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***5.3482E-05***	***cpu'.v2***	***sp2***
EI-11.3.2	1.4358E-06	1.0000E-02	9.8000E-01	3.6178E-02	1.0000E+00	9.9464E-01	***4.0714E-03***	***cpu'.v2***	***sp2'xf1***
EI-11.3.3	7.7367E-09	1.0000E-02	9.8000E-01	3.6178E-02	1.0000E+00	5.3597E-03	***4.0714E-03***	***cpu'.v2***	***sp2'xf1'***
EI-11.4.1	1.0309E-08	1.0000E-02	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***5.3482E-05***	***cpu'.v2'***	***sp2***
EI-11.4.2	2.9301E-08	1.0000E-02	2.0000E-02	3.6178E-02	1.0000E+00	9.9464E-01	***4.0714E-03***	***cpu'.v2'***	***sp2'xf1***
EI-11.4.3	1.5789E-10	1.0000E-02	2.0000E-02	3.6178E-02	1.0000E+00	5.3597E-03	***4.0714E-03***	***cpu'.v2'***	***sp2'xf1'***
	5.8570E-05	**6.2629E-05**							
EI-12.1.1	2.08888E-05	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***2.1919E-05***	***cpu.v4***	***sp4***
EI-12.1.2	3.7569E-07	9.9000E-01	9.8000E-01	1.7728E-02	1.0000E+00	9.9464E-01	***2.1960E-05***	***cpu.v4***	***sp4'xf1***
EI-12.1.3	1.9083E-07	9.9000E-01	9.8000E-01	1.7728E-02	1.0000E+00	5.3597E-03	***2.0700E-03***	***cpu.v4***	***sp4'xf1'***
EI-12.2.1	4.2710E-07	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***2.1960E-05***	***cpu.v4'***	***sp4***
EI-12.2.2	7.2272E-07	9.9000E-01	2.0000E-02	1.7728E-02	1.0000E+00	9.9464E-01	***2.0700E-03***	***cpu.v4'***	***sp4'xf1***
EI-12.2.3	3.8944E-09	9.9000E-01	2.0000E-02	1.7728E-02	1.0000E+00	5.3597E-03	***2.0700E-03***	***cpu.v4'***	***sp4'xf1'***

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EI-12.3.1	2.1139E-07	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***2.1960E-05***	***cpu'.v4***	***sp4***
EI-12.3.2	3.5771E-07	1.0000E-02	9.8000E-01	1.7728E-02	1.0000E+00	9.9464E-01	***2.0700E-03***	***cpu'.v4***	***sp4'xf1***
EI-12.3.3	1.9276E-09	1.0000E-02	9.8000E-01	1.7728E-02	1.0000E+00	5.3597E-03	***2.0700E-03***	***cpu'.v4***	***sp4'xf1'***
EI-12.4.1	4.3141E-09	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***2.1960E-05***	***cpu'.v4'***	***sp4***
EI-12.4.2	7.3002E-09	1.0000E-02	2.0000E-02	1.7728E-02	1.0000E+00	9.9464E-01	***2.0700E-03***	***cpu'.v4'***	***sp4'xf1***
EI-12.4.3	3.9338E-11	1.0000E-02	2.0000E-02	1.7728E-02	1.0000E+00	5.3597E-03	***2.0700E-03***	***cpu'.v4'***	***sp4'xf1'***
	2.3192E-05	**2.5337E-05**		***5.7316E-05***	8.0508E-05				
EI-13.1.1	5.0221E-05	9.9000E-01	9.8000E-01	1.0000E+00	1.0000E+00	9.9464E-01	***5.2042E-05***	***cpu.v1***	***xf1***
EI-13.1.2	6.2930E-06	9.9000E-01	9.8000E-01	1.0000E+00	1.0000E+00	5.3597E-03	***1.2102E-03***	***cpu.v1***	***xf1'***
EI-13.2.1	2.3834E-05	9.9000E-01	2.0000E-02	1.0000E+00	1.0000E+00	9.9464E-01	***1.2102E-03***	***cpu.v1'***	***xf1***
EI-13.2.2	1.2843E-07	9.9000E-01	2.0000E-02	1.0000E+00	1.0000E+00	5.3597E-03	***1.2102E-03***	***cpu.v1'***	***xf1'***
EI-13.3.1	1.1796E-05	1.0000E-02	9.8000E-01	1.0000E+00	1.0000E+00	9.9464E-01	***1.2102E-03***	***cpu'v1***	***xf1***
EI-13.3.2	6.3566E-08	1.0000E-02	9.8000E-01	1.0000E+00	1.0000E+00	5.3597E-03	***1.2102E-03***	***cpu'v1***	***xf1'***
EI-13.4.1	2.4074E-07	1.0000E-02	2.0000E-02	1.0000E+00	1.0000E+00	9.9464E-01	***1.2102E-03***	***cpu'v1'***	***xf1***
EI-13.4.2	1.2973E-09	1.0000E-02	2.0000E-02	1.0000E+00	1.0000E+00	5.3597E-03	***1.2102E-03***	***cpu'v1'***	***xf1'***
	9.2578E-05	**9.2702E-05**							
EI-14.1.1	4.9760E-05	9.9000E-01	9.8000E-01	1.0000E+00	1.0000E+00	9.9464E-01	***5.1565E-05***	***cpu.v1***	***xf1***
EI-14.1.2	6.0377E-06	9.9000E-01	9.8000E-01	1.0000E+00	1.0000E+00	5.3597E-03	***1.1611E-03***	***cpu.v1***	***xf1'***
EI-14.2.1	2.2867E-05	9.9000E-01	2.0000E-02	1.0000E+00	1.0000E+00	9.9464E-01	***1.1611E-03***	***cpu.v1'***	***xf1***
EI-14.2.2	1.2322E-07	9.9000E-01	2.0000E-02	1.0000E+00	1.0000E+00	5.3597E-03	***1.1611E-03***	***cpu.v1'***	***xf1'***
EI-14.3.1	1.1318E-05	1.0000E-02	9.8000E-01	1.0000E+00	1.0000E+00	9.9464E-01	***1.1611E-03***	***cpu'v1***	***xf1***
EI-14.3.2	6.0987E-08	1.0000E-02	9.8000E-01	1.0000E+00	1.0000E+00	5.3597E-03	***1.1611E-03***	***cpu'v1***	***xf1'***

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EI-14.4.1	2.3098E-07	1.0000E-02	2.0000E-02	1.0000E+00	1.0000E+00	9.9464E-01	***1.1611E-03***	*cpu'v1'*	*xf1*
EI-14.4.2	1.2446E-09	1.0000E-02	2.0000E-02	1.0000E+00	1.0000E+00	5.3597E-03	***1.1611E-03***	*cpu'v1'*	*xf1'*
	9.0399E-05	**9.0514E-05**							
EI-15.1.1	2.6120E-05	9.9000E-01	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***2.7933E-05***	*cpu.v2*	*sp2*
EI-15.1.2	9.7519E-07	9.9000E-01	9.8000E-01	3.6178E-02	1.0000E+00	9.9464E-01	***2.7933E-05***	*cpu.v2*	*sp2'xf1*
EI-15.1.3	2.4532E-08	9.9000E-01	9.8000E-01	3.6178E-02	1.0000E+00	5.3597E-03	***1.3040E-04***	*cpu.v2*	*sp2'xf1'*
EI-15.2.1	5.3306E-07	9.9000E-01	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***2.7933E-05***	*cpu.v2'*	*sp2*
EI-15.2.2	9.2908E-08	9.9000E-01	2.0000E-02	3.6178E-02	1.0000E+00	9.9464E-01	***1.3040E-04***	*cpu.v2'*	*sp2'xf1*
EI-15.2.3	5.0065E-10	9.9000E-01	2.0000E-02	3.6178E-02	1.0000E+00	5.3597E-03	***1.3040E-04***	*cpu.v2'*	*sp2'xf1'*
EI-15.3.1	2.6384E-07	1.0000E-02	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***2.7933E-05***	*cpu'.v2*	*sp2*
EI-15.3.2	4.5985E-08	1.0000E-02	9.8000E-01	3.6178E-02	1.0000E+00	9.9464E-01	***1.3040E-04***	*cpu'.v2*	*sp2'xf1*
EI-15.3.3	2.4779E-10	1.0000E-02	9.8000E-01	3.6178E-02	1.0000E+00	5.3597E-03	***1.3040E-04***	*cpu'.v2*	*sp2'xf1'*
EI-15.4.1	5.3845E-09	1.0000E-02	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***2.7933E-05***	*cpu'.v2'*	*sp2*
EI-15.4.2	9.3847E-10	1.0000E-02	2.0000E-02	3.6178E-02	1.0000E+00	9.9464E-01	***1.3040E-04***	*cpu'.v2'*	*sp2'xf1*
EI-15.4.3	5.0570E-12	1.0000E-02	2.0000E-02	3.6178E-02	1.0000E+00	5.3597E-03	***1.3040E-04***	*cpu'.v2'*	*sp2'xf1'*
	2.8063E-05	**2.8164E-05**							
EI-16				No	calculation				
EI-17.1	**2.1658E-05**								
EI-17.2	**2.5536E-06**			No	protection	systems			
EI-17.3	**0.0000E+00**								
EI-17.4	**3.1620E-09**				Total	EI-17.1:	***2.4214E-05***		

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EI-18.1.1	4.72605E-06	9.90000E-01	9.80000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***4.97479E-06***	***cpu.v1***	***sp1***
EI-18.1.2	9.99522E-08	9.90000E-01	9.80000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***4.97479E-06***	***cpu.v1***	***sp1'xg3***
EI-18.1.3	5.35716E-10	9.90000E-01	9.80000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***4.97479E-06***	***cpu.v1***	***sp1'xg3'xf3***
EI-18.1.4	1.77833E-10	9.90000E-01	9.80000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***3.06463E-04***	***cpu.v1***	***sp1'xg3'xf3'***
EI-18.2.1	9.64500E-08	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***4.97479E-06***	***cpu.v1'***	***sp1***
EI-18.2.2	1.25661E-07	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***3.06463E-04***	***cpu.v1'***	***sp1'xg3***
EI-18.2.3	6.73506E-10	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***3.06463E-04***	***cpu.v1'***	***sp1'xg3'xf3***
EI-18.2.4	3.62926E-12	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***3.06463E-04***	***cpu.v1'***	***sp1'xg3'xf3'***
EI-18.3.1	4.77379E-08	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***4.97479E-06***	***cpu'.v1***	***sp1***
EI-18.3.2	6.21957E-08	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***3.06463E-04***	***cpu'.v1***	***sp1'xg3***
EI-18.3.3	3.33351E-10	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***3.06463E-04***	***cpu'.v1***	***sp1'xg3'xf3***
EI-18.3.4	1.79630E-12	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***3.06463E-04***	***cpu'.v1***	***sp1'xg3'xf3'***
EI-18.4.1	9.74243E-10	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***4.97479E-06***	***cpu'.v1'***	***sp1***
EI-18.4.2	1.26930E-09	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***3.06463E-04***	***cpu'.v1'***	***sp1'xg3***
EI-18.4.3	6.80309E-12	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***3.06463E-04***	***cpu'.v1'***	***sp1'xg3'xf3***
EI-18.4.4	3.66591E-14	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***3.06463E-04***	***cpu'.v1'***	***sp1'xg3'xf3'***
	5.1620E-06	***4.9989E-06***	***5.1620E-06***						
EI-19.1	3.2944E-05								
EI-19.2	3.8844E-06			No	protection	systems			
EI-19.3	8.7529E-06								
EI-19.4	2.4990E-06				**Total**	**EI-19:**	***4.8080E-05***		

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EIa-20rsb	0.0000E+00								
EIb-20rsb	4.1333E-06			No	protection	systems			
EIc-20rsb	5.7819E-06								
EId-20rsb	8.0864E-05				Total	EI-20:	*9.0779E-05*		
EI-21 to 22				Oil Tanks Explosion					
tq1c	2.5057E-06								
tq1p	1.6952E-06								
tq1s	1.6951E-06								
tq2c	3.0999E-05								
tq2p	2.4803E-06								
tq2s	2.4799E-06								
tq3c	3.2417E-06								
tq-4c	2.0112E-06								
tq-4p	1.6918E-06								
tq-4s	1.6915E-06								
tq-5c	1.2200E-06								
tq-5p	5.9400E-08								
tq-5s	4.8477E-08								
					Total	EI-21to 22:	*5.1819E-05*		
EI-23.1.1	4.5284E-06	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	*4.7667E-06*	*cpu.v1*	*sp1*
EI-23.1.2	9.5858E-08	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	*4.7710E-06*	*cpu.v1*	*sp1'xg4*
EI-23.1.3	5.1489E-10	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	*4.7814E-06*	*cpu.v1*	*sp1'xg4'xf4*
EI-23.1.4	1.9978E-10	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	*3.4428E-04*	*cpu.v1*	*sp1'xg4'xf4'*
EI-23.2.1	9.2499E-08	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	*4.7710E-06*	*cpu.v1'*	*sp1*

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EI-23.2.2	1.9605E-09	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***4.7814E-06***	***cpu.v1'***	***sp1'xg4***
EI-23.2.3	7.5662E-10	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***3.4428E-04***	***cpu.v1'***	***sp1'xg4'xf4***
EI-23.2.4	4.0771E-12	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***3.4428E-04***	***cpu.v1'***	***sp1'xg4'xf4'***
EI-23.3.1	4.5782E-08	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***4.7710E-06***	***cpu'.v1***	***sp1***
EI-23.3.2	9.7037E-10	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***4.7814E-06***	***cpu'.v1***	***sp1'xg4***
EI-23.3.3	3.7449E-10	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***3.4428E-04***	***cpu'.v1***	***sp1'xg4'xf4***
EI-23.3.4	2.0180E-12	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***3.4428E-04***	***cpu'.v1***	***sp1'xg4'xf4'***
EI-23.4.1	9.3433E-10	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***4.7710E-06***	***cpu'.v1'***	***sp1***
EI-23.4.2	1.9803E-11	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***4.7814E-06***	***cpu'.v1'***	***sp1'xg4***
EI-23.4.3	7.6426E-12	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***3.4428E-04***	***cpu'.v1'***	***sp1'xg4'xf4***
EI-23.4.4	4.1183E-14	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***3.4428E-04***	***cpu'.v1'***	***sp1'xg4'xf4'***
		4.7682E-06	***4.7884E-06***						
EI-24.1.1	2.0790E-04	9.9000E-01	9.8000E-01	9.6681E-01	1.0000E+00	1.0000E+00	***2.2164E-04***	***cpu.v3***	***sp3***
EI-24.1.2	7.0986E-06	9.9000E-01	9.8000E-01	3.3189E-02	9.9464E-01	1.0000E+00	***2.2164E-04***	***cpu.v3***	***sp3'xg2***
EI-24.1.3	5.5514E-08	9.9000E-01	9.8000E-01	3.3189E-02	5.3597E-03	9.9464E-01	***3.2340E-04***	***cpu.v3***	***sp3'xg2'xf2***
EI-24.1.4	5.9837E-10	9.9000E-01	9.8000E-01	3.3189E-02	5.3597E-03	5.3597E-03	***6.4689E-04***	***cpu.v3***	***sp3'xg2'xf2'***
EI-24.2.1	4.2428E-06	9.9000E-01	2.0000E-02	9.6681E-01	1.0000E+00	1.0000E+00	***2.2164E-04***	***cpu.v3'***	***sp3***
EI-24.2.2	2.1138E-07	9.9000E-01	2.0000E-02	3.3189E-02	9.9464E-01	1.0000E+00	***3.2340E-04***	***cpu.v3'***	***sp3'xg2***
EI-24.2.3	2.2662E-09	9.9000E-01	2.0000E-02	3.3189E-02	5.3597E-03	9.9464E-01	***6.4689E-04***	***cpu.v3'***	***sp3'xg2'xf2***
EI-24.2.4	1.2212E-11	9.9000E-01	2.0000E-02	3.3189E-02	5.3597E-03	5.3597E-03	***6.4689E-04***	***cpu.v3'***	***sp3'xg2'xf2'***
EI-24.3.1	2.1000E-06	1.0000E-02	9.8000E-01	9.6681E-01	1.0000E+00	1.0000E+00	***2.2164E-04***	***cpu'.v3***	***sp3***
EI-24.3.2	1.0462E-07	1.0000E-02	9.8000E-01	3.3189E-02	9.9464E-01	1.0000E+00	***3.2340E-04***	***cpu'.v3***	***sp3'xg2***
EI-24.3.3	1.1217E-09	1.0000E-02	9.8000E-01	3.3189E-02	5.3597E-03	9.9464E-01	***6.4689E-04***	***cpu'.v3***	***sp3'xg2'xf2***
EI-24.3.4	6.0442E-12	1.0000E-02	9.8000E-01	3.3189E-02	5.3597E-03	5.3597E-03	***6.4689E-04***	***cpu'.v3***	***sp3'xg2'xf2'***

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EI-24.4.1	4.2857E-08	1.0000E-02	2.0000E-02	9.6681E-01	1.0000E+00	1.0000E+00	***2.2164E-04***	***cpu'.v3'***	***sp3***
EI-24.4.2	2.1352E-09	1.0000E-02	2.0000E-02	3.3189E-02	9.9464E-01	1.0000E+00	***3.2340E-04***	***cpu'.v3'***	***sp3'xg2***
EI-24.4.3	2.2891E-11	1.0000E-02	2.0000E-02	3.3189E-02	5.3597E-03	9.9464E-01	***6.4689E-04***	***cpu'.v3'***	***sp3'xg2'xf2***
EI-24.4.4	1.2335E-13	1.0000E-02	2.0000E-02	3.3189E-02	5.3597E-03	5.3597E-03	***6.4689E-04***	***cpu'.v3'***	***sp3'xg2'xf2'***
		2.2176E-04	***2.2196E-04***						
EI-25.1.1	7.8638E-05	9.9000E-01	9.8000E-01	1.0000E+00	9.9464E-01	1.0000E+00	***8.1490E-05***	***cpu.v2***	***xg2***
EI-25.1.2	4.2148E-07	9.9000E-01	9.8000E-01	1.0000E+00	5.3597E-03	9.9464E-01	***8.1490E-05***	***cpu.v2***	***xg2'xf2***
EI-25.1.3	4.9690E-09	9.9000E-01	9.8000E-01	1.0000E+00	5.3597E-03	5.3597E-03	***1.7829E-04***	***cpu.v2***	***xg2'xf2'***
EI-25.2.1	1.6049E-06	9.9000E-01	2.0000E-02	1.0000E+00	9.9464E-01	1.0000E+00	***8.1490E-05***	***cpu.v2'***	***xg2***
EI-25.2.2	1.8819E-08	9.9000E-01	2.0000E-02	1.0000E+00	5.3597E-03	9.9464E-01	***1.7829E-04***	***cpu.v2'***	***xg2'xf2***
EI-25.2.3	1.0141E-10	9.9000E-01	2.0000E-02	1.0000E+00	5.3597E-03	5.3597E-03	***1.7829E-04***	***cpu.v2'***	***xg2'xf2'***
EI-25.3.1	7.9432E-07	1.0000E-02	9.8000E-01	1.0000E+00	9.9464E-01	1.0000E+00	***8.1490E-05***	***cpu'.v2***	***xg2***
EI-25.3.2	9.3145E-09	1.0000E-02	9.8000E-01	1.0000E+00	5.3597E-03	9.9464E-01	***1.7829E-04***	***cpu'.v2***	***xg2'xf2***
EI-25.3.3	5.0192E-11	1.0000E-02	9.8000E-01	1.0000E+00	5.3597E-03	5.3597E-03	***1.7829E-04***	***cpu'.v2***	***xg2'xf2'***
EI-25.4.1	1.6211E-08	1.0000E-02	2.0000E-02	1.0000E+00	9.9464E-01	1.0000E+00	***8.1490E-05***	***cpu'.v2'***	***xg2***
EI-25.4.2	1.9009E-10	1.0000E-02	2.0000E-02	1.0000E+00	5.3597E-03	9.9464E-01	***1.7829E-04***	***cpu'.v2'***	***xg2'xf2***
EI-25.4.3	1.0243E-12	1.0000E-02	2.0000E-02	1.0000E+00	5.3597E-03	5.3597E-03	***1.7829E-04***	***cpu'.v2'***	***xg2'xf2'***
		8.1508E-05	***8.1618E-05***						
EI-26.1.1	2.2300E-04	9.9000E-01	9.8000E-01	9.6681E-01	1.0000E+00	1.0000E+00	***2.3774E-04***	***cpu.v3***	***sp3***
EI-26.1.2	7.6142E-06	9.9000E-01	9.8000E-01	3.3189E-02	9.9464E-01	1.0000E+00	***2.3774E-04***	***cpu.v3***	***sp3'xg2***
EI-26.1.3	4.2363E-08	9.9000E-01	9.8000E-01	3.3189E-02	5.3597E-03	9.9464E-01	***2.4679E-04***	***cpu.v3***	***sp3'xg2'xf2***
EI-26.1.4	1.5620E-09	9.9000E-01	9.8000E-01	3.3189E-02	5.3597E-03	5.3597E-03	***1.6887E-03***	***cpu.v3***	***sp3'xg2'xf2'***
EI-26.2.1	4.5510E-06	9.9000E-01	2.0000E-02	9.6681E-01	1.0000E+00	1.0000E+00	***2.3774E-04***	***cpu.v3'***	***sp3***
EI-26.2.2	1.6131E-07	9.9000E-01	2.0000E-02	3.3189E-02	9.9464E-01	1.0000E+00	***2.4679E-04***	***cpu.v3'***	***sp3'xg2***

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EI-26.2.3	5.9159E-09	9.9000E-01	2.0000E-02	3.3189E-02	5.3597E-03	9.9464E-01	1.6887E-03	cpu.v3'	sp3'xg2'xf2
EI-26.2.4	3.1878E-11	9.9000E-01	2.0000E-02	3.3189E-02	5.3597E-03	5.3597E-03	1.6887E-03	cpu.v3'	sp3'xg2'xf2'
EI-26.3.1	2.2525E-06	1.0000E-02	9.8000E-01	9.6681E-01	1.0000E+00	1.0000E+00	2.3774E-04	cpu'.v3	sp3
EI-26.3.2	7.9839E-08	1.0000E-02	9.8000E-01	3.3189E-02	9.9464E-01	1.0000E+00	2.4679E-04	cpu'.v3	sp3'xg2
EI-26.3.3	2.9281E-09	1.0000E-02	9.8000E-01	3.3189E-02	5.3597E-03	9.9464E-01	1.6887E-03	cpu'.v3	sp3'xg2'xf2
EI-26.3.4	1.5778E-11	1.0000E-02	9.8000E-01	3.3189E-02	5.3597E-03	5.3597E-03	1.6887E-03	cpu'.v3	sp3'xg2'xf2'
EI-26.4.1	4.5970E-08	1.0000E-02	2.0000E-02	9.6681E-01	1.0000E+00	1.0000E+00	2.3774E-04	cpu'.v3'	sp3
EI-26.4.2	1.6294E-09	1.0000E-02	2.0000E-02	3.3189E-02	9.9464E-01	1.0000E+00	2.4679E-04	cpu'.v3'	sp3'xg2
EI-26.4.3	5.9757E-11	1.0000E-02	2.0000E-02	3.3189E-02	5.3597E-03	9.9464E-01	1.6887E-03	cpu'.v3'	sp3'xg2'xf2
EI-26.4.4	3.2200E-13	1.0000E-02	2.0000E-02	3.3189E-02	5.3597E-03	5.3597E-03	1.6887E-03	cpu'.v3'	sp3'xg2'xf2'
		2.3776E-04	2.3794E-04						
EI-27.1.1	0.0000E+00	9.9000E-01	9.8000E-01	1.0000E+00	9.9464E-01	1.0000E+00	0.0000E+00	cpu.v2	xg2
EI-27.1.2	0.0000E+00	9.9000E-01	9.8000E-01	1.0000E+00	5.3597E-03	9.9464E-01	0.0000E+00	cpu.v2	xg2'xf2
EI-27.1.3	0.0000E+00	9.9000E-01	9.8000E-01	1.0000E+00	5.3597E-03	5.3597E-03	0.0000E+00	cpu.v2	xg2'xf2'
EI-27.2.1	0.0000E+00	9.9000E-01	2.0000E-02	1.0000E+00	9.9464E-01	1.0000E+00	0.0000E+00	cpu.v2'	xg2
EI-27.2.2	0.0000E+00	9.9000E-01	2.0000E-02	1.0000E+00	5.3597E-03	9.9464E-01	0.0000E+00	cpu.v2'	xg2'xf2
EI-27.2.3	0.0000E+00	9.9000E-01	2.0000E-02	1.0000E+00	5.3597E-03	5.3597E-03	0.0000E+00	cpu.v2'	xg2'xf2'
EI-27.3.1	0.0000E+00	1.0000E-02	9.8000E-01	1.0000E+00	9.9464E-01	1.0000E+00	0.0000E+00	cpu'.v2	xg2
EI-27.3.2	0.0000E+00	1.0000E-02	9.8000E-01	1.0000E+00	5.3597E-03	9.9464E-01	0.0000E+00	cpu'.v2	xg2'xf2
EI-27.3.3	0.0000E+00	1.0000E-02	9.8000E-01	1.0000E+00	5.3597E-03	5.3597E-03	0.0000E+00	cpu'.v2	xg2'xf2'
EI-27.4.1	0.0000E+00	1.0000E-02	2.0000E-02	1.0000E+00	9.9464E-01	1.0000E+00	0.0000E+00	cpu'.v2'	xg2
EI-27.4.2	0.0000E+00	1.0000E-02	2.0000E-02	1.0000E+00	5.3597E-03	9.9464E-01	0.0000E+00	cpu'.v2'	xg2'xf2
EI-27.4.3	0.0000E+00	1.0000E-02	2.0000E-02	1.0000E+00	5.3597E-03	5.3597E-03	0.0000E+00	cpu'.v2'	xg2'xf2'

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EI-28.1	0.0000E+00								
EI-28.2	0.0000E+00								
EI-28.3	0.0000E+00								
EI-28.4	0.0000E+00								
EI-29.1.1	2.2793E-05	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***2.3917E-05***	***cpu.v4***	***sp4***
EI-29.1.2	4.0917E-07	9.9000E-01	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***2.3917E-05***	***cpu.v4***	***sp4'xg2***
EI-29.1.3	3.9014E-09	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***4.2549E-05***	***cpu.v4***	***sp4'xg2'xf2***
EI-29.1.4	4.2047E-11	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	***8.5098E-05***	***cpu.v4***	***sp4'xg2'xf2'***
EI-29.2.1	4.6516E-07	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***2.3917E-05***	***cpu.v4'***	***sp4***
EI-29.2.2	1.4856E-08	9.9000E-01	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***4.2549E-05***	***cpu.v4'***	***sp4'xg2***
EI-29.2.3	1.5924E-10	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***8.5098E-05***	***cpu.v4'***	***sp4'xg2'xf2***
EI-29.2.4	8.5810E-13	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***8.5098E-05***	***cpu.v4'***	***sp4'xg2'xf2'***
EI-29.3.1	2.3023E-07	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***2.3917E-05***	***cpu'.v4***	***sp4***
EI-29.3.2	7.3527E-09	1.0000E-02	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***4.2549E-05***	***cpu'.v4***	***sp4'xg2***
EI-29.3.3	7.8817E-11	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***8.5098E-05***	***cpu'.v4***	***sp4'xg2'xf2***
EI-29.3.4	4.2471E-13	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	***8.5098E-05***	***cpu'.v4***	***sp4'xg2'xf2'***
EI-29.4.1	4.6986E-09	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***2.3917E-05***	***cpu'.v4'***	***sp4***
EI-29.4.2	1.5006E-10	1.0000E-02	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***4.2549E-05***	***cpu'.v4'***	***sp4'xg2***
EI-29.4.3	1.6085E-12	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***8.5098E-05***	***cpu'.v4'***	***sp4'xg2'xf2***
EI-29.4.4	8.6676E-15	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***8.5098E-05***	***cpu'.v4'***	***sp4'xg2'xf2'***
		2.3929E-05	**2.3959E-05**						
EI-30.1.1	3.1280E-04	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***3.2823E-04***	***cpu.v4***	***sp4***
EI-30.1.2	5.6180E-06	9.9000E-01	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***3.2839E-04***	***cpu.v4***	***sp4'xg2***
EI-30.1.3	1.0522E-07	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***1.1475E-03***	***cpu.v4***	***sp4'xg2'xf2***

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EI-30.1.4	9.4496E-10	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	***1.9125E-03***	***cpu.v4***	***sp4'xg2'xf2'***
EI-30.2.1	6.3869E-06	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***3.2839E-04***	***cpu.v4'***	***sp4***
EI-30.2.2	4.0064E-07	9.9000E-01	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***1.1475E-03***	***cpu.v4'***	***sp4'xg2***
EI-30.2.3	3.5788E-09	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***1.9125E-03***	***cpu.v4'***	***sp4'xg2'xf2***
EI-30.2.4	1.9285E-11	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***1.9125E-03***	***cpu.v4'***	***sp4'xg2'xf2'***
EI-30.3.1	3.1612E-06	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***3.2839E-04***	***cpu'.v4***	***sp4***
EI-30.3.2	1.9830E-07	1.0000E-02	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***1.1475E-03***	***cpu'.v4***	***sp4'xg2***
EI-30.3.3	1.7713E-09	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***1.9125E-03***	***cpu'.v4***	***sp4'xg2'xf2***
EI-30.3.4	9.5451E-12	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	***1.9125E-03***	***cpu'.v4***	***sp4'xg2'xf2'***
EI-30.4.1	6.4514E-08	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***3.2839E-04***	***cpu'.v4'***	***sp4***
EI-30.4.2	4.0468E-09	1.0000E-02	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***1.1475E-03***	***cpu'.v4'***	***sp4'xg2***
EI-30.4.3	3.6150E-11	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***1.9125E-03***	***cpu'.v4'***	***sp4'xg2'xf2***
EI-30.4.4	1.9480E-13	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***1.9125E-03***	***cpu'.v4'***	***sp4'xg2'xf2'***
		3.2875E-04	***3.2978E-04***						
EI-31.1.1	1.8610E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***1.9589E-04***	***cpu.v1***	***sp1***
EI-31.1.2	3.9358E-06	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***1.9589E-04***	***cpu.v1***	***sp1'xg2***
EI-31.1.3	2.6878E-08	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***2.4960E-04***	***cpu.v1***	***sp1'xg2'xf2***
EI-31.1.4	2.4140E-10	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***4.1600E-04***	***cpu.v1***	***sp1'xg2'xf2'***
EI-31.2.1	3.7979E-06	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***1.9589E-04***	***cpu.v1'***	***sp1***
EI-31.2.2	1.0234E-07	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***2.4960E-04***	***cpu.v1'***	***sp1'xg2***
EI-31.2.3	9.1423E-10	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***4.1600E-04***	***cpu.v1'***	***sp1'xg2'xf2***
EI-31.2.4	4.9264E-12	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***4.1600E-04***	***cpu.v1'***	***sp1'xg2'xf2'***

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EI-31.3.1	1.8798E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***1.9589E-04***	***cpu'.v1***	***sp1***
EI-31.3.2	5.0656E-08	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***2.4960E-04***	***cpu'.v1***	***sp1'xg2***
EI-31.3.3	4.5250E-10	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***4.1600E-04***	***cpu'.v1***	***sp1'xg2'xf2***
EI-31.3.4	2.4383E-12	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***4.1600E-04***	***cpu'.v1***	***sp1'xg2'xf2'***
EI-31.4.1	3.8362E-08	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***1.9589E-04***	***cpu'.v1'***	***sp1***
EI-31.4.2	1.0338E-09	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***2.4960E-04***	***cpu'.v1'***	***sp1'xg2***
EI-31.4.3	9.2347E-12	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***4.1600E-04***	***cpu'.v1'***	***sp1'xg2'xf2***
EI-31.4.4	4.9762E-14	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***4.1600E-04***	***cpu'.v1'***	***sp1'xg2'xf2'***
		1.9593E-04	**1.9602E-04**						
EI-32.1.1	1.8330E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***1.9295E-04***	***cpu.v1***	***sp1***
EI-32.1.2	3.8767E-06	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***1.9295E-04***	***cpu.v1***	***sp1'xg2***
EI-32.1.3	6.5042E-08	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***6.0400E-04***	***cpu.v1***	***sp1'xg2'xf2***
EI-32.1.4	5.2573E-10	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***9.0600E-04***	***cpu.v1***	***sp1'xg2'xf2'***
EI-32.2.1	3.7409E-06	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***1.9295E-04***	***cpu.v1'***	***sp1***
EI-32.2.2	2.4766E-07	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***6.0400E-04***	***cpu.v1'***	***sp1'xg2***
EI-32.2.3	1.9911E-09	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***9.0600E-04***	***cpu.v1'***	***sp1'xg2'xf2***
EI-32.2.4	1.0729E-11	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	**5.3597E-03**	***9.0600E-04***	***cpu.v1'***	***sp1'xg2'xf2'***
EI-32.3.1	1.8515E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***1.9295E-04***	***cpu'.v1***	***sp1***
EI-32.3.2	1.2258E-07	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***6.0400E-04***	***cpu'.v1***	***sp1'xg2***
EI-32.3.3	9.8549E-10	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***9.0600E-04***	***cpu'.v1***	***sp1'xg2'xf2***
EI-32.3.4	5.3104E-12	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***9.0600E-04***	***cpu'.v1***	***sp1'xg2'xf2'***
EI-32.4.1	3.7787E-08	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***1.9295E-04***	***cpu'.v1'***	***sp1***
EI-32.4.2	2.5016E-09	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***6.0400E-04***	***cpu'.v1'***	***sp1'xg2***

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EI-32.4.3	2.0112E-11	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	9.0600E-04	cpu'.v1'	sp1'xg2'xf2
EI-32.4.4	1.0838E-13	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	9.0600E-04	cpu'.v1'	sp1'xg2'xf2'
		1.9325E-04	1.9371E-04						
EI-33.1.1	3.8320E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	4.0337E-04	cpu.v1	sp1
EI-33.1.2	8.1044E-06	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	4.0337E-04	cpu.v1	sp1'xg2
EI-33.1.3	2.3609E-07	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	2.1924E-03	cpu.v1	sp1'xg2'xf2
EI-33.1.4	2.1203E-09	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	3.6540E-03	cpu.v1	sp1'xg2'xf2'
EI-33.2.1	7.8204E-06	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	4.0337E-04	cpu.v1'	sp1
EI-33.2.2	8.9896E-07	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	2.1924E-03	cpu.v1'	sp1'xg2
EI-33.2.3	8.0303E-09	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	3.6540E-03	cpu.v1'	sp1'xg2'xf2
EI-33.2.4	4.3272E-11	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	3.6540E-03	cpu.v1'	sp1'xg2'xf2'
EI-33.3.1	3.8707E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	4.0337E-04	cpu'.v1	sp1
EI-33.3.2	4.4494E-07	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	2.1924E-03	cpu'.v1	sp1'xg2
EI-33.3.3	3.9746E-09	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	3.6540E-03	cpu'.v1	sp1'xg2'xf2
EI-33.3.4	2.1418E-11	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	3.6540E-03	cpu'.v1	sp1'xg2'xf2'
EI-33.4.1	7.8994E-08	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	4.0337E-04	cpu'.v1'	sp1
EI-33.4.2	9.0804E-09	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	2.1924E-03	cpu'.v1'	sp1'xg2
EI-33.4.3	8.1114E-11	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	3.6540E-03	cpu'.v1'	sp1'xg2'xf2
EI-33.4.4	4.3709E-13	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	3.6540E-03	cpu'.v1'	sp1'xg2'xf2'
		4.0468E-04	4.0665E-04						
EI-34.1.1	2.8100E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	2.9579E-04	cpu.v1	sp1
EI-34.1.2	5.9429E-06	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	2.9579E-04	cpu.v1	sp1'xg2
EI-34.1.3	8.1920E-08	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	7.6073E-04	cpu.v1	sp1'xg2'xf2
EI-34.1.4	8.8289E-10	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	1.5215E-03	cpu.v1	sp1'xg2'xf2'

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EI-34.2.1	5.7347E-06	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***2.9579E-04***	***cpu.v1'***	***sp1***
EI-34.2.2	3.1193E-07	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***7.6073E-04***	***cpu.v1'***	***sp1'xg2***
EI-34.2.3	3.3438E-09	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***1.5215E-03***	***cpu.v1'***	***sp1'xg2'xf2***
EI-34.2.4	1.8018E-11	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***1.5215E-03***	***cpu.v1'***	***sp1'xg2'xf2'***
EI-34.3.1	2.8384E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***2.9579E-04***	***cpu'.v1***	***sp1***
EI-34.3.2	1.5439E-07	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***7.6073E-04***	***cpu'.v1***	***sp1'xg2***
EI-34.3.3	1.6550E-09	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***1.5215E-03***	***cpu'.v1***	***sp1'xg2'xf2***
EI-34.3.4	8.9181E-12	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***1.5215E-03***	***cpu'.v1***	***sp1'xg2'xf2'***
EI-34.4.1	5.7926E-08	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***2.9579E-04***	***cpu'.v1'***	***sp1***
EI-34.4.2	3.1508E-09	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***7.6073E-04***	***cpu'.v1'***	***sp1'xg2***
EI-34.4.3	3.3775E-11	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***1.5215E-03***	***cpu'.v1'***	***sp1'xg2'xf2***
EI-34.4.4	1.8200E-13	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***1.5215E-03***	***cpu'.v1'***	***sp1'xg2'xf2'***
		2.9613E-04	***2.9669E-04***						
EI-35.1.1	6.2100E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***6.5368E-04***	***cpu.v1***	***sp1***
EI-35.1.2	1.3134E-05	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***6.5368E-04***	***cpu.v1***	***sp1'xg2***
EI-35.1.3	7.1073E-07	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***6.6000E-03***	***cpu.v1***	***sp1'xg2'xf2***
EI-35.1.4	5.7447E-09	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***9.9000E-03***	***cpu.v1***	***sp1'xg2'xf2'***
EI-35.2.1	1.2673E-05	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***6.5368E-04***	***cpu.v1'***	***sp1***
EI-35.2.2	2.7062E-06	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***6.6000E-03***	***cpu.v1'***	***sp1'xg2***
EI-35.2.3	2.1757E-08	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***9.9000E-03***	***cpu.v1'***	***sp1'xg2'xf2***
EI-35.2.4	1.1724E-10	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***9.9000E-03***	***cpu.v1'***	***sp1'xg2'xf2'***
EI-35.3.1	6.2727E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***6.5368E-04***	***cpu'.v1***	***sp1***
EI-35.3.2	1.3394E-06	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***6.6000E-03***	***cpu'.v1***	***sp1'xg2***

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EI-35.3.3	1.0769E-08	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***9.9000E-03***	***cpu'.v1***	***sp1'xg2'xf2***
EI-35.3.4	5.8028E-11	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***9.9000E-03***	***cpu'.v1***	***sp1'xg2'xf2'***
EI-35.4.1	1.2801E-07	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***6.5368E-04***	***cpu'.v1'***	***sp1***
EI-35.4.2	2.7336E-08	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***6.6000E-03***	***cpu'.v1'***	***sp1'xg2***
EI-35.4.3	2.1977E-10	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***9.9000E-03***	***cpu'.v1'***	***sp1'xg2'xf2***
EI-35.4.4	1.1842E-12	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***9.9000E-03***	***cpu'.v1'***	***sp1'xg2'xf2'***
		6.5803E-04	***6.6441E-04***						
EI-36.1.1	3.2230E-04	9.9000E-01	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***3.3926E-04***	***cpu.v1***	***sp1***
EI-36.1.2	6.8163E-06	9.9000E-01	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***3.3926E-04***	***cpu.v1***	***sp1'xg2***
EI-36.1.3	1.4045E-07	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***1.3043E-03***	***cpu.v1***	***sp1'xg2'xf2***
EI-36.1.4	1.7660E-09	9.9000E-01	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***3.0433E-03***	***cpu.v1***	***sp1'xg2'xf2'***
EI-36.2.1	6.5775E-06	9.9000E-01	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***3.3926E-04***	***cpu.v1'***	***sp1***
EI-36.2.2	5.3481E-07	9.9000E-01	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***1.3043E-03***	***cpu.v1'***	***sp1'xg2***
EI-36.2.3	6.6882E-09	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***3.0433E-03***	***cpu.v1'***	***sp1'xg2'xf2***
EI-36.2.4	3.6040E-11	9.9000E-01	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***3.0433E-03***	***cpu.v1'***	***sp1'xg2'xf2'***
EI-36.3.1	3.2555E-06	1.0000E-02	9.8000E-01	9.7918E-01	1.0000E+00	1.0000E+00	***3.3926E-04***	***cpu'.v1***	***sp1***
EI-36.3.2	2.6470E-07	1.0000E-02	9.8000E-01	2.0820E-02	9.9464E-01	1.0000E+00	***1.3043E-03***	***cpu'.v1***	***sp1'xg2***
EI-36.3.3	3.3103E-09	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	9.9464E-01	***3.0433E-03***	***cpu'.v1***	***sp1'xg2'xf2***
EI-36.3.4	1.7838E-11	1.0000E-02	9.8000E-01	2.0820E-02	5.3597E-03	5.3597E-03	***3.0433E-03***	***cpu'.v1***	***sp1'xg2'xf2'***
EI-36.4.1	6.6439E-08	1.0000E-02	2.0000E-02	9.7918E-01	1.0000E+00	1.0000E+00	***3.3926E-04***	***cpu'.v1'***	***sp1***
EI-36.4.2	5.4021E-09	1.0000E-02	2.0000E-02	2.0820E-02	9.9464E-01	1.0000E+00	***1.3043E-03***	***cpu'.v1'***	***sp1'xg2***
EI-36.4.3	6.7557E-11	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	9.9464E-01	***3.0433E-03***	***cpu'.v1'***	***sp1'xg2'xf2***
EI-36.4.4	3.6404E-13	1.0000E-02	2.0000E-02	2.0820E-02	5.3597E-03	5.3597E-03	***3.0433E-03***	***cpu'.v1'***	***sp1'xg2'xf2'***

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		3.3997E-04	3.4110E-04						
EI-37.1.1	3.9389E-05	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	4.1332E-05	cpu.v4	sp4
EI-37.1.2	7.0712E-07	9.9000E-01	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	4.1333E-05	cpu.v4	sp4'xg2
EI-37.1.3	1.7018E-08	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	1.8560E-04	cpu.v4	sp4'xg2'xf2
EI-37.1.4	1.3756E-10	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	2.7840E-04	cpu.v4	sp4'xg2'xf2'
EI-37.2.1	8.0388E-07	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	4.1333E-05	cpu.v4'	sp4
EI-37.2.2	6.4800E-08	9.9000E-01	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	1.8560E-04	cpu.v4'	sp4'xg2
EI-37.2.3	5.2097E-10	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	2.7840E-04	cpu.v4'	sp4'xg2'xf2
EI-37.2.4	2.8073E-12	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	2.7840E-04	cpu.v4'	sp4'xg2'xf2'
EI-37.3.1	3.9788E-07	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	4.1333E-05	cpu'.v4	sp4
EI-37.3.2	3.2073E-08	1.0000E-02	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	1.8560E-04	cpu'.v4	sp4'xg2
EI-37.3.3	2.5785E-10	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	2.7840E-04	cpu'.v4	sp4'xg2'xf2
EI-37.3.4	1.3895E-12	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	2.7840E-04	cpu'.v4	sp4'xg2'xf2'
EI-37.4.1	8.1200E-09	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	4.1333E-05	cpu'.v4'	sp4
EI-37.4.2	6.5455E-10	1.0000E-02	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	1.8560E-04	cpu'.v4'	sp4'xg2
EI-37.4.3	5.2623E-12	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	2.7840E-04	cpu'.v4'	sp4'xg2'xf2
EI-37.4.4	2.8356E-14	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	2.7840E-04	cpu'.v4'	sp4'xg2'xf2'
		4.1422E-05	4.1594E-05						
EI-38.1.1	1.0200E-04	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	1.0703E-04	cpu.v4	sp4
EI-38.1.2	1.8310E-06	9.9000E-01	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	1.0703E-04	cpu.v4	sp4'xg2
EI-38.1.3	5.8072E-08	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	6.3333E-04	cpu.v4	sp4'xg2'xf2
EI-38.1.4	9.3879E-10	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	1.9000E-03	cpu.v4	sp4'xg2'xf2'
EI-38.2.1	2.0816E-06	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	1.0703E-04	cpu.v4'	sp4

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EI-38.2.2	2.2112E-07	9.9000E-01	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***6.3333E-04***	***cpu.v4'***	***sp4'xg2***
EI-38.2.3	3.5554E-09	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***1.9000E-03***	***cpu.v4'***	***sp4'xg2'xf2***
EI-38.2.4	1.9159E-11	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***1.9000E-03***	***cpu.v4'***	***sp4'xg2'xf2'***
EI-38.3.1	1.0303E-06	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***1.0703E-04***	***cpu'.v4***	***sp4***
EI-38.3.2	1.0944E-07	1.0000E-02	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***6.3333E-04***	***cpu'.v4***	***sp4'xg2***
EI-38.3.3	1.7598E-09	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***1.9000E-03***	***cpu'.v4***	***sp4'xg2'xf2***
EI-38.3.4	9.4827E-12	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	***1.9000E-03***	***cpu'.v4***	***sp4'xg2'xf2'***
EI-38.4.1	2.1027E-08	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***1.0703E-04***	***cpu'.v4'***	***sp4***
EI-38.4.2	2.2335E-09	1.0000E-02	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***6.3333E-04***	***cpu'.v4'***	***sp4'xg2***
EI-38.4.3	3.5914E-11	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***1.9000E-03***	***cpu'.v4'***	***sp4'xg2'xf2***
EI-38.4.4	1.9352E-13	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***1.9000E-03***	***cpu'.v4'***	***sp4'xg2'xf2'***
		1.0736E-04	**1.0802E-04**						
EI-39.1.1	1.2890E-04	9.9000E-01	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***1.3526E-04***	***cpu.v4***	***sp4***
EI-39.1.2	2.3140E-06	9.9000E-01	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***1.3526E-04***	***cpu.v4***	***sp4'xg2***
EI-39.1.3	5.3640E-08	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***5.8500E-04***	***cpu.v4***	***sp4'xg2'xf2***
EI-39.1.4	4.3357E-10	9.9000E-01	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	***8.7750E-04***	***cpu.v4***	***sp4'xg2'xf2'***
EI-39.2.1	2.6307E-06	9.9000E-01	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	***1.3526E-04***	***cpu.v4'***	***sp4***
EI-39.2.2	2.0425E-07	9.9000E-01	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	***5.8500E-04***	***cpu.v4'***	***sp4'xg2***
EI-39.2.3	1.6421E-09	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	***8.7750E-04***	***cpu.v4'***	***sp4'xg2'xf2***
EI-39.2.4	8.8484E-12	9.9000E-01	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	***8.7750E-04***	***cpu.v4'***	***sp4'xg2'xf2'***
EI-39.3.1	1.3020E-06	1.0000E-02	9.8000E-01	9.8227E-01	1.0000E+00	1.0000E+00	***1.3526E-04***	***cpu'.v4***	***sp4***
EI-39.3.2	1.0109E-07	1.0000E-02	9.8000E-01	1.7728E-02	9.9464E-01	1.0000E+00	***5.8500E-04***	***cpu'.v4***	***sp4'xg2***
EI-39.3.3	8.1273E-10	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	9.9464E-01	***8.7750E-04***	***cpu'.v4***	***sp4'xg2'xf2***

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EI-39.3.4	4.3795E-12	1.0000E-02	9.8000E-01	1.7728E-02	5.3597E-03	5.3597E-03	8.7750E-04	cpu'.v4	sp4'xg2'xf2'
EI-39.4.1	2.6572E-08	1.0000E-02	2.0000E-02	9.8227E-01	1.0000E+00	1.0000E+00	1.3526E-04	cpu'.v4'	sp4
EI-39.4.2	2.0631E-09	1.0000E-02	2.0000E-02	1.7728E-02	9.9464E-01	1.0000E+00	5.8500E-04	cpu'.v4'	sp4'xg2
EI-39.4.3	1.6586E-11	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	9.9464E-01	8.7750E-04	cpu'.v4'	sp4'xg2'xf2
EI-39.4.4	8.9378E-14	1.0000E-02	2.0000E-02	1.7728E-02	5.3597E-03	5.3597E-03	8.7750E-04	cpu'.v4'	sp4'xg2'xf2'
		1.3554E-04	1.3608E-04						
EI-40.1.1	8.8240E-04	9.9000E-01	9.8000E-01	1.0000E+00	9.9464E-01	1.0000E+00	9.1440E-04	cpu.v2	xg2
EI-40.1.2	4.7294E-06	9.9000E-01	9.8000E-01	1.0000E+00	5.3597E-03	9.9464E-01	9.1440E-04	cpuv2	xg2'xf2
EI-40.1.3	3.3445E-08	9.9000E-01	9.8000E-01	1.0000E+00	5.3597E-03	5.3597E-03	1.2000E-03	cpuv2	xg2'xf2'
EI-40.2.1	1.8008E-05	9.9000E-01	2.0000E-02	1.0000E+00	9.9464E-01	1.0000E+00	9.1440E-04	cpuv2'	xg2
EI-40.2.2	1.2666E-07	9.9000E-01	2.0000E-02	1.0000E+00	5.3597E-03	9.9464E-01	1.2000E-03	cpuv2'	xg2'xf2
EI-40.2.3	6.8254E-10	9.9000E-01	2.0000E-02	1.0000E+00	5.3597E-03	5.3597E-03	1.2000E-03	cpuv2'	xg2'xf2'
EI-40.3.1	8.9131E-06	1.0000E-02	9.8000E-01	1.0000E+00	9.9464E-01	1.0000E+00	9.1440E-04	cpu'v2	xg2
EI-40.3.2	6.2692E-08	1.0000E-02	9.8000E-01	1.0000E+00	5.3597E-03	9.9464E-01	1.2000E-03	cpu'v2	xg2'xf2
EI-40.3.3	3.3782E-10	1.0000E-02	9.8000E-01	1.0000E+00	5.3597E-03	5.3597E-03	1.2000E-03	cpu'v2	xg2'xf2'
EI-40.4.1	1.8190E-07	1.0000E-02	2.0000E-02	1.0000E+00	9.9464E-01	1.0000E+00	9.1440E-04	cpu'v2'	xg2
EI-40.4.2	1.2794E-09	1.0000E-02	2.0000E-02	1.0000E+00	5.3597E-03	9.9464E-01	1.2000E-03	cpu'v2'	xg2'xf2
EI-40.4.3	6.8944E-12	1.0000E-02	2.0000E-02	1.0000E+00	5.3597E-03	5.3597E-03	1.2000E-03	cpu'v2'	xg2'xf2'
		9.1445E-04	9.1485E-04						
EI-41.1	3.5050E-04				Total	EI-41:	3.5050E-04		
EI-42.1.1	2.1893E-04	9.9000E-01	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	2.3412E-04	cpu.v2	sp2
EI-42.1.2	8.1882E-06	9.9000E-01	9.8000E-01	3.6178E-02	9.9464E-01	1.0000E+00	2.3454E-04	cpu.v2	sp2'xg2
EI-42.1..3	4.7385E-08	9.9000E-01	9.8000E-01	3.6178E-02	5.3597E-03	9.9464E-01	2.5324E-04	cpu.v2	sp2'xg2'xf2

Framework A.4.1 Average Societal Risk in Terms of Unavilability/Availability Variables

EI-42.1.4	1.0214E-09	9.9000E-01	9.8000E-01	3.6178E-02	5.3597E-03	5.3597E-03	***1.0130E-03***	cpu.v2	sp2'xg2'xf2'
EI-42.1.4	1.0214E-09	9.9000E-01	9.8000E-01	3.6178E-02	5.3597E-03	5.3597E-03	***1.0130E-03***	cpu.v2	sp2'xg2'xf2'
EI-42.2.1	4.4759E-06	9.9000E-01	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***2.3454E-04***	cpu.v2'	sp2
EI-42.2.2	1.8043E-07	9.9000E-01	2.0000E-02	3.6178E-02	9.9464E-01	1.0000E+00	***2.5324E-04***	cpu.v2'	sp2'xg2
EI-42.2..3	3.8684E-09	9.9000E-01	2.0000E-02	3.6178E-02	5.3597E-03	9.9464E-01	***1.0130E-03***	cpu.v2'	sp2'xg2'xf2
EI-42.2.4	2.0845E-11	9.9000E-01	2.0000E-02	3.6178E-02	5.3597E-03	5.3597E-03	***1.0130E-03***	cpu.v2'	sp2'xg2'xf2'
EI-42.3.1	2.2153E-06	1.0000E-02	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***2.3454E-04***	cpu'.v2	sp2
EI-42.3.2	8.9302E-08	1.0000E-02	9.8000E-01	3.6178E-02	9.9464E-01	1.0000E+00	***2.5324E-04***	cpu'.v2	sp2'xg2
EI-42.3..3	1.9147E-09	1.0000E-02	9.8000E-01	3.6178E-02	5.3597E-03	9.9464E-01	***1.0130E-03***	cpu'.v2	sp2'xg2'xf2
EI-42.3.4	1.0317E-11	1.0000E-02	9.8000E-01	3.6178E-02	5.3597E-03	5.3597E-03	***1.0130E-03***	cpu'.v2	sp2'xg2'xf2'
EI-42.4.1	4.5211E-08	1.0000E-02	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***2.3454E-04***	cpu'.v2'	sp2
EI-42.4.2	1.8225E-09	1.0000E-02	2.0000E-02	3.6178E-02	9.9464E-01	1.0000E+00	***2.5324E-04***	cpu'.v2'	sp2'xg2
EI-42.4..3	3.9074E-11	1.0000E-02	2.0000E-02	3.6178E-02	5.3597E-03	9.9464E-01	***1.0130E-03***	cpu'.v2'	sp2'xg2'xf2
EI-42.4.4	2.1056E-13	1.0000E-02	2.0000E-02	3.6178E-02	5.3597E-03	5.3597E-03	***1.0130E-03***	cpu'.v2'	sp2'xg2'xf2'
		2.3418E-04	***2.3397E-04***						
EI-43	0.0000E+00								
EI-44.1.1	1.1931E-04	9.9000E-01	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***1.2759E-04***	cpu.v2	sp2
EI-44.1.2	4.4544E-06	9.9000E-01	9.8000E-01	3.6178E-02	9.9464E-01	1.0000E+00	***1.2759E-04***	cpu.v2	sp2'xg2
EI-44.1.3	0.0000E+00	9.9000E-01	9.8000E-01	3.6178E-02	5.3597E-03	9.9464E-01	***0.0000E+00***	cpu.v2	sp2'xg2'xf2
EI-44.1.4	0.0000E+00	9.9000E-01	9.8000E-01	3.6178E-02	5.3597E-03	5.3597E-03	***0.0000E+00***	cpu.v2	sp2'xg2'xf2'
EI-44.2.1	2.4349E-06	9.9000E-01	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***1.2759E-04***	cpu.v2'	sp2
EI-44.2.2	0.0000E+00	9.9000E-01	2.0000E-02	3.6178E-02	9.9464E-01	1.0000E+00	***0.0000E+00***	cpu.v2'	sp2'xg2

Framework A.4.1 Average Societal Risk in Terms of Unavilability/Availability Variables

EI-44.2.3	0.0000E+00	9.9000E-01	2.0000E-02	3.6178E-02	5.3597E-03	9.9464E-01	***0.0000E+00***	***cpu.v2'***	***sp2'xg2'xf2***
EI-44.2.4	0.0000E+00	9.9000E-01	2.0000E-02	3.6178E-02	5.3597E-03	5.3597E-03	***0.0000E+00***	***cpu.v2'***	***sp2'xg2'xf2'***
EI-44.3.1	1.2051E-06	1.0000E-02	9.8000E-01	9.6382E-01	1.0000E+00	1.0000E+00	***1.2759E-04***	***cpu'.v2***	***sp2***
EI-44.3.2	0.0000E+00	1.0000E-02	9.8000E-01	3.6178E-02	9.9464E-01	1.0000E+00	***0.0000E+00***	***cpu'.v2***	***sp2'xg2***
EI-44.3.3	0.0000E+00	1.0000E-02	9.8000E-01	3.6178E-02	5.3597E-03	9.9464E-01	***0.0000E+00***	***cpu'.v2***	***sp2'xg2'xf2***
EI-44.3.4	0.0000E+00	1.0000E-02	9.8000E-01	3.6178E-02	5.3597E-03	5.3597E-03	***0.0000E+00***	***cpu'.v2***	***sp2'xg2'xf2'***
EI-44.4.1	2.4595E-08	1.0000E-02	2.0000E-02	9.6382E-01	1.0000E+00	1.0000E+00	***1.2759E-04***	***cpu'.v2'***	***sp2***
EI-44.4.2	0.0000E+00	1.0000E-02	2.0000E-02	3.6178E-02	9.9464E-01	1.0000E+00	***0.0000E+00***	***cpu'.v2'***	***sp2'xg2***
EI-44.4.3	0.0000E+00	1.0000E-02	2.0000E-02	3.6178E-02	5.3597E-03	9.9464E-01	***0.0000E+00***	***cpu'.v2'***	***sp2'xg2'xf2***
EI-44.4.4	0.0000E+00	1.0000E-02	2.0000E-02	3.6178E-02	5.3597E-03	5.3597E-03	***0.0000E+00***	***cpu'.v2'***	***sp2'xg2'xf2'***
		1.2743E-04	**1.2729E-04**						

Framework A.4.1 Average Societal Risk in Terms of Unavilability/Availability Variables

The Average Individual Risk Expression as a function of availability variables will be given by the sum of the following terms:									
3.9679E-03									
-5.1538E-10	c.v1.p1								
2.1290E-03	c.v1.p1.xf1								
2.9730E-04	c.v1.p1.xf2								
1.1596E-05	c.v1.p1.xf3								
1.3058E-05	c.v1.p1.xf4								
1.7308E-10	c.v1.p1.xg1								
3.7039E-04	c.v1.p1.xg2								
-2.9730E-04	c.v1.p1.xg2.xf2								
1.1596E-05	c.v1.p1.xg3								
-1.1596E-05	c.v1.p1.xg3.xf3								
4.0000E-10	c.v1.p1.xg4								
-1.3058E-05	c.v1.p1.xg4.xf4								
-2.2162E-03	c.v1.xf1								
-2.9730E-04	c.v1.xf2								
-1.1596E-05	c.v1.xf3								
-1.3058E-05	c.v1.xf4								
-1.7308E-10	c.v1.xg1								
-3.7039E-04	c.v1.xg2								
2.9730E-04	c.v1.xg2.xf2								
-1.1596E-05	c.v1.xg3								
1.1596E-05	c.v1.xg3.xf3								
-4.0000E-10	c.v1.xg4								
1.3058E-05	c.v1.xg4.xf4								
-3.1475E-06	c.v2.p2								
1.6161E-04	c.v2.p2.xf1								
2.9222E-05	c.v2.p2.xf2								
-4.1883E-06	c.v2.p2.xg2								
-2.9222E-05	c.v2.p2.xg2.xf2								
-1.5848E-04	c.v2.xf1								

Framework A.4.2 - Average Individual Risk Expression in Terms of Availability Variables

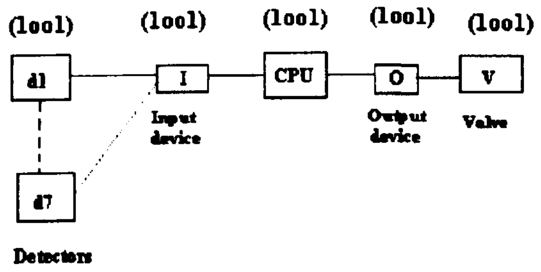
-4.3929E-05	c.v2.xf2								
4.1883E-06	c.v2.xg2								
4.3929E-05	c.v2.xg2.xf2								
6.7900E-05	c.v3.p3.xf2								
4.2619E-06	c.v3.p3.xg2								
-6.7900E-05	c.v3.p3.xg2.xf2								
-6.7900E-05	c.v3.xf2								
-4.2619E-06	c.v3.xg2								
6.7900E-05	c.v3.xg2.xf2								
-7.7692E-09	c.v4.p4								
4.1004E-04	c.v4.p4.xf1								
9.4597E-05	c.v4.p4.xf2								
7.5310E-05	c.v4.p4.xg2								
-9.4597E-05	c.v4.p4.xg2.xf2								
-4.1004E-04	c.v4.xf1								
-9.4597E-05	c.v4.xf2								
-7.5310E-05	c.v4.xg2								
9.4597E-05	c.v4.xg2.xf2								
5.3011E-05	c.xf2								
4.5042E-04	c.xg1								
-4.5042E-04	c.xg2								
-5.3011E-05	cxf2								
-2.8213E-03	p1								
2.9730E-04	p1.xg2								
1.3058E-05	p1.xg4								
-1.8351E-04	p2								
2.9222E-05	p2.xg2								
-7.2162E-05	p3								
6.7900E-05	p3.xg2								
-5.7995E-04	p4								
9.4597E-05	p4.xg2								

Framework A.4.2 - Average Individual Risk Expression in Terms of Availability Variables

-1.3242E-05	v1.p1.xg1.xf4								
1.3242E-05	v1.p1.xg4.xf4								
-9.1204E-05	v1.xf1								
9.1204E-05	v1xf1								
4.5042E-04	xg1								
-9.5415E-04	xg2								
-1.3058E-05	xg4								
8.2651E-06									

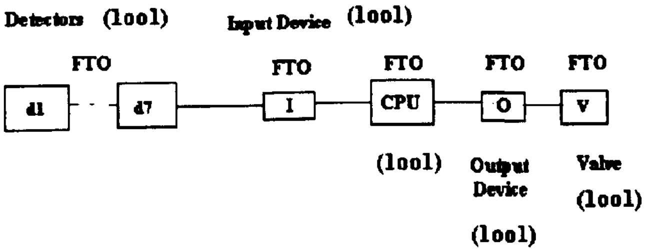
Framework A.4.2 - Average Individual Risk Expression in Terms of Availability Variables

Appendix 5



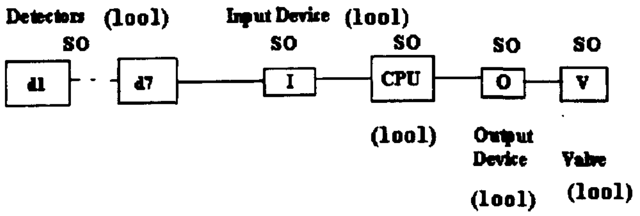
7 detection units / 7 detectors
1 input device
1 CPU
1 output device
1 blockage valve

Figure A.5.1- Case 1 – Schematic Block Diagram – Turret's Fire and Gas Detection Systems



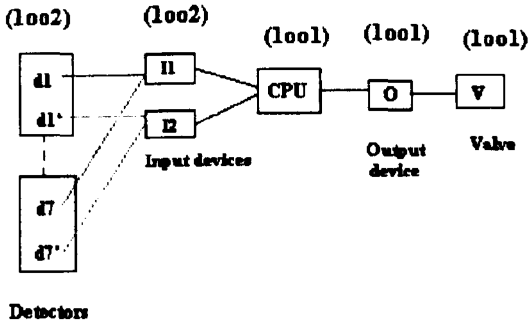
7 detection units/7 detectors (1oo1)
1 input device (1oo1)
1 CPU (1oo1)
1 output device (1oo1)
1 blockage valve (1oo1)

Figure A.5.1.A- Case 1 –Critical Safety Unavailability Block Diagram – Turret's Fire and Gas Detection Systems



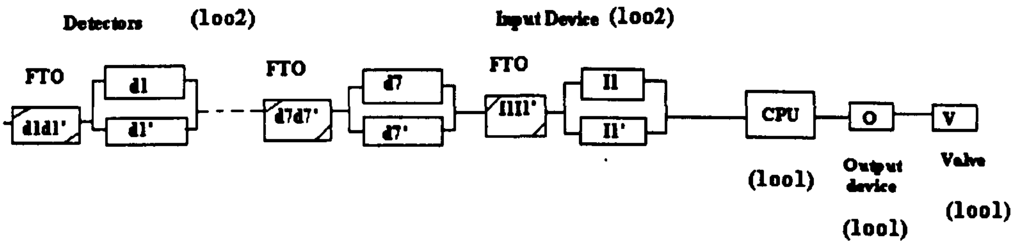
7 detection units / 7 detectors (1oo1)
1 input device (1oo1)
1 CPU (1oo1)
1 output device (1oo1)
1 blockage valve (1oo1)

Figure A.5.1.B – Case 1 – Spurious Operation Block Diagram – Turret's Fire and Gas Detection Systems



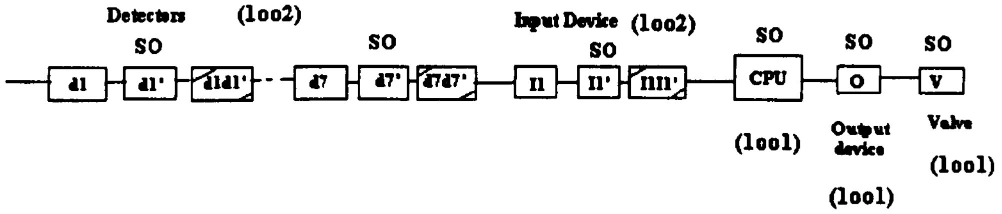
7 detection units / 14 detectors
2 input devices
1 CPU
1 output device
1 blockage valve

Figure A.5.2 – Case 2 – Schematic Diagram – Turret's Fire and Gas Detection Systems



7 detection units (1oo2)
1 input device (1oo2)
1 CPU (1oo1)
1 output device (1oo1)
1 blockage valve (1oo1)

Figure A.5.2.A – Case 2 - Critical Safety Unavailability Block Diagram – Turret's Fire and Gas Detection Systems



7 detection units (1oo2)
1 input device (1oo2)
1 CPU (1oo1)
1 output device (1oo1)
1 blockage valve (1oo1)

Figure A.5.2.B –Case 2 - Spurious Operation Block Diagram – Turret's Fire and Gas Detection Systems

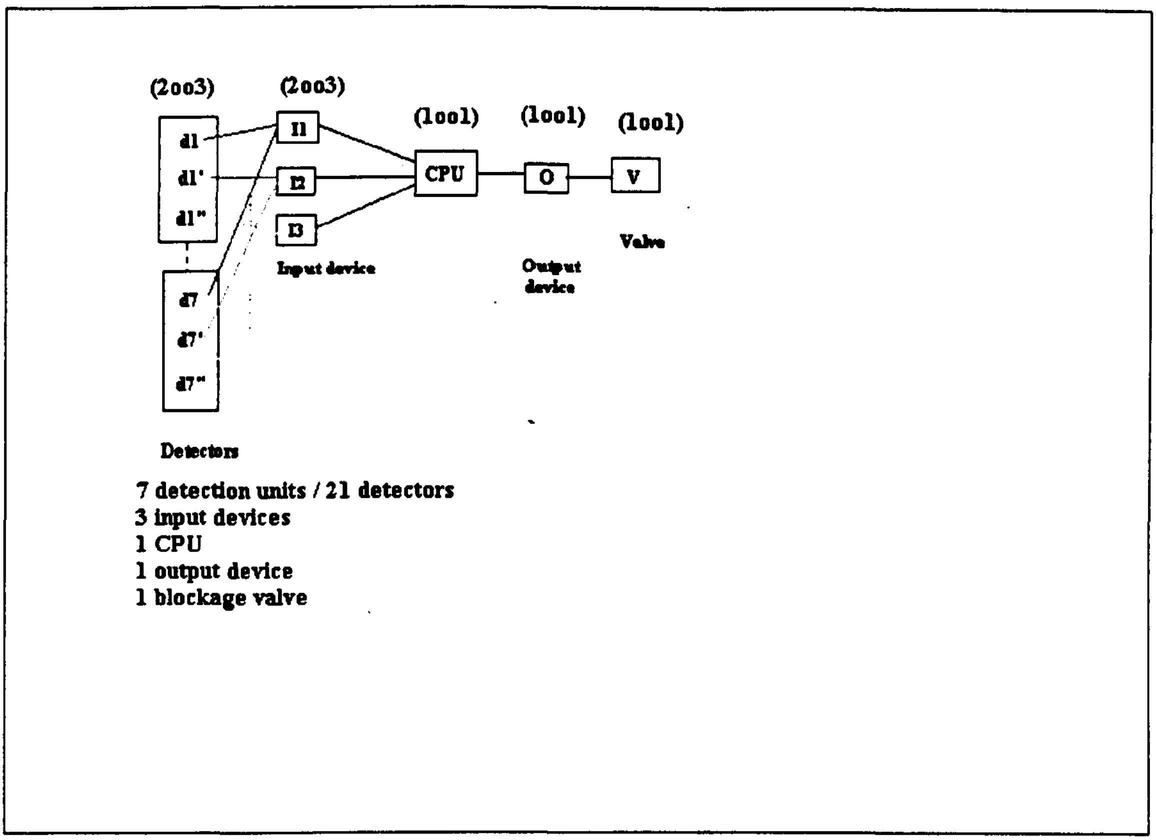


Figure A.5.3 –Case 3 - Schematic Block Diagram – Turret's Fire and Gas Detection Systems

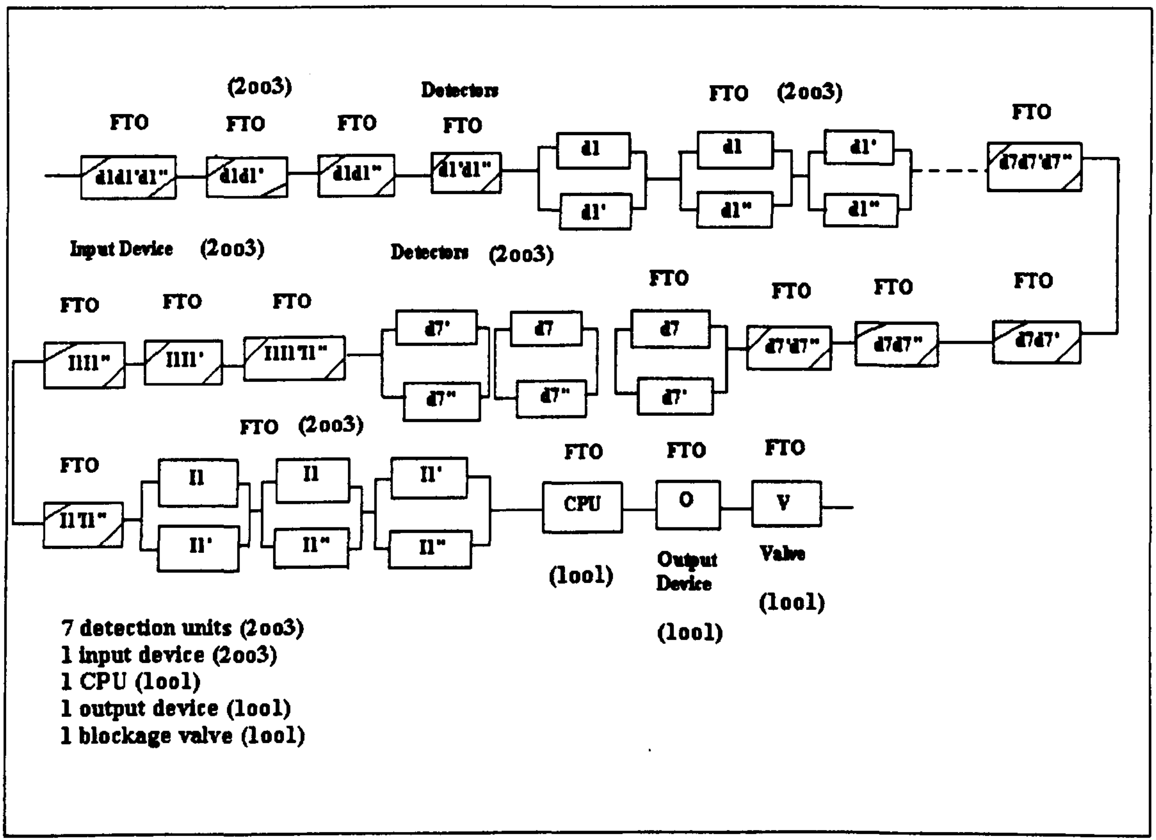


Figure A.5.3.A –Case 3 – Critical Safety Unavailability Block Diagram – Turret's Fire and Gas Detection Systems

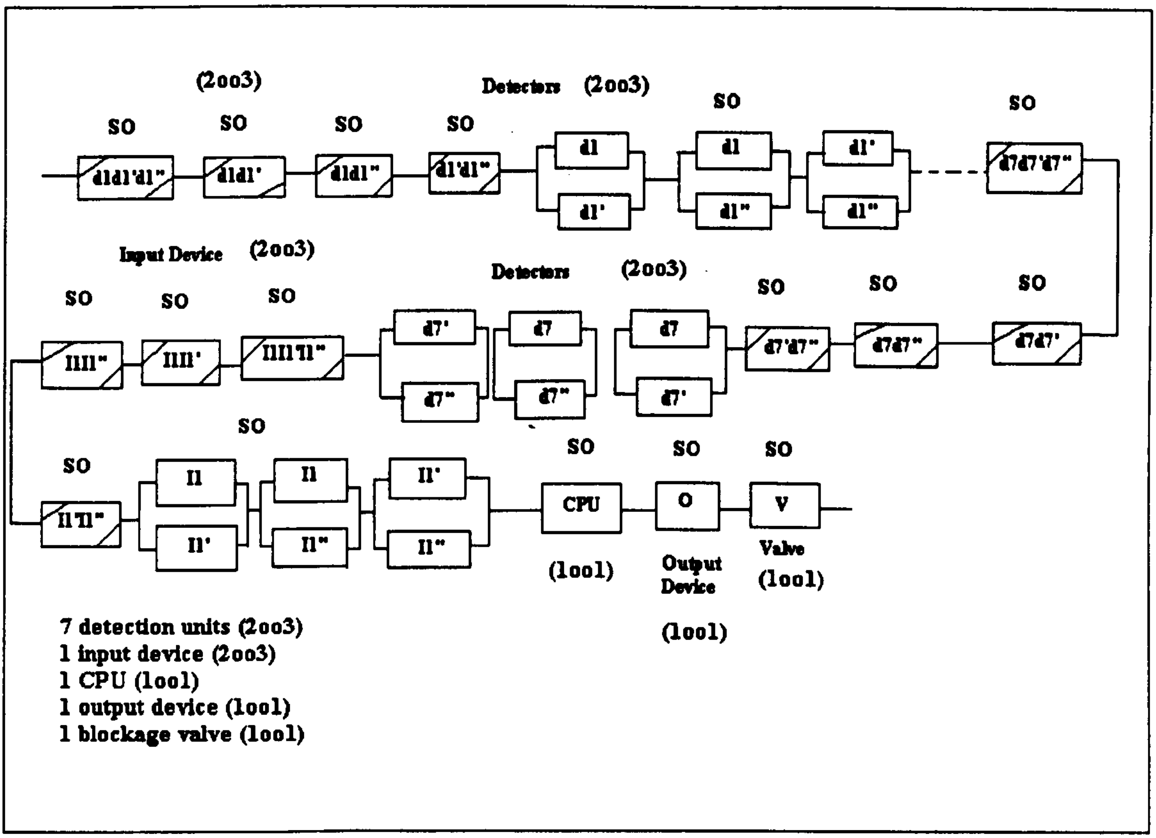


Figure A.5.3.B – Case 3 - Spurious Operation Block Diagram – Turret's Fire and Gas Detection Systems

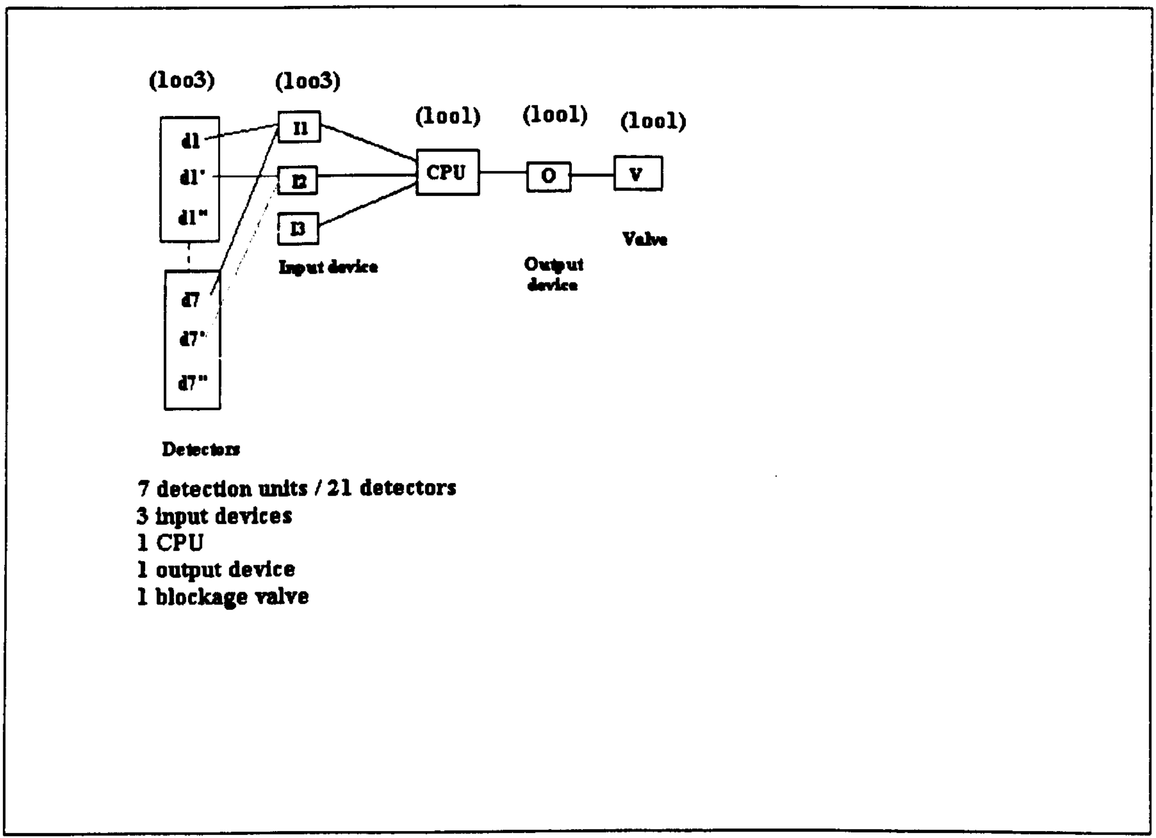


Figure A.5.4 – Case 4 - Schematic Block Diagram – Turret's Fire and Gas Detection Systems

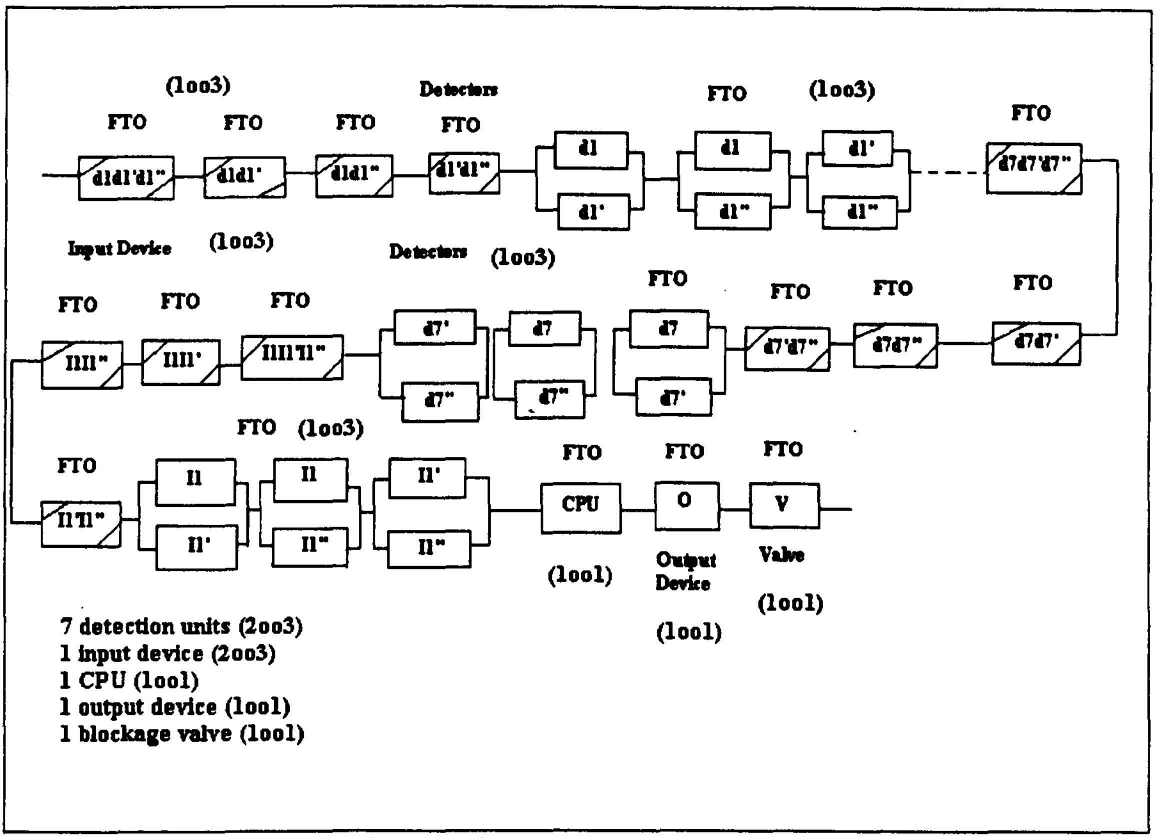


Figure A.5.4.A – Case 4 – Critical Safety Unavailability Block Diagram– Turret's Fire and Gas Detection Systems

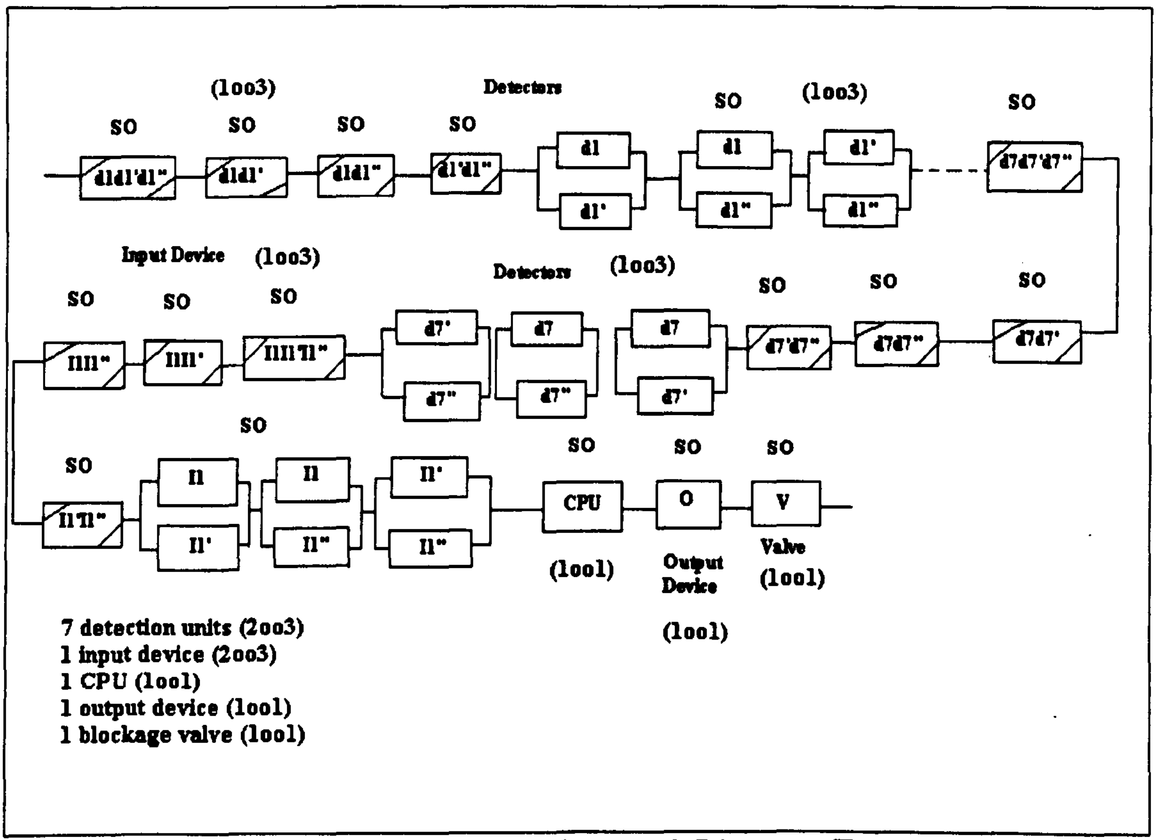
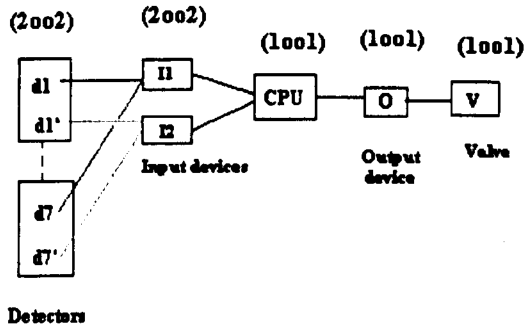
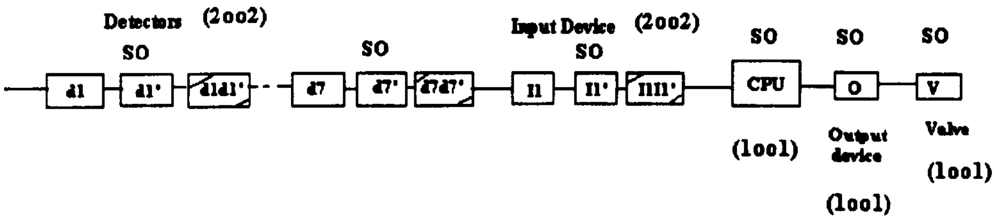


Figure A.5.4.B – Case 4 –Spurious Operation Block Diagram– Turret's Fire and Gas Detection Systems



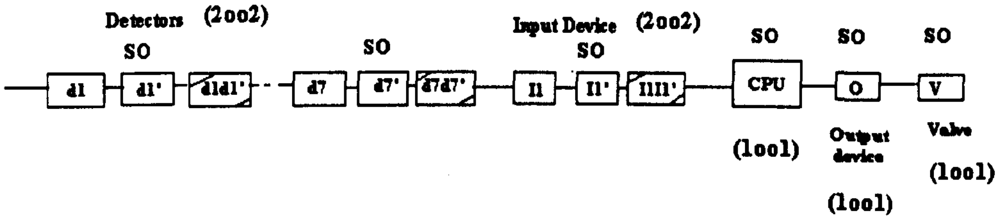
7 detection units / 14 detectors
2 input devices
1 CPU
1 output device
1 blockage valve

Figure A.5.5 – Critical Safety Unavailability Block Diagram – Turret's Fire and Gas Detection Systems



7 detection units (1oo2)
1 input device (1oo2)
1 CPU (1oo1)
1 output device (1oo1)
1 blockage valve (1oo1)

Figure A.5.5.A–Spurious Operation Block Diagram – Turret's Fire and Gas Detection Systems



7 detection units (1oo2)
1 input device (1oo2)
1 CPU (1oo1)
1 output device (1oo1)
1 blockage valve (1oo1)

Figure A.5.5.B – Case 5 – Spurious Operation Block Diagram – Turret's Fire and Gas Detection Systems

Case Number Voting Logic	Approximate Critical Safety Unavailability (CSU)		Approximate rate for Spurious Trips (STR)	
	Fire or Gas Detector	Input Card	Fire or Gas Detector	Input Card
Case1 **1oo1**	$7\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$7\lambda^S$	λ^S
Case 2 **1oo2**	$7\frac{2p2}{p1+2p2}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$\frac{2p2}{p1+2p2}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$7\frac{2}{p1+2p2}\lambda^S$	$\frac{2}{p1+2p2}\lambda^S$
Case 3 **2oo3**	$7\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$7\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^S$	$\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^S$
Case 4 **1oo3**	$7\frac{3p3}{p1+2p2+3p3}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$\frac{3p3}{p1+2p2+3p3}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$7\frac{3}{p1+2p2+3p3}\lambda^S$	$\frac{3}{p1+2p2+3p3}\lambda^S$
Case 5 **2oo2**	$7\frac{2}{p1+2p2}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\left(\lambda^F\frac{\tau}{2}+TIF\right)$	$7\frac{2}{p1+2p2}\lambda^S$	$\frac{2}{p1+2p2}\lambda^S$

Table A.5.1 – Formulas for CSU and STR Calculation – Turret's Fire and Gas Detection Systems

Note: In order to calculate the CSU and STR for the process plant, for the pump room and the machine room, the number seven in the formulas shown (which is associated with 7 fire detection units and 7 gas detection units installed in the turret) should be replaced by the numbers 10, 4 and 8 respectively (since the process plant has 10 detection units installed, the pump room has 4 detection units installed and the machine room has 8 detection units installed.

Case Number Voting Logic	Approximate Critical Safety Unavailability (CSU)		Approximate rate for Spurious Trips (STR)	
	Pressure Sensor	Input Card	Pressure Sensor	Input Card
Case1 1oo1	$\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	λ^{S}	λ^{S}
Case 2 1oo2	$\frac{2p2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2p2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\lambda^{S}$ $7\frac{2}{p1+2p2}\lambda^{S}$	$\frac{2}{p1+2p2}\lambda^{S}$
Case 3 2oo3	$\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^{S}$	$\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^{S}$
Case 4 1oo3	$\frac{3p3}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3p3}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3}{p1+2p2+3p3}\lambda^{S}$	$\frac{3}{p1+2p2+3p3}\lambda^{S}$
Case 5 2oo2	$\frac{2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\lambda^{S}$	$\frac{2}{p1+2p2}\lambda^{S}$

Table A.5.2 – Formulas for CSU and STR Calculations – Pressure Sensor System

Case Number Voting Logic	Approximate Critical Safety Unavailability (CSU)	Approximate rate for Spurious Trips (STR)
	CPU	CPU
Case1 1oo1	$\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	λ^{S}
Case 2 1oo2	$\frac{2p2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\lambda^{S}$
Case 3 2oo3	$\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^{S}$
Case 4 1oo3	$\frac{3p3}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3}{p1+2p2+3p3}\lambda^{S}$
Case 5 2oo2	$\frac{2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\lambda^{S}$

Table A.5.3 Formulas for CSU and STR Calculations – CPU System

Case Number Voting Logic	Approximate Critical Safety Unavailability (CSU)		Approximate rate for Spurious Trips (STR)	
	Valve	Output Card	Valve	Output Card Input Card
Case1 1oo1	$\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	λ^{s}	λ^{s}
Case 2 1oo2	$\frac{2p2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2p2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\lambda^{s}$ $7\frac{2}{p1+2p2}\lambda^{s}$	$\frac{2}{p1+2p2}\lambda^{s}$
Case 3 2oo3	$\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3(p2+p3)}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^{s}$	$\frac{3(p2+p3)}{p1+2p2+3p3}\lambda^{s}$
Case 4 1oo3	$\frac{3p3}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3p3}{p1+2p2+3p3}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{3}{p1+2p2+3p3}\lambda^{s}$	$\frac{3}{p1+2p2+3p3}\lambda^{s}$
Case 5 2oo2	$\frac{2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\left(\lambda^{F}\frac{\tau}{2}+TIF\right)$	$\frac{2}{p1+2p2}\lambda^{s}$	$\frac{2}{p1+2p2}\lambda^{s}$

Table A.5.4 – Formulas for CSU and STR Calculations – Actuation System

Appendix 6

Module subset	Total Rate of FTO failures per 10^6 hrs	Coverage factor for self test for FTO failures	Module complexity factor	Rate of undetect. FTO failures per 10^6hrs.	Probability of test independent failures	Multiplicity distribution			Manual Test period in hrs.
	λFtot	C	cM	λF	TIF probability	p1	p2	p3	τ
Fire	3,00E-06	0,00	1,00	3,0000E-06	0,0050	0,90	0,1		2160
Detector	3,00E-06	0,00	1,00	3,0000E-06	0,0050	0,82	0,16	0,02	2160
Gas	2,0000E-06	0,00	1,00	2,0000E-06	0,0050	0,90	0,1		2160
Detector	2,0000E-06	0,00	1,00	2,0000E-06	0,0050	0,82	0,16	0,02	2160
Pressure	6,7110E-06	0,00	1,00	6,7110E-06	0,0050	0,90	0,1		2160
sensor	6,7110E-06	0,00	1,00	6,7110E-06	0,0050	0,82	0,16	0,02	2160
Input card	4,5000E-07		1,00	4,5000E-07	0,0000	0,90	0,1		2160
	4,5000E-07		1,00	4,5000E-07	0,0000	0,82	0,16	0,02	2160
CPU	1,2000E-05	0,90	1,00	1,2000E-06	0,0001	0,90	0,1		2160
	1,2000E-05	0,90	1,00	1,2000E-06	0,0001	0,82	0,16	0,02	2160
Output card	4,5000E-07		1,00	4,5000E-07	0,0000	0,90	0,1		2160
	4,5000E-07		1,00	4,5000E-07	0,0000	0,82	0,16	0,02	2160
Valve	8,0000E-06		1,00	8,0000E-06	0,0010	0,90	0,1		2160
	8,0000E-06		1,00	8,0000E-06	0,0010	0,82	0,16	0,02	2160

Framework A.6.1 - Data Used for Critical Safety Calculations

Safety System	Case Number	Turret		Process	Plant	Pump	Room	Machine	Room
		CSU	CSA	CSU	CSA	CSU	CSA	CSU	CSA
Fire Detection	Case 1	5,81660E-02	9,41834E-01	8,28860E-02	9,17114E-01	3,34460E-02	9,66554E-01	6,64060E-02	9,33594E-01
	Case 2	1,05756E-02	9,89424E-01	1,50702E-02	9,84930E-01	6,08109E-03	9,93919E-01	1,20738E-02	9,87926E-01
	Case 3	2,61747E-02	9,73825E-01	3,72987E-02	9,62701E-01	1,50507E-02	9,84949E-01	2,98827E-02	9,70117E-01
	Case 4	2,90830E-03	9,97092E-01	4,14430E-03	9,95856E-01	1,67230E-03	9,98328E-01	3,32030E-03	9,96680E-01
	Case 5	1,05756E-01	8,94244E-01	1,50702E-01	8,49298E-01	6,08109E-02	9,39189E-01	1,20738E-01	8,79262E-01
Gas Detection	Case 1	5,06060E-02	9,49394E-01	7,20860E-02	9,27914E-01	2,91260E-02	9,70874E-01	5,77660E-02	9,42234E-01
	Case 2	9,20109E-03	9,90799E-01	1,31065E-02	9,86893E-01	5,29564E-03	9,94704E-01	1,05029E-02	9,89497E-01
	Case 3	2,27727E-02	9,77227E-01	3,24387E-02	9,67561E-01	1,31067E-02	9,86893E-01	2,59947E-02	9,74005E-01
	Case 4	2,53030E-03	9,97470E-01	3,60430E-03	9,96396E-01	1,45630E-03	9,98544E-01	2,88830E-03	9,97112E-01
	Case 5	9,20109E-02	9,07989E-01	1,31065E-01	8,68935E-01	5,29564E-02	9,47044E-01	1,05029E-01	8,94971E-01
Pressure Sensor	Case 1	1,27339E-02	9,87266E-01	1,27339E-02	9,87266E-01	1,27339E-02	9,87266E-01	1,27339E-02	9,87266E-01
	Case 2	2,31525E-03	9,97685E-01	2,31525E-03	9,97685E-01	2,31525E-03	9,97685E-01	2,31525E-03	9,97685E-01
	Case 3	5,73025E-03	9,94270E-01	5,73025E-03	9,94270E-01	5,73025E-03	9,94270E-01	5,73025E-03	9,94270E-01
	Case 4	6,36694E-04	9,99363E-01	6,36694E-04	9,99363E-01	6,36694E-04	9,99363E-01	6,36694E-04	9,99363E-01
	Case 5	2,31525E-02	9,76847E-01	2,31525E-02	9,76847E-01	2,31525E-02	9,76847E-01	2,31525E-02	9,76847E-01
CPU	Case 1	1,39600E-03	9,98604E-01	1,39600E-03	9,98604E-01	1,39600E-03	9,98604E-01	1,39600E-03	9,98604E-01
	Case 2	2,53818E-04	9,99746E-01	2,53818E-04	9,99746E-01	2,53818E-04	9,99746E-01	2,53818E-04	9,99746E-01
	Case 3	6,28200E-04	9,99372E-01	6,28200E-04	9,99372E-01	6,28200E-04	9,99372E-01	6,28200E-04	9,99372E-01
	Case 4	6,98000E-05	9,99930E-01	6,98000E-05	9,99930E-01	6,98000E-05	9,99930E-01	6,98000E-05	9,99930E-01
	Case 5	2,53818E-03	9,97462E-01	2,53818E-03	9,97462E-01	2,53818E-03	9,97462E-01	2,53818E-03	9,97462E-01
Actuator (Valve)	Case 1	1,01260E-02	9,89874E-01	1,01260E-02	9,89874E-01	1,01260E-02	9,89874E-01	1,01260E-02	9,89874E-01
	Case 2	1,84109E-03	9,98159E-01	1,84109E-03	9,98159E-01	1,84109E-03	9,98159E-01	1,84109E-03	9,98159E-01
	Case 3	4,55670E-03	9,95443E-01	4,55670E-03	9,95443E-01	4,55670E-03	9,95443E-01	4,55670E-03	9,95443E-01
	Case 4	5,06300E-04	9,99494E-01	5,06300E-04	9,99494E-01	5,06300E-04	9,99494E-01	5,06300E-04	9,99494E-01
	Case 5	1,84109E-02	9,81589E-01	1,84109E-02	9,81589E-01	1,84109E-02	9,81589E-01	1,84109E-02	9,81589E-01

Framework A.6.2 – Critical Safety Unavailability/Availability Values Calculated for the Studied Safety Systems

Module subset	Total Rate of SO failures per 10^6 hrs λStot	Coverage factor for self test of SO failures C	Module complexity factor cM	Rate of (1) undetect. SO failures per 10^6hrs. λS	Multiplicity distribution			Manual Test period in hrs. τ
					p1	p2	p3	
Fire Detector	2,0000E-06		1,00	2,0000E-06	0,90	0,1		2160
	2,0000E-06		1,00	2,0000E-06	0,82	0,16	0,02	2160
Gas detector	2,0000E-06		1,00	2,0000E-06	0,90	0,1		2160
	2,0000E-06		1,00	2,0000E-06	0,82	0,16	0,02	2160
Pressure	1,6000E-06		1,00	1,6000E-06	0,90	0,1		2160
Sensor	1,6000E-06		1,00	1,6000E-06	0,82	0,16	0,02	2160
Input card	1,3500E-06		1,00	1,3500E-06	0,90	0,1		2160
	1,3500E-06		1,00	1,3500E-06	0,82	0,16	0,02	2160
CPU	1,2000E-05	0,90	1,00	1,2000E-06	0,90	0,1		2160
	1,2000E-05	0,90	1,00	1,2000E-06	0,82	0,16	0,02	2160
Output card	4,5000E-07		1,00	4,5000E-07	0,90	0,1		2160
	4,5000E-07		1,00	4,5000E-07	0,82	0,16	0,02	2160
Valve	8,0000E-06		1,00	8,0000E-06	0,90	0,1		2160
	8,0000E-06		1,00	8,0000E-06	0,82	0,16	0,02	

Framework A.6.3 – Data used for Spurious Trip Rate (STR) Calculations

Note 1: The rate of undetectable SO failures λ S is obtained by multiplying the total SO failures λ**Stot** with the factors **(1-C).cM**

Safety System	Case Number	Turret		Process Plant		Pump Room		Machine Room	
		Spurious Trip Rate (STR)	Number of spurious trips per year	Spurious Trip Rate (STR)	Number of spurious trips (per year)	Spurious Trip Rate (STR)	Number of spurious trips p/year	Spurious Trip Rate (STR)	Number of spurious trips per year
Fire Detection	*Case 1*	*1,53500E-05*	*1,34466E-01*	*2,13500E-05*	*1,87026E-01*	*9,35000E-06*	*8,19060E-02*	*1,73500E-05*	*1,51986E-01*
	Case 2	*2,79091E-05*	*2,44484E-01*	*3,88182E-05*	*3,40047E-01*	*1,70000E-05*	*1,48920E-01*	*3,15455E-05*	*2,76338E-01*
	Case 3	*6,90750E-06*	*6,05097E-02*	*9,60750E-06*	*8,41617E-02*	*4,20750E-06*	*3,68577E-02*	*7,80750E-06*	*6,83937E-02*
	Case 4	*3,83750E-05*	*3,36165E-01*	*5,33750E-05*	*4,67565E-01*	*2,33750E-05*	*2,04765E-01*	*4,33750E-05*	*3,79965E-01*
	Case 5	*2,79091E-06*	*2,44484E-02*	*3,88182E-06*	*3,40047E-02*	*1,70000E-06*	*1,48920E-02*	*3,15455E-06*	*2,76338E-02*
Gas Detection	*Case 1*	*1,53500E-05*	*1,34466E-01*	*2,13500E-05*	*1,87026E-01*	*9,35000E-06*	*8,19060E-02*	*1,73500E-05*	*1,51986E-01*
	Case 2	*2,79091E-05*	*2,44484E-01*	*3,88182E-05*	*3,40047E-01*	*1,70000E-05*	*1,48920E-01*	*3,15455E-05*	*2,76338E-01*
	Case 3	*6,90750E-06*	*6,05097E-02*	*9,60750E-06*	*8,41617E-02*	*4,20750E-06*	*3,68577E-02*	*7,80750E-06*	*6,83937E-02*
	Case 4	*3,83750E-05*	*3,36165E-01*	*5,33750E-05*	*4,67565E-01*	*2,33750E-05*	*2,04765E-01*	*4,33750E-05*	*3,79965E-01*
	Case 5	*2,79091E-06*	*2,44484E-02*	*3,88182E-06*	*3,40047E-02*	*1,70000E-06*	*1,48920E-02*	*3,15455E-06*	*2,76338E-02*
Pressure Sensor	*Case 1*	*2,95000E-06*	*2,58420E-02*	*2,95000E-06*	*2,58420E-02*	*2,95000E-06*	*2,58420E-02*	*2,95000E-06*	*2,58420E-02*
	Case 2	*5,36364E-06*	*4,69855E-02*	*5,36364E-06*	*4,69855E-02*	*5,36364E-06*	*4,69855E-02*	*5,36364E-06*	*4,69855E-02*
	Case 3	*1,32750E-06*	*1,16289E-02*	*1,32750E-06*	*1,16289E-02*	*1,32750E-06*	*1,16289E-02*	*1,32750E-06*	*1,16289E-02*
	Case 4	*7,37500E-06*	*6,46050E-02*	*7,37500E-06*	*6,46050E-02*	*7,37500E-06*	*6,46050E-02*	*7,37500E-06*	*6,46050E-02*
	Case 5	*5,36364E-07*	*4,69855E-03*	*5,36364E-07*	*4,69855E-03*	*5,36364E-07*	*4,69855E-03*	*5,36364E-07*	*4,69855E-03*
CPU	*Case 1*	*1,20000E-06*	*1,05120E-02*	*1,20000E-06*	*1,05120E-02*	*1,20000E-06*	*1,05120E-02*	*1,20000E-06*	*1,05120E-02*
	Case 2	*2,18182E-06*	*1,91127E-02*	*2,18182E-06*	*1,91127E-02*	*2,18182E-06*	*1,91127E-02*	*2,18182E-06*	*1,91127E-02*
	Case 3	*5,40000E-07*	*4,73040E-03*	*5,40000E-07*	*4,73040E-03*	*5,40000E-07*	*4,73040E-03*	*5,40000E-07*	*4,73040E-03*
	Case 4	*3,00000E-06*	*2,62800E-02*	*3,00000E-06*	*2,62800E-02*	*3,00000E-06*	*2,62800E-02*	*3,00000E-06*	*2,62800E-02*
	Case 5	*2,18182E-07*	*1,91127E-03*	*2,18182E-07*	*1,91127E-03*	*2,18182E-07*	*1,91127E-03*	*2,18182E-07*	*1,91127E-03*
Actuator (Valve)	*Case 1*	*8,45000E-06*	*7,40220E-02*	*8,45000E-06*	*7,40220E-02*	*8,45000E-06*	*7,40220E-02*	*8,45000E-06*	*7,40220E-02*
	Case 2	*1,53636E-05*	*1,34585E-01*	*1,53636E-05*	*1,34585E-01*	*1,53636E-05*	*1,34585E-01*	*1,53636E-05*	*1,34585E-01*
	Case 3	*3,80250E-06*	*3,33099E-02*	*3,80250E-06*	*3,33099E-02*	*3,80250E-06*	*3,33099E-02*	*3,80250E-06*	*3,33099E-02*
	Case 4	*2,11250E-05*	*1,85055E-01*	*2,11250E-05*	*1,85055E-01*	*2,11250E-05*	*1,85055E-01*	*2,11250E-05*	*1,85055E-01*
	Case 5	*1,53636E-06*	*1,34585E-02*	*1,53636E-06*	*1,34585E-02*	*1,53636E-06*	*1,34585E-02*	*1,53636E-06*	*1,34585E-02*

Framework A.6.4 – Spurious Trip Rate (STR) Values Calculated for the Studied Safety Systems

Appendix 7

Component	Price	Number of Componts.	Number of Loops	CIEH Component Cost	CIMV	Price per loop	CIIC total	CIMC	CIRS		CIRT	TOTAL
									No of	Price		
Gas detector	1881.39	7	7	13169.75	3292.44	1216.1	8512.70	6243.72	1	1881.39	656.22	*33756.22*
Input Dev.	1442.40	1		1442.40	576.96			504.84	1	1442.40	1458.27	*5424.87*
Total												*39181.10*

Table A.7.1 - Costs related to the Turret's Gas Detection System (xg1) - Case 1

(*) Includes : input card - binary =627,13 pounds plus rack =815,27 pounds that makes a total of 1442,40 pounds

Maximum recommended number points for each input card: 32

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Note 1: All values in pounds

Component	Number of Components	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	7	6	1	420.00	4.00E-06	2	1881.39	1941.39	476.18
Input Dev.	1	12	1	*30.00*	1.80E-06	2	1442.40	1502.40	23.69
Total				*450.00*					*499.87*

Table A.7.1A- Maintenance, Test and Repair Costs related to the Turret's Gas Detection System (xg1) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LSO year* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR+* (Pounds)	*LCA+CIR+ CYCtotal* (Pounds)
Case 1	5.06060E-02	1.53500E-05	0.1344660	639.13	4000.51	450.00	499.87	2816.70	3128.88	5945.58	39181.10	**45126.68**
Case 2	9.20109E-03	2.79091E-05	0.2444836	1162.05	7273.66	900.00	999.75	5633.40	6257.76	11891.16	72923.91	**84815.07**
Case 3	2.27727E-02	6.90750E-06	0.0605097	287.61	1800.23	1350.00	1499.62	8450.10	9386.64	17836.74	105731.03	**123567.77**
Case 6	2.53030E-03	3.83750E-05	0.3361650	1597.82	10001.28	1350.00	1499.62	8450.10	9386.64	17836.74	105731.03	**123567.77**
Case 5	9.20109E-02	2.7909E-06	0.0244484	116.21	727.37	900.00	999.75	5633.40	6257.76	11891.16	72923.91	**84815.07**

Tabela A.7.1.B - Costs related to the Turret's Gas Detection System (xg1) - Case 1

Case Number	*Critical Safey Unavailability (CSA)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case 0	1.0000E+00	9.07989E-01	5.8790501E-03
Case 1	5.06060E-02	0.0000E+00	5.8790501E-03
Case 2	9.20109E-03	9.49394E-01	5.8790501E-03
Case 3	2.27727E-02	9.90799E-01	5.8790501E-03
Case 6	2.53030E-03	9.77227E-01	5.8790501E-03
Case 5	9.20109E-02	9.97470E-01	5.8790501E-03

Tabela A.7.1.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Turret's Gas Detection System (xg1)

Discount rate	6.25933		
Life time	20	years	
Expected accident frequency	1.84900E-02	per year	
Average loss per accident (assets)	5.5245E+07	Pounds	
Life value	3.0000E+06	Pounds	
Gas Price	0.08	(U$/m3)	
	0.05	Pounds	
Gas produc.	164000	m3/day	
Oil price	15.50	(U$/barrel)	
	9.72	Pounds	
Oil produc.	2074.30	m3/day	
	13047.35	barrels/day	
Return average time of to normal production =	50	minutes	
Depressur. average time for the plant due to ESD:	15	minutes	
Oil calculat. loss due to Spurious Operation =	**4403.72**	Pounds	
Gas calculat. loss due to Spurious Operation =	268.74	Pounds	(not producted)
	80.62	Pounds	(burned gas)
Total Gas Loss	**349.36**	Pounds	
Total Loss due to Spurious Operation *(LUC) =*	***4,753.08***	Pounds	

Table A.7.D - Data used for Loss Calculation

LCA+CIR+ CYCtot. (Pounds)	*LSO (Pounds)*
45126.68	4000.51
84815.07	7273.66
123567.77	1800.23
123567.77	10001.28
84815.07	727.37

Table A. 7.1. E -Case 1- Costs involved in Turret's Gas Detection System (xg1)

N° of Deaths per year	Value of Life (Pounds)	Loss Lives/yr. (LLyear) (Pounds)	Benefit in Loss Lives /year (Pounds)	*Total Benefit Loss Lives LL* (Pounds)	CSU	*RELyear* (Pounds)	*Benefit REL year-REL* (Pounds)	*Total Benefit RELoss* (Pounds)	*Total Benefit* (Pounds)	*LCC* *(Pounds)*
5.879050E-03	3.0000E+06	1.763715E+04	1.613296E-04	**1.009815E-03**	5.06060E-02	67433.25	1265081.60	**7918563.19**	**7918563.19**	***-7869436.00***
5.879050E-03	3.0000E+06	1.763715E+04	1.683656E-04	**1.053856E-03**	9.20109E-03	12260.59	1320254.25	**8263907.05**	**8263907.05**	***-8171818.32***
5.879050E-03	3.0000E+06	1.763715E+04	1.660593E-04	**1.039420E-03**	2.27727E-02	30344.96	1302169.88	**8150711.00**	**8150711.00**	***-8025343.00***
5.879050E-03	3.0000E+06	1.763715E+04	1.694991E-04	**1.060951E-03**	2.53030E-03	3371.66	1329143.18	**8319545.78**	**8319545.78**	***-8185976.73***
5.879050E-03	3.0000E+06	1.763715E+04	1.542937E-04	**9.657751E-04**	9.20109E-02	122605.90	1209908.94	**7573219.32**	**7573219.33**	***-7487676.89***
5.879050E-03	3.0000E+06	1.763715E+04			1.0000E+00	1332514.84				

Table A. 7.1. F -Case 1- Life Cycle Cost Calculated for the Turret's Gas Detection System (xg1)

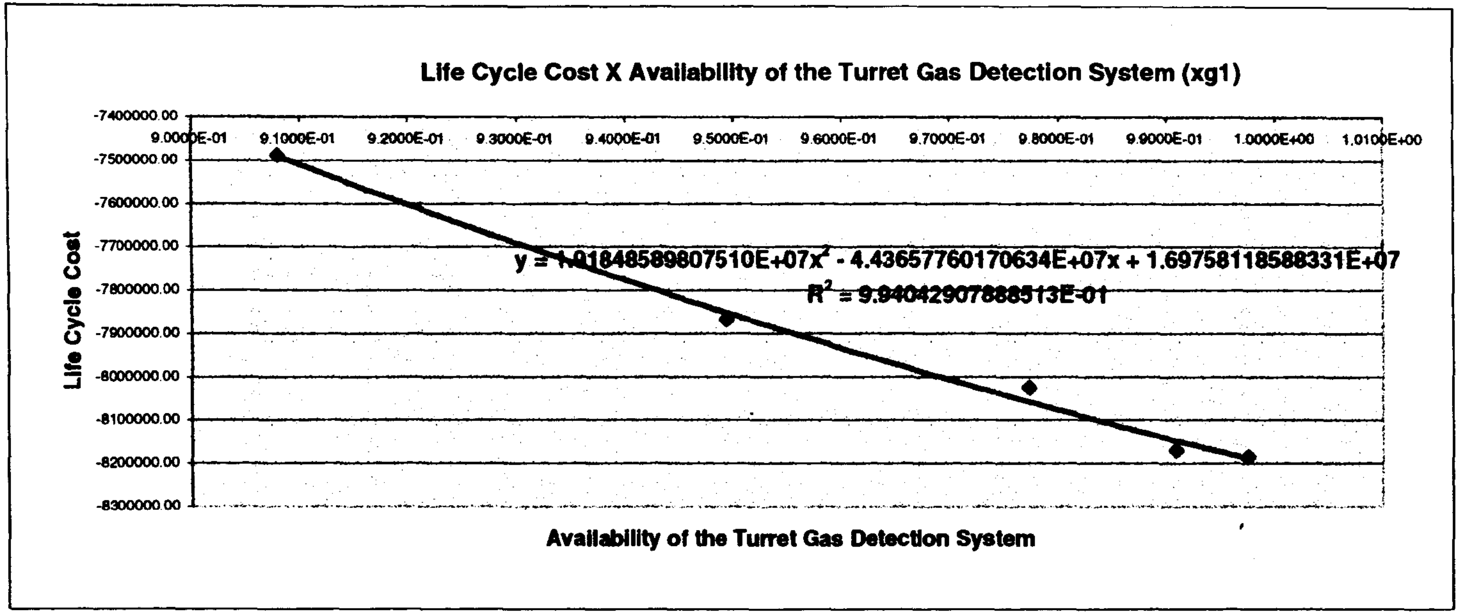


Figure A.7.1.- Life Cycle Cost versus Critical Availability - Turret's Gas Detection System (xgl)

Case Number	*CSU- xgl*	*CSA*	*LCC*
Case1	5.06060E-02	9.493940E-01	-7869436.00
Case2	9.20109E-03	9.907989E-01	-8171818.32
Case3	2.27727E-02	9.772273E-01	-8025343.00
Case6	2.53030E-03	9.974697E-01	-8185976.73
Case5	9.20109E-02	9.079891E-01	-7487676.89

Table A.7.1.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Turret's Gas Detection System (xgl)

Component	Price	Number of componts.	Number of Loops	CIEH Component Cost	CIMV	CIIC		CIMC	CIRS		CIRT
						Price per loop	total		No of	Price	
Gas detector	1881.39	14	14	**26339.50**	**6584.88**	1216.10	**17025.4**	**12487.44**	1	**1881.39**	**656.22**
Input card	1442.40	2		**2884.80**	**1153.92**			**1009.68**	1	**1442.40**	1458.27
TOTAL											

Table A.7.1.2 - Case 2- Cost related to the Turret's Gas Detection System (xgl)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	14	6	1	**840.00**	4.00E-06	2	**1881.39**	1941.39	**952.37**
Input Dev.	2	12	1	**60.00**	1.80E-06	2	1442.40	1502.40	**47.38**
TOTAL				***900.00***					***999.75***

Table A.7.1.2 A- Case 2- Maintenance, Test and Repair Costs related to the Turret's Gas Detection System (xgl)

Component	Price	Number of componts.	Number of Loops	CIEH Compont. Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop	total		No of	Price		
Gas detector	1881.39	21	21	39509.25	9877.31	1216.1	25538.10	18731.17	2	1881.39	656.22	**96193.45**
Input card	1442.40	3		4327.20	1730.88			1514.52	1	506.71	1458.27	**9537.59**
TOTAL												***105731.03***

Table A.7.1.3 - Case 3- Cost related to the Turret's Gas Detection System (xg1)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	21	6	1	**1260.00**	4.00E-06	2	1881.39	1941.39	**1428.55**
Input Dev.	3	12	1	**90.00**	1.80E-06	2	1442.40	1502.40	**71.07**
TOTAL				***1350.00***					***1499.62***

Table A.7.1.3A - Case 3- Cost related to the Turret's Gas Detection System (xg1)

Component	Price (Pounds)	Number of componts.	Number of Loops	CIEH Component Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop (Pounds)	total (Pounds)		No of	Price		
Fire detector	2947.52	7	7	20632.61	5,158.15	1216.1	8512.7	8575.87	1	2947.52	656.22	**46483.07**
Input Dev (*)	2696.66	1		2696.66	1,078.67			943.83	1	2696.66	1458.27	**8874.10**
TOTAL												*55357.17*

Table A.7.2 - Costs related to the Turret's Fire Detection System (xf1) - Case 1

(*) Includes : input card -analogic = 1881,39 pounds plus rack =815,27 pounds that makes a total of 2696,66 pounds

Maximum recommended number points for each input card: 32

Component	Number of components	Test Period (months)	Man-hours per test	Test costs per year (Pounds)	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	7	6	1	**420.00**	5.00E-06	2	2947.52	**3007.52**	**922.10**
Input Dev.	1	12	1	**30.00**	1.80E-06	2	2696.66	2756.66	**43.47**
TOTAL				*450.00*					*965.57*

Table A.7.2A- Maintenance, Test and Repair Costs related to the Turret's Fire Detection System (xf1) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LSOyear* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR* *(Pounds)*	*LCA+CIR +CYCtotal* *(Pounds)*
Case1	5.81660E-02	1.53500E-05	0.1344660	639.13	**4000.51**	450.00	965.57	2816.70	6043.83	8860.53	55357.17	**64217.70**
Case2	1.05756E-02	2.79091E-05	0.2444836	1162.05	**7273.66**	900.00	1931.14	5633.40	12087.66	17721.06	102955.66	**120676.71**
Case3	2.61747E-02	6.90750E-06	0.0605097	287.61	**1800.23**	1350.00	2896.71	8450.10	18131.49	26581.59	153501.66	**180083.25**
Case6	2.90830E-03	3.83750E-05	0.3361650	1597.82	**10001.28**	1350.00	2896.71	8450.10	18131.49	26581.59	153501.66	**180083.25**
Case 5	1.05756E-01	2.79091E-06	0.0244484	116.21	**727.37**	900.00	1931.14	5633.40	12087.66	17721.06	102955.66	**120676.71**

Tabela A.7.2.B - Costs related to the Turret's Fire Detection System (xf1) - Case 1

Case Number	*CSU*	*CSA*	*ASR*
Case0	1.0000E+00	0.0000000E+00	8.7468911E-03
Case1	5.81660E-02	9.4183400E-01	5.8790501E-03
Case2	1.05756E-02	9.8942436E-01	5.7341396E-03
Case3	2.61747E-02	9.7382530E-01	5.7816380E-03
Case6	2.90830E-03	9.9709170E-01	5.7107929E-03
Case5	1.05756E-01	8.9424364E-01	6.0239605E-03

Tabela A.7.2.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Turret's Fire Detection System (xf1)

LCA+CIR+ CYCtot. (Pounds)	*LSO (Pounds)*
64217.70	4000.51
120676.71	7273.66
180083.25	1800.23
180083.25	10001.28
120676.71	727.37

Table A. 7.2. E -Case 1- Costs involved in Turret's Fire Detection System (xf1)

N° of Deaths per year	**Value of Life (Pounds)**	**Loss Lives/yr. (LLyear) (Pounds)**	**Benefit in Loss Lives /year (Pounds)**	***Total Benefit Loss Lives LL* (Pounds)**	**CSU**	***RELyear* (Pounds)**	***Benefit REL year-REL* (Pounds)**	***Total Benefit RELoss* (Pounds)**	***Total Benefit* (Pounds)**	***LCC (Pounds)***
5.87905E-03	3.0000E+06	17637.15	8603.52	**53852.29**	5.81660E-02	59415.65	962068.57	**6021904.66**	**6075756.95**	***-6007538.75***
5.73414E-03	3.0000E+06	17202.42	9038.25	**56573.42**	1.05756E-02	10802.85	1010681.38	**6326188.26**	**6382761.67**	***-6272532.36***
5.78164E-03	3.0000E+06	17344.91	8895.76	**55681.49**	2.61747E-02	26737.04	994747.18	**6226450.86**	**6282132.35**	***-6126830.46***
5.71079E-03	3.0000E+06	17132.38	9108.29	**57011.82**	2.90830E-03	2970.78	1018513.44	**6375211.72**	**6432223.55**	***-6268720.60***
6.02396E-03	3.0000E+06	18071.88	8168.79	**51131.16**	1.05756E-01	108028.46	913455.76	**5717621.07**	**5768752.24**	***-5665069.21***
8.7468911E-03	3.0000E+06	26240.67			1.0000E+00	1021484.22				

Table A. 7.2. F -Case 1- Life Cycle Cost Calculated for the Turret's Fire Detection System (xf1)

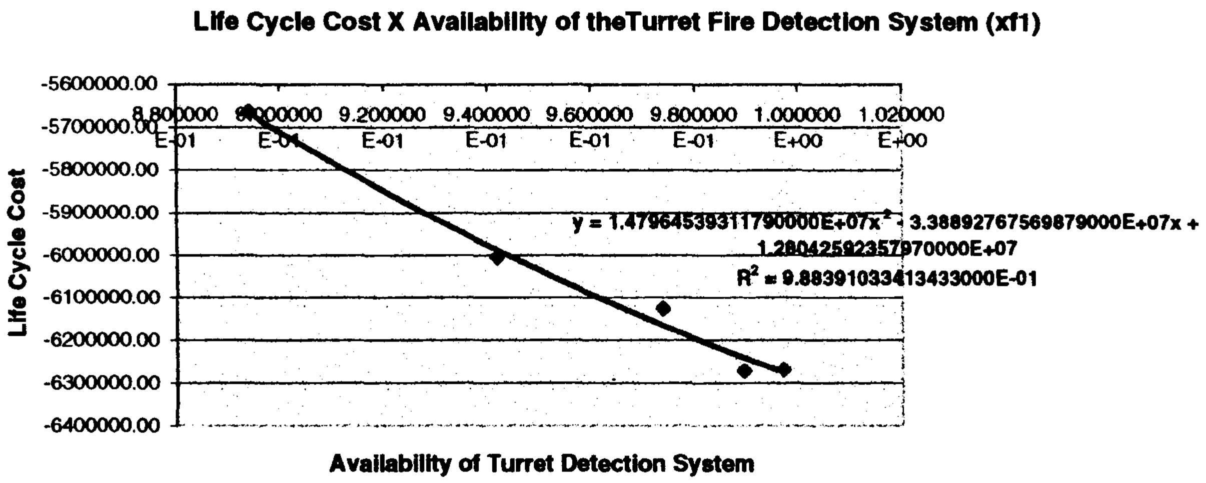


Figure A.7.2 - Life Cycle Cost versus Critical Availability - Turret's Fire Detection System (xf1)

Case Number	*CSU-xf1*	*CSA*	*LCC*
Case1	5.81660E-02	9.418340E-01	-6007538.75
Case2	1.05756E-02	9.894244E-01	-6272532.36
Case3	2.61747E-02	9.738253E-01	-6126830.46
Case4	2.90830E-03	9.970917E-01	-6268720.60
Case 5	1.05756E-01	8.942436E-01	-5665069.21

Table A.7.2.G - Life Cycle Values (LCC) Obtained for Different Cases Related to Turret's Fire Detection System (xf1)

Component	Price	Number of compponts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Fire detector	2947.52	14	14	41265.22	10316.31	1216.10	17025.40	17151.73	1	2947.52	656.22	**89362.40**
Input Dev.	2696.66	2		5393.33	2157.33			1887.66	1	2696.66	1458.27	**13593.26**
TOTAL												***102955.66***

Table A.7.2.2 - Case 2- Cost related to the Turret's Fire Detection System (xf1)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	14	6	1	840.00	5.00E-06	2	2947.52	3007.52	**1844.21**
Input Dev.	2	12	1	60.00	1.80E-06	2	2696.66	2756.66	**86.93**
TOTAL				***900.00***					***1931.14***

Table A.7.2.2 A- Case 2- Maintenance, Test and Repair Costs related to the Turret's Fire Detection System (xf1)

Component	Price	Number of componts.		CIEH	CIMV		CIIC	CIMC	CIRS		CIRT	TOTAL
			Number of Loops	Compont. Cost		Price per loop	total		No of	Price		
Fire detector	2947.52	21	21	61897.83	15474.46	1216.1	25538.10	25727.60	2	5895.03	656.22	**135189.24**
Input Dev.	2696.66	3		8089.99	3236.00			2831.50	1	2696.66	1458.27	**18312.42**
TOTAL												***153501.66***

Table A.7.3.2 - Case 3- Cost related to the Turret's Fire Detection System (xf1)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	21	6	1	1260.00	5.00E-06	2	2947.52	3007.52	**2766.31**
Input Dev.	3	12	1	90.00	1.80E-06	2	2696.66	2756.66	**130.40**
TOTAL				***1350.00***					***2896.71***

Table A.7.3.2 A- Case 3- Maintenance, Test and Repair Costs related to the Turret's Fire Detection System (xf1)

Component	Price (Pounds)	Number of componts.	Number of Loops	CIEH Component Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop (Pounds)	Total (Pounds)		No of	Price		
Gas	1881.39	10	10	18813.93	4,703.48	1216.1	12161	8919.60	1	1881.39	656.22	47135.63
detector												
Input Dev.	1442.40	1		1442.40	576.96			504.84	1	1442.40	1458.27	5424.87
TOTAL												*52560.50*

Table A.7.3 - Costs related to the Process Plant's Gas Detection System (xg2) - Case 1

(*) Includes : input card - binary =627,13 pounds plus rack =815,27 pounds that makes a total of 1442,40 pounds

Maximum recommended number points for each input card: 32

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Component	Number of components	Test Period (months)	Man-hours per test	Test costs per year (Pounds)	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas	10	6	1	600.00	4.00E-06	2	1881.39	1941.39	680.26
detector									
Input Dev.	1	12	1	*30.00*	1.80E-06	2	1442.40	1502.40	23.69
TOTAL				*630.00*					*703.95*

Table A.7.3A- Maintenance, Test and Repair Costs related to the Process Plant's Gas Detection System (xg2) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LSOyear* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR* *(Pounds)*	*LCA+CIR +CYCtotal* *(Pounds)*
Case 1	7.20860E-02	2.13500E-05	0.1870260	888.95	**5564.23**	630.00	703.95	3943.38	4406.28	8349.66	***52560.50***	**60910.16**
Case 2	1.31065E-02	3.88182E-05	0.3400473	1616.27	**10116.78**	1260.00	1407.91	7886.76	8812.56	16699.32	99682.72	**116382.04**
Case 3	3.24387E-02	9.60750E-06	0.0841617	400.03	**2503.90**	1890.00	2111.86	11830.13	13218.84	25048.97	145869.25	**170918.22**
Case 6	3.60430E-03	5.33750E-05	0.4675650	2222.37	**13910.58**	1890.00	2111.86	11830.13	13218.84	25048.97	145869.25	**170918.22**
Case 5	1.31065E-01	3.88182E-06	0.0340047	161.63	**1011.68**	1260.00	1407.91	7886.76	8812.56	16699.32	99682.72	**116382.04**

Tabela A.7.3.B - Costs related to the Process Plant's Gas Detection System (xg2) - Case 1

Case Number	*CSU*	*CSA*	*ASR*
Case 0	1.0000E+00	0.0000E+00	6.06162E-03
Case 1	7.20860E-02	9.27914E-01	5.87905E-03
Case 2	1.31065E-02	9.86893E-01	5.86745E-03
Case 3	3.24387E-02	9.67561E-01	5.87125E-03
Case 6	3.60430E-03	9.96396E-01	5.86558E-03
Case 5	1.31065E-01	8.68935E-01	5.89065E-03

Tabela A.7.3.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Process Plant's Gas Detection System (xg2)

LCA+CIR+ CYCtot. *(Pounds)*	*LUC* *(Pounds)*
60910.16	5564.23
116382.04	10116.78
170918.22	2503.90
170918.22	13910.58
116382.04	1011.68

Table A.7.3. E -Case 1- Costs involved in Process Plant's Gas Detection System (xg2)

N^0 of Deaths per year	Value of Life (Pounds)	Loss Lives/yr. (LLyear) (Pounds)	Benefit in Loss Lives/year (Pounds)	*Total Benefit Loss Lives LL* (Pounds)	CSU	*RELyear* (Pounds)	*Benefit REL year-REL* (Pounds)	*Total Benefit REL* (Pounds)	*Total Benefit* (Pounds)	*LCC* *(Pounds)*
5.87905E-03	3.0000E+06	17637.15	547.70	**3428.20**	7.20860E-02	96055.66	1236459.18	**7739406.02**	**7742834.22**	***-7676359.83***
5.86745E-03	3.0000E+06	17602.34	582.51	**3646.11**	1.31065E-02	17464.67	1315050.18	**8231333.02**	**8234979.12**	***-8108480.30***
5.87125E-03	3.0000E+06	17613.75	571.10	**3574.68**	3.24387E-02	43225.05	1289289.79	**8070090.28**	**8073664.96**	***-7900242.83***
5.86558E-03	3.0000E+06	17596.73	588.12	**3681.21**	3.60430E-03	4802.78	1327712.06	**8310587.92**	**8314269.13**	***-8129440.33***
5.89065E-03	3.0000E+06	17671.96	512.88	**3210.30**	1.31065E-01	174646.66	1157868.18	**7247479.03**	**7250689.33**	***-7133295.61***
6.06162E-03	3.0000E+06	18184.85			1.0000E+00	1332514.84				

Table A.7.3. F -Case 1- Life Cycle Cost Calculated for the Process Plant's Gas Detection System (xg2)

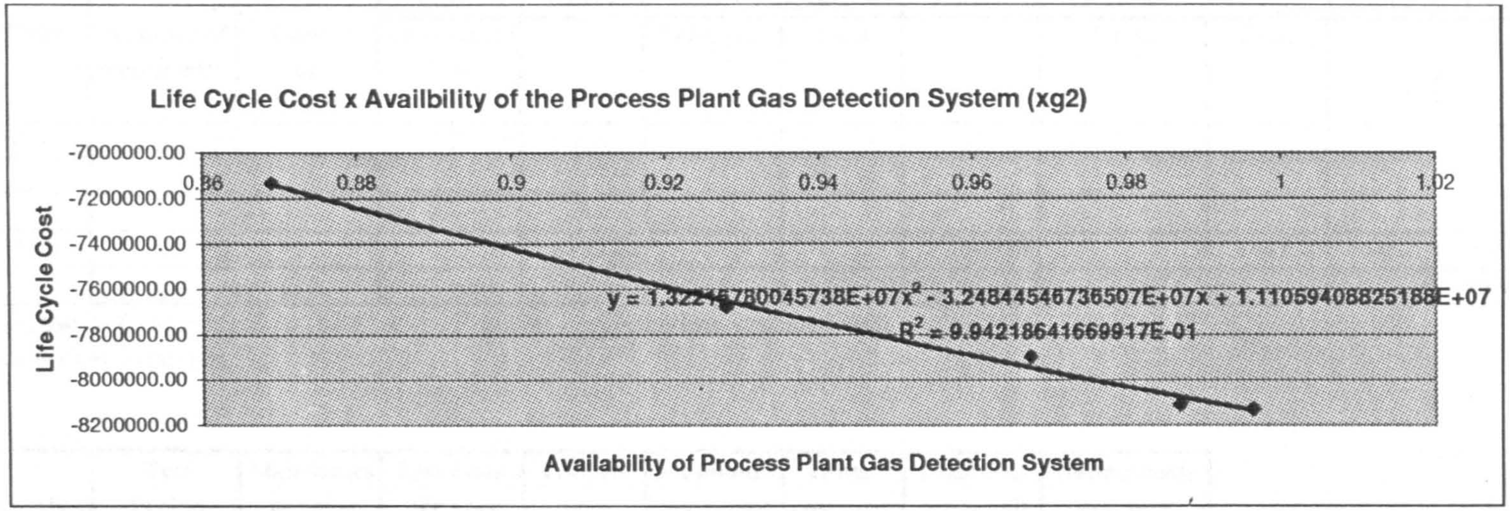


Figure A.7.3.- Life Cycle Cost versus Critical Availability - Process Plant's Gas Detection System (xg2)

Case Number	*CSU- xg2*	*CSA*	*LCC*
Case1	7.20860E-02	9.279140E-01	-7676359.83
Case2	1.31065E-02	9.868935E-01	-8108480.30
Case3	3.24387E-02	9.675613E-01	-7900242.83
Case4	3.60430E-03	9.963957E-01	-8129440.33
Case 5	1.31065E-01	8.689345E-01	-7133295.61

Table A.7.3.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Process Plant's Gas Detection (
System (xg1)

Component	Price	Number of componts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Gas detector	1881.39	20	20	37627.86	9406.97	1216.10	24322.00	17839.21	1	1881.39	656.22	**91733.65**
Input Dev.	1442.40	2		2884.80	1153.92			1009.68	1	1442.40	1458.27	**7949.08**
TOTAL												*99682.72*

Table A.7.3.2 - Case 2- Cost related to the Process Plant's Gas Detection System (xg2)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	20	6	1	**1200.00**	4.00E-06	2	1881.39	1941.39	**1360.53**
Input Dev.	2	12	1	**60.00**	1.80E-06	2	1442.40	1502.40	**47.38**
Total				***1260.00***					***1407.91***

Table A.7.3.2 A- Case 2- Maintenance, Test and Repair Costs related to the Process Plant's Gas Detection System (xg2)

Component	Price	Number of componts.	Number of Loops	CIEH Compont. Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop	total		No of	Price		
Gas detector	1881.39	30	30	56441.79	14110.45	1216.1	36483.00	26758.81	2	1881.39	656.22	**136331.66**
Input card	1442.40	3		4327.20	1730.88			1514.52	1	506.71	1458.27	**9537.59**
TOTAL												***145869.25***

Table A.7.3.3 - Case 3- Cost related to the Process Plant's Gas Detection System (xg2)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	30	6	1	**1800.00**	4.00E-06	2	1881.39	1941.39	**2040.79**
Input Dev.	3	12	1	**90.00**	1.80E-06	2	1442.40	1502.40	**71.07**
Total				***1890.00***					***2111.86***

Table A.7.3.3 A- Case 3- Maintenance, Test and Repair Costs related to the Process Plant's Gas (xf2) Detection System (xg2)

Component	Price (Pounds)	Number of componts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop (Pounds)	Total (Pounds)		No of	Price		
Fire detector	2947.52	10	10	29475.16	7,368.79	1216.1	12161	12251.24	1	2947.52	656.22	64859.92
Input Dev.	2696.66	1		2696.66	1,078.67			943.83	1	2696.66	1458.27	8874.10
TOTAL												*73734.02*

Table A.7.4 - Costs related to the Process Plant's Fire Detection System (xf2) - Case 1

(*) Includes : input card -analogic = 1881,39 pounds plus rack =815,27 pounds that makes a total of 2696,66 pounds

Maximum recommended number points for each input card: 32

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Component	Number of components	Test Period (months)	Man-hours per test	Test costs per year (Pounds)	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	10	6	1	600.00	5.00E-06	2	2947.52	3007.52	1317.29
Input Dev.	1	12	1	30.00	1.80E-06	2	2696.66	2756.66	43.47
Total				*630.00*					*1360.76*

Table A.7.4A- Maintenance, Test and Repair Costs related to the Process Plant's Fire Detection System (xf2) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LSOyear* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair cost per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)
Case1	8.28860E-02	2.13500E-05	0.1870260	888.95	**5564.23**	630.00	1360.76	3943.38	8517.44	12460.82
Case2	1.50702E-02	3.88182E-05	0.3400473	1616.27	**10116.78**	1260.00	2721.52	7886.76	17034.88	24921.63
Case3	3.72987E-02	9.60750E-06	0.0841617	400.03	**2503.90**	1980.00	4212.68	12393.47	26368.54	38762.02
Case6	4.14430E-03	5.33750E-05	0.4675650	2222.37	**13910.58**	1980.00	4212.68	12393.47	26368.54	38762.02
Case 5	1.50702E-01	3.88182E-06	0.0340047	161.63	**1011.68**	1260.00	2721.52	7886.76	17034.88	24921.63

Tabela A.7.4.B - Costs related to the Process Plant's Fire Detection System (xf2) - Case 1

Case Number	*CSU*	*CSA*	*ASR*
Case0	1.00000E+00	0.00000E+00	5.91462E-03
Case1	8.28860E-02	9.17114E-01	5.87905E-03
Case2	1.50702E-02	9.84930E-01	5.87642E-03
Case3	3.72987E-02	9.62701E-01	5.87728E-03
Case6	4.14430E-03	9.95856E-01	5.87600E-03
Case5	1.50702E-01	8.49298E-01	5.88168E-03

Tabela A.7.4.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Process Plant's Fire Detection System (xf2)

LCA+CIR+ **CYCtot.** *(Pounds)*	*LUC* *(Pounds)*
86194.84	5564.23
164631.00	10116.78
261551.73	2503.90
261551.73	13910.58
164631.00	1011.68

Table A7.4. .E-Case 1- Costs involved in Process Plant's Fire Detection System (xf2)

N^0 of Deaths per year	**Value of Life (Pounds)**	**Loss Lives/yr (LLyear) (Pounds)**	**Benefit in Loss Lives/year (Pounds)**	***Total Benefit Loss Lives LL*** **(Pounds)**	**CSU (Pounds)**	***RELyear*** **(Pounds)**	***Benefit REL year-REL*** **(Pounds)**	***Total Benefit REL*** **(Pounds)**	***Total Benefit*** **(Pounds)**	***LCC (Pounds)***
5.87905E-03	3.0000E+06	17637.15	106.71	**667.94**	8.28860E-02	84666.74	936817.48	**5863849.76**	**5864517.70**	*-5772758.63*
5.87642E-03	3.0000E+06	17629.26	114.60	**717.33**	1.50702E-02	15393.95	1006090.27	**6297451.00**	**6298168.33**	*-6123420.55*
5.87728E-03	3.0000E+06	17631.85	112.02	**701.14**	3.72987E-02	38100.03	983384.19	**6155326.15**	**6156027.29**	*-5891971.66*
5.87600E-03	3.0000E+06	17627.99	115.87	**725.29**	4.14430E-03	4233.34	1017250.88	**6367308.98**	**6368034.27**	*-6092571.96*
5.88168E-03	3.0000E+06	17645.04	98.82	**618.55**	1.50702E-01	153939.53	867544.69	**5430248.52**	**5430867.07**	*-5265224.39*
5.91462E-03	3.0000E+06	17743.86	0.00		1.0000E+00	1021484.22				

Table A.7.4. F-Case 1- Life Cycle Cost Calculated for the Process Plant's Fire Detection System (xf2)

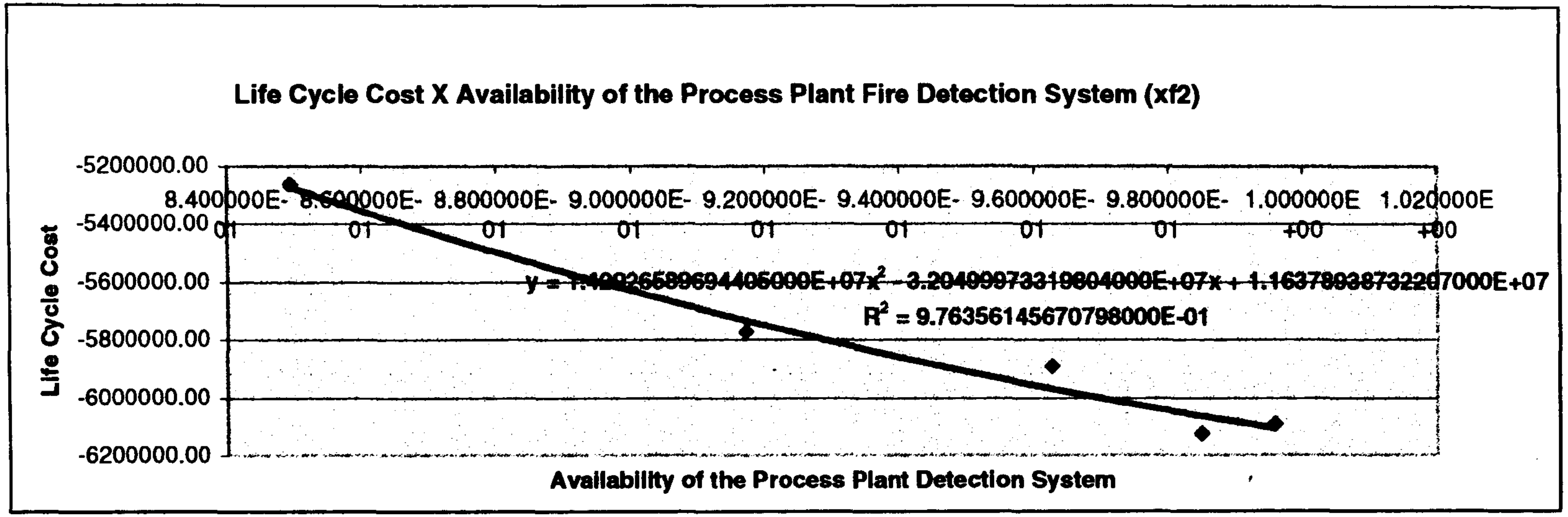


Figure A.7.4.- Life Cycle Cost versus Critical Availability - Process Plant's Fire Detection System (xf2)

Case Number	*CSU- xf2*	*CSA*	*LCC*
Case1	8.28860E-02	9.171140E-01	-5772758.63
Case2	1.50702E-02	9.849298E-01	-6123420.55
Case3	3.72987E-02	9.627013E-01	-5891971.66
Case4	4.14430E-03	9.958557E-01	-6092571.96
Case 5	1.50702E-01	8.492982E-01	-5265224.39

Table A.7.4.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Process Plant's Fire Detection (xf2)

Component	Price	Number of componts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Fire detector	2947.52	20	20	58950.32	14737.58	1216.10	24322.00	24502.47	1	2947.52	656.22	**126116.11**
Input Dev.	2696.66	2		5393.33	2157.33			1887.66	1	2696.66	1458.27	**13593.26**
TOTAL												*139709.37*

Table A.7.4.2 - Case 2- Cost related to the Process Plant's Fire Detection System (xf2)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	20	6	1	**1200.00**	5.00E-06	2	**2947.52**	3007.52	**2634.58**
Input Dev.	2	12	1	**60.00**	1.80E-06	2	2696.66	2756.66	**86.93**
TOTAL				***1260.00***					***2721.52***

Table A.7.4.2 A- Case 2- Maintenance, Test and Repair Costs related to the Process Plant's Fire Detection System (xf2)

Component	Price	Number of componts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Compont. Cost		Price per loop	total		No of	Price		
Fire detector	2947.52	30	30	88425.47	22106.37	1216.1	36483.00	36753.71	2	5895.03	656.22	**190319.81**
Input Dev.	2696.66	6		16179.98	6471.99			5662.99	1	2696.66	1458.27	**32469.90**
TOTAL												*222789.71*

Table A.7.4.3 - Case 3- Cost related to the Process Plant's Fire Detection System (xf2)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	30	6	1	**1800.00**	5.00E-06	2	**2947.52**	3007.52	**3951.88**
Input Dev.	6	12	1	**180.00**	1.80E-06	2	2696.66	2756.66	**260.80**
TOTAL				*1980.00*					*4212.68*

Table A.7.4.3 A- Case 3- Maintenance, Test and Repair Costs related to the Process Plant's Fire Detection System (xf2)

Component	Price	Number of Componts.	Number of Loops	CIEH Component Cost	CIMV	Price per loop	CIIC total	CIMC	CIRS		CIRT	TOTAL
									No of	Price		
Gas	1881.39	4	4	**7525.57**	**1881.39**	1216.1	**4864.40**	**3567.84**	1	**1881.39**	**656.22**	***20376.82***
detector												
Input Dev.	1442.40	1		1442.40	576.96			**504.84**	1	**1442.40**	**1458.27**	**5424.87**
												25801.69

Table A.7.5 - Costs related to the Pump Room's Gas Detection System (xg3) - Case 1

(*) Includes : input card - binary =627,13 pounds plus rack =815,27 pounds that makes a total of 1442,40 pounds

Maximum recommended number points for each input card: 32

Rate (May,98): 1pound = 1,828645 R$ and 1U$ = 1,1468 R$

Component	Number of Components	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas	4	6	1	**240.00**	4.00E-06	2	1881.39	1941.39	**272.11**
detector									
Input Dev.	1	12	1	***30.00***	1.80E-06	2	1442.40	1502.40	**23.69**
Total				***270.00***					***295.80***

Table A.7.5A- Maintenance, Test and Repair Costs related to the Pump Room's Gas Detection System (xg3) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spur.trips per year*	*LSOyear* (Pounds)	*LSO* (Pounds) (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR* (Pounds)	*LCA+CIR+ CYCtotal* (Pounds)
Case 1	2.91260E-02	9.35000E-06	0.0819060	389.31	**2436.79**	270.00	295.80	1690.02	1851.48	3541.50	25801.69	**29343.19**
Case 2	5.29564E-03	1.70000E-05	0.1489200	707.83	**4430.54**	540.00	591.59	3380.04	3702.96	7083.00	46165.10	**53248.10**
Case 3	1.31067E-02	4.20750E-06	0.0368577	175.19	**1096.56**	810.00	887.39	5070.06	5554.45	10624.50	65592.82	**76217.32**
Case 6	1.45630E-03	2.33750E-05	0.2047650	973.26	**6091.99**	810.00	887.39	5070.06	5554.45	10624.50	65592.82	**76217.32**
Case 5	5.29564E-02	1.70000E-06	0.0148920	70.78	**443.05**	540.00	591.59	3380.04	3702.96	7083.00	46165.10	**53248.10**

Tabela A.7.5.B - Costs related to the Pump Room's Gas Detection System (xg3) - Case 1

Case Number	*Critical Safey Unavailability (CSA)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case 0	1.0000E+00	9.47044E-01	5.8790531E-03
Case 1	2.91260E-02	0.0000E+00	5.8791733E-03
Case 2	5.29564E-03	9.70874E-01	5.8790501E-03
Case 3	1.31067E-02	9.94704E-01	5.8790471E-03
Case 6	1.45630E-03	9.86893E-01	5.8790480E-03
Case 5	5.29564E-02	9.98544E-01	5.8790466E-03

Tabela A.7.5.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Pump Room's Gas Detection System (xg3)

LCA+CIR+ CYCtot. (Pounds)	*LSO (Pounds)*
29343.19	2436.79
53248.10	4430.54
76217.32	1096.56
76217.32	6091.99
53248.10	443.05

Table A.7.5 E -Case 1- Costs involved in Pump Room's Gas Detection System (xg3)

N^0 of Deaths per year	**Value of Life (Pounds)**	**Loss Lives/yr. (LLyear) (Pounds)**	**Benefit in Loss Lives /year (Pounds)**	***Total Benefit Loss Lives LL*** **(Pounds)**	**CSU**	***RELyear*** **(Pounds)**	***Benefit REL year-REL*** **(Pounds)**	***Total Benefit RELoss*** **(Pounds)**	***Total Benefit*** **(Pounds)**	***LCC (Pounds)***
5.87905E-03	3.0000E+06	17637.15	3.6968567E-01	**2.3139846E+00**	2.91260E-02	38810.83	1293704.01	**8097720.35**	**8097722.66**	***-8065942.68***
5.87905E-03	3.0000E+06	17637.14	3.7875970E-01	**2.3707820E+00**	5.29564E-03	7056.51	1325458.33	**8296481.08**	**8296483.45**	***-8238804.81***
5.87905E-03	3.0000E+06	17637.14	3.7578544E-01	**2.3521651E+00**	1.31067E-02	17464.87	1315049.97	**8231331.73**	**8231334.08**	***-8154020.20***
5.87905E-03	3.0000E+06	17637.14	3.8022163E-01	**2.3799327E+00**	1.45630E-03	1940.54	1330574.30	**8328503.64**	**8328506.02**	***-8246196.71***
5.87905E-03	3.0000E+06	17637.16	3.6061164E-01	**2.2571872E+00**	5.29564E-02	70565.14	1261949.70	**7898959.62**	**7898961.88**	***-7845270.72***

Table A.7.5. F -Case 1- Life Cycle Cost Calculated for the Pump Rooms's Gas Detection System (xg3)

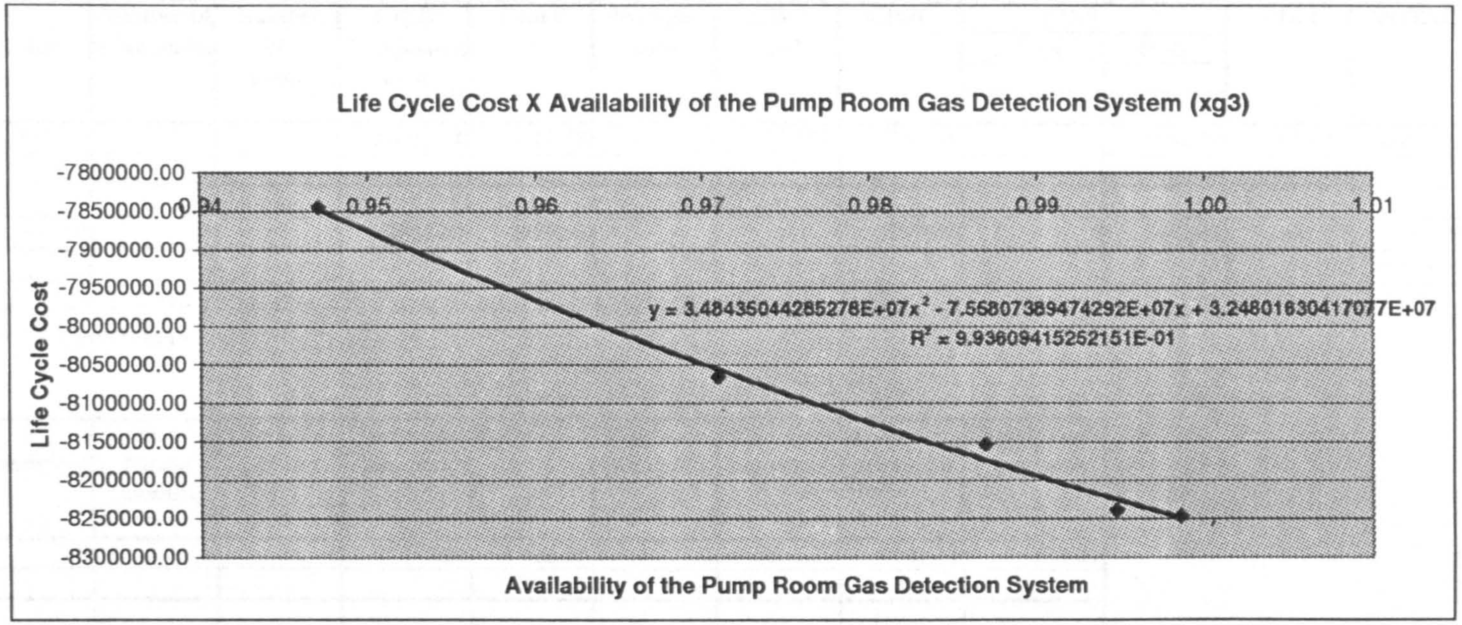


Figure A.7.5.- Life Cycle Cost versus Critical Availability - Pump Room's Gas Detection System (xg3)

Case Number	*CSU-xg3*	*CSA*	*LCC*
Case1	2.9126E-02	9.70874E-01	***-8065942.68***
Case2	5.2956E-03	9.94704E-01	***-8238804.81***
Case3	1.3107E-02	9.86893E-01	***-8154020.20***
Case6	1.4563E-03	9.98544E-01	***-8246196.71***
Case5	5.2956E-02	9.47044E-01	***-7845270.72***

Table A.7.5.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Pump Room's Gas Detection System (xg3)

Component	Price	Number of Componts.	Number of Loops	CIEH Component Cost	CIMV	Price per loop	CIIC total	CIMC	CIRS		CIRT	TOTAL
									No of	Price		
Gas detector	1881.39	8	8	**15051.14**	**3762.79**	1216.10	**9728.8**	**7135.68**	1	**1881.39**	**656.22**	***38216.03***
Input Dev.	1442.40	2		**2884.80**	**1153.92**			**1009.68**	1	**1442.40**	1458.27	***7949.08***
Total												***46165.10***

Table A.7.5.2 - Case 2- Cost related to the Pump Room's Gas Detection System (xg3)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	8	6	1	**480.00**	4.00E-06	2	1881.39	1941.39	**544.21**
Input Dev.	2	12	1	**60.00**	1.80E-06	2	1442.40	1502.40	**47.38**
Total				***540.00***					***591.59***

Table A.7.5.2 A- Case 2- Maintenance, Test and Repair Costs related to the Pump Room's Gas Detection System (xg3)

Component	Price	Number of Componts.	Number of Loops	CIEH Component Cost	CIMV	Price per loop	CIIC total	CIMC	CIRS		CIRT	TOTAL
									No of	Price		
Gas detector	1881.39	12	12	22576.72	5644.18	1216.10	14593.2	10703.52	1	1881.39	656.22	*56055.23*
Input card	1442.40	3		4327.20	1730.88			1514.52	1	506.71	1458.27	*9537.59*
Total												*65592.82*

Table A.7.5.3 - Case 3- Cost related to the Pump Room's Gas Detection System (xg3)

OBS: All values are given in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	12	6	1	720.00	4.00E-06	2	1881.39	1941.39	816.32
Input Dev.	3	12	1	90.00	1.80E-06	2	1442.40	1502.40	71.07
Total				*810.00*					*887.39*

Table A.7.5.3 A- Case 3- Maintenance, Test and Repair Costs related to the Pump Room's Gas Detection System (xg3)

Component	Price (Pounds)	Number of componts.	Number of Loops	CIEH Component Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop (Pounds)	total (Pounds)		No of	Price		
Fire	2947.52	4	4	11790.06	2,947.52	1216.1	4864.4	4900.49	1	2947.52	656.22	*28106.21*
detector												
Input Dev.	2696.66	1		2696.66	1,078.67			943.83	1	2696.66	1458.27	*8874.10*
Total												*36980.31*

Table A.7.6 - Costs related to the Pump Room's Fire Detection System (xf3) - Case 1

Component	Number of Components	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
detector									
Input card/	1	12	1	30.00	1.80E-06	2	2696.66	2756.66	43.47
Total				*270.00*					*570.38*

Table A.7.6A- Maintenance, Test and Repair Costs related to the Pump Room's Fire Detection System (xf3) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LSO year* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR* *(Pounds)*	*LCA+CIR +CYCtotal* *(Pounds)*
Case1	3.34460E-02	9.35000E-06	0.0819060	389.31	**2436.79**	270.00	570.38	1690.02	3570.22	5260.24	36980.31	**42240.55**
Case2	6.08109E-03	1.70000E-05	0.1489200	707.83	**4430.54**	540.00	1140.77	3380.04	7140.44	10520.48	66201.95	**76722.43**
Case3	1.50507E-02	4.20750E-06	0.0368577	175.19	**1096.56**	810.00	1711.15	5070.06	10710.66	15780.72	95423.58	**111204.30**
Case6	1.67230E-03	2.33750E-05	0.2047650	973.26	**6091.99**	810.00	1711.15	5070.06	10710.66	15780.72	95423.58	**111204.30**
Case 5	6.08109E-02	1.70000E-06	0.0148920	70.78	**443.05**	540.00	1140.77	3380.04	7140.44	10520.48	66201.95	**76722.43**

Tabela A.7.6.B - Costs related to the Pump Room's Fire Detection System (xf3) - Case 1

Case Number	*Critical Safey Unavailability (CSU)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case0	1.0000E+00	0.0000E+00	5.879157E-03
Case1	3.34460E-02	9.66554E-01	5.879050E-03
Case2	6.08109E-03	9.93919E-01	5.879047E-03
Case3	1.50507E-02	9.84949E-01	5.879048E-03
Case6	1.67230E-03	9.98328E-01	5.879047E-03
Case5	6.08109E-02	9.39189E-01	5.879053E-03

Tabela A.7.6.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Pump Room's Fire Detection System (xf3)

LCA+CIR+ CYCtot. (Pounds)	*LSO (Pounds)*
42240.55	2436.79
76722.43	4430.54
111204.30	1096.56
111204.30	6091.99
76722.43	443.05

Table A.7.6.E- Case 1 -Costs involved in Pump Room's Fire Detection System (xf3)

N⁰ of Deaths per year	Value of Life (Pounds)	Loss Lives per year (LLyear) (Pounds)	Benefit in Loss Lives /year (Pounds)	*Total Benefit Loss Lives LL* (Pounds)	CSU	*RELyear* (Pounds)	*Benefit REL year-REL* (Pounds)	*Total Benefit RELoss* (Pounds)	*Total Benefit* (Pounds)	*LCC (Pounds)*
5.87905E-03	3.0000E+06	17637.15	3.2050E-01	**2.006136E+00**	3.34460E-02	34164.56	987319.66	**6179959.57**	**6179961.58**	***-6135284.23***
5.87905E-03	3.0000E+06	17637.14	3.2957735E-01	**2.062933E+00**	6.08109E-03	6211.74	1015272.48	**6354925.51**	**6354927.58**	***-6273774.61***
5.87905E-03	3.0000E+06	17637.14	3.2660308E-01	**2.044316E+00**	1.50507E-02	15374.05	1006110.17	**6297575.56**	**6297577.61**	***-6185276.75***
5.87905E-03	3.0000E+06	17637.14	3.3103928E-01	**2.072084E+00**	1.67230E-03	1708.23	1019775.99	**6383114.47**	**6383116.54**	***-6265820.26***
5.87905E-03	3.0000E+06	17637.16	3.1142928E-01	**1.949339E+00**	6.08109E-02	62117.38	959366.84	**6004993.63**	**6004995.58**	***-5927830.10***
5.87916E-03	3.0000E+06	17637.47	0.0000000E+00		1.0000E+00	1021484.22				

Table A.7.6.F - Case 1 - Life Cycle Cost Calculated for the Pump Rooms's Fire Detection System (xf3)

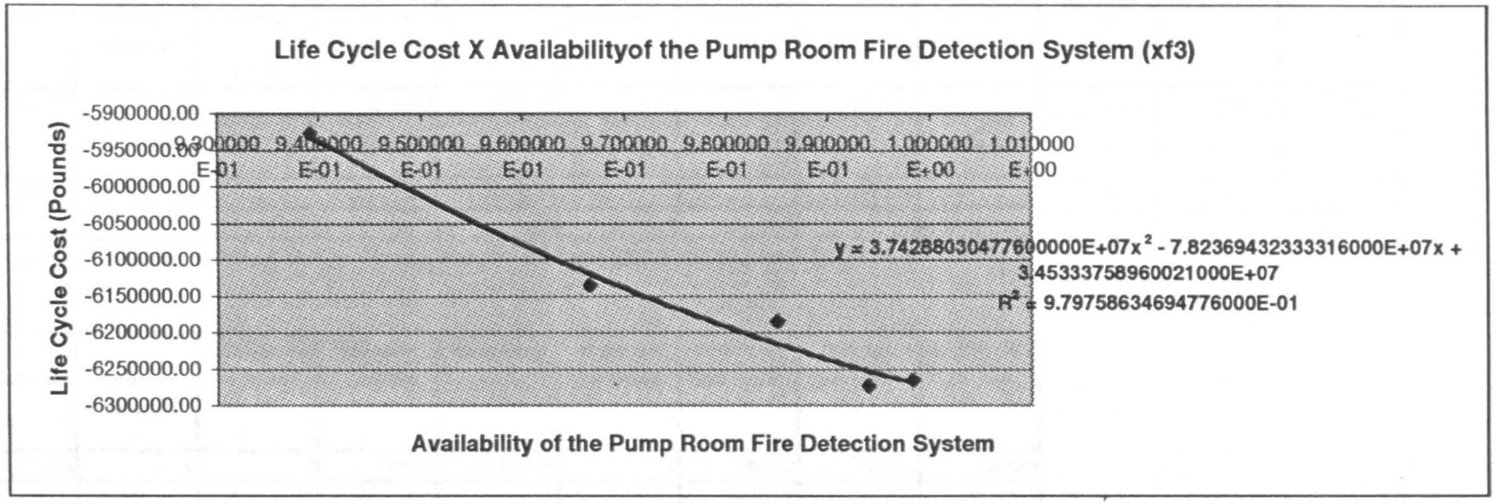


Figure A.7.6 - Life Cycle Cost versus Critical Availability - Pump Room's Fire Detection System (xf3)

Case Number	*CSU - xf3*	*CSA*	*LCC*
Case1	3.34460E-02	9.665540E-01	-6135284.23
Case2	6.08109E-03	9.939189E-01	-6273774.61
Case3	1.50507E-02	9.849493E-01	-6185276.75
Case4	1.67230E-03	9.983277E-01	-6265820.26
Case 5	6.08109E-02	9.391891E-01	-5927830.10

Table A.7.6.G - Life Cycle Values (LCC) Obtained for Different Cases Related to Pump Room's Fire Detection System (xf3)

Component	Price	Number of compon ts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Fire detector	2947.52	8	8	23580.13	5895.03	1216.10	9728.80	9800.99	1	2947.52	656.22	*52608.69*
Input Dev.	2696.66	2		5393.33	2157.33			1887.66	1	2696.66	1458.27	*13593.26*
Total												*66201.95*

Table A.7.6.2 - Case 2 - Costs related to the Pump Room's Fire Detection System (xf3)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	8	6	1	480.00	5.00E-06	2	2947.52	3007.52	1053.83
Input Dev.	2	12	1	60.00	1.80E-06	2	2696.66	2756.66	86.93
Total				*540.00*					*1140.77*

Table A.7.6.2A- Case 2 - Maintenance, Test and Repair Costs related to the Pump Room's Fire Detection System (xf3)

Component	Price	Number of compônts.	Number of Loops	CIEH	CIMV	Price per loop	CIIC	CIMC	CIRS		CIRT	TOTAL
				Compont. Cost			total		No of	Price		
Fire detector	2947.52	12	12	35370.19	8842.55	1216.1	14593.20	14701.48	1	2947.52	656.22	77111.16
Input Dev.	2696.66	3		8089.99	3236.00			2831.50	1	2696.66	1458.27	*18312.42*
Total												*95423.58*

Table A.7.6.3 - Case 3 - Costs related to the Pump Room's Fire Detection System (xf3)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	12	6	1	720.00	5.00E-06	2	2947.52	3007.52	1580.75
Input Dev.	3	12	1	90.00	1.80E-06	2	2696.66	2756.66	130.40
Total				*810.00*					*1711.15*

Table A.7.6.3A- Case 3 - Maintenance, Test and Repair Costs related to the Pump Room's Fire Detection System (xf3)

Component	Price	Number of Componts.	Number of Loops	CIEH Component Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop	total		No of	Price		
Gas detector	1881.39	8	8	15051.14	3762.79	1216.1	9728.80	7135.68	1	1881.39	656.22	*38216.03*
Input Dev.	1442.40	1		1442.40	576.96			504.84	1	1442.40	1458.27	*5424.87*
Total												*43640.90*

Table A.7.7 - Costs related to the Machine Room's Gas Detection System (xg4) - Case 1

Component	Number of Components	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	8	6	1	480.00	4.00E-06	2	1881.39	1941.39	544.21
Input Dev.	1	12	1	*30.00*	1.80E-06	2	1442.40	1502.40	23.69
Total				*510.00*					*567.90*
Total				*270.00*					*570.38*

Table A.7.7A- Maintenance, Test and Repair Costs related to the Machine Room's Gas Detection System (xg4) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spur.trips per year*	*LSOyear* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR+* (Pounds)	*LCA+CIR+ CYCtotal* (Pounds)
Case 1	5.77660E-02	1.73500E-05	0.1519860	722.40	**4521.75**	510.00	567.90	3192.26	3554.68	6746.94	43640.90	**50387.84**
Case 2	1.05029E-02	3.15455E-05	0.2763382	1313.46	**8221.37**	1020.00	1135.80	6384.52	7109.36	13493.88	81843.52	**95337.39**
Case 3	2.59947E-02	7.80750E-06	0.0683937	325.08	**2034.79**	1530.00	1703.70	9576.77	10664.04	20240.82	119110.44	**139351.26**
Case 6	2.88830E-03	4.33750E-05	0.3799650	1806.00	**11304.38**	1530.00	1703.70	9576.77	10664.04	20240.82	119110.44	**139351.26**
Case 5	1.05029E-01	3.15455E-06	0.0276338	131.35	**822.14**	1020.00	1135.80	6384.52	7109.36	13493.88	81843.52	**95337.39**

Tabela A.7.7.B - Costs related to the Machine Room's Gas Detection System (xg4) - Case 1

Case Number	*Critical Safey Unavailability (CSU)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case 0	1.0000E+00	0.0000E+00	5.87936E-03
Case 1	5.77660E-02	9.42234E-01	5.87905E-03
Case 2	1.05029E-02	9.89497E-01	5.87903E-03
Case 3	2.59947E-02	9.74005E-01	5.87904E-03
Case 6	2.88830E-03	9.97112E-01	5.87903E-03
Case 5	1.05029E-01	8.94971E-01	5.87907E-03

Tabela A.7.7.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Machine Room's Gas Detection System (xg4)

LCA+CIR+ CYCtot. (Pounds)	*LUC (Pounds)*
50387.84	***4521.75***
95337.39	***8221.37***
139351.26	***2034.79***
139351.26	***11304.38***
95337.39	***822.14***

Table A.7.7.E- Case 1 -Costs involved in Machine Room's Gas Detection System (xg4)

N^0 of Deaths per year	**Value of Life (Pounds)**	**Loss Lives per year (LLyear) (Pounds)**	**Benefit in Loss Lives /year (Pounds)**	***Total Benefit Loss Lives LL* (Pounds)**	**CSU**	***RELyear* (Pounds)**	***Benefit REL year-REL* (Pounds)**	***Total Benefit RELoss* (Pounds)**	***Total Benefit* (Pounds)**	***LCC (Pounds)***
5.87903E-03	3.0000E+06	17637.10	9.9046477E-01	**6.1996458E+00**	1.05029E-02	13995.28	1318519.56	**8253049.04**	**8253055.23**	***-8149496.47***
5.87904E-03	3.0000E+06	17637.12	9.7495783E-01	**6.1025828E+00**	2.59947E-02	34638.32	1297876.52	**8123837.43**	**8123843.53**	***-7982457.49***
5.87903E-03	3.0000E+06	17637.10	9.9808682E-01	**6.2473548E+00**	2.88830E-03	3848.70	1328666.14	**8316559.83**	**8316566.07**	***-8165910.44***
5.87907E-03	3.0000E+06	17637.20	8.9584614E-01	**5.6073966E+00**	1.05029E-01	139952.82	1192562.02	**7464639.23**	**7464644.83**	***-7368485.30***
5.87936E-03	3.0000E+06	17638.09			1.0000E+00	1332514.84				

Table A.7.7.F - Case 1 - Life Cycle Cost Calculated for the Machine Rooms's Gas Detection System (xg4)

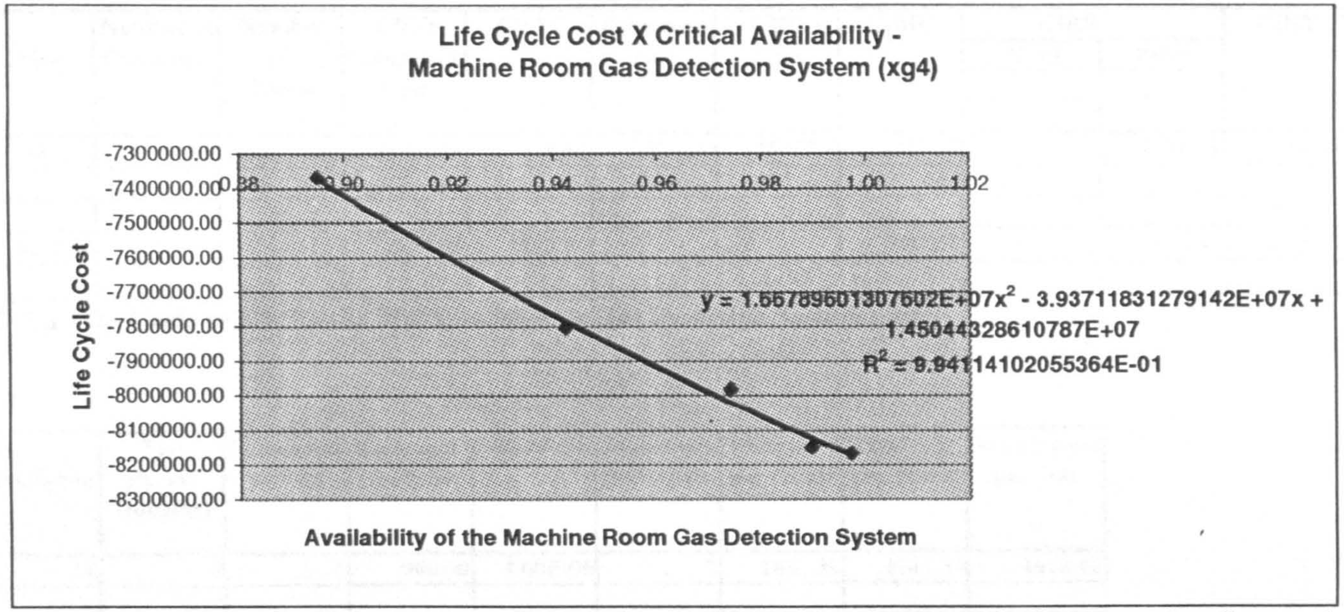


Figure A.7.7.- Life Cycle Cost versus Critical Availability - Machine Room's Gas Detection System (xg4)

Case Number	*CSU*	*CSA*	*LCC*
Case1	5.7766E-02	9.42234E-01	***-7803940.44***
Case2	1.0503E-02	9.89497E-01	***-8149496.47***
Case3	2.5995E-02	9.74005E-01	***-7982457.49***
Case6	2.8883E-03	9.97112E-01	***-8165910.44***
Case5	1.0503E-01	8.94971E-01	***-7368485.30***

Table A.7.7.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Machine Room's Gas Detection System (xg4)

Component	Price	Number of Componts.	Number of Loops	CIEH Componen Cost	CIMV	Price per loop	CIIC total	CIMC	CIRS No of	CIRS Price	CIRT	TOTAL
Gas detector	1881.39	16	16	**30102.29**	**7525.57**	1216.10	**19457.6**	**14271.37**	1	**1881.39**	**656.22**	***73894.44***
Input Dev.	1442.40	2		**2884.80**	**1153.92**			**1009.68**	1	**1442.40**	1458.27	***7949.08***
												81843.52

Table A.7.7.2- Case 2 - Costs related to the Machine Room's Gas Detection System (xg4)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rat	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	16	6	1	**960.00**	4.00E-06	2	1881.39	1941.39	**1088.42**
Input Dev.	2	12	1	**60.00**	1.80E-06	2	1442.40	1502.40	**47.38**
Total				***1020.00***					***1135.80***

Table A.7.7.2A- Case 2- Maintenance, Test and Repair Costs related to the Machine Room's Gas Detection System (xg4)

Componen	Price	Number of Componts.	Number of Loops	CIEH Componen Cost	CIMV	Price per loop	CIIC total	CIMC	CIRS		CIRT	TOTAL
									No of	Price		
Gas detector	1881.39	24	24	45153.43	11288.36	1216.10	29186.4	21407.05	2	1881.39	656.22	*109572.85*
Input card	1442.40	3		4327.20	1730.88			1514.52	1	506.71	1458.27	*9537.59*
Total												119110.44

Table A.7.7.3- Case 3 - Costs related to the Machine Room's Gas Detection System (xg4)

Componen	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rat	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Gas detector	24	6	1	1440.00	4.00E-06	2	1881.39	1941.39	1632.63
Input Dev.	3	12	1	90.00	1.80E-06	2	1442.40	1502.40	71.07
Total				*1530.00*					*1703.70*

Table A.7.7.3A- Case 3- Maintenance, Test and Repair Costs related to the Machine Room's Gas Detection System (xg4)

Componen	Price (Pounds)	Number of componts.	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Componen Cost		Price per loop (Pounds)	total (Pounds)		No of	Price		
Fire detector	2947.52	8	8	23580.13	5,895.03	1216.1	9728.8	9800.99	1	2947.52	656.22	*52608.69*
Input Dev.	2696.66	1		2696.66	1,078.67			943.83	1	2696.66	1458.27	*8874.10*
Total												*61482.79*

Table A.7.8 - Costs related to the Machine Room's Fire Detection System (xf4) - Case 1

Componen	Number of components	Test Period (months)	Man-hours per test	Test costs per year (Pounds)	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	8	6	1	480.00	5.00E-06	2	2947.52	3007.52	1053.83
Input card/	1	12	1	30.00	1.80E-06	2	2696.66	2756.66	43.47
Total				*510.00*					*1097.30*

Table A.7.8A- Maintenance, Test and Repair Costs related to the Machine Room's Fire Detection System (xf4) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spur.trips per year*	*LSOyear* (Pounds)	*LSO* (Pounds)	**Test costs per year (Pounds)**	**Repair costs per year (Pounds)**	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR+* (Pounds)	*LCA+CIR+ CYCtotal* (Pounds)
Case1	6.64060E-02	1.73500E-05	0.1519860	722.40	**4521.75**	510.00	1097.30	3192.26	6868.37	10060.62	61482.79	**71543.41**
Case2	1.20738E-02	3.15455E-05	0.2763382	1313.46	**8221.37**	1020.00	2194.60	6384.52	13736.73	20121.25	115206.89	**135328.14**
Case3	2.98827E-02	7.80750E-06	0.0683937	325.08	**2034.79**	1530.00	3291.90	9576.77	20605.10	30181.87	171878.52	**202060.39**
Case6	3.32030E-03	4.33750E-05	0.3799650	1806.00	**11304.38**	1530.00	3291.90	9576.77	20605.10	30181.87	171878.52	**202060.39**
Case 5	1.20738E-01	3.15455E-06	0.0276338	131.35	**822.14**	1020.00	2194.60	6384.52	13736.73	20121.25	115206.89	**135328.14**

Tabela A.7.8.B - Costs related to the Machine Room's Fire Detection System (xf4) - Case 1

Case Number	*Critical Safey Unavailability (CSU)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case0	1.0000E+00	0.0000E+00	5.87928E-03
Case1	6.64060E-02	9.33594E-01	5.87905E-03
Case2	1.20738E-02	9.87926E-01	5.87904E-03
Case3	2.98827E-02	9.70117E-01	5.87904E-03
Case6	3.32030E-03	9.96680E-01	5.87903E-03
Case5	1.20738E-01	8.79262E-01	5.87906E-03

Tabela A.7.8.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Machine Room's Fire Detection System (xf4)

LCA+CIR+ **CYCtot.** *(Pounds)*	*LUC* *(Pounds)*
71543.41	4521.75
135328.14	8221.37
202060.39	2034.79
202060.39	11304.38
135328.14	822.14

Table A.7.8.E- Case 1 -Costs involved in Machine Room's Fire Detection System (xf4)

N^0 of Deaths per year	Value of Life (Pounds)	Loss Lives per year (LLyear) (Pounds)	Benefit in Loss Lives /year (Pounds)	*Total Benefit Loss Lives LL* (Pounds)	CSU	*RELyear* (Pounds)	*Benefit REL year-REL* (Pounds)	*Total Benefit RELoss* (Pounds)	*Total Benefit* (Pounds)	*LCC* *(Pounds)*
5.87904E-03	3.0000E+06	17637.11	7.3162747E-01	**4.5794978E+00**	1.20738E-02	12333.21	1009151.01	**6316609.17**	**6316613.75**	***-6173064.24***
5.87904E-03	3.0000E+06	17637.12	7.1843877E-01	**4.4969453E+00**	2.98827E-02	30524.71	990959.52	**6202742.62**	**6202747.12**	***-5998651.94***
5.87903E-03	3.0000E+06	17637.10	7.3811006E-01	**4.6200744E+00**	3.32030E-03	3391.63	1018092.59	**6372577.48**	**6372582.10**	***-6159217.32***
5.87906E-03	3.0000E+06	17637.19	6.5115402E-01	**4.0757879E+00**	1.20738E-01	123332.15	898152.07	**5621830.22**	**5621834.30**	***-5485684.02***
5.87928E-03	3.0000E+06	17637.84			1.0000E+00	1021484.22				

Table A.7.8.F - Case 1 - Life Cycle Cost Calculated for the Machine Rooms's Fire Detection System (xf4)

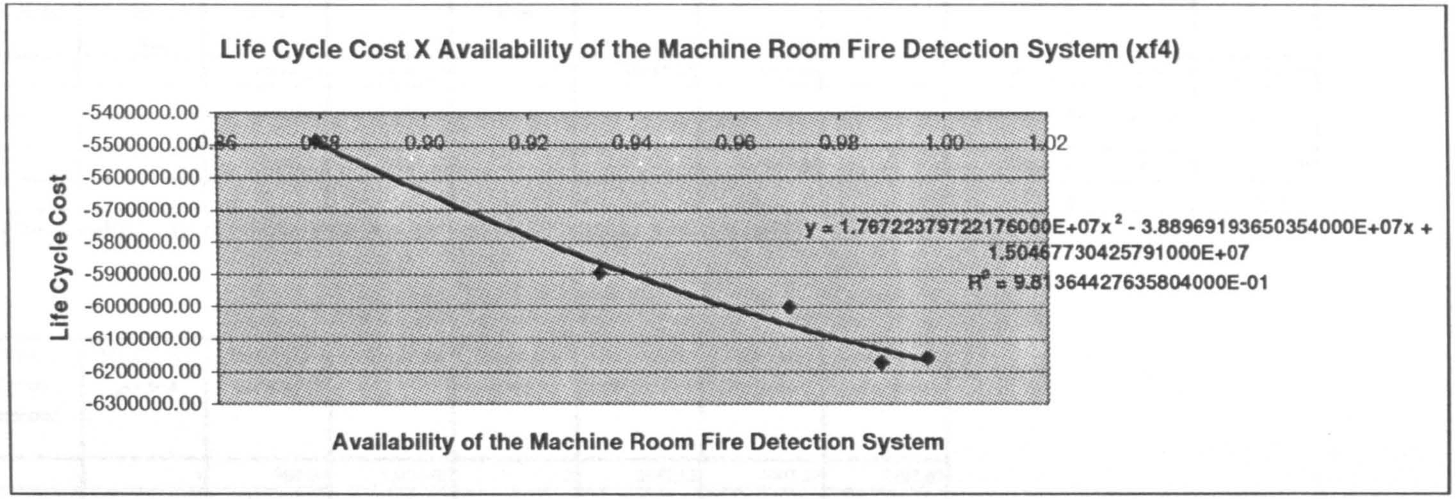


Figure A.7.8.- Life Cycle Cost versus Critical Availability - Machine Room's Fire Detection System (xf4)

Case Number	*CSU-Fire*	*CSA*	*LCC*
Case1	6.64060E-02	9.335940E-01	-5893158.86
Case2	1.20738E-02	9.879262E-01	-6173064.24
Case3	2.98827E-02	9.701173E-01	-5998651.94
Case4	3.32030E-03	9.966797E-01	-6159217.32
Case 5	1.20738E-01	8.792618E-01	-5485684.02

Table A.7.8.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Machine Room's Fire Detection System (xf4)

				CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
Component	Price	Number of componts.	Number of Loops	Component Cost		Price per loop	total		No of	Price		
Fire detector	2947.52	16	16	**47160.25**	**11790.06**	1216.10	**19457.60**	**19601.98**	1	**2947.52**	**656.22**	**101613.63**
Input Dev.	**2696.66**	2		5393.33	2157.33			1887.66	1	2696.66	**1458.27**	13593.26
Total												***115206.89***

Table A.7.8.2- Case 2 - Costs related to the Machine Room’s Fire Detection System (xf4)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire detector	16	6	1	**960.00**	5.00E-06	2	**2947.52**	3007.52	**2107.67**
Input Dev.	2	12	1	**60.00**	1.80E-06	2	2696.66	2756.66	**86.93**
Total				***1020.00***					***2194.60***

Table A.7.8.2A- Case 2- Maintenance, Test and Repair Costs related to the Machine Room’s Fire Detection System (xf4)

				CIEH	CIMV		CIIC	CIMC	CIRS		CIRT	TOTAL
Component	Price	Number of componts.	Number of Loops	Compont. Cost		Price per loop	total		No of	Price		
Fire	2947.52	24	24	70740.38	17685.09	1216.1	29186.40	29402.97	2	5895.03	656.22	153566.10
detector												
Input Dev.	2696.66	3		8089.99	3236.00			2831.50	1	2696.66	1458.27	18312.42
Total												*171878.52*

Table A.7.8.3- Case 3 - Costs related to the Machine Room's Fire Detection System (xf4)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Fire	24	6	1	1440.00	5.00E-06	2	2947.52	3007.52	3161.50
detector									
Input Dev.	3	12	1	90.00	1.80E-06	2	2696.66	2756.66	130.40
Total				*1530.00*					*3291.90*

Table A.7.8.3A- Case 3- Maintenance, Test and Repair Costs related to the Machine Room's Fire Detection System (xf4)

Component	Price	Number of	Number of Loops	CIEH	CIMV		CIIC	CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Pressure	81.07	1	1	81.07	20.27	1216.1	1216.1	329.36	1	81.07	300.00	*2027.88*
sensor												
Input card	1442.40	1		1442.40	576.96			504.84	1	1442.40	1458.27	*5424.87*
Total												*7452.75*

Table A.7.9 - Costs related to the Pressure Sensor's System (p) - Case 1

(*) Includes : input card - binary =627,13 pounds plus rack =815,27 pounds that makes a total of 1442,40 pounds

Maximum recommended number points for each input card: 32

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Note 1: All values in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Pressure	1	6	0.5	30.00	8.31E-06	2	81.07	141.07	10.27
sensor									
Input card	1	12	1	30.00	1.80E-06	2	1442.40	1502.40	23.69
Total				*60.00*					*33.96*

Table A.7.9A- Maintenance, Test and Repair Costs related to the Pressure Sensor System (p) - Case 1

Case Number	***CSU***	***Spurious Trip Rate (STR)***	***Number of spurious trips per year***	***LSO year*** **(Pounds)**	***LSO*** **(Pounds)**	**Test costs per year (Pounds)**	**Repair costs per year (Pounds)**	***CYCtesting*** **(Pounds)**	***CYCrepair*** **(Pounds)**	***CYCtotal*** **(Pounds)**	***LCA+CIR+*** **(Pounds)**	***LCA+CIR+ CYCtotal*** **(Pounds)**
Case1	1.2734E-02	2.95000E-06	0.0258420	122.83	***768.83***	60.00	***33.96***	375.56	212.57	**588.13**	***7452.75***	***8040.88***
Case2	2.3153E-03	5.36364E-06	0.0469855	223.33	***1397.87***	120.00	75.01	751.12	469.49	**1220.61**	**11623.75**	***12844.37***
Case3	5.7302E-03	1.32750E-06	0.0116289	55.27	***345.97***	180.00	112.51	1126.68	704.24	**1830.92**	**15794.76**	***17625.68***
Case6	6.3669E-04	7.37500E-06	0.0646050	307.07	***1922.07***	180.00	112.51	1126.68	704.24	**1830.92**	**15794.76**	***17625.68***
Case 5	2.3153E-02	5.36364E-07	0.0046985	22.33	***139.79***	120.00	75.01	751.12	469.49	**1220.61**	**11623.75**	***12844.37***

Tabela A.7.9.B - Costs related to the Pressure Sensor's System (p) - Case 1

Case Number	***Critical Safey Unavailability (CSA)***	***Critical Safey Availability (CSA)***	***Average Societal Risk (ASR)***
Case0	1.0000E+00	0.000E+00	1.1699065E-02
Case1	1.2734E-02	9.87266E-01	5.8790501E-03
Case2	2.3153E-03	9.97685E-01	5.8176314E-03
Case3	5.7302E-03	9.94270E-01	5.8377631E-03
Case6	6.3669E-04	9.99363E-01	5.8077362E-03
Case5	2.3153E-02	9.76847E-01	5.9404688E-03

Tabela A.7.9.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Pressure Sensor's System (p)

LCA+CIR+ CYCtot. (Pounds)	*LUC (Pounds)*
8040.88	768.83
12844.37	1397.87
17625.68	345.97
17625.68	1922.07
12844.37	139.79

Table A.7.9.E- Case 1 -Costs involved in Pressure Sensor's System (p)

N^0 of Deaths per year	Value of Life (Pounds)	Loss Lives per year (LLyear) (Pounds)	Benefit in Loss Lives /year (Pounds)	*Total Benefit Loss Lives LL* (Pounds)	CSU	*RELyear* (Pounds)	*Benefit REL year-REL* (Pounds)	*Total Benefit RELoss* (Pounds)	*Total Benefit* (Pounds)	*LCC* *(Pounds)*
5.81763E-03	3.0000E+06	17452.89	17644.30	**110441.50**	2.31525E-03	3085.11	1329429.74	**8321339.43**	**8431780.93**	***-8417538.69***
5.83776E-03	3.0000E+06	17513.29	17583.91	**110063.47**	5.73025E-03	7635.64	1324879.20	**8292856.15**	**8402919.62**	***-8384947.97***
5.80774E-03	3.0000E+06	17423.21	17673.99	**110627.31**	6.36694E-04	848.40	1331666.44	**8335339.68**	**8445967.00**	***-8426419.25***
5.94047E-03	3.0000E+06	17821.41	17275.79	**108134.86**	2.31525E-02	30851.06	1301663.78	**8147543.15**	**8255678.01**	***-8242693.86***
1.1699065E-02	3.0000E+06	35097.20			1.0000E+00	1332514.84				

Table A.7.9.F - Case 1 - Life Cycle Cost Calculated for the Pressure Sensor's System (p)

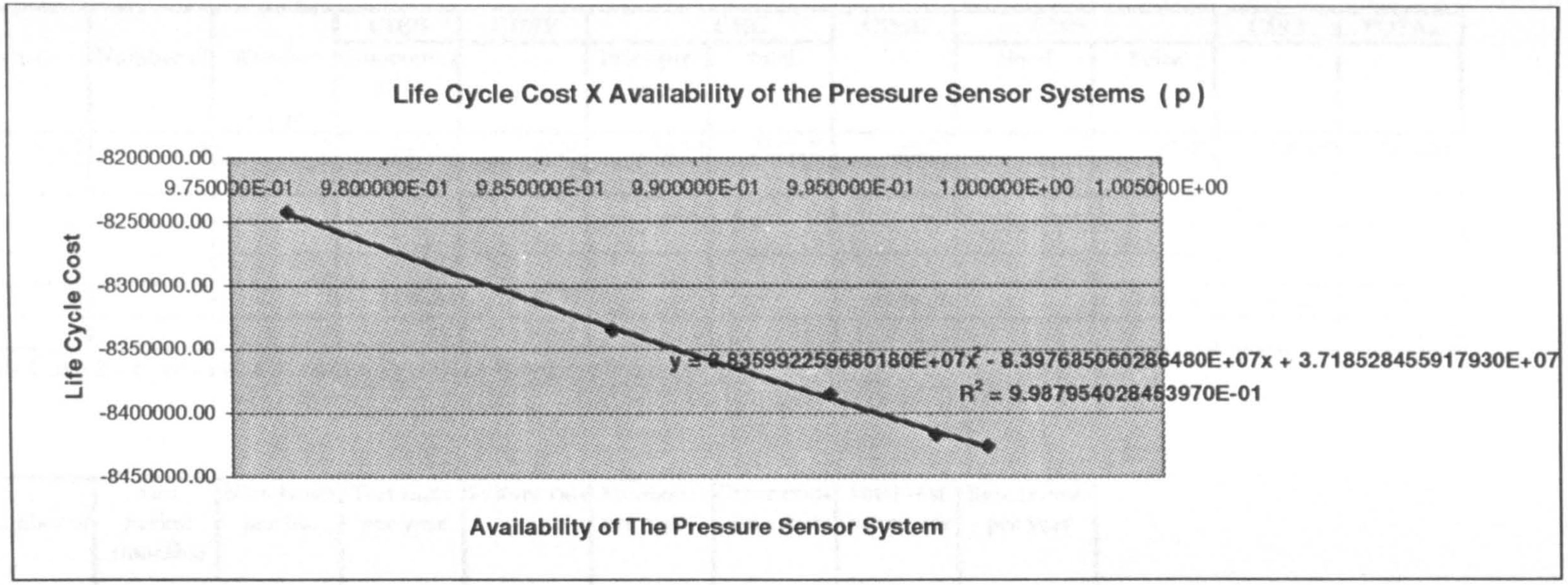


Figure A.7.9.- Life Cycle Cost versus Critical Availability - Pressure Sensor's System (p)

Case Number	*CSU*	*CSA*	*LCC*
Case1	1.27339E-02	9.872661E-01	-8334919.76
Case2	2.31525E-03	9.976847E-01	-8417538.69
Case3	5.73025E-03	9.942698E-01	-8384947.97
Case4	6.36694E-04	9.993633E-01	-8426419.25
Case 5	2.31525E-02	9.768475E-01	-8242693.86

Table A.7.9.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Pressure Sensor's System (p)

Component	Price	Number of	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Pressure	81.07	2	2	**162.15**	**40.54**	1216.10	**2432.20**	**658.72**	1	**81.07**	**300.00**	*3674.68*
sensor												
Input card	1442.40	2		**2884.80**	**1153.92**			**1009.68**	1	**1442.40**	**1458.27**	*7949.08*
Total												*11623.75*

Table A.7.9.2- Case 2 - Costs related to the Pressure Sensor's System (p)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Pressure	2	6	0.5	**60.00**	8.31E-06	2	81.07	181.07	**26.37**
sensor									
Input card	2	12	1	**60.00**	1.80E-06	2	1442.40	1542.40	**48.64**
Total				*120.00*					*75.01*

Table A.7.9.2A- Case 2- Maintenance, Test and Repair Costs related to the Pressure Sensor's System (p)

				CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
Component	Price	Number of	Number of Loops	Component Cost		Price per loop	total		No of	Price		
Pressure	81.07	3	3	243.22	60.805	1216.10	3648.3	988.08	1	81.07	300.00	5321.48
sensor												
Input card	1442.40	3		4327.204	1730.8816			1514.52	1	1442.40	1458.27	10473.28
Total												*15794.76*

Table A.7.9.3- Case 3 - Costs related to the Pressure Sensor's System (p)

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Pressure	3	6	0.5	90.00	8.31E-06	2	81.07	181.07	39.55
sensor									
Input card	3	12	1	90.00	1.80E-06	2	1442.40	1542.40	72.96
Total				*180.00*					*112.51*

Table A.7.9.3A- Case 3 - Maintenance, Test and Repair Costs related to the Pressure Sensor's System (p)

Component	Price (Pounds)	Number of componts.	Number of Loops	CIEH Componen Cost	CIMV	CIIC Price per loop (Pounds)	CIIC total (Pounds)	CIMC	CIRS No of	CIRS Price	CIRT	TOTAL
CPU	4000.00	1.00		4000.00	1600.00			1400.00	1.00	4000.00	2000.00	**13000.00**
in PLC (*)												
TOTAL												***13000.00***

Table A.7.10 - Costs related to the CPU's System (c) - Case 1

(*) Includes: electrical source

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Note 1: All values in pounds

Component	Number of components	Test Period (months)	Man-hours per test	Test costs per year (Pounds)	Failure rat	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
CPU	1	12	1	**30.00**	2.40E-06	3	4000.00	**4090.00**	**85.99**
in PLC									
TOTAL				***30.00***					***85.99***

Table A.7.10A- Maintenance, Test and Repair Costs related to the CPU System (c) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LSO year* (Pounds)	*LSO* (Pounds)	Test costs per year (Pounds)	Repair costs per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR* (Pounds)	*LCA+CIR+ CYCtotal* (Pounds)
Case1	1.39600E-03	1.20000E-06	0.0105120	49.96	**312.74**	30.00	85.99	187.78	538.23	726.01	13000.00	**13726.01**
Case2	2.53818E-04	2.18182E-06	0.0191127	90.84	**568.62**	60.00	171.98	375.56	1076.46	1452.02	20000.00	**21452.02**
Case3	6.28200E-04	5.40000E-07	0.0047304	22.48	**140.73**	90.00	257.96	563.34	1614.68	2178.02	27000.00	**29178.02**
Case6	6.98000E-05	3.00000E-06	0.0262800	124.91	**781.86**	90.00	257.96	563.34	1614.68	2178.02	27000.00	**29178.02**
Case5	2.53818E-03	2.18182E-07	0.0019113	9.08	**56.86**	60.00	171.98	375.56	1076.46	1452.02	20000.00	**21452.02**

Tabela A.7.10.B - Costs related to the CPU System (c) - Case 1

Case Number	*Critical Safey Unavailability (CSA)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case0	1.0000E+00	0.000000E+00	9.0019283E-03
Case1	1.39600E-03	9.9860400E-01	5.8790501E-03
Case2	2.53818E-04	9.9974618E-01	5.8754782E-03
Case3	6.28200E-04	9.9937180E-01	5.8766490E-03
Case6	6.98000E-05	9.9993020E-01	5.8749027E-03
Case5	2.53818E-03	9.9746182E-01	5.8826220E-03

Tabela A.7.10.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the CPU System (c)

LCA+CIR+ CYCtot. (Pounds)	*LSO (Pounds)*
13726.01	312.74
21452.02	568.62
29178.02	140.73
29178.02	781.86
21452.02	56.86

Table A.7.10.E- Case 1 -Costs involved in the CPU System (c)

N^0 of Deaths per year	**Value of Life (Pounds)**	**Loss Lives per year (LLyear) (Pounds)**	**Benefit in Loss Lives /year (Pounds)**	***Total Benefit Loss Lives LL*** **(Pounds)**	**CSU**	***RELyear*** **(Pounds)**	***Benefit REL year-REL*** **(Pounds)**	***Total Benefit RELoss*** **(Pounds)**	***Total Benefit*** **(Pounds)**	***LCC (Pounds)***
5.87905E-03	3.0000E+06	17637.15	9368.63	**58641.38**	1.39600E-03	1860.19	1330654.65	**8329006.58**	**8387647.95**	***-8373609.20***
5.87548E-03	3.0000E+06	17626.43	9379.35	**58708.45**	2.53818E-04	338.22	1332176.63	**8338533.12**	**8397241.56**	***-8375220.92***
5.87665E-03	3.0000E+06	17629.95	9375.84	**58686.46**	6.28200E-04	837.09	1331677.76	**8335410.53**	**8394096.99**	***-8364778.23***
5.87490E-03	3.0000E+06	17624.71	9381.08	**58719.25**	6.98000E-05	93.01	1332421.83	**8340067.95**	**8398787.20**	***-8368827.32***
5.88262E-03	3.0000E+06	17647.87	9357.92	**58574.30**	2.53818E-03	3382.16	1329132.68	**8319480.04**	**8378054.34**	***-8356545.46***
9.001928E-03	3.0000E+06	27005.78			1.0000E+00	1332514.84				

Table A.7.10.F - Case 1 - Life Cycle Cost Calculated for the CPU System (c)

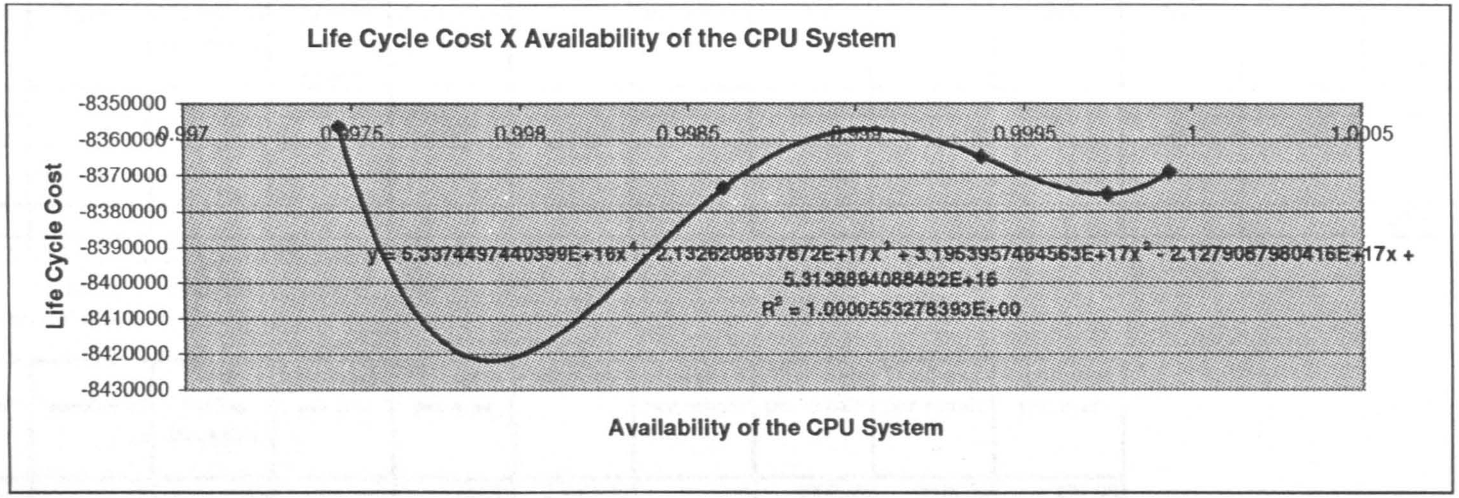


Figure A.7.10.- Life Cycle Cost versus Critical Availability - CPU System (c)

Case Number	*CSU*	*CSA*	*LCC*
Case1	1.39600E-03	9.986040E-01	-8373609.20
Case2	2.53818E-04	9.997462E-01	-8375220.92
Case3	6.28200E-04	9.993718E-01	-8364778.23
Case4	6.98000E-05	9.999302E-01	-8368827.32
Case 5	2.53818E-03	9.974618E-01	-8356545.46

Table A.7.10.G - Life Cycle Values (LCC) Obtained for Different Cases Related to CPU System (c)

Component	Price	Number of componts.	Number of Loops	CIEH Component Cost	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
						Price per loop	total		No of	Price		
CPU in PLC	4000	2		8000.00	3200.00			2800.00	1	4000.00	2000.00	20000.00
TOTAL												*20000.00*

Table A.7.10.2 - Case 2 - Costs related to the CPU's System (c)

(*) Includes: electrical source

Note 1: All values in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
CPU in PLC	2	12	1	60.00	2.40E-06	3	4000.00	4090.00	171.98
TOTAL				*60.00*					*171.98*

Table A.7.10.2A- Case 2 - Maintenance, Test and Repair Costs related to the CPU System (c)

Component	Price	Number of componts.	Number of Loops	CIEH	CIMV		CIIC	CIMC	CIRS		CIRT	TOTAL
				Compont. Cost		Price per loop	total		No of	Price		
CPU in PLC	4000.00	3		12000.00	4800.00			4200.00	1	4000.00	2000.00	**27000.00**
TOTAL												***27000.00***

Table A.7.10.3 - Case 3 - Costs related to the CPU's System (c)

(*) Includes: electrical source

Note 1: All values in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
CPU in PLC	3	12	1	90.00	2.40E-06	3	4000.00	4090.00	**257.96**
TOTAL				***90.00***					***257.96***

Table A.7.10.3A- Case 3 - Maintenance, Test and Repair Costs related to the CPU System (c)

				CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
Component	Price	Number of	Number of Loops	Component Cost		Price per loop	total		No of	Price		
Output device	1442.40	1		1442.40	576.96			504.84	1	1442.40	300.00	*4266.60*
Valve	6271.31	1	1	6271.31	1567.83	1216.1	1216.1	2263.81	1	6271.31	1458.27	*19048.63*
Total												*23315.23*

Table A.7.11 - Costs related to the Actuation (Valve) System (v) - Case 1

(*) Includes : output card - binary =627,13 pounds plus rack =815,27 pounds that makes a total of 1442,40 pounds

Maximum recommended number points for each input card: 32

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Note 1: All values in pounds

Component	Number of components	Test Period (months)	Man-hours per test	Test costs per year	Failure rate per 10^6 hr	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Output card	1	12	1	30.00	9.00E-07	2	1442.40	1502.40	11.84
Valve	1	12	0.5	15.00	1.60E-05	2	6271.31	6331.31	887.40
Total				*45.00*					*899.24*

Table A.7.11A- Maintenance, Test and Repair Costs related to the Actuation (Valve) System (v) - Case 1

Case Number	*CSU*	*Spurious Trip Rate (STR)*	*Number of spurious trips per year*	*LUCyear* (Note**) (Pounds)	*LUC* (Pounds)	Test costs per year (Pounds)	Repair cost per year (Pounds)	*CYCtesting* (Pounds)	*CYCrepair* (Pounds)	*CYCtotal* (Pounds)	*LCA+CIR (Pounds)*	*LCA+CIR +CYCtotal (Pounds)*
Case1	1.01260E-02	8.45000E-06	0.0740220	351.83	***2202.24***	45.00	899.24	281.67	5628.65	**5910.32**	***23315.23***	***29225.55***
Case2	1.84109E-03	1.53636E-05	0.1345855	639.70	***4004.07***	90.00	1798.48	563.34	11257.30	**11820.64**	**37158.48**	***48979.12***
Case3	4.55670E-03	3.80250E-06	0.0333099	158.32	***991.01***	135.00	2697.72	845.01	16885.95	**17730.95**	**51001.73**	***68732.68***
Case6	5.06300E-04	2.11250E-05	0.1850550	879.58	***5505.59***	135.00	2697.72	845.01	16885.95	**17730.95**	**51001.73**	***68732.68***
Case 5	1.84109E-02	1.53636E-06	0.0134585	63.97	***400.41***	90.00	1798.48	563.34	11257.30	**11820.64**	**37158.48**	***48979.12***

Tabela A.7.11.B - Costs related to the Actuation (Valve) System (v) - Case 1

Case Number	*Critical Safey Unavailability (CSA)*	*Critical Safey Availability (CSA)*	*Average Societal Risk (ASR)*
Case0	1.0000E+00	0.0000E+00	9.00193E-03
Case1	1.01260E-02	9.89874E-01	5.87905E-03
Case2	1.84109E-03	9.98159E-01	5.85291E-03
Case3	4.55670E-03	9.95443E-01	5.86148E-03
Case6	5.06300E-04	9.99494E-01	5.84870E-03
Case 5	1.84109E-02	9.81589E-01	5.90519E-03

Tabela A.7.11.C - Critical Safety Unavailability / Availability Values and Average Societal Risk Values (fatalities/year) Calculated for Different Cases related to the Actuation (Valve) System (v)

LCA+CIR+ CYCtot. (Pounds)	*LUC (Pounds)*
29225.55	*2202.24*
48979.12	*4004.07*
68732.68	*991.01*
68732.68	*5505.59*
48979.12	*400.41*

Table A.7.11.E- Case 1 -Costs involved in the Actuation (Valve) System (v)

N^0 of Deaths per year	Value of Life (Pounds)	Loss Lives per year (LLyear) (Pounds)	Benefit in Loss Lives /year (Pounds)	*Total Benefit Loss Lives LL* (Pounds)	CSU	*RELyear* (Pounds)	*Benefit REL year-REL* (Pounds)	*Total Benefit RELoss* (Pounds)	*Total Benefit* (Pounds)	*LCC (Pounds)*
5.87905E-03	3.0000E+06	17637.15	9368.63	**58641.38**	1.012600E-02	13493.05	1319021.80	*8256192.70*	**8314834.08**	**-8283406.29**
5.85291E-03	3.0000E+06	17558.74	9447.05	**59132.18**	1.841091E-03	2453.28	1330061.56	*8325294.23*	**8384426.41**	**-8331443.23**
5.86148E-03	3.0000E+06	17584.44	9421.35	**58971.31**	4.556700E-03	6071.87	1331840.19	*8336427.25*	**8395398.56**	**-8325674.87**
5.84870E-03	3.0000E+06	17546.10	9459.68	**59211.26**	5.063000E-04	674.65	1331840.19	*8336427.25*	**8395638.51**	**-8321400.24**
5.90519E-03	3.0000E+06	17715.56	9290.22	**58150.57**	1.841091E-02	24532.81	1307982.03	*8187091.17*	**8245241.74**	**-8195862.22**
9.00193E-03	3.0000E+06	27005.78			1.000000E+00	1332514.84				

Table A.7.11.F - Case 1 - Life Cycle Cost Calculated for the Actuation System (v)

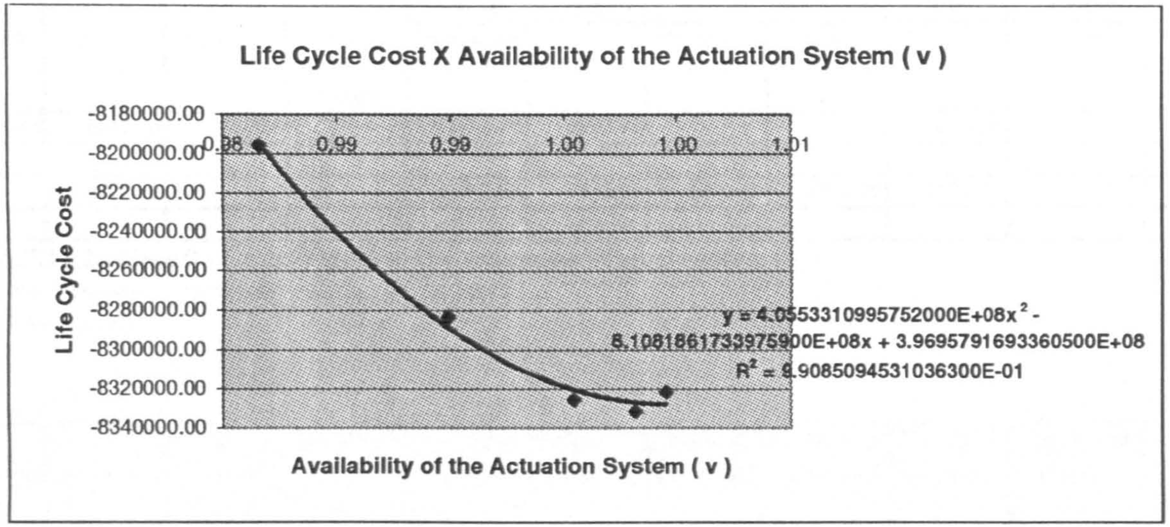


Figure A.7.11.- Life Cycle Cost versus Critical Availability - Actuation (Valve) System (v)

Case Number	*CSU*	*CSA*	*LCC*
Case1	1.01260E-02	9.898740E-01	-8283406.29
Case2	1.84109E-03	9.981589E-01	-8331443.23
Case3	4.55670E-03	9.954433E-01	-8325674.87
Case4	5.06300E-04	9.994937E-01	-8321400.24
Case 5	1.84109E-02	9.815891E-01	-8195862.22

Table A.7.11.G - Life Cycle Values (LCC) Obtained for Different Cases Related to the Actuation (Valve) System (v)

Component	Price	Number of	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Output card	**1442.40**	2		**2884.80**	**1153.92**			**1009.68**	1	**1442.40**	**300.00**	*6790.81*
Valve	6271.31	2	2	**12542.62**	**3135.66**	1216.10	**2432.20**	**4527.62**	1	**6271.31**	**1458.27**	*30367.67*
Total												*37158.48*

Table A.7.11.2 - Case 2 - Costs related to the Actuation (Valve) System (v)

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Note 1: All values in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate per 10^6 hr	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Output card	2	12	1	**60.00**	9.00E-07	2	**1442.40**	1502.40	**23.69**
Valve	2	12	0.5	**30.00**	1.60E-05	2	6271.31	6331.31	**1774.79**
Total				***90.00***					***1798.48***

Table A.7.11.2A- Case 2 - Maintenance, Test and Repair Costs related to the Actuation (Valve) System (v)

Component	Price	Number of	Number of Loops	CIEH	CIMV	CIIC		CIMC	CIRS		CIRT	TOTAL
				Component Cost		Price per loop	total		No of	Price		
Output card	1442.40	3		4327.20	1730.88			1514.52	1	**1442.40**	300.00	***9315.01***
Valve	6271.31	3	3	18813.93	4703.48	1216.10	3648.3	6791.43	1	**6271.31**	1458.27	***41686.72***
Total												***51001.73***

Table A.7.11.3 - Case 3 - Costs related to the Actuation (Valve) System (v)

Rate (May,98): 1pound = 1,828645 R$ and 1US$ = 1,1468 R$

Note 1: All values in pounds

Component	Number of	Test Period (months)	Man-hours per test	Test costs per year	Failure rate per 10^6 hr	Manhours per repair	Other costs per repair	Total cost per repair	Repair costs per year
Output card	3	12	1	90.00	9.00E-07	2	1442.40	1502.40	**35.53**
Valve	3	12	0.5	45.00	1.60E-05	2	6271.31	6331.31	**2662.19**
Total				***135.00***					***2697.72***

Table A.7.11.3A- Case 3 - Maintenance, Test and Repair Costs related to the Actuation (Valve) System (v)

Appendix 8

PILOT PROJECT - January 1998

ASSUMPTIONS

Minimum Atractivity Rate	15.0%
Royalties (Oil):	10.0%
Royalties (Gas):	10.0%
Income taxes:	25.0%
Social Contribution Parcel:	8.0%
Operation Beginning Date:	Sep-97
Basic Date :	Jun-98
Mon, Ve ctor Conc. in first year:	Jul-98
Price Levels :	Feb-98

Simulation Date: 17-Jun-98

Financial Indicators

NET PRESENT VALUE (NPV) (MMUS$) =	227.01
INTERNAL RATE OF RETURN (per yr.) =	37.43%
FINANTIAL EXPOSITION (MMUS$) =	-210.77
NET UNIT PROFIT (US$/BOE) =	4.11
UNIT COST (US$/BOE) investment=	4.90
operational =	3.00
taxes=	0.96
production =	8.87

NPV/UPDT. INVESTM. .T. (US$/US$) =	0.84
NPV/UPDT. EXPENSES .T. (US$/US$) =	0.35
TIME OF RETURN from the project beginning=	4a. 4m.
TIME OF RETURN from the operation beginning=	4a. 8m.
Production volume break even NP(MMBOE) =	35.90
Expected Production=	0.22

	INVESTMENT		OPERATIONAL COST			RESIDUAL VALUE		SOCIAL C.	Income Tx.	EXPENSES		INCOME		CASH FLOW	
	NOMINAL	Updated	Operation	ROYALTIES	T. (Updated)	NOMINAL	Total (Updated)	NOMINAL	NOMINAL	NOMINAL	Updated	NOMINAL	Updated	NOMINAL	Updated
1998	267.90	264.80	2.26	7.10	9.26			1.49	4.66	283.41	280.13	70.17	69.36	-213.24	-210.77
1999			7.32	18.96	22.58			10.85	33.91	71.04	61.06	187.01	160.73	115.97	99.67
2000	7.00	5.23	16.63	14.44	23.23			6.86	21.44	66.37	49.60	142.60	106.58	76.23	56.97
2001			20.74	11.62	21.03			4.53	14.15	51.04	33.17	114.74	74.57	63.71	41.40
2002			20.74	11.62	18.28			4.52	14.11	50.99	28.81	114.59	64.76	63.61	35.95
2003			20.74	11.62	15.90			4.51	14.09	50.95	25.04	114.48	56.26	63.53	31.22
2004			20.74	11.62	13.83			4.51	14.09	50.95	21.77	114.48	48.92	63.53	27.15
2005			20.74	11.62	12.02			4.51	14.09	50.95	18.93	114.48	42.54	63.53	23.61
2006			20.74	11.62	10.45			4.53	14.15	51.04	16.49	114.74	37.08	63.71	20.59
2007			20.74	11.62	9.09			4.53	14.15	51.04	14.34	114.74	32.24	63.71	17.90
2008			20.74	11.62	7.90			6.54	20.42	59.31	14.49	114.74	28.03	55.43	13.54
2009			20.74	11.62	6.87			6.54	20.42	59.31	12.60	114.74	24.38	55.43	11.78
2010			20.74	11.62	5.98			6.59	20.60	59.54	11.00	114.74	21.20	55.20	10.20
2011			20.74	11.62	5.20			6.59	20.60	59.54	9.57	114.74	18.43	55.20	8.87
2012			20.74	11.62	4.52			6.59	20.60	59.54	8.32	114.74	16.03	55.20	7.71
2013			20.74	11.62	3.93			6.59	20.60	59.54	7.23	114.74	13.94	55.20	6.71
2014			20.74	11.62	3.42			6.59	20.60	59.54	6.29	114.74	12.12	55.20	5.83
2015			20.74	11.62	2.97			6.59	20.60	59.54	5.47	114.74	10.54	55.20	5.07
2016			20.74	11.62	2.58			6.59	20.60	59.54	4.76	114.74	9.16	55.20	4.41
2017			20.74	11.62	2.25			6.59	20.60	59.54	4.14	114.74	7.97	55.20	3.83
2018			20.74	11.62	1.95			6.59	20.60	59.54	3.60	114.74	6.93	55.20	3.33
2019			20.74	11.62	1.70			6.59	20.60	59.54	3.13	114.74	6.03	55.20	2.90
2020						-18.61	-0.85			18.61	0.85			-18.61	-0.85
2021															
2022															
	274.90	270.03	420.19	261.27	204.95	-18.61	-0.85	129.81	405.65	1,510.42	640.78	2,578.95	867.78	1,068.53	227.01

Framework A.8.1 -Net Present Value (NPV) Before The Accident's Occurrence (in U$ Millions)

	DAILY POTENTIAL PRODUCTION (Oper. Factor= 100%)				
	OIL (m3/d)	GAS (Mm3/d)	GLP (m3/d)	LGN/C5+ (m3/d)	OTHERS (m3/d)
1998	2074.3	164.0			
1999	5683.0	477.0			
2000	4207.0	345.0			
2001	3284.0	271.0			
2002	3284.0	271.0			
2003	3284.0	271.0			
2004	3284.0	271.0			
2005	3284.0	271.0			
2006	3284.0	271.0			
2007	3284.0	271.0			
2008	3284.0	271.0			
2009	3284.0	271.0			
2010	3284.0	271.0			
2011	3284.0	271.0			
2012	3284.0	271.0			
2013	3284.0	271.0			
2014	3284.0	271.0			
2015	3284.0	271.0			
2016	3284.0	271.0			
2017	3284.0	271.0			
2018	3284.0	271.0			
2019	3284.0	271.0			
2020					

17-Jun-98

Maximum	20656	271			

Framework A.8.1.A - Maximum Daily Potential Production

	NON DEPRECIABLE INVESTMENTS					DEPRECIABLE INVESTMENTS						DEPRECIATION	TOTAL INVESTM.
	Exploration Investment	Drilling	X-tree	Others	TOTAL 1	E&P Unit	E&P Mooring	E&P PRE- OP	Others	Lines	TOTAL 2		
1998			17.10		17.10	171.00				79.80	250.80	25.08	267.90
1999												25.08	
2000											7.00	25.78	7.00
2001												25.78	
2002												25.78	
2003												25.78	
2004												25.78	
2005												25.78	
2006												25.78	
2007												25.78	
2008												0.70	
2009												0.70	
2010													
2011													
2012													
2013													
2014													
2015													
2016													
2017													
2018													
2019													
2020													
2021													
2022													
TOTAL			17.10		17.10	171.00				79.80	257.80	257.80	274.90

Framework A.8.1.B - Investments - Before Accident's Occurrence (in U$ Millions)

17-Jun-98

Equipment life time in years: 20 NPV 227.01

Equipment	Original Cost (US$ MM)	Year of Installation	Year of decommissioning	Residual value (US$ MM)
Unit	84.10	1998	2020	-8.41
Lines	84.00	1998	2020	-8.40
X-trees	18.00	1998	2020	-1.80
	186.10			-18.61

Framework A.8.1.C - Residual Value - Before na Accident's Occurrence (in U$ Millions)

PILOT PROJECT - January 1998

ASSUMPTIONS

Minimum Atractivity Rate	15.0%
Royalties (Oil):	10.0%
Royalties (Gas):	10.0%
Income taxes:	25.0%
Social Contribution Parcel:	8.0%
Operation Beginning Date:	Sep-99
Basic Date :	Jun-98
Price Levels :	Feb-98

Financial Indicators

NET PRESENT VALUE (NPV) (MMUS$) =	**158.37**
INTERNAL RATE OF RETURN (per yr.) =	**26.49%**
FINANTIAL EXPOSITION (MMUS$) =	**-234.40**
NET UNIT PROFIT (US$/BOE) =	**3.32**
UNIT COST (US$/BOE): investment=	**6.69**
operational =	**3.24**
taxes=	**1.33**
production =	**11.26**

NPV/UPDT. INVESTM. ıT. (US$/US$) =	**0.50**
NPV/UPDT. EXPENSES ıT. (US$/US$) =	**0.25**
TIME OF RETURN from the project beginning=	**6 yr.7 m.**
TIME OF RETURN from the operation beginning=	**4 yr. 11 m.**
Production volume break even NP(MMBOE) =	**44.85**
Expected Production=	**0.29**

Simulation Date: **17-Jun-98**

	INVESTMENT		**OPERATIONAL COST**			**RESIDUAL VALUE**		**SOCIAL C.**	**Income Tx.**	**EXPENSES**		**INCOME**		**CASH FLOW**	
	NOMINAL	**Updated**	**Operation**	**ROYALTIES**	**T. (Updated)**	**NOMINAL**	**T. (Updated)**	**NOMINAL**	**NOMINAL**	**NOMINAL**	**Updated**	**NOMINAL**	**Updated**	**NOMINAL**	**Updated**
1998	262.29	259.25						0.03	0.11	262.43	259.39	42.05	41.56	-220.38	-217.83
1999	68.66	59.01	2.26	6.89	7.87			2.20	6.87	86.89	74.68	68.03	58.47	-18.86	-16.21
2000			7.32	19.54	20.08			10.77	33.66	71.29	53.28	192.88	144.15	121.59	90.87
2001			16.63	14.88	20.48			6.72	21.01	59.25	38.50	146.94	95.50	87.70	57.00
2002			20.74	11.62	18.28			4.07	12.71	49.14	27.77	114.59	64.76	65.46	36.99
2003			20.74	11.62	15.90			4.06	12.68	49.10	24.13	114.48	56.26	65.38	32.13
2004			20.74	11.62	13.83			4.06	12.68	49.10	20.98	114.48	48.92	65.38	27.94
2005			20.74	11.62	12.02			4.06	12.68	49.10	18.24	114.48	42.54	65.38	24.29
2006			20.74	11.62	10.45			4.08	12.75	49.19	15.89	114.74	37.08	65.56	21.18
2007			20.74	11.62	9.09			4.08	12.75	49.19	13.82	114.74	32.24	65.56	18.42
2008			20.74	11.62	7.90			6.04	18.88	57.28	13.99	114.74	28.03	57.47	14.04
2009			20.74	11.62	6.87			6.59	20.60	59.54	12.65	114.74	24.38	55.20	11.73
2010			20.74	11.62	5.98			6.59	20.60	59.54	11.00	114.74	21.20	55.20	10.20
2011			20.74	11.62	5.20			6.59	20.60	59.54	9.57	114.74	18.43	55.20	8.87
2012			20.74	11.62	4.52			6.59	20.60	59.54	8.32	114.74	16.03	55.20	7.71
2013			20.74	11.62	3.93			6.59	20.60	59.54	7.23	114.74	13.94	55.20	6.71
2014			20.74	11.62	3.42			6.59	20.60	59.54	6.29	114.74	12.12	55.20	5.83
2015			20.74	11.62	2.97			6.59	20.60	59.54	5.47	114.74	10.54	55.20	5.07
2016			20.74	11.62	2.58			6.59	20.60	59.54	4.76	114.74	9.16	55.20	4.41
2017			20.74	11.62	2.25			6.59	20.60	59.54	4.14	114.74	7.97	55.20	3.83
2018			20.74	11.62	1.95			6.59	20.60	59.54	3.60	114.74	6.93	55.20	3.33
2019			20.74	11.62	1.70			6.59	20.60	59.54	3.13	114.74	6.03	55.20	2.90
2020						-22.82	-1.04			22.82	1.04			-22.82	-1.04
2021															
2022															
	330.95	318.27	399.45	250.46	177.28	-22.82	-1.04	122.68	383.37	1,509.72	637.86	2,514.33	796.23	1,004.61	158.37

Framework A.8.2 - Net Present Value (NPV) after a Severe Damage Occurrence in year 1 (in U$ Millions)

	NON DEPRECIABLE INVESTMENTS					DEPRECIABLE INVESTMENTS						DEPRECIATION	TOTAL INVESTM.
	Exploration Investment	Drilling	X-tree	Others	TOTAL 1	E&P Unit	E&P Mooring	E&P PRE- OP	Others	Lines	TOTAL 2		
1998			17.10		17.10	113.67		3.17	48.55	79.80	245.19	24.52	262.29
1999						61.83		6.83			68.66	31.39	68.66
2000												31.39	
2001												31.39	
2002												31.39	
2003												31.39	
2004												31.39	
2005												31.39	
2006												31.39	
2007												31.39	
2008												6.87	
2009													
2010													
2011													
2012													
2013													
2014													
2015													
2016													
2017													
2018													
2019													
2020													
2021													
2022													
TOTAL			17.10		17.10	175.50		10.00	48.55	79.80	313.85	313.85	330.95

Framework A.8.2.A- Investments - After a Severe Damage Occurrence in year 1 (in U$ Millions)

17-Jun-98

Equipment life time in years: 20

NPV 158.37

Equipment	Original Cost (US$ MM)	Year of Installation	Year of decommissioning	Residual value (US$ MM)
Unit	84.10	1998	2020	-8.41
Lines	84.00	1998	2020	-8.40
X-trees	18.00	1998	2020	-1.80
Unit	42.50	1998	2020	-4.21
	228.15			-22.82

Framework A.8.2.B - Residual Value - After a Severe Damage Occurrence in year 1 (in U$ Millions)

PILOT PROJECT - January 1998

ASSUMPTIONS

Minimum Atractivity Rate	15.0%
Royalties (Oil):	10.0%
Royalties (Gas):	10.0%
Income taxes:	25.0%
Social Contribution Parcel:	8.0%
Operation Beginning Date:	Sep-00
Basic Date :	Jun-98
Mon, Ve ctor Conc. in first year:	Jul-98
Price Levels :	Feb-98

Financial Indicators

NET PRESENT VALUE (NPV) (MMUS$) =	109.74
INTERNAL RATE OF RETURN (per yr.) =	22.53%
FINANTIAL EXPOSITION (MMUS$) =	-239.34
NET UNIT PROFIT (US$/BOE) =	2.67
UNIT COST (US$/BOE) investment=	8.41
operational =	3,48
taxes=	1,86
production =	13,76

NPV/UPDT. INVESTM. ıT. (US$/US$) =	0.32
NPV/UPDT. EXPENSES ıT. (US$/US$) =	0.17
TIME OF RETURN from the project beginning=	8a. 11m.
TIME OF RETURN from the operation beginning=	6a. 3m.
Production volume break even NP(MMBOE) =	54.00
Expected Production=	0.36

Simulation date: 17-Jun-98

	INVESTMENT		OPERATIONAL COST			RESIDUAL VALUE		SOCIAL C.	Income Tx.	EXPENSES		INCOME		CASH FLOW	
	NOMINAL	Updated	Operation	ROYALTIES	T. (Updated)	NOMINAL	Total (Updated)	NOMINAL	NOMINAL	NOMINAL	Updated	NOMINAL	Updated	NOMINAL	Updated
1998	155.64	153.84						4.25	13.29	173.18	171.17	84.10	83.13	-89.08	-88.05
1999	156.86	134.82								156.86	134.82			-156.86	-134.82
2000	75.00	56.05	2.26	7.10	7.00			1.90	5.94	92.21	68.92	70.17	52.44	-22.04	-16.47
2001			7.32	20.13	17.84			10.74	33.56	71.75	46.63	198.75	129.17	126.99	82.53
2002			16.63	14.88	17.81			6.26	19.55	57.32	32.39	146.75	82.93	89.44	50.54
2003			20.74	11.62	15.90			3.61	11.27	47.23	23.21	114.48	56.26	67.25	33.05
2004			20.74	11.62	13.83			3.61	11.27	47.23	20.18	114.48	48.92	67.25	28.74
2005			20.74	11.62	12.02			3.61	11.27	47.23	17.55	114.48	42.54	67.25	24.99
2006			20.74	11.62	10.45			3.63	11.34	47.32	15.29	114.74	37.08	67.42	21.79
2007			20.74	11.62	9.09			3.63	11.34	47.32	13.30	114.74	32.24	67.42	18.94
2008			20.74	11.62	7.90			3.63	11.34	47.32	11.56	114.74	28.03	67.42	16.47
2009			20.74	11.62	6.87			3.63	11.34	47.32	10.05	114.74	24.38	67.42	14.32
2010			20.74	11.62	5.98			6.59	20.60	59.54	11.00	114.74	21.20	55.20	10.20
2011			20.74	11.62	5.20			6.59	20.60	59.54	9.57	114.74	18.43	55.20	8.87
2012			20.74	11.62	4.52			6.59	20.60	59.54	8.32	114.74	16.03	55.20	7.71
2013			20.74	11.62	3.93			6.59	20.60	59.54	7.23	114.74	13.94	55.20	6.71
2014			20.74	11.62	3.42			6.59	20.60	59.54	6.29	114.74	12.12	55.20	5.83
2015			20.74	11.62	2.97			6.59	20.60	59.54	5.47	114.74	10.54	55.20	5.07
2016			20.74	11.62	2.58			6.59	20.60	59.54	4.76	114.74	9.16	55.20	4.41
2017			20.74	11.62	2.25			6.59	20.60	59.54	4.14	114.74	7.97	55.20	3.83
2018			20.74	11.62	1.95			6.59	20.60	59.54	3.60	114.74	6.93	55.20	3.33
2019			20.74	11.62	1.70			6.59	20.60	59.54	3.13	114.74	6.03	55.20	2.90
2020						-25.15	-1.15			25.15	1.15			-25.15	-1.15
2021															
2022															
	387.50	344.71	378.72	239.64	153.22	-25.15	-1.15	114.39	357.48	1,502.87	629.72	2,449.61	739.46	946.74	109.74

Framework A.8.3 - Net Present Value (NPV) - After a Total Damage Occurrence in year 1 (with insurance) (in U$ Millions)

	NON DEPRECIABLE INVESTMENTS					DEPRECIABLE INVESTMENTS						DEPRECIATION	TOTAL INVESTM.
	Exploration Investment	Drilling	X-tree	Others	TOTAL 1	E&P Unit	E&P Mooring	E&P PRE- OP	Others	Lines	TOTAL 2		
1998			17.10		17.10	16.74		1.86	40.14	79.80	138.54	13.85	155.64
1999						95.76		10.64	50.46		156.86		156.86
2000						67.50		7.50			75.00	37.04	75.00
2001												37.04	
2002												37.04	
2003												37.04	
2004												37.04	
2005												37.04	
2006												37.04	
2007												37.04	
2008												37.04	
2009												37.04	
2010													
2011													
2012													
2013													
2014													
2015													
2016													
2017													
2018													
2019													
2020													
2021													
2022													
TOTAL			17.10		17.10	180.00		20.00	90.60	79.80	370.40	384.25	387.50

Framework A.8.3.B - Investments - After a Total Damage Occurrence in year 1 (in U$ Millions)

17-Jun-98

Equipment life time in years: 20

NPV 109.74

Equipment	Original Cost (US$ MM)	Year of Installation	Year of decommissioning	Residual value (US$ MM)
Unit	84.10	1998	2020	-8.41
Lines	84.00	1998	2020	-8.40
X-trees	18.00	1998	2020	-1.80
Unit	40.14	1998	2020	-4.01
	50.46			-2.52
	276.70			-25.15

Framework A.8.3.C - Residual Value - After a Total Damage Occurrence in year 1 (U$ Millions)

Appendix 9

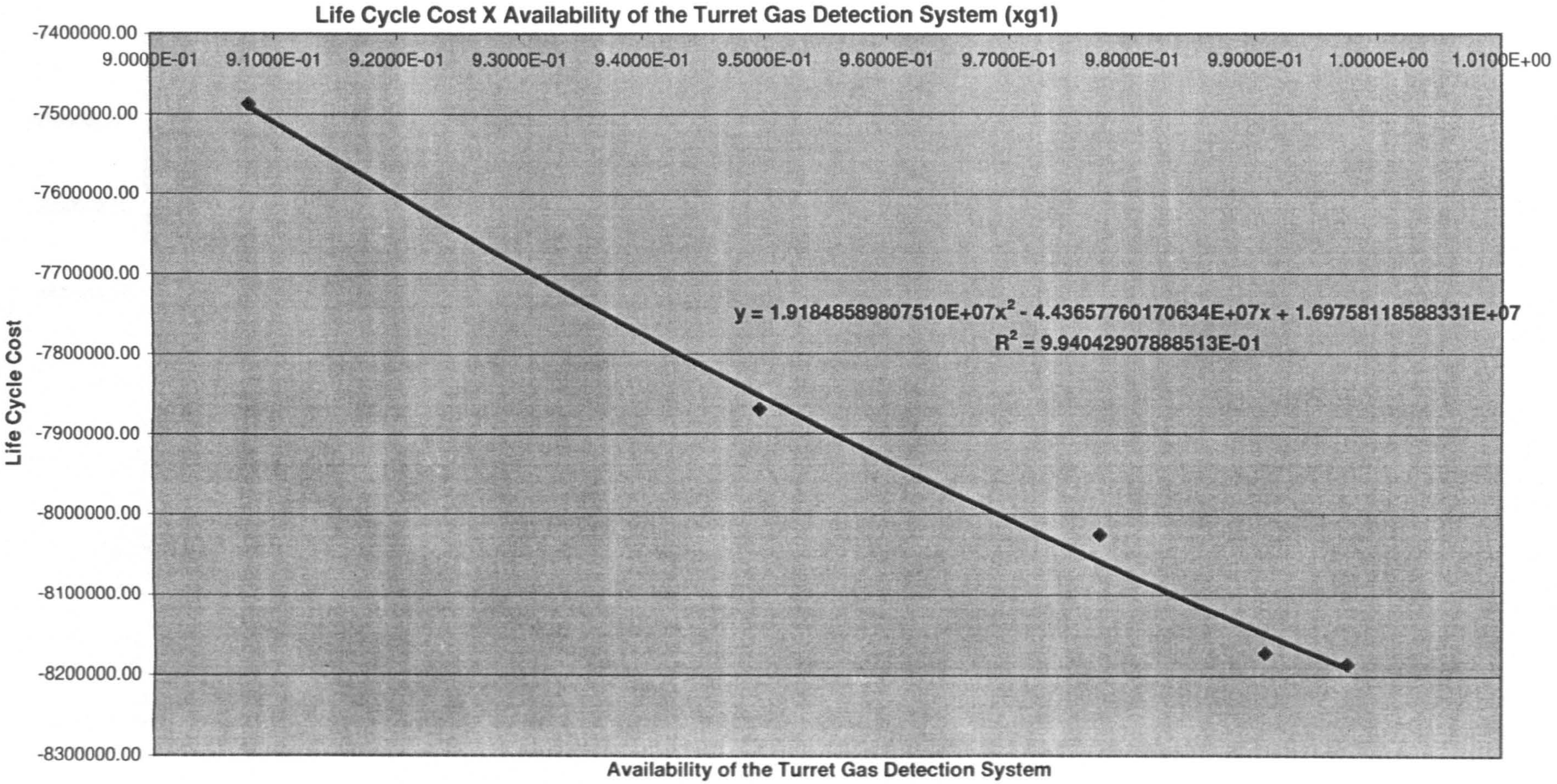


Figure A.91A -Life Cycle Cost X Availability of the Turret Gas Detection System (xg1)

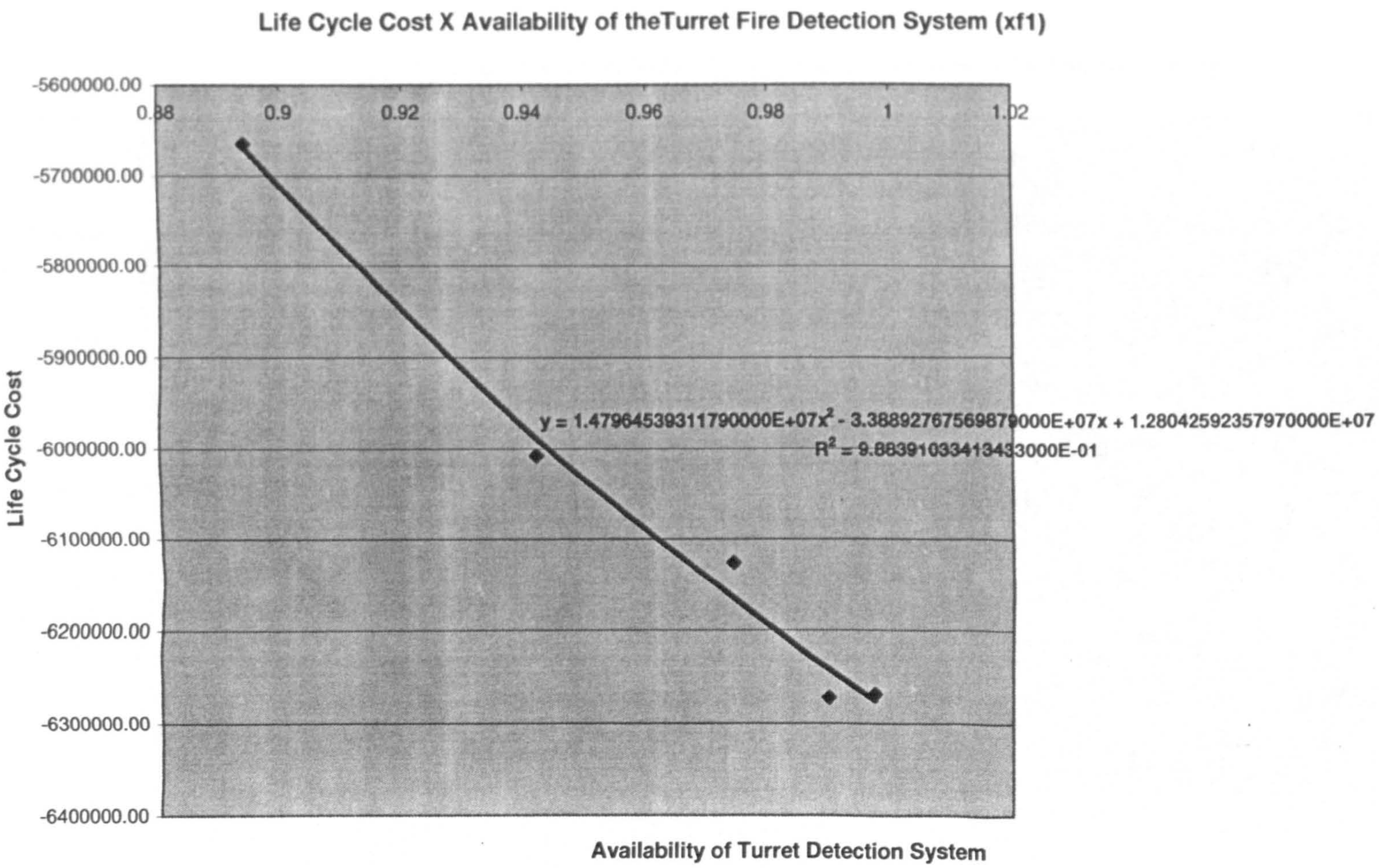


Figure A.9.1.B - Life Cycle Cost X Availability of theTurret Fire Detection System (xf1)

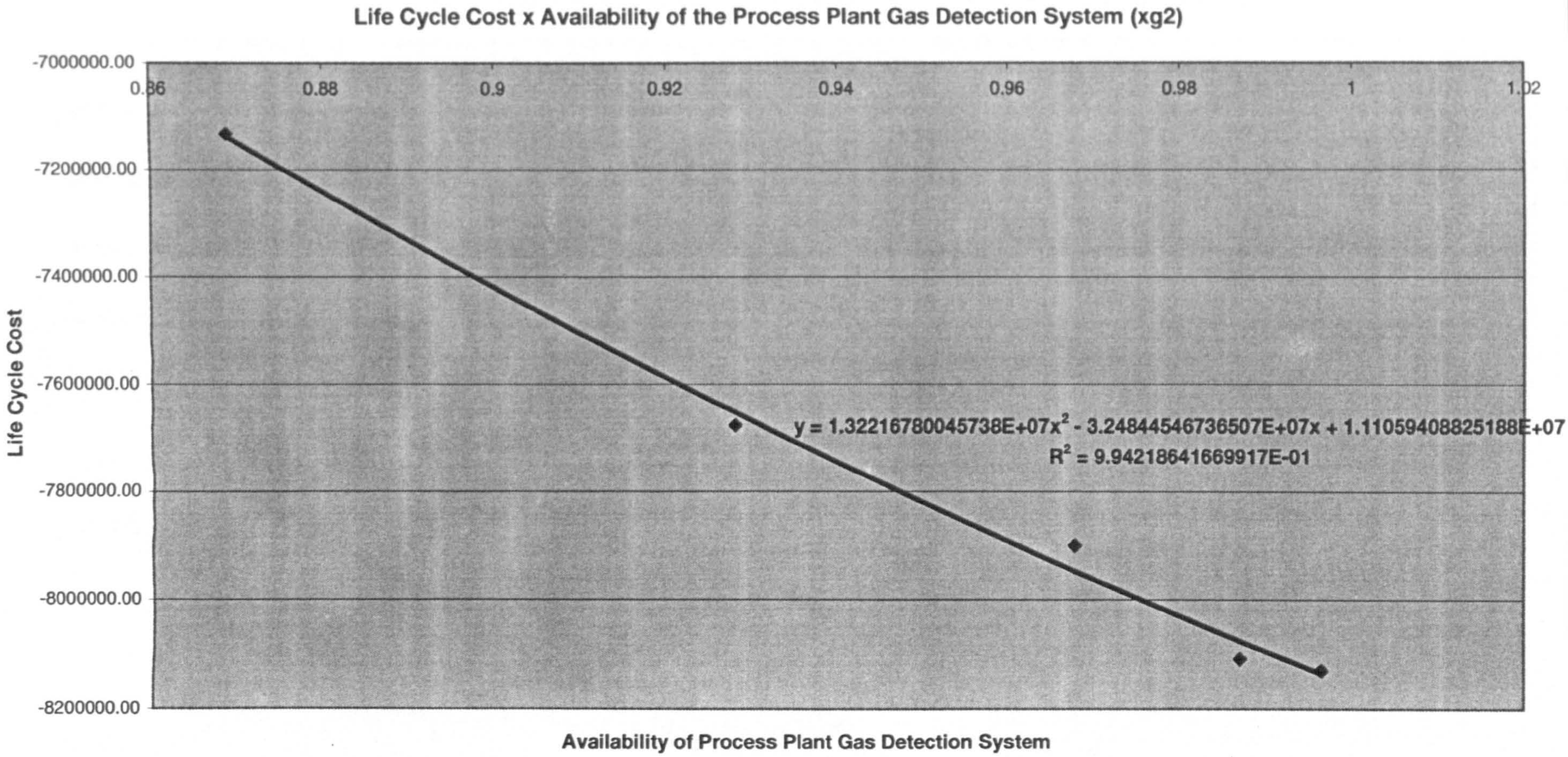


Figure A.9.2A - Life Cycle Cost x Availbility of the Process Plant Gas Detection System (xg2)

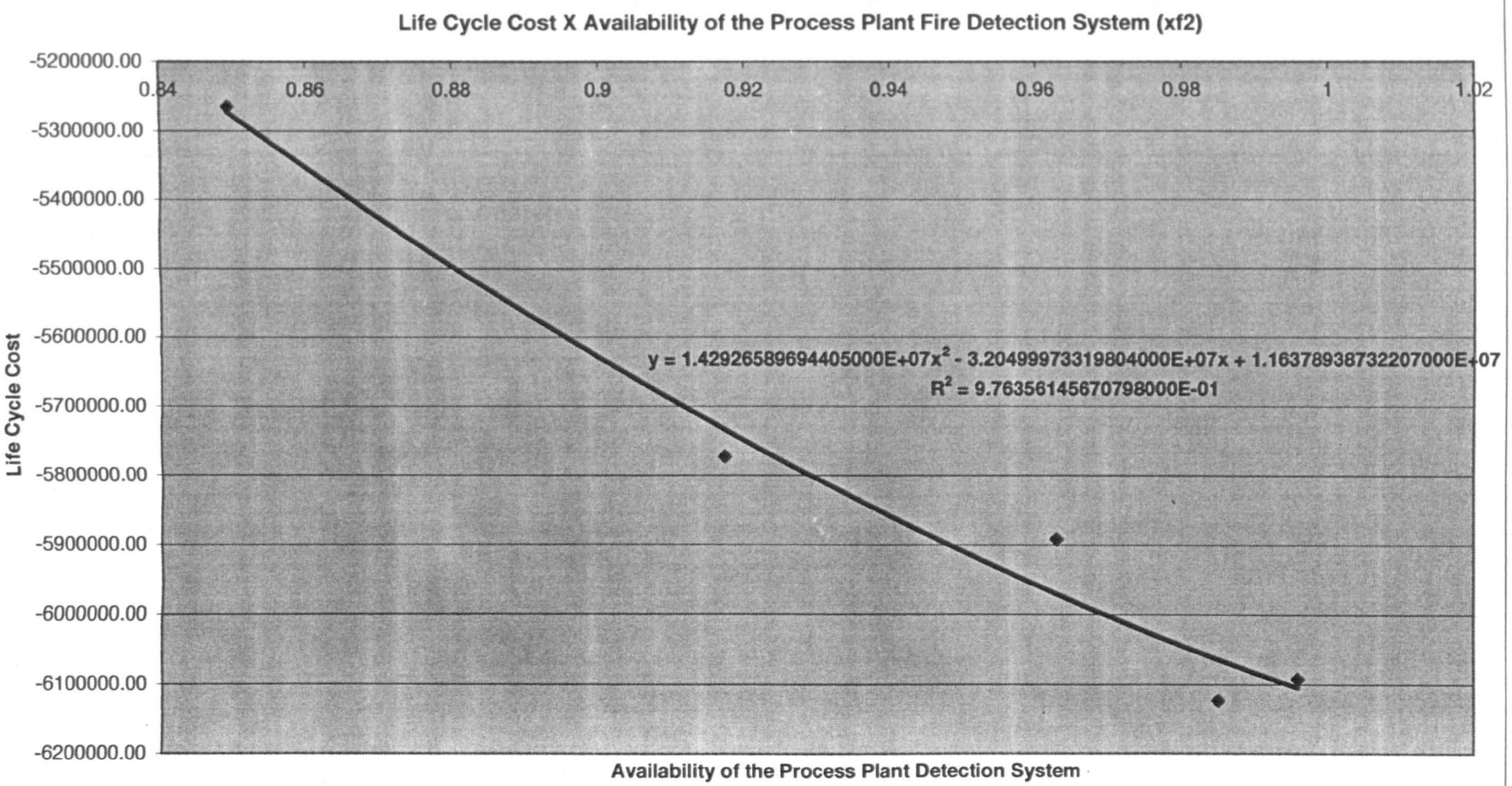


Figure A.9.2.B - Life Cycle Cost X Availability of the Process Plant Fire Detection System (xf2)

Life Cycle Cost X Availability of the Pump Room Gas Detection System (xg3)

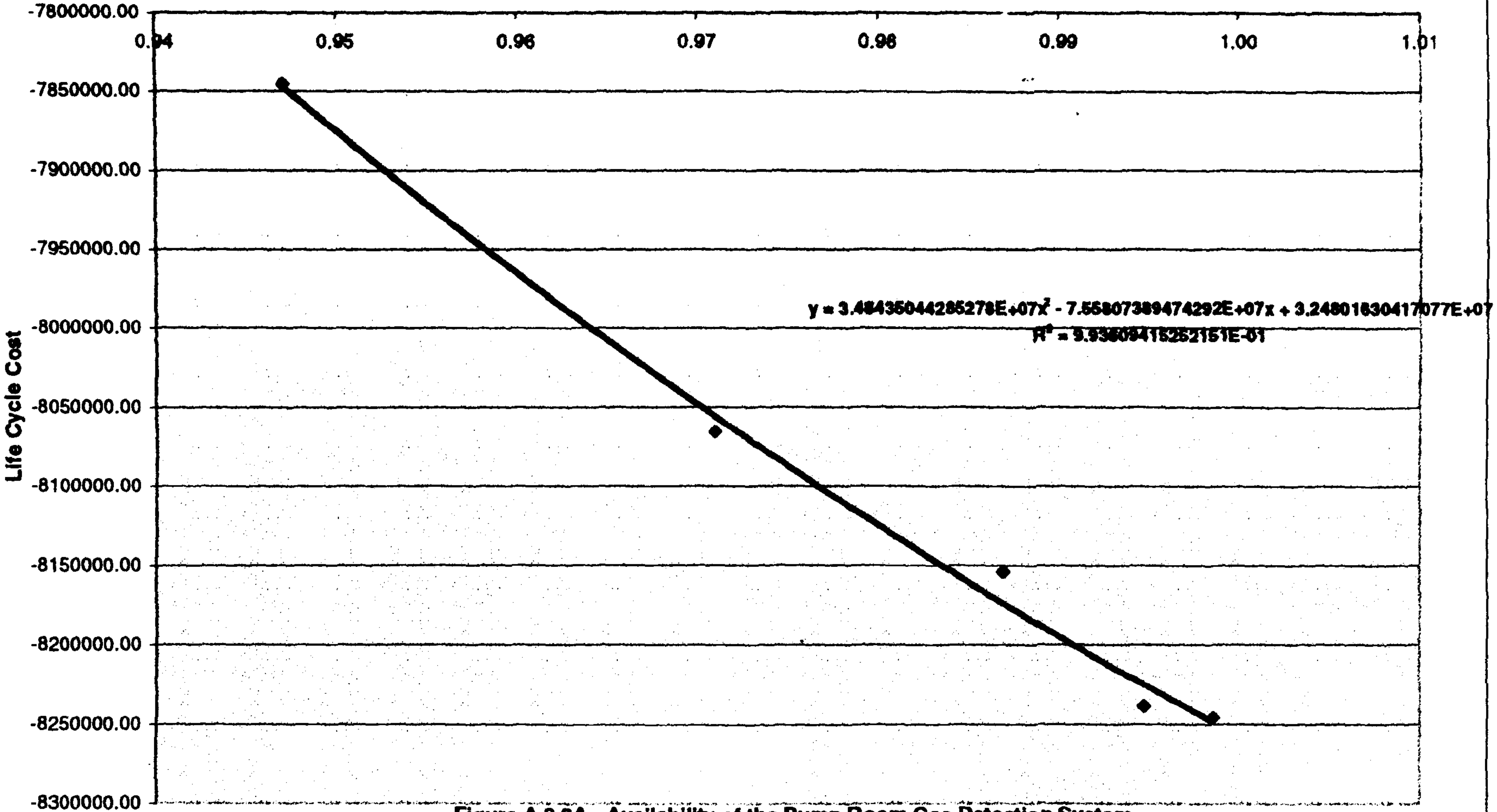


Figure A.9.3A - Availability of the Pump Room Gas Detection System

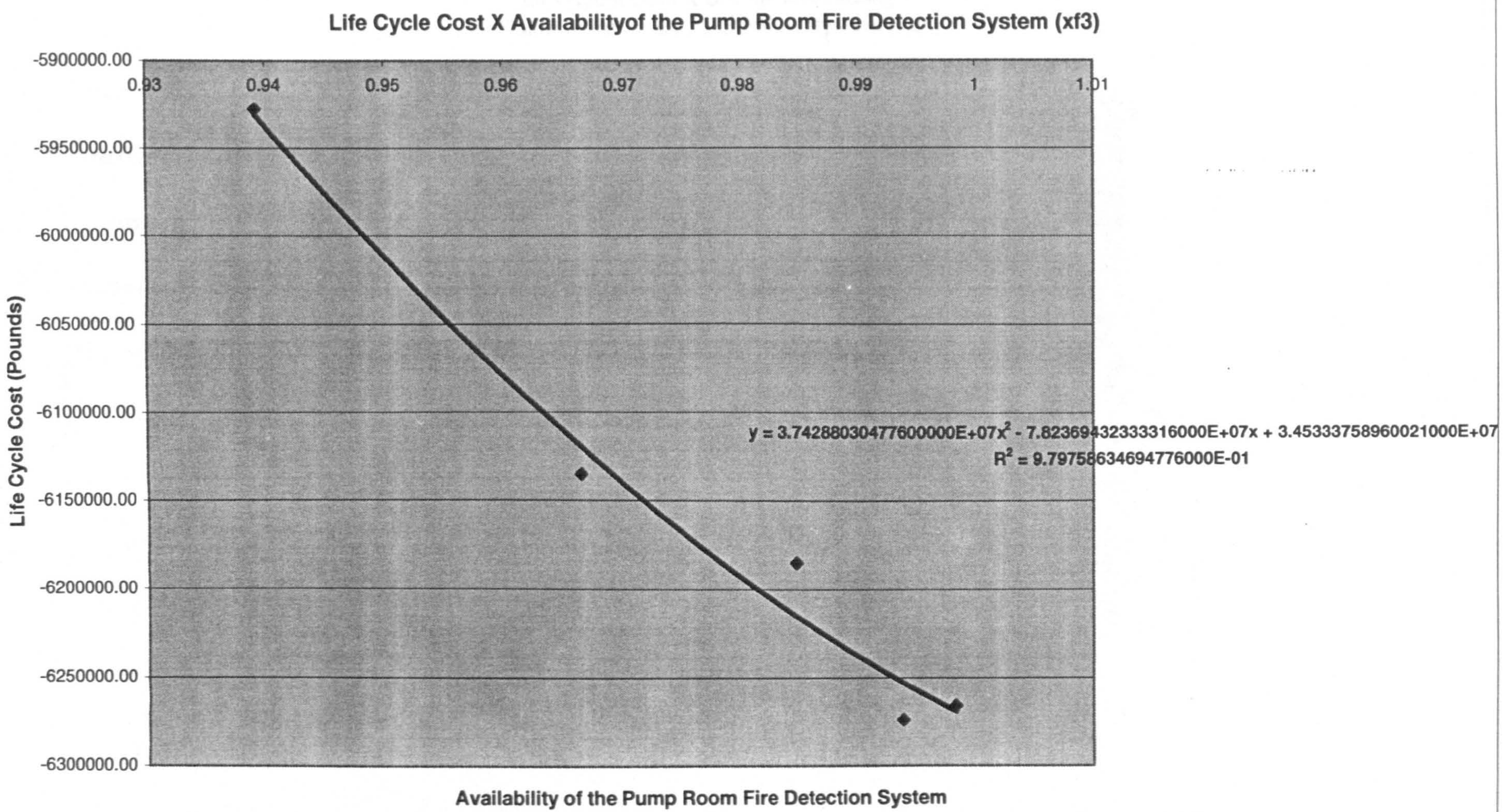


Figure A.9.3.B -Life Cycle Cost X Availabilityof the Pump Room Fire Detection System (xf3)

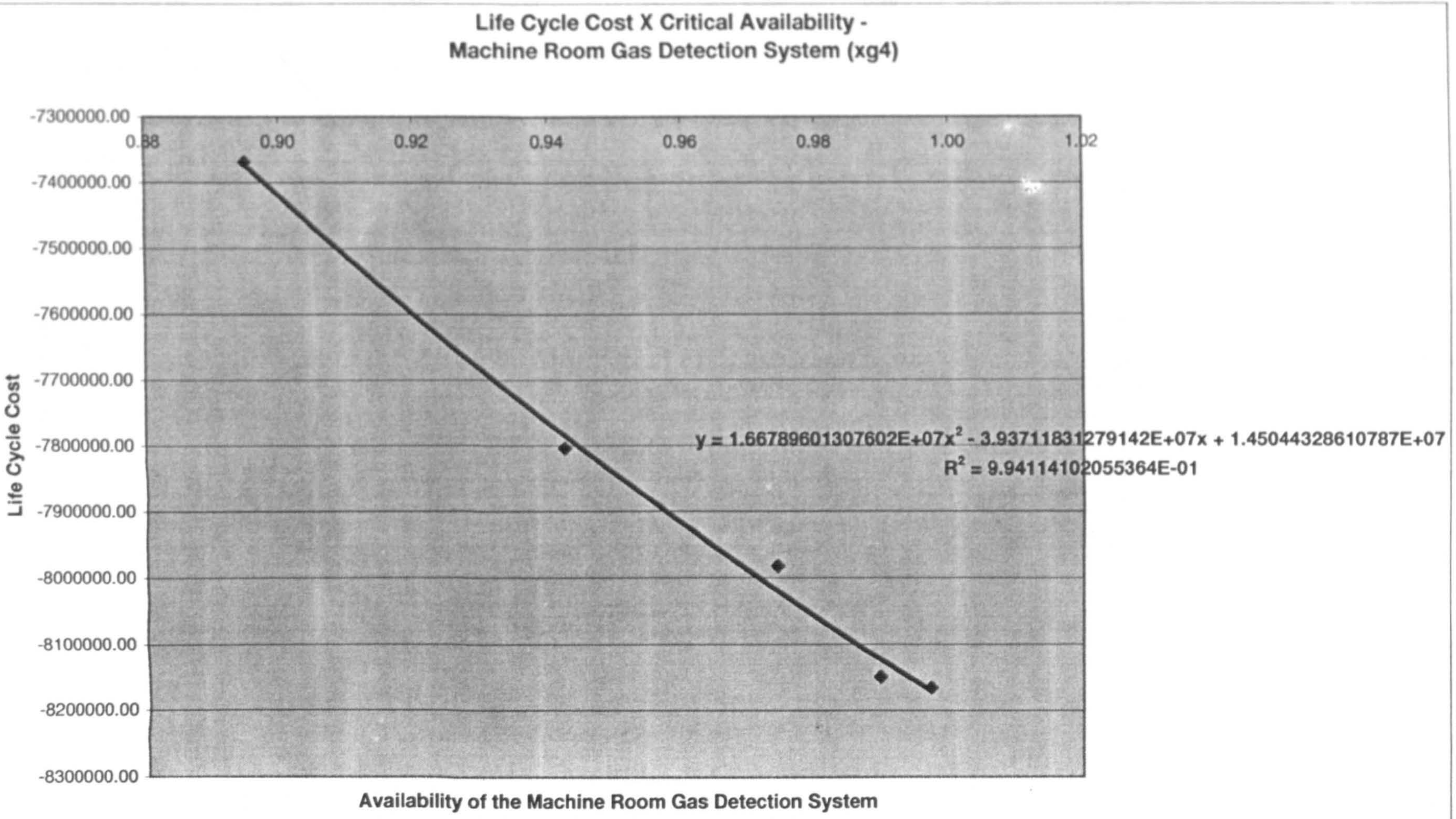


Figure A.9.4A - Life Cycle Cost X Critical Availability - Machine Room Gas Detection System (xg4)

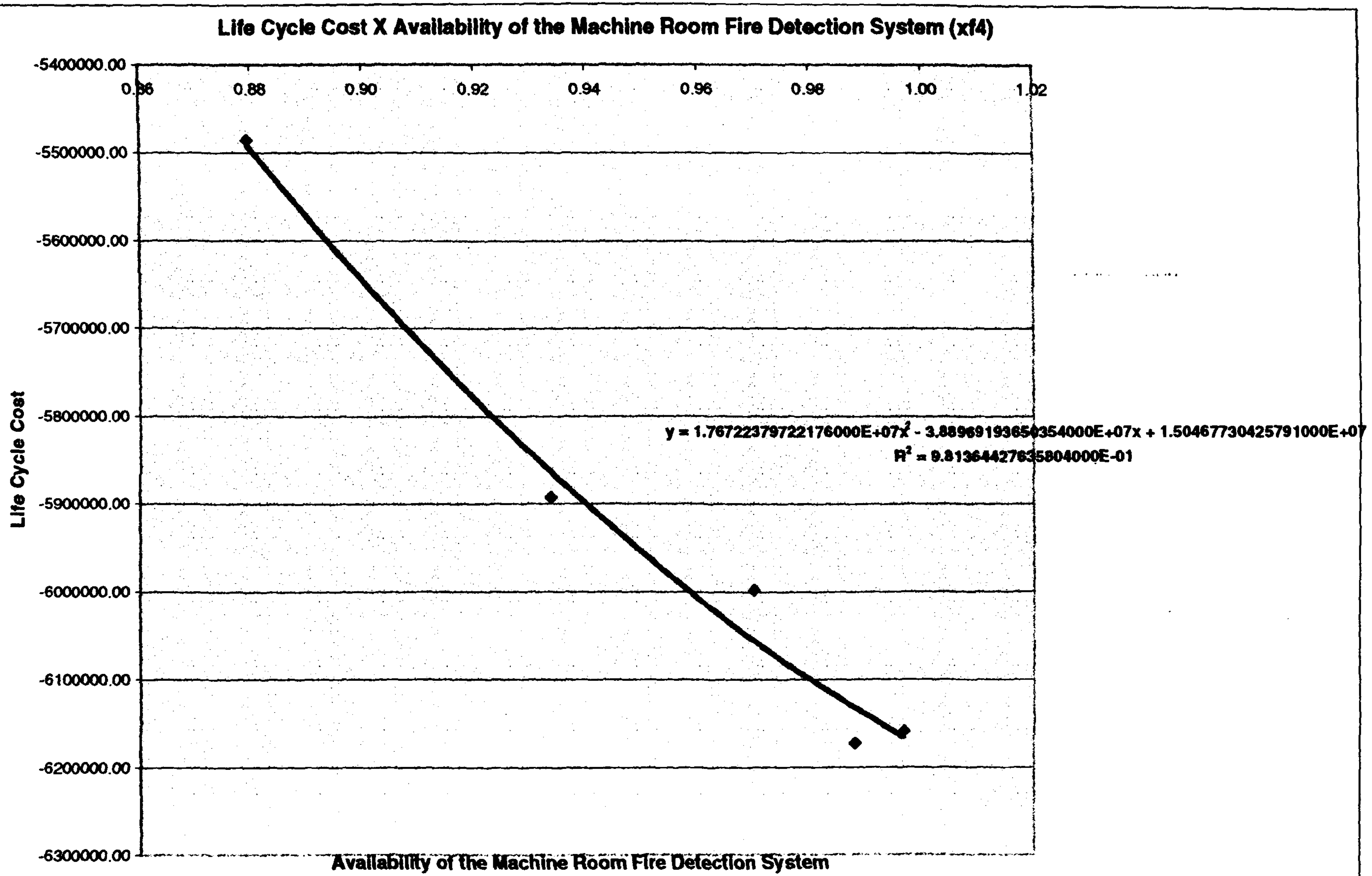


Figure A.9.4B -Life Cycle Cost X Availability of the Machine Room Fire Detection System (xf4)

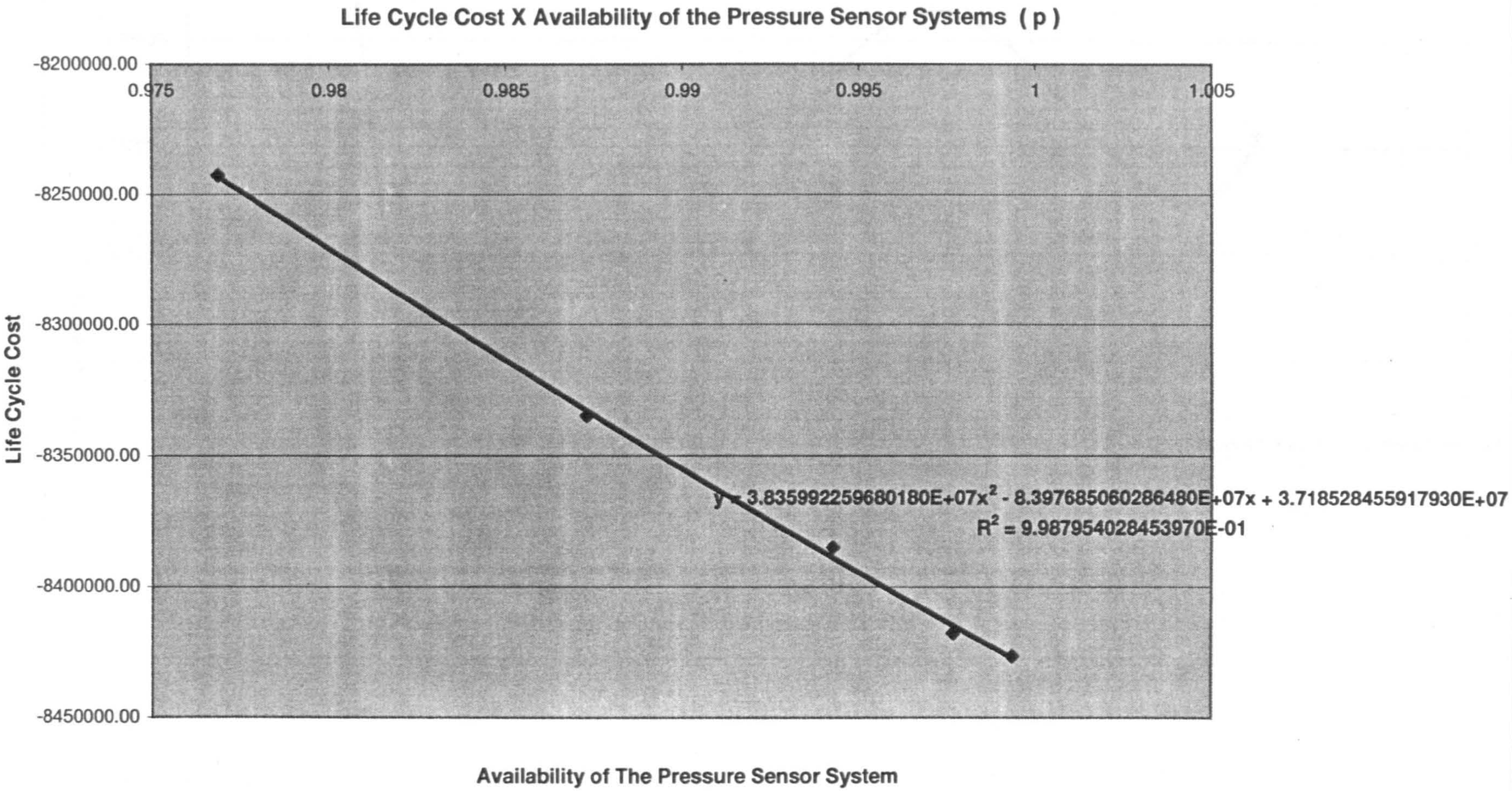


Figure A.9.5 - Life Cycle Cost X Availability of the Pressure Sensor Systems (p)

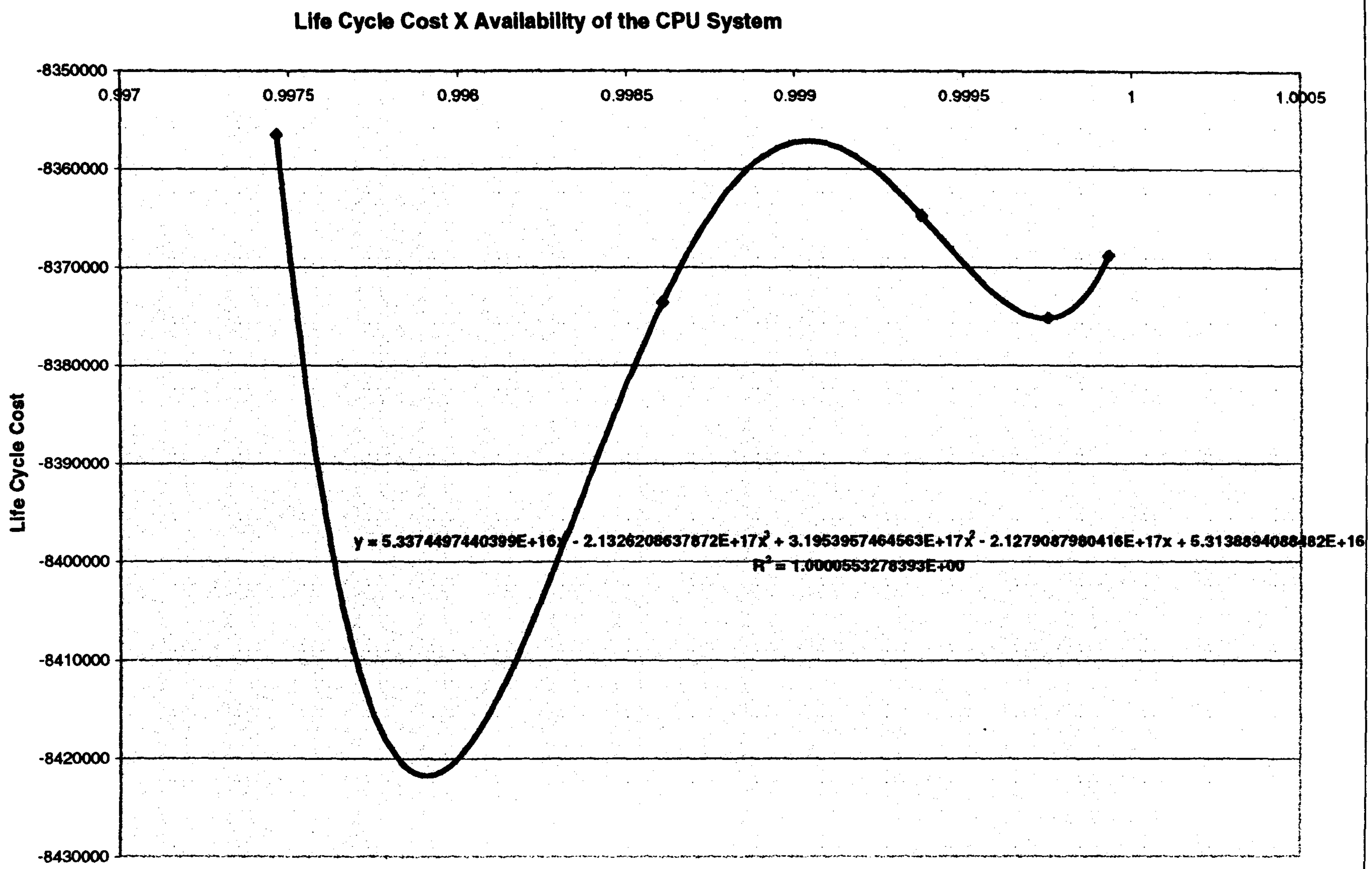


Figure A.9.6 - Availability of the CPU System

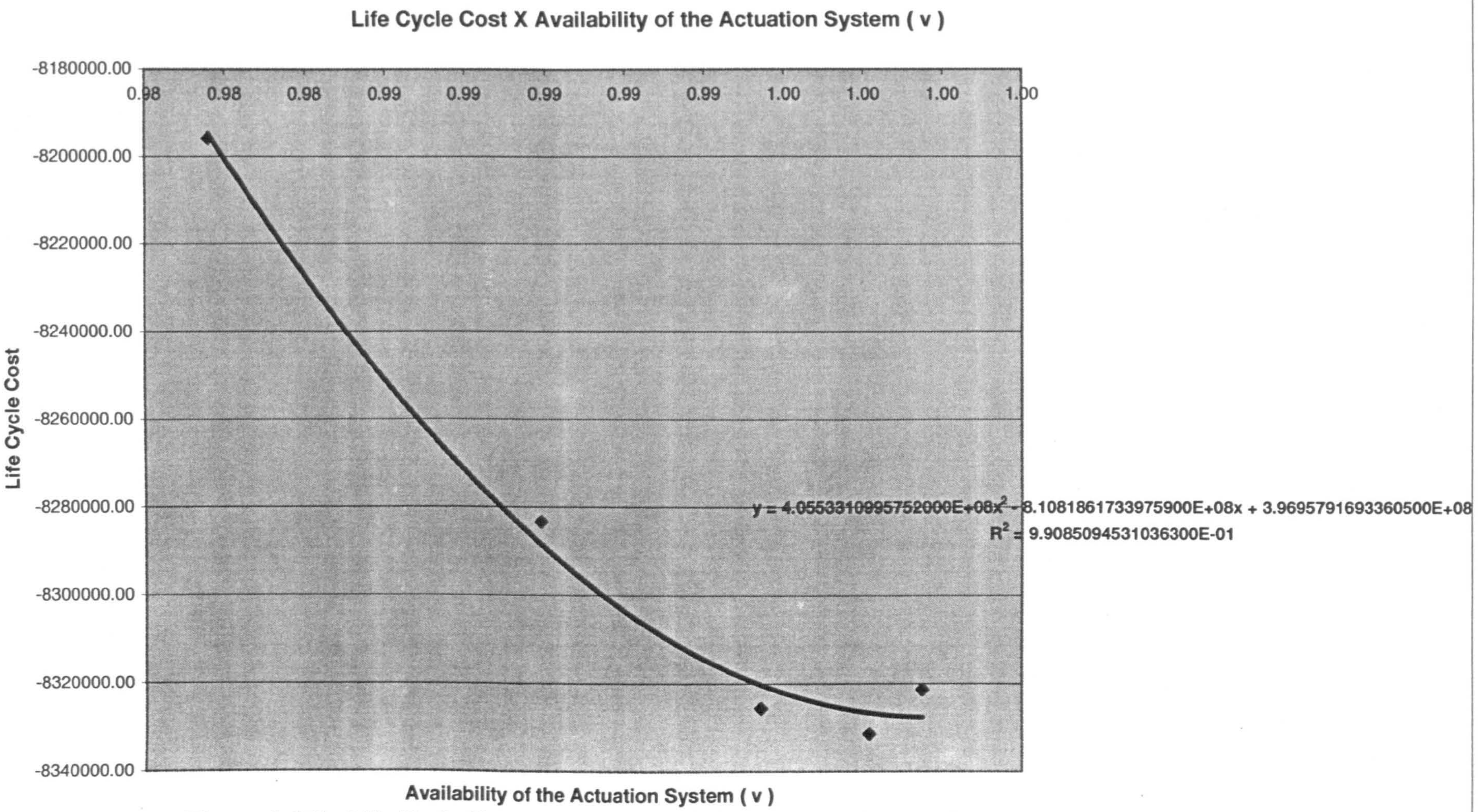


Figure A.9.7 - Life Cycle Cost x Availability of the Actuation System (v)

Appendix 10

EI-11.1.3	3.03214E-05	c.v2								
	-3.03214E-05	c.v2.xf1								
	-3.03214E-05	c.v2.p2								
	3.03214E-05	c.v2.p2.xf1								
EI-12.1.1	6.68174E-06	c.v4.p4								
EI-12.1.2	1.20000E-07	c.v4.xf1								
	-1.20000E-07	c.v4.p4.xf1								
EI-12.1.3	1.00000E-11	c.v4								
	-1.00000E-11	c.v4.xf1								
	-1.00000E-11	c.v4.p4								
	1.00000E-11	c.v4.p4.xf1								
EI-13.1.1	1.59819E-05	c.v1.xf1								
EI-13.1.2	2.37179E-04	c.v1								
	-2.37179E-04	c.v1.xf1								
EI-14.1.1	1.59819E-05	c.v1.xf1								
EI-14.1.2	2.37179E-04	c.v1								
	-2.37179E-04	c.v1.xf1								
EI-25.1.2	4.98047E-05	c.v2.xf2								

Framework A.10.1 - Frequency of Impaiment to TSR and Escape Routes Expressions in Terms of Availability Variables

-2.47000E-08	c.v1.p1.xg4.	xf4								
3.57000E-08	c.v1									
EI-9.1.1	1.59600E-05	c.v4.p4								
EI-9.1.2	1.56776E-04	c.v4.xf1								
	-1.56776E-04	c.v4.p4.xf1								
EI-9.1.3	2.36666E-03	c.v4								
	-2.36666E-03	c.v4.xf1								
	-2.36666E-03	c.v4.p4								
	2.36666E-03	c.v4.p4.xf1								
EI-10.1.2	1.94193E-04	c.v1.xf1								
	-1.94193E-04	c.v1.p1.xf1								
EI-10.1.3	2.78929E-03	c.v1								
	-2.78929E-03	c.v1.xf1								
	-2.78929E-03	c.v1.p1								
	2.78929E-03	c.v1.p1.xf1								
EI-11.1.1	1.80306E-05	c.v.p2								
EI-11.1.2	1.05759E-05	c.v2.xf1								
	-1.05759E-05	c.v2.p2.xf1								

Framework A.10.1 - Frequency of Impaiment to TSR and Escape Routes Expressions in Terms of Availability Variables

The following events, expressed in terms of availbility variables, impact the TSR :										
EI-23.1.1	1.92000E-05	c.v1.p1								
EI-23.1.2	9.78000E-07	c.v1.xg4								
	-9.78000E-07	c.v1.p1.xg4								
EI-23.1.3	1.10000E-08	c.v1.xf4								
	-1.10000E-08	c.v1.xg4.xf4								
	-1.10000E-08	c.v1.p1.xf4								
	1.10000E-08	c.v1.p1.xg4.	xf4							
EI-23.1.4	3.57000E-08	c.v1								
	-3.57000E-08	c.v1.xf4								
	-3.57000E-08	c.v1.xg4								
	3.57000E-08	c.v1.xg4.xf4								
	-3.57000E-08	c.v1.p1								
	3.57000E-08	c.v1.p1.xf4								
	3.57000E-08	c.v1.p1.xg4								
	-3.57000E-08	c.v1.p1.xg4.	xf4							
That gives an expression for the Frequency of Impairment to the TSR in terms of availability variables , composed by the sum of the following terms :										
1.91643E-05	c.v1.p1									
9.42300E-07	c.v1.xg4									
-9.42300E-07	c.v1.p1.xg4									
-2.47000E-08	c.v1.xf4									
2.47000E-08	c.v1.xg4.xf4									
2.47000E-08	c.v1.p1.xf4									

Framework A.10.1 - Frequency of Impaiment to TSR and Escape Routes Expressions in Terms of Availability Variables

	-4.98047E-05	c.v2.xg2.xf2								
EI-44.1.2	1.27427E-04	c.v2.xg2								
	-1.27427E-04	c.v2.p2.xg2								
That gives	***an expression for the Frequency of Impairment to the Escape Routes terms of availability variables , composed by the sum of the following terms :***									
	-2.34401E-03	c.v4.p4								
	-2.20976E-03	c.v4.xf1								
	2.20976E-03	c.v4.p4.xf1								
	2.36666E-03	c.v4								
	-3.03750E-03	c.v1.xf1								
	2.59510E-03	c.v1.p1.xf1								
	3.26365E-03	c.v1								
	-2.78929E-03	c.v1.p1								
	-1.22908E-05	c.v2.p2								
	-1.97456E-05	c.v2.xf1								
	1.97456E-05	c.v2.p2.xf1								
	3.03214E-05	c.v2								
	4.98047E-05	c.v2.xf2								
	-4.98047E-05	c.v2.xg2.xf2								
	1.27427E-04	c.v2.xg2								
	-1.27427E-04	c.v2.p2.xg2								
The Frequency of Impairment to the Structure is equal to the following value which refer to events that present no safety protection:										
	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									

Framework A.10.1 - Frequency of Impaiment to TSR and Escape Routes Expressions in Terms of Availability Variables

	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									
	7.57E-07									
	9.841E-06									

Framework A.10.1 - Frequency of Impaiment to TSR and Escape Routes Expressions in Terms of Availability Variables

Final AIR Expression		*Cost Expression*		*Impact to TSR Expression*			*Impact to ER Expression*		
(AIR - given by the sum of)		*(FCOST- given by the sum of)*		*(ITSR- given bythe sum of)*			*(IER- given bythe sum of)*		
3.9679E-03		1.479645393117900E+07	$xf1^2$	1.10000E-08	c.v1.xf4		-2.20976E-03	c.v4.xf1	
-5.1538E-10	c.v1.p1	-3.388927675698790E+07	xf1	-1.10000E-08	c.v1.xg4.xf4		2.20976E-03	c.v4.p4.xf1	
2.1290E-03	c.v1.p1.xf1	1.280425923579700E+07		-1.10000E-08	c.v1.p1.xf4		2.36666E-03	c.v4	
2.9730E-04	c.v1.p1.xf2	1.429265896944050E+07	$xf2^2$	1.10000E-08	c.v1.p1.xg4.xf4		-3.03750E-03	c.v1.xf1	
1.1596E-05	c.v1.p1.xf3	-3.204999733198040E+07	xf2				2.59510E-03	c.v1.p1.xf1	
1.3058E-05	c.v1.p1.xf4	1.163789387322070E+07					3.26365E-03	c.v1	
1.7308E-10	c.v1.p1.xg1	3.742880304776000E+07	$xf3^2$				-2.78929E-03	c.v1.p1	
3.7039E-04	c.v1.p1.xg2	-7.823694323333160E+07	xf3				-1.22908E-05	c.v2.p2	
-2.9730E-04	c.v1.p1.xg2.xf2	3.453337589600210E+07					-1.97456E-05	c.v2.xf1	
1.1596E-05	c.v1.p1.xg3	1.767223797221760E+07	$xf4^2$				1.97456E-05	c.v2.p2.xf1	
-1.1596E-05	c.v1.p1.xg3.xf3	-3.889691936503540E+07	xf4				3.03214E-05	c.v2	
4.0000E-10	c.v1.p1.xg4	1.504677304257910E+07					4.98047E-05	c.v2.xf2	
-1.3058E-05	c.v1.p1.xg4.xf4	1.918485898075100E+07	$xg1^2$				-4.98047E-05	c.v2.xg2.xf2	
-2.2162E-03	c.v1.xf1	-4.436577601706340E+07	xg1				1.27427E-04	c.v2.xg2	
-2.9730E-04	c.v1.xf2	1.697581185883310E+07					-1.27427E-04	c.v2.p2.xg2	
-1.1596E-05	c.v1.xf3	1.322167800457380E+07	$xg2^2$						
-1.3058E-05	c.v1.xf4	-3.248445467365070E+07	xg2						
-1.7308E-10	c.v1.xg1	1.110594088251880E+07							
-3.7039E-04	c.v1.xg2	3.484350442852780E+07	$xg3^2$						
2.9730E-04	c.v1.xg2.xf2	-7.558073894742920E+07	xg3						
-1.1596E-05	c.v1.xg3	3.248016304170770E+07							
1.1596E-05	c.v1.xg3.xf3	1.667896013076020E+07	$xg4^2$						
-4.0000E-10	c.v1.xg4	-3.937118312791420E+07	xg4						
1.3058E-05	c.v1.xg4.xf4	1.450443286107870E+07							
-3.1475E-06	c.v2.p2	3.835992259680180E+07	$p1^2$						
1.6161E-04	c.v2.p2.xf1	-8.397685060286480E+07	p1						

Framework A.10.2 - Final Expressions for Average Individual Risk (AIR), for Costs (FCOST) and for the Frequencies of Impairment to Temporary Safety Refuge and to the Emergency Escape Routes (ITSR and IIER)

Final AIR Expression		*Cost Expression*		*Impact to TSR Expression*			*Impact to ER Expression*		
(AIR - given by	*the sum of)*	*(FCOST- given by the sum of)*		*(ITSR- given bythe sum of)*			*(IER- given bythe sum of)*		
2.9222E-05	c.v2.p2.xf2	3.718528455917930E+07							
-4.1883E-06	c.v2.p2.xg2	3.835992259680180E+07	$p2^2$						
-2.9222E-05	c.v2.p2.xg2.xf2	-8.397685060286480E+07	p2						
-1.5848E-04	c.v2.xf1	3.718528455917930E+07							
-4.3929E-05	c.v2.xf2	3.835992259680180E+07	$p3^2$						
4.1883E-06	c.v2.xg2	-8.397685060286480E+07	p3						
4.3929E-05	c.v2.xg2.xf2	3.718528455917930E+07							
6.7900E-05	c.v3.p3.xf2	3.835992259680180E+07	$p4^2$						
4.2619E-06	c.v3.p3.xg2	-8.397685060286480E+07	p4						
-6.7900E-05	c.v3.p3.xg2.xf2	3.718528455917930E+07							
-6.7900E-05	c.v3.xf2	4.055331099575200E+08	$v1^2$						
-4.2619E-06	c.v3.xg2	-8.108186173397590E+08	v1						
6.7900E-05	c.v3.xg2.xf2	3.969579169336050E+08							
-7.7692E-09	c.v4.p4	4.055331099575200E+08	$v2^2$						
4.1004E-04	c.v4.p4.xf1	-8.108186173397590E+08	v2						
9.4597E-05	c.v4.p4.xf2	3.969579169336050E+08							
7.5310E-05	c.v4.p4.xg2	4.055331099575200E+08	$v3^2$						
-9.4597E-05	c.v4.p4.xg2.xf2	-8.108186173397590E+08	v3						
-4.1004E-04	c.v4.xf1	3.969579169336050E+08							
-9.4597E-05	c.v4.xf2	4.055331099575200E+08	$v4^2$						
-7.5310E-05	c.v4.xg2	-8.108186173397590E+08	v4						
9.4597E-05	c.v4.xg2.xf2	3.969579169336050E+08							
5.3011E-05	c.xf2	5.337449744039940E+16	c^4						
4.5042E-04	c.xg2	-2.132620863787150E+17	c^3						
-4.5042E-04	c.xg2	3.195395746456260E+17	c^2						
-5.3011E-05	cxf2	-2.127908798041550E+17	c						

Framework A.10.2 - Final Expressions for Average Individual Risk (AIR), for Costs (FCOST) and for the Frequencies of Impairment to Temporary Safety Refuge and to the Emergency Escape Routes (ITSR and IIER)

Final AIR Expression		*Cost Expression*		*Impact to TSR Expression*			*Impact to ER Expression*		
(AIR - given by the sum of)		*(FCOST- given by the sum of)*		*(ITSR- given bythe sum of)*			*(IER- given bythe sum of)*		
-2.8213E-03	**p1**	5.313889408848230E+16							
2.9730E-04	**p1.xg2**	3.742880304776000E+07	**$xf3^2$**						
1.3058E-05	**p1.xg4**	-7.823694323333160E+07	**xf3**						
-1.8351E-04	**p2**	3.453337589600210E+07							
2.9222E-05	**p2.xg2**	1.767223797221760E+07	**$xf4^2$**						
-7.2162E-05	**p3**	-3.889691936503540E+07	**xf4**						
6.7900E-05	**p3.xg2**	1.504677304257910E+07							
-5.7995E-04	**p4**	1.918485898075100E+07	**$xg1^2$**						
9.4597E-05	**p4.xg2**	-4.436577601706340E+07	**xg1**						
-1.3242E-05	**v1.p1.xg4.xf4**	1.697581185883310E+07							
1.3242E-05	**v1.p1.xg4.xf4**	1.322167800457380E+07	**$xg2^2$**						
-9.1204E-05	**v1.xf1**	-3.248445467365070E+07	**xg2**						
9.1204E-05	**v1xf1**	1.110594088251880E+07							
4.5042E-04	**xg2**	3.484350442852780E+07	**$xg3^2$**						
-9.5415E-04	**xg2**	-7.558073894742920E+07	**xg3**						
-1.3058E-05	**xg4**	3.248016304170770E+07							
8.2651E-06		1.667896013076020E+07	**$xg4^2$**						
		-3.937118312791420E+07	**xg4**						
		1.450443286107870E+07							
		3.835992259680180E+07	**$p1^2$**						
		-8.397685060286480E+07	**p1**						
		3.718528455917930E+07							
		3.835992259680180E+07	**$p2^2$**						
		-8.397685060286480E+07	**p2**						
		3.718528455917930E+07							
		3.835992259680180E+07	**$p3^2$**						

Framework A.10.2 - Final Expressions for Average Individual Risk (AIR), for Costs (FCOST) and for the Frequencies of Impairment to Temporary Safety Refuge and to the Emergency Escape Routes (ITSR and IIER)

		-8.397685060286480E+07	p3						
		3.718528455917930E+07							
		3.835992259680180E+07	$p4^2$						
		-8.397685060286480E+07	p4						
		3.718528455917930E+07							
		4.055331099575200E+08	$v1^2$						
		-8.108186173397590E+08	v1						
		3.969579169336050E+08							
		4.055331099575200E+08	$v2^2$						
		-8.108186173397590E+08	v2						
		3.969579169336050E+08							
		4.055331099575200E+08	$v3^2$						
		-8.108186173397590E+08	v3						
		3.969579169336050E+08							
		4.055331099575200E+08	$v4^2$						
		-8.108186173397590E+08	v4						
		3.969579169336050E+08							
		5.337449744039940E+16	c^4						
		-2.132620863787150E+17	c^3						
		3.195395746456260E+17	c^2						
		-2.127908798041550E+17	c						
		5.313889408848230E+16							

Framework A.10.2 - Final Expressions for Average Individual Risk (AIR), for Costs (FCOST) and for the Frequencies of Impairment to Temporary Safety Refuge and to the Emergency Escape Routes (ITSR and IIER)

Appendix 11

Solver Report 1	AIR < 3.79e-04	IER < 10-4	
Minimise I FCOST	ITSR <10-4	0.999 < x < 0.9999	SIL 3

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	Goal Cell	(minimise)		
Cell	Name	Final Value	Constraints	
H23	FCOST	-£ 133,072,928.00		
F23	AIR	2.173323E-04	F23<=0.000379	
J23	IER	7.270396E-05	J23<=0.0001	
I23	ITSR	1.099493E-16	I23<=0.0001	
J53	xf1	9.999000E-01	J53<=0.9999	J53>=0.999
J54	xf2	9.999000E-01	J54<=0.9999	J54>=0.999
J55	xf3	9.999000E-01	J55<=0.9999	J55>=0.999
J56	xf4	9.999000E-01	J56<=0.9999	J56>=0.999
J57	xg1	9.999000E-01	J57<=0.9999	J57>=0.999
J58	xg2	9.999000E-01	J58<=0.9999	J58>=0.999
J59	xg3	9.999000E-01	J59<=0.9999	J59>=0.999
J60	xg4	9.999000E-01	J60<=0.9999	J60>=0.999
J61	p1	9.999000E-01	J61<=0.9999	J61>=0.999
J62	p2	9.999000E-01	J62<=0.9999	J62>=0.999
J63	p3	9.999000E-01	J63<=0.9999	J63>=0.999
J64	p4	9.999000E-01	J64<=0.9999	J64>=0.999
J65	v1	9.999000E-01	J65=0.9999	J65=0.9999
J66	v2	9.999000E-01	J66=0.9999	J66=0.9999
J67	v3	9.999000E-01	J67=0.9999	J67=0.9999
J68	v4	9.999000E-01	J68=0.9999	J68=0.9999
J69	c	9.997393E-01	J69<=0.9999	J69>=0.999

Table A.11.1 - Solver Report 1 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 2	AIR < 3.79e-04	IER < 10-4	
Minimise I FCOST	ITSR <10-4	0.99 < x < 0.999	SIL 2

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Goal Cell (minimise)

Cell	Name	Final Value	Constraints	
H23	FCOST	-£ 133,057,504.00		
F23	AIR	2.176586E-04	F23<=0.000379	
J23	IER	7.335401E-05	J23<=0.0001	
I23	ITSR	1.095505E-14	I23<=0.0001	
J65	v1	9.990000E-01	J65=0.999	
J66	v2	9.990000E-01	J66=0.999	
J67	v3	9.990000E-01	J67=0.999	
J68	v4	9.990000E-01	J68=0.999	
J53	xf1	9.990000E-01	J53>=0.99	J53<=0.999
J54	xf2	9.990000E-01	J54>=0.99	J54<=0.999
J55	xf3	9.990000E-01	J55>=0.99	J55<=0.999
J56	xf4	9.990000E-01	J56>=0.99	J56<=0.999
J57	xg1	9.990000E-01	J57>=0.99	J57<=0.999
J58	xg2	9.990000E-01	J58>=0.99	J58<=0.999
J59	xg3	9.990000E-01	J59>=0.99	J59<=0.999
J60	xg4	9.990000E-01	J60>=0.99	J60<=0.999
J61	p1	9.990000E-01	J61>=0.99	J61<=0.999
J62	p2	9.990000E-01	J62>=0.99	J62<=0.999
J63	p3	9.990000E-01	J63>=0.99	J63<=0.999
J64	p4	9.990000E-01	J64>=0.99	J64<=0.999
J69	c	9.979083E-01	J69>=0.99	J69<=0.999

Table A.11.2 - Solver Report 2 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 3	**AIR < 3.79e-04**	**IER < 10-4**	
Minimise I FCOST	**ITSR <10-4**	**0.90 < x < 0.99**	**SIL 1**

Relatório criado: 7/09/98 16:47:50

Goal Cell (minimise)

Cell	Name	Final Value	Constraints	
H23	FCOST	**£ 194,525,696.00**		
F23	**AIR**	2.207949E-04	F23<=0.000379	
J23	**IER**	8.086512E-05	J23<=0.0001	
I23	**ITSR**	1.067329E-12	I23<=0.0001	
J53	**xf1**	9.900000E-01	J53<=0.99	J53>=0.9
J54	**xf2**	9.900000E-01	J54<=0.99	J54>=0.9
J55	**xf3**	9.900000E-01	J55<=0.99	J55>=0.9
J56	**xf4**	9.900000E-01	J56<=0.99	J56>=0.9
J57	**xg1**	9.900000E-01	J57<=0.99	J57>=0.9
J58	**xg2**	9.900000E-01	J58<=0.99	J58>=0.9
J59	**xg3**	9.900000E-01	J59<=0.99	J59>=0.9
J60	**xg4**	9.900000E-01	J60<=0.99	J60>=0.9
J61	**p1**	9.900000E-01	J61<=0.99	J61>=0.9
J62	**p2**	9.900000E-01	J62<=0.99	J62>=0.9
J63	**p3**	9.900000E-01	J63<=0.99	J63>=0.9
J64	**p4**	9.900000E-01	J64<=0.99	J64>=0.9
J65	**v1**	9.900000E-01	J65=0.99	J65=0.99
J66	**v2**	9.900000E-01	J66=0.99	J66=0.99
J67	**v3**	9.900000E-01	J67=0.99	J67=0.99
J68	**v4**	9.900000E-01	J68=0.99	J68=0.99
J69	**c**	9.900000E-01	J69<=0.99	J69>=0.9

Table A.11.3 - Solver Report 3 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 4	AIR < 3.79e-04	IER < 10-4	
Minimise I FCOST	AIR > 2.21e-04		
	ITSR <10-4	0.90 < x < 0.99	SIL 1

Goal Cell (minimise)

Cell	Name	Final Value	Constraints	
H23	FCOST	£ 194,895,200.00		
F23	AIR	2.263829E-04	F23<=0.000379	
J23	IER	1.000043E-04	J23<=0.0001	
I23	ITSR	3.368321E-12	I23<=0.0001	
F23	AIR	2.263829E-04	F23>=0.000221	
J53	xf1	9.649899E-01	J53<=0.99	J53>=0.9
J54	xf2	9.899445E-01	J54<=0.99	J54>=0.9
J55	xf3	9.899997E-01	J55<=0.99	J55>=0.9
J56	xf4	9.900000E-01	J56<=0.99	J56>=0.9
J57	xg1	9.900000E-01	J57<=0.99	J57>=0.9
J58	xg2	9.885686E-01	J58<=0.99	J58>=0.9
J59	xg3	9.899997E-01	J59<=0.99	J59>=0.9
J60	xg4	9.899989E-01	J60<=0.99	J60>=0.9
J61	p1	9.684451E-01	J61<=0.99	J61>=0.9
J62	p2	9.886592E-01	J62<=0.99	J62>=0.9
J63	p3	9.899576E-01	J63<=0.99	J63>=0.9
J64	p4	9.858222E-01	J64<=0.99	J64>=0.9
J65	v1	9.900000E-01	J65=0.99	J65=0.99
J66	v2	9.900000E-01	J66=0.99	J66=0.99
J67	v3	9.900000E-01	J67=0.99	J67=0.99
J68	v4	9.900000E-01	J68=0.99	J68=0.99
J69	c	9.900000E-01	J69<=0.99	J69>=0.9

Table A.11.4 - Solver Report 4 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 5	**AIR < 3.79e-04**	**IER < 10-4**	
Minimise I FCOST	**AIR > 2.19e-04**		
	ITSR <10-4	**0.99 < x < 0.999**	**SIL 2**

	Goal Cell	(minimise)		
Cell	**Name**	**Final Value**	**Constraints**	
H23	**FCOST**	**-£ 132,951,680.00**		
F23	**AIR**	2.193722E-04	F23<=0.000379	
J23	**IER**	7.767994E-05	J23<=0.0001	
I23	**ITSR**	4.394308E-14	I23<=0.0001	
F23	**AIR**	2.193722E-04	F23>=0.000219	
J53	**xf1**	9.902971E-01	J53<=0.999	J53>=0.99
J54	**xf2**	9.989985E-01	J54<=0.999	J54>=0.99
J55	**xf3**	9.990000E-01	J55<=0.999	J55>=0.99
J56	**xf4**	9.990000E-01	J56<=0.999	J56>=0.99
J57	**xg1**	9.990000E-01	J57<=0.999	J57>=0.99
J58	**xg2**	9.989368E-01	J58<=0.999	J58>=0.99
J59	**xg3**	9.990000E-01	J59<=0.999	J59>=0.99
J60	**xg4**	9.990000E-01	J60<=0.999	J60>=0.99
J61	**p1**	9.959523E-01	J61<=0.999	J61>=0.99
J62	**p2**	9.988125E-01	J62<=0.999	J62>=0.99
J63	**p3**	9.989947E-01	J63<=0.999	J63>=0.99
J64	**p4**	9.984114E-01	J64<=0.999	J64>=0.99
J65	**v1**	9.900020E-01	J65<=0.999	J65>=0.99
J66	**v2**	9.989811E-01	J66<=0.999	J66>=0.99
J67	**v3**	9.989996E-01	J67<=0.999	J67>=0.99
J68	**v4**	9.989505E-01	J68<=0.999	J68>=0.99
J69	**c**	9.978750E-01	J69<=0.999	J69>=0.99

Table A.11.5 - Solver Report 5 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 6	AIR < 3.79e-04	IER < 10-4
Minimise I FCOST	AIR = 2.175e-04	
	ITSR <10-4	0.999 < x < 0.9999 SIL 3

Goal Cell (minimise)

Cell	Name	Final Value	Constraints	
H23	FCOST	-£ 133,051,744.00		
F23	AIR	2.17521603E-04	F23<=0.000379	
J23	IER	7.29439760E-05	J23<=0.0001	
I23	ITSR	1.20508484E-16	I23<=0.0001	
F23	AIR	2.17521603E-04	F23=0.0002175	
J53	xf1	9.99187656E-01	J53<=0.9999	J53>=0.999
J54	xf2	9.99899988E-01	J54<=0.9999	J54>=0.999
J55	xf3	9.99900000E-01	J55<=0.9999	J55>=0.999
J56	xf4	9.99900000E-01	J56<=0.9999	J56>=0.999
J57	xg1	9.99900000E-01	J57<=0.9999	J57>=0.999
J58	xg2	9.99899566E-01	J58<=0.9999	J58>=0.999
J59	xg3	9.99900000E-01	J59<=0.9999	J59>=0.999
J60	xg4	9.99900000E-01	J60<=0.9999	J60>=0.999
J61	p1	9.99890234E-01	J61<=0.9999	J61>=0.999
J62	p2	9.99899261E-01	J62<=0.9999	J62>=0.999
J63	p3	9.99899983E-01	J63<=0.9999	J63>=0.999
J64	p4	9.99896292E-01	J64<=0.9999	J64>=0.999
J65	v1	9.99161370E-01	J65=0.9999	J65>=0.999
J66	v2	9.99899718E-01	J66=0.9999	J66>=0.999
J67	v3	9.99899996E-01	J67=0.9999	J67>=0.999
J68	v4	9.99899525E-01	J68=0.9999	J68>=0.999
J69	c	9.99000018E-01	J69<=0.9999	J69>=0.999

Table A.11.6 - Solver Report 6 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 7	**AIR < or = 3.79e-04**	**IER < 10-4**
Minimise I FCOST	**AIR > or = 2.175e-04**	
	ITSR <10-4	**0.999 < x < 0.9999 SIL 3**

Goal Cell (minimise)

Cell	**Name**	**Final Value**	**Constraints**	
H23	**FCOST**	**-£ 133,086,304.00**		
F23	**AIR**	2.175217E-04	F23<=0.000379	
J23	**IER**	7.254659E-05	J23<=0.0001	
I23	**ITSR**	1.097114E-16	I23<=0.0001	
F23	**AIR**	2.175217E-04	F23>=0.0002175	
J53	**xf1**	9.99900000E-01	J53=0.9999	J53=0.9999
J54	**xf2**	9.99900000E-01	J54=0.9999	J54=0.9999
J55	**xf3**	9.99900000E-01	J55=0.9999	J55=0.9999
J56	**xf4**	9.99900000E-01	J56=0.9999	J56=0.9999
J57	**xg1**	9.99900000E-01	J57=0.9999	J57=0.9999
J58	**xg2**	9.99900000E-01	J58=0.9999	J58=0.9999
J59	**xg3**	9.99900000E-01	J59=0.9999	J59=0.9999
J60	**xg4**	9.99900000E-01	J60=0.9999	J60=0.9999
J61	**p1**	9.99900000E-01	J61=0.9999	J61=0.9999
J62	**p2**	9.99900000E-01	J62=0.9999	J62=0.9999
J63	**p3**	9.99900000E-01	J63=0.9999	J63=0.9999
J64	**p4**	9.99900000E-01	J64=0.9999	J64=0.9999
J65	**v1**	9.99900000E-01	J65=0.9999	J65=0.9999
J66	**v2**	9.99900000E-01	J66=0.9999	J66=0.9999
J67	**v3**	9.99900000E-01	J67=0.9999	J67=0.9999
J68	**v4**	9.99900000E-01	J68=0.9999	J68=0.9999
J69	**c**	9.97575426E-01	J69<=0.9999	J69>=0.999

Table A.11.7 - Solver Report 7 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 8	**AIR < or = 3.79e-04**	**IER < 10-4**
Minimise I FCOST	**AIR > or = 2.176e-04**	
	ITSR <10-4	**0.999 < x < 0.9999 SIL 3**

Goal Cell		(minimise)		
Cell	**Name**	**Final Value**	**Constraints**	
H23	**FCOST**	**-£ 132,276,064.00**		
F23	**AIR**	2.176000E-04	F23<=0.000379	
J23	**IER**	7.248158E-05	J23<=0.0001	
I23	**ITSR**	1.096130E-16	I23<=0.0001	
F23	**AIR**	2.176000E-04	F23>=0.0002176	
J53	**xf1**	9.999000E-01	J53=0.9999	J53=0.9999
J54	**xf2**	9.999000E-01	J54=0.9999	J54=0.9999
J55	**xf3**	9.999000E-01	J55=0.9999	J55=0.9999
J56	**xf4**	9.999000E-01	J56=0.9999	J56=0.9999
J57	**xg1**	9.999000E-01	J57=0.9999	J57=0.9999
J58	**xg2**	9.999000E-01	J58=0.9999	J58=0.9999
J59	**xg3**	9.999000E-01	J59=0.9999	J59=0.9999
J60	**xg4**	9.999000E-01	J60=0.9999	J60=0.9999
J61	**p1**	9.999000E-01	J61=0.9999	J61=0.9999
J62	**p2**	9.999000E-01	J62=0.9999	J62=0.9999
J63	**p3**	9.999000E-01	J63=0.9999	J63=0.9999
J64	**p4**	9.999000E-01	J64=0.9999	J64=0.9999
J65	**v1**	9.999000E-01	J65=0.9999	J65=0.9999
J66	**v2**	9.999000E-01	J66=0.9999	J66=0.9999
J67	**v3**	9.999000E-01	J67=0.9999	J67=0.9999
J68	**v4**	9.999000E-01	J68=0.9999	J68=0.9999
J69	**c**	9.966814E-01	J69<=0.9999	J69>=0.999

Table A.11.8 - Solver Report 8 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 9	AIR < or = 3.79e-04	IER < 10-4	
Minimise I FCOST	SIL 3 for c	ITSR <10-4	
	0.999 < x < 0.9999, SIL 3 for fire detection		0.99 < x < 0.999, SIL 2 for gas detection, PSL and actuation

Goal Cell (minimise)

Cell	Name	Final Value	Constraints	
H23	FCOST	-£ 133,024,320.00		
F23	AIR	2.174166E-04	F23<=0.000379	
J23	IER	7.308563E-05	J23<=0.0001	
I23	ITSR	1.098488E-14	I23<=0.0001	
J53	xf1	9.999000E-01	J53>=0.999	J53<=0.9999
J54	xf2	9.999000E-01	J54>=0.999	J54<=0.9999
J55	xf3	9.999000E-01	J55>=0.999	J55<=0.9999
J56	xf4	9.999000E-01	J56>=0.999	J56<=0.9999
J57	xg1	9.990000E-01	J57>=0.99	J57<=0.999
J58	xg2	9.990000E-01	J58>=0.99	J58<=0.999
J59	xg3	9.990000E-01	J59>=0.99	J59<=0.999
J60	xg4	9.990000E-01	J60>=0.99	J60<=0.999
J61	p1	9.990000E-01	J61>=0.99	J61<=0.999
J62	p2	9.990000E-01	J62>=0.99	J62<=0.999
J63	p3	9.990000E-01	J63>=0.99	J63<=0.999
J64	p4	9.990000E-01	J64>=0.99	J64<=0.999
J65	v1	9.990000E-01	J65>=0.99	J65<=0.999
J66	v2	9.990000E-01	J66>=0.99	J66<=0.999
J67	v3	9.990000E-01	J67>=0.99	J67<=0.999
J68	v4	9.990000E-01	J68>=0.99	J68<=0.999
J69	c	9.997252E-01	J69>=0.999	J69<=0.9999

Table A.11.9 - Solver Report 9 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST

Solver Report 10	**AIR < or = 3.79e-04**	**IER < 10-4**	
Minimise I FCOST	**c = 0.9999**	**ITSR <10-4**	
	0.999 < x < 0.9999, SIL 3 for fire detection		**0.99 < x < 0.999, SIL 2 for gas detection, PSL and actuation**

Goal Cell (minimise)

Cell	**Name**	**Final Value**	**Constraints**	
H23	FCOST	-£ 133,029,936.00		
F23	AIR	2.174009E-04	F23<=0.000379	
J23	IER	7.309841E-05	J23<=0.0001	
I23	ITSR	1.098680E-14	I23<=0.0001	
J53	xf1	9.999000E-01	J53>=0.999	J53<=0.9999
J54	xf2	9.999000E-01	J54>=0.999	J54<=0.9999
J55	xf3	9.999000E-01	J55>=0.999	J55<=0.9999
J56	xf4	9.999000E-01	J56>=0.999	J56<=0.9999
J57	xg1	9.990000E-01	J57>=0.99	J57<=0.999
J58	xg2	9.990000E-01	J58>=0.99	J58<=0.999
J59	xg3	9.990000E-01	J59>=0.99	J59<=0.999
J60	xg4	9.990000E-01	J60>=0.99	J60<=0.999
J61	p1	9.990000E-01	J61>=0.99	J61<=0.999
J62	p2	9.990000E-01	J62>=0.99	J62<=0.999
J63	p3	9.990000E-01	J63>=0.99	J63<=0.999
J64	p4	9.990000E-01	J64>=0.99	J64<=0.999
J65	v1	9.990000E-01	J65>=0.99	J65<=0.999
J66	v2	9.990000E-01	J66>=0.99	J66<=0.999
J67	v3	9.990000E-01	J67>=0.99	J67<=0.999
J68	v4	9.990000E-01	J68>=0.99	J68<=0.999
J69	c	9.999000E-01	J69=0.9999	J69=0.9999

Table A.11.10 - Solver Report 10 - Results Obtained for FCOST, AIR, IER, ITSR and for Availability Values of the Studied Safety Systems, Regarding the Established Constraints and Minimization of FCOST