# Impact of Process Safety Management Performance and Human Error on Off-Site Risk - A Comparative Study

## Volume II - Appendices

**A Thesis Submitted to the University of Sheffield for the Degree of Doctor of Philosophy**

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**by**

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# *Appendix 1*

**A sample of modified PRIMA Audit questionnaires with keywords and answers sheets with responses from interviewees**

Table A1.1. A Sample of Modified PRIMA Audit Questionnaires with Keywords on Key Audit Area of Human Factors of Operations (OP/HF) - Theme D: Resources for the Job

| *OP/HF THEME D ARE THERE ADEQUATE RESOURCES FOR THE JOB* | | | | | |
|---|---|---|---|---|---|
| **LEVEL 5** | **SYSTEM CLIMATE** | | | | |
| **NO** | **CUE WORDS** | **QUESTION** | **COMMENTS** | **INTERVIEWEE** | **KEY AREA** |
| D.5.1 | **Access to trained and experienced operators** | What is the level of access to trained and experienced operators and supervisors? | | General Manager Production manager. | All |
| D.5.2 | **Head office influence on site manning levels** | How strong an influence does the company head office exert on site policy on manning levels? | | General manager. Production manager. | 1 |
| **LEVEL 4** | **ORGANISATIONAL PROCESSES AND STRUCTURES** | | | | |
| D.4.1 | **Ensuring adequate manning levels** | What are the allocations of responsibility for ensuring adequate manning levels? | | Production manager. | 1 |
| D.4.2 | **Updating operating procedures** | What are the allocations of responsibility for ensuring operating procedures are kept up-to-date and are usable and available? | | Production management | 3 |

| | | | | | |
|---|---|---|---|---|---|
| D.4.3 | **Informing equipment problem to engineering management.** | What are the allocations of responsibility for ensuring that engineering management are informed of equipment problem identified during operations? | | Production management | 2 |
| D.4.4 | **Training needs of operation personnel** | What are the allocations of responsibility for identifying and implementing the training needs of operations personnel? | | Production management | 8 |
| D.4.5 | **Responsibility as promotion criteria** | What are the allocations of responsibility for developing selection and promotion criteria within operations? | | Production management | 8 |
| D.4.6 | **Assessing competency of employees** | What is the system for assessing the competency of employees?- Assessment may be in the form of on-the-job evaluation, trade tests, certification checks, comparing experience against job descriptions, formal written tests, | | Production management | 8 |
| D.4.7 | **Budget to review installing new equipment** | Is their usually budget provided in design projects for a review of the operational implications of installing new equipment, with emphasis on operator error potential? | | General manager, Production management. | All |
| **LEVEL 3** | **COMMUNICATIONS, CONTROL AND FEEDBACK** | | | | |
| D.3.1 | **Planning the personnel for operations** | Describe the system for planning the provision of personnel for operations.<br>This may cover the procedures for estimating manning level, allocating manning levels, allocating manning to each area of operation and assigning appropriately competent personnel to tasks. | | Production management. | 1 |

| | | | | | |
|---|---|---|---|---|---|
| D.3.2 | **Technical skill training for operators** | Outline the programme of technical skills training for operators.<br>This may include:<br>Training programmes : on-the-job, off-the job , refresher , management skills;<br>Training procedures;<br>Training needs assessment;<br>Training effectiveness assessment, revision of training<br>Refresher training;<br>Training of operators and supervisors (including contractors) should include:<br>- process hazards;<br>- safety interlocks;<br>- the use of procedures;<br>- the use of the PTW system;<br>- the consequences of equipment failure;<br>- the engineering of plant and processes ;<br>- technical theory on plant and processes ;<br>- the operation of valve, gauges etc. | | Production management. | 8 |
| D.3.3 | **Develop/reviewing written information for operations** | What resources are allocated for developing and reviewing written information for operations?<br>This should cover use of manufacturers' manuals input from HAZOP, development of shortened job aides and checklist, extent of proceduralisation and the consideration of usability aspects in procedure formats, design and content . Do operators make an input to operating procedures? | | Production Manager. | 8 |

| | | | | | |
|---|---|---|---|---|---|
| D.3.4 | **Cover for personnel shortages** | How is cover provided for personnel shortages? | | Production Manager. Shift lead, operators. | 1 |
| D.3.5 | **Controls on overtime** | What controls are there on the amount of overtime worked? | | Production Manager, Shift lead and operators. | 1 |
| D.3.6 | **Document on training, selection, promotion and manning level** | What documentation is available covering policy on training , selection and promotion and manning level requirements? | | Production management. | 1 |
| D.3.7 | **Assessing quality of operator/hardware interfaces** | What resources are available for assessing the quality of operator - hardware interfaces and making suggestions for improvement to engineering management?<br>For example: is there a *systematic* means of passing on operational problems such as equipment status identification difficulties to engineering management? | | Production management. | 2 |
| **LEVEL 2** | **OPERATOR RELIABILITY** | | | | |
| D.2.1 | **Coping with emergencies** | Are there always sufficient experienced operators available to cope with abnormal and emergency events? | | Shift lead, Operators. | 8,1 |
| D.2.2 | **Overcoming manning shortages** | How are manning shortages overcome? | | Shift lead, Operators. | 1 |
| D.2.3 | **Assessing competency** | How was your competence assessed before you were given your current job? | | Shift lead, Operators. | 8 |
| D.2.4 | **Introduction to new operating procedure.** | How are you introduced to new operating procedures? | | Shift lead, Operators. | 3 |

| | | | | | |
|---|---|---|---|---|---|
| D.2.5 | **Familiarisation with equipment, pipe, vessels interfaces** | Do you feel you are familiar with all equipment, piping and vessel interfaces such as gauges, valves and displays that you are required to work with? | | Shift lead, Operators. | 8,2 |
| D.2.6 | **Safe working procedures/practice** | What are the main safe working procedures and practice associated with your job? | | Shift lead, Operators. | 3 |
| D.2.7 | **Experience of other plants** | Have you experience of other plants? If so , how do they compare with your present plant in terms of ease of operation and support available to you make your job easier? | | Shift lead, Operators. | 8 |
| D.2.8 | **Usefulness of operating procedures** | How useful are the written operating procedures? | | Shift lead, Operators. | 3 |
| D.2.9 | **Review/updating operating procedures** | Are the written operating procedures regularly reviewed and updated, and how are you informed of changes? | | Shift lead, Operators. | 3 |
| D.2.11 | **Clarity of indicator on plant status** | How clear and unambiguous are the indicators of the operational status of the plant? | | Shift lead, Operators. | 2 |

Table A1.2. A Sample of Structures Answer Sheets for PRIMA Audit Questionnaires with Responses from the Interviewees; Key Audit Area of Human Factors of Operation (OP/HF) - Theme D: Resources for the Job

| *OP/HF THEME D ARE THERE ADEQUATE RESOURCES FOR THE JOB* | | | | | | |
|---|---|---|---|---|---|---|
| **NO** | **QUE WORD** | **Interviewee 1** | **Interviewee 2** | **Interviewee 3** | **Interviewee 4** | **Interviewee 5** |
| **LEVEL 5** | **SYSTEM CLIMATE** | | | | | |
| D.5.1 | **Access to trained and experienced operators** | **Managing Director,**<br>Good access due to job rotation | **Plant Manager,**<br>No problem, more than half of operators have worked more than 5 years | | | |
| D.5.2 | **Head office influence on site manning levels** | **Managing Director,**<br>Minimum influence-the plant manager supposed to control manning level | **Plant Manager,**<br>Minimum influence from Head Office | | | |

| LEVEL 4 | ORGANISATIONAL PROCESSES AND STRUCTURES | | | | | |
|---|---|---|---|---|---|---|
| D.4.1 | **Ensuring adequate manning levels** | | **Plant Manager,** Based on supervisors request to the manager with view to meet production and maintenance workload | | | |
| D.4.2 | **Updating operating procedures** | | **Plant Manager** It is the duty of Plant Manager and the Plant Engineer to update, but unable to do so due to tight work schedule | | | |
| D.4.3 | **Informing equipment problem to management.** | | **Plant Manager**, Through supervisor and operators | | | |
| D.4.4 | **Training needs of operation personnel** | | **Plant Manager,** Supervisor recommends to plant engineer | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| D.4.5 | **Responsibility as promotion criteria** | | **Plant Manager**, Managing Director developed the promotion criteria | | | |
| D.4.6 | **Assessing competency of employees** | | **Plant Manager**, On the job evaluation through supervisor observations and pass to plant | | | |
| D.4.7 | **Budget to review installing new equipment** | | **Plant Manager**, No review, budget decided by Head Office | | | |
| **LEVEL 3** | **COMMUNICATIONS CONTROL AND FEEDBACK** | | | | | |
| D.3.1 | **Planning the personnel for operations** | | **Plant Manager**, Planning done by Plant Manager based on experience | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| D.3.2 | **Technical skill training for operators** | | **Plant Manager**, On job training. Probation period for new workers. Work under Supervisor or | | | |
| D.3.3 | **Developing /reviewing written information for operations** | | **Plant Manager** No specific budget allocated. | | | |
| D.3.4 | **Cover for personnel shortages** | **Plant Manager,** Personnel work on overtime | **Supervisor 1**, Enough personnel, but probably cannot achieve target | **Supervisor 2,** Enough personnel, if not enough can pull from maintenance staff trained to job | **Supervisor 3,** By working overtime | **Operator 1,** Pull from other section<br><br>**Operator 2**, Staff from other |
| D.3.5 | **Controls on overtime** | **Plant Manager,** No control as long within Labour law. | **Supervisor 1,** No time limit as long as agreed by workers | **Operator 1,** No control | **Operator 2,** Overtime-as long workers willing | |

| | | | | | | |
|---|---|---|---|---|---|---|
| D.3.6 | | **Plant Manager**<br>No documentation available | | | | |
| D.3.7 | **Assessing quality of operator /hardware interfaces** | **Plant Manager**<br>No proper system -only carried out at early stage of plant operation | | | | |
| **LEVEL 2** | **OPERATOR. RELIABILITY** | | | | | |
| **NO** | **QUE WORD** | **Interviewee 1** | **Interviewee 2** | **Interviewee 1** | **Interviewee 1** | **Interviewee 1** |
| D.2.1 | **Coping with emergencies** | **Supervisor 1,**<br>Not enough experience operator | **Supervisor 2,**<br>Adequate number of experience workers | **Supervisor 3,**<br>Sufficient number of experienced staff | **Operator 1,**<br>Sufficient for present workload | |
| D.2.2 | **Overcoming manning shortages** | **Supervisor 1,**<br>Pull out from other section | **Supervisor 2,**<br>Take worker from other section | **Supervisor 3,**<br>From other section | **Operator 2,**<br>Overtime | |

| | | | | | | |
|---|---|---|---|---|---|---|
| D.2.3 | **Assessing competency** | **Supervisor 1,** From experience and observed by management | **Supervisor 2,** Observation and interview | **Supervisor 3,** Interview | **Operator 1,** Experience | **Operator 2,** Through observation |
| D.2.4 | **Introduction to new operating procedure.** | **Supervisor 1,** Through special training | **Supervisor 2,** Explained by plant engineer | **Supervisor 3,** Through special training | **Operator 1,** Through staff meeting | Operator 2, Training and meeting |
| D.2.5 | **Familiarisation with equipment, pipe and vessels interfaces** | **Supervisor 1, Very familiar** | **Supervisor 2,** Very familiar | **Supervisor 3,** Familiar since process is quite simple | **Operator 1,** Familiar | Operator 2, Quite familiar |
| D.2.6 | **Safe working procedures /practice** | **Supervisor 1,** Procedure available for maintenance task, e.g. for cylinder, tank and hoses | **Supervisor 2,** Loading, unloading of tankers and ship | **Supervisor 3,** Most all main task | **Operator 1,** Loading, unloading and cylinder filling | Operator 2, Drum filling procedures |

| | | | | | | |
|---|---|---|---|---|---|---|
| D.2.7 | **Experience of other plants** | **Supervisor 1,** This plant is less systematic | **Supervisor 2,** Present plant better than Esso plant | **Supervisor 3,** No previous experience | **Operator 1,** No previous experience | **Operator 2,** This plant is easier to operate |
| D.2.8 | **Usefulness of operating procedures** | **Supervisor 1,** Quite useful | **Supervisor 2,** Useful | **Supervisor 3,** Useful | **Operator 1,** Useful, but at times need explanation from supervisor | **Operator 2,** Useful, but would better if in Malaysian Language |
| D.2.9 | **Review/ updating operating procedures** | **Supervisor 1,** Not yet reviewed so far | **Supervisor 2,** No review | **Supervisor 3,** No review | **Operator 1,** No review | **Operator 2,** No review |
| D.2.11 | **Clarity of indicator on plant status** | **Supervisor 1,** Adequate and reliable | **Supervisor 2,** Easy to use | **Supervisor 3,** Clear | **Operator 1,** Clear and easy to identify | **Operator 2,** Clear |

Table A1.3. PRIMA Key Areas for OP/HF used for the two sites

| No. | Key OP/HF Topics |
|---|---|
| 1 | Manning levels |
| 2 | Operator-Hardware interface |
| 3 | Operating Procedures<br>• clarity<br>• usability<br>• coverage<br>• availability |
| 4 | Shift pattern and handover arrangement |
| 5 | Control room ergonomics |
| 6 | Incident/near miss analysis |
| 7 | Communication between levels, functions and locations |
| 8 | Operator competence and support |
| 9 | Control of conflicts |

# *Appendix 2*

**A Sample of Summary of Statements of Criteria that made up the Judgement for the PRIMA Control Loops**

Appendix 2A: A Sample of Summary of Statements of Criteria that made up the Judgement for the Control Loop for Site A

Key Audit Area - Hazard Review of Design (DES/HAZ) Control and Monitoring Loop

**Level 5 →Level 4**

The senior management, which is made up of the Managing Director and Plant Manager only relied on the country regulations and some limited industrial guidance and norms concerning hazard reviews of the engineered design of new plant or process or modification to such plant or process. Apart from the legal requirements no guidance and norms were taken into the site policies and no formal standards available for hazard review of design. The allocation of the authority, roles and to review hazard at the design stage rests squarely on the Plant Manager. Without adequate resources and competency to do the job the task seems to be quite impossible.

**Level 4 →Level 3**

The management seems to agree the need to carry out hazard reviews of plant/ process design and modification. But without appropriate system in place (i.e. in the site policies and standards) such need cannot be translated into actions. Formal training procedure for the competent personal, provision of standard procedures and channels for communication, and procurement of necessary tools to carry out hazard reviews of designs and modifications were found to be grossly inadequate. No formal means existed to resolve conflicting pressures on hazard review of designs and modifications.

**Level 3 →Level 2**

The Plant Manager has very little knowledge to carry out the task of hazard review of design using appropriate tools for the task. The company do not provide the necessary training to build up competency of personnel in that area. Economic and resources pressures were found to be the main stumbling block to the ability to review new designs, modifications and ensure the follow-up process are resolved with minimum impact to safety.

**Level 2 →Level 3**

No formal assessments were carried out to check effectiveness of hazard reviews of plant design and modifications. There was no monitoring of the adequacy of standards, procedures, communication process, resources allocation and resolving conflict was not carried out.

**Level 3 →Level 4**

There is no system to collect and assessing information on the effectiveness of hazard review of design on site. The site does not have specific Safety Department which made the task more difficult. Results of incidents and near miss analyses seldom go beyond the immediate cause which made the attempt to look at the inadequacy or faulty reviewed of hazards from design and modifications very difficult. As such no feedback on the effectiveness of hazard reviews exists to improve the site policy, standards, personnel authority and responsibilities. No allocation of resources was found for this purpose.

Appendix 2B: A Sample of Summary of Statements of Criteria that made up the Judgement for the Control Loop for Site B

Key Audit Area - Hazard Review of Design (DES/HAZ) Control and Monitoring Loop

**Level 5 →Level 4**

The Works Manager was to be very knowledgeable about the national regulations, industrial guidance and previous multinational owner standards and norms concerning hazard review of on the engineered design of new plant or process or modification to such plant or process. However, unlike the Works Manager, the Plant Manager being the most senior manager on site lacked experience in that area as he has only been with site less than five years and was not around during the design and construction of the plant. Following the system set by the previous multinational owner the legal requirements, guidance and norms were taken into the site policies and standards for hazard review of design. The lack qualified and experienced personnel on site to review design hazards causes some concern. However there is allocation of the authority, roles and responsibility in the organisational structure from the parent company to review hazards at the design stage and there is a provision adequate resources to do the job. System climate comes mainly from the lack of competent personnel on site so has some effect on its implementation. Nevertheless, the site was found to benefit from the system set for hazard review of design from its previous multinational owner.

**Level 4 →Level 3**

The management was found to be committed in implementing hazard review of plant/ process design and modification as provided by the site policies and standards. Despite the lack of experienced personnel at the management level there is a training procedure for the personnel, provision of standard procedures and channels for communication, and procurement of necessary tools to carry out hazard reviews of design and modification when the need arises. Conflicting pressures on hazard review of designs and modifications could be resolved through formal meetings by the project team that to supervise new designs and modifications.

**Level 3 →Level 2**

Despite lacking in experience the Plant Manager has the necessary knowledge to carry out the task of hazard review of design using appropriate tools for the task. Training on HAZOP, Fault Tree and Hazard Identification is given as part of post employment training for those above the supervisory level. Conflicting pressures on the need to review new design, modifications and the follow-up process are resolved with minimum impact to safety.

**Level 2 →Level 3**

The effectiveness of hazard reviews of plant design and modifications are assessed in an ad-hoc manner. Monitoring the adequacy of standards, procedures, communication process, resources allocation and resolving conflicts are done as the need arises especially from lessons learnt from the implementation of a new project or major modifications.

**Level 3 →Level 4**

No formal systems are in place for collecting and assessing information on the effectiveness of hazard review of design as the site does not have a specific Safety Department to do that as at Site C. Results of incidents and near miss analysis seldom look at inadequate or faulty reviews of hazards from a particular design and modifications. Feedback on the effectiveness of hazard reviews is used as to improve the site policy, standards, personnel authority and responsibilities as well as the allocation of resources were found not being implemented of late.

Appendix 2C: A Sample of Summary of Statements of Criteria that made up the Judgement for the Control Loop for Site C

Key Audit Area- Hazard Review of Design (DES/HAZ) Control and Monitoring Loop

**Level 5 →Level 4**

There was strong evidence that senior management knows about the national regulations, industrial guidance and previous multinational owner standards and norms concerning hazard review of the engineered design of new plant or process or modification to such plant or process. The legal requirements, guidance and norms were taken into account into the site policies and standards for hazard review of design. The site allocated qualified and experience personnel with the authority, roles and responsibility in the organisational structure to review hazard at the design stage and provided them with adequate resources to do the job. System climate factors such as economic pressures and lack of resources have not much effect on its implementation. The site was found to benefit from the system set for hazard reviews of design from its previous multinational owner.

**Level 4 →Level 3**

The management shows good commitment in implementing hazard reviews of plant/ process design and modification as provided by the site policies and standards. They were achieved through proper selection and training procedure for the personnel, provision of standard procedures and channels for communication, and procurement of necessary tools to carry out the job. Conflicting pressures on hazard review of designs and modifications were resolved through formal meetings by a special project team for new designs and modifications that have the potential to jeopardised the plant/process integrity on site.

**Level 3 →Level 2**

Competent personnel with the necessary knowledge and experience carried out the task of hazard review and design using appropriate tools for the task. The personnel have gained a lot of experience of the subject through the construction of a number of new plants and major modifications at the works over 20 years period of expansion. Pressures on the need to reduce, or where feasible to eliminate hazards from new design and modifications and the follow-up process is resolved without sacrificing such need.

**Level 2 →Level 3**

To a good extent the effectiveness of hazard reviews of plant design and modifications are assessed in a systematic manner. Monitoring the adequacy of standards, procedures, communication process, resources allocation and resolving conflict is done in an ad hoc manner, i.e. as the need arise especially from post mortem on the implementation of a new project or major modifications.

**Level 3 →Level 4**

Some forms of systems are in place and utilised for collecting and assessing information on the effectiveness of hazard review of design. This includes results from analysing incidents and near misses which point to inadequate or faulty reviews of hazards from a particular design and modifications. To a certain extent relevant information on the effectiveness of hazard reviews is used as feedback to improve the site policy, standards, personnel authority and responsibilities as well as the allocation of resources.

# *Appendix 3*

## Selecting Hazardous Task Using SPEAR Screening Process

**Selecting Hazardous Task using SPEAR Screening Process**

**1. Development of an inventory of operator tasks**

The inventories of operator tasks were determined by reference to the plant procedures, maintenance schedules, and discussion with the site operators, supervisors and plant manager. One potential difficulty was to ensure that all tasks are described at a similar level of detail. To overcome this problem a task classification based upon three dimension was used;

- classifying the task as control room, maintenance or on-plant situation
- checking whether the task involved routine situations, unusual but planned situations or rare event such as plant emergencies.
- subdividing the task further into the activities of planning, task execution and verification (or checking)

## 2. Identification of a subset of critical task with risk potential

The identification of the subset of critical tasks from original task inventory was achieved by applying series of questions to identify three aspects of the tasks which determine the risk potential as follows;

- the intrinsic hazard associated with the task (i.e. high pressure, toxic, or flammable hazard)
- the extent to which the nature of the task has the potential to release the hazard e.g. breaking open a line would have a higher risk potential than painting it i.e. its vulnerability
- the frequency with which the task is performed e.g. a task performed daily has a greater potential to release hazard than one performed yearly

These three factors were assessed using a series of questions to produce an index in each case. The diagnostic questions and corresponding indexes used to assess the factor are given below;

Table A3.1 Calculation of Intrinsic Hazard Score (IHS)

| Intrinsic Hazard | Score | |
|---|---|---|
| | Site A | Site B |
| 1. To what extent does the task involve the use or control of hazardous materials or operations- i.e. in this case toxic material | 3 | 3 |
| 2 To what extent is the task to be carried out in hazardous area/environment (e.g. enclosed room) | 3 | 3 |
| Intrinsic Hazard Score (IHS) = (S - 2)/4 | 1 | 1 |

Score Values;

High = 3

Medium = 2

Low = 1

Intrinsic Hazard Score (IHS) = (S - 2)/4

Where; S = Sum of scores for both questions

Table A3..2. Method of Calculating Intrinsic Vulnerability Score (IVS); Sample of PREI calculation for ammonia filling operation

| Nature of Interaction | Site A | Site B |
|---|---|---|
| 1. To what extent does the task potentially bring personnel into direct contact with hazardous materials/operations/situation? | 3 | 3 |
| 2. To what extent does the task involve dismantling/reassembly of plant equipment? | 3 | 3 |
| 3. To what extent does the task involve modifying existing processes/plant equipment | 1 | 1 |
| 4. To what extent are process control systems influenced by the task? | 3 | 2 |
| 5. To what extent are safety system influenced by the task? | 3 | 3 |
| 6. To what extent are process isolations/de-isolations required for the tasks? | 3 | 3 |
| 7. To what extent is special access required? | 1 | 1 |
| Intrinsic Vulnerability Score (IVS) = (S - 7)/14 | 0.5 | 0.36 |

Score Values;

High = 3

Medium = 2

Low = 1

Intrinsic Vulnerability Score (IVS) = (S - 7)/14

Where; S = Sum of scores for all questions

Table A3.3. Method for assessing Index of Frequency Score (IFS)

| Task Frequency | Score |
|---|---|
| Once or more per shift | 6 |
| Once per 24 hours | 5 |
| Once per week | 4 |
| Once per month | 3 |
| Once per year | 2 |
| Less than once a year | 1 |

Index of Frequency Score = (S-1)/5

Where S = Score for task frequency

Table A3.4. Sample of Index of Frequency Score (IFS) calculations

| | Site A | Site B |
|---|---|---|
| Task Frequency | 5 | 4 |
| Index of Frequency Score = (S-1)/5 | 0.8 | 0.6 |

The three calculations produce three indices each ranging from 0 to 1.

These were then combined to give an overall measure of potential risk (PREI) using the following formula;

Potential Risk Exposure Index (PREI) = (IHS+IVS + IFS)/3

The PREI ranges from 0 (minimum potential risk) to 1 (maximum potential risk)

Table A3.5. Sample of PREI calculation for ammonia filling operations

| | IHS | IVS | IFS | PREI= (IHS+ IVS + IFS)/3 |
|---|---|---|---|---|
| Site A | 1 | 0.5 | 0.8 | 0.77 |
| Site B | 1 | 0.36 | 0.6 | 0.65 |

Similar calculations were made on all major activities on sight in order to rank each activity based on the PREI. Activity with a high PREI indicates it is subjected to high degree of human error influences.

From site inspection it was determined that Site A activities could be broken into of 5 main areas;

1. Ammonia bulk storage
2. Road tanker and skid tank filling area
3. Cylinder and drum filling
4. Ammonia solution tank
5. Skid tanks and cylinders storage

Similarly site inspection revealed that Site B activities were made up of 6 main areas;

1. Ammonia bulk storage
2. Rail tanker filling area
3. Road tanker and skid tank filling area
4. Cylinder and drum filling
5. Ammonia solution tank
6. Skid tanks and cylinders storage

# 3. Development of Task Inventory

## 3.1. Task Identification

- The initial stage of the screening process requires a complete list, or inventory, of all the task on the unit that have significant human involvement. A task inventory was checked on the cylinder filling and road tanker/skid tank loading. The main source for this is through limited procedures manual, observation and explanation by the plant management.
- Another separate manual covered 'emergency procedures' which provides general procedures in the event of any emergency at sites. This covered fires and ammonia releases

## 3.2. Classification of tasks

The first stage of the development of the inventory involved applying the task classification to the tasks. Only the first two dimensions of the classification were applied, i.e. the physical location of the task (activity type), and the task demands.

i. Activity type

The task covered by the site operators only since maintenance work is not involved with critical task that could lead to major releases at this site. The emphasis on multi-skilling resulting most of the critical task like bulk tanker unloading being carried solely by operators.

Classification of task into control room and field operations is difficult because the site does not have a proper control room. Rather the control panel located on the field, i.e. one at the unloading location and the other at the cylinder filling bays. Only the plant start/shut down and emergency stop but to located in the manager office.

**ii. Task demand**

This classification dimension intended to represent the difficulty and complexity of a task for the average operator.

- Routine task: tasks where the operator does not have to think as they carried out frequently and are familiar to him

- Infrequently tasks: Tasks where the operator has not had so much practice but are fairly standard. The operator will have to plan his action in advance, probably consult the procedures in the control room before attempting the task

- Contingency task: These tasks could also describe as rare. Procedures exist, and due to lack of practice they will need to be followed closely. Emergency procedures are a good example of tasks that would fall into this category.

Table A3.6. PREI for Activities on Site A

| Tasks | Intrinsic Hazards | | | Nature of Interaction | | | | | | | | Frequency | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score on questions | | | Score on questions | | | | | | | | | | | |
| | Q1 | Q 2 | **IHS** | Q1 | Q2 | Q3 | Q4 | Q 5 | Q6 | Q7 | **IVS** | Score | **IFS** | **PREI** | **PREI Ranking** |
| 1. Ammonia Bulk Storage Loading and unloading | 3 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 1 | 0.43 | 5 | 0.8 | **0.74** | **3** |
| 2. Road Tanker/Skid Tanks Loading | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 3 | 3 | 1 | 0.64 | 6 | 1 | **0.88** | **1** |
| 3. Cylinders and drums filling | 3 | 3 | 1 | 3 | 2 | 1 | 2 | 2 | 2 | 1 | 0.43 | 6 | 1 | **0.81** | **2** |
| 4. Aqueous solutions filling | 2 | 2 | 0.5 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0.07 | 6 | 1 | **0.52** | **5** |
| 5. Cylinders and drum checking, stacking and loading | 3 | 2 | 0.75 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 0.14 | 6 | 1 | **0.63** | **4** |

IHS - Intrinsic Hazard Score = ( S-2 )/4

IFS - Index of Frequency Score (S-1 )/5

IVS - Intrinsic Vulnerability Score = ( S-7 )/14

PREI - Potential Risk Index = ( IHS +IVS +IFS )/3

Table A3.7. PREI for Activities on Site B

| **Tasks** | **Intrinsic Hazards** | | | **Nature of Interaction** | | | | | | | | **Frequency** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score on questions | | | Score on questions | | | | | | | | | | | |
| | Q1 | Q 2 | **IHS** | Q1 | Q2 | Q3 | Q4 | Q 5 | Q6 | Q7 | **IVS** | Score | **IFS** | **PREI** | **PREI Ranking** |
| 1. Bulk Storage Loading and unloading | 3 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 1 | 0.43 | 5 | 0.8 | **0.74** | **3** |
| 2. Rail Tanker Loading | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 3 | 2 | 1 | 0.57 | 5 | 0.8 | **0.79** | **2** |
| 3. Road Tanker/Skid Tanks Loading | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 3 | 3 | 1 | 0.64 | 5 | 0.8 | **0.81** | **1** |
| 4. Cylinders and drums filling | 3 | 3 | 1 | 3 | 2 | 1 | 1 | 2 | 2 | 1 | 0.36 | 6 | 1 | **0.79** | **2** |
| 5. Aqueous solutions filling | 2 | 2 | 0.5 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0.07 | 6 | 1 | **0.52** | **5** |
| 6. Cylinders and drum checking, stacking and loading | 3 | 2 | 0.75 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 0.14 | 6 | 1 | **0.63** | **4** |

IHS - Intrinsic Hazard Score = ( S-2 )/4
IVS - Intrinsic Vulnerability Score = ( S-7 )/14
IFS - Index of frequency Score = ( S-1 )/5
PREI-Potential Risk Index = ( IHS +IVS +IFS )/3

Table A3.8. PREI for Ammonia Loading Operations - Site A

| **Tasks** | **Intrinsic Hazards** | | | **Nature of Interaction** | | | | | | | | **Frequency** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score on questions | | | Score on questions | | | | | | | | | | | |
| | Q1 | Q 2 | **IHS** | Q1 | Q2 | Q3 | Q4 | Q 5 | Q6 | Q7 | **IVS** | Score | **IFS** | **PREI** | **PREI Ranking** |
| 1. Prepare Plant | 2 | 2 | 0.5 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 0.21 | 5 | 0.8 | **0.50** | **5** |
| 2. Prepare Road Tanker | 2 | 2 | 0.5 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 0.28 | 6 | 1 | **0.59** | **3** |
| 3. Filling of Road Tanker | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 3 | 3 | 1 | 0.64 | 6 | 1 | **0.88** | **1** |
| 4. Monitor Transfer | 1 | 2 | 0.25 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 6 | 1 | **0.42** | **6** |
| 5. Decouple Road Tanker | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 2 | 3 | 1 | 0.5 | 6 | 1 | **0.83** | **2** |
| 6. Final Checks | 2 | 2 | 0.5 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 0.07 | 6 | 1 | **0.52** | **4** |

IHS - Intrinsic Hazard Score = ( S-2 )/4
IVS - Intrinsic Vulnerability Score = ( S-7 )/14
IFS - Index of Frequency Score = ( S-1 )/5
Potential Risk Index (PREI) = ( IHS +IVS +IFS )/3

Table A3.9. PREI for Ammonia Loading Operation - Site B

| **Tasks** | **Intrinsic Hazards** | | | **Nature of Interaction** | | | | | | | | **Frequency** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Score on questions | | | Score on questions | | | | | | | | | | | |
| | Q1 | Q 2 | **IHS** | Q1 | Q2 | Q3 | Q4 | Q 5 | Q6 | Q7 | **IVS** | Score | **IFS** | **PREI** | **PREI Ranking** |
| 1. Prepare Plant | 2 | 1 | 0.25 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 0.21 | 5 | 0.8 | **0.42** | **4** |
| 2. Prepare Road Tanker | 2 | 2 | 0.5 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | 0.35 | 5 | 0.8 | **0.55** | **2** |
| 3. Filling of Road Tanker | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 3 | 3 | 1 | 0.57 | 5 | 0.8 | **0.79** | **1** |
| 4. Monitor Transfer | 1 | 2 | 0.25 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 0.07 | 5 | 0.8 | **0.37** | **5** |
| 5. Decouple Road Tanker | 3 | 3 | 1 | 3 | 3 | 1 | 2 | 2 | 3 | 1 | 0.57 | 5 | 0.8 | **0.79** | **1** |
| 6. Final Checks | 2 | 2 | 0.5 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 0.07 | 5 | 0.8 | **0.47** | **3** |

IHS - Intrinsic Hazard Score = ( S-2 )/4

IFS - Index of Frequency Score = ( S-1 )/5

IVS - Intrinsic Vulnerability Score = ( S-7 )/14

Potential Risk Index (PREI) = ( IHS +IVS +IFS )/3

PAGE

NUMBERING

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## Predictive Human Error Analysis (PHEA) for Site A and Site B

**Table A5.1- Predictive Human Error Analysis (PHEA) for Site A**

| SYSTEM GOAL = LOADING OF AMMONIA ROAD TO TANKER<br>PLAN = DO IN SEQUENCE | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Task** | **Error Type (Planning Error)** | **Description** | **Consequences (F, S)<br>F=Frequency , S= Severity<br>Low (L), Medium(M), High(H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | **F** | **S** | | |
| Loading of ammonia to road tanker. | Incorrect plan executed. | Filling operation carried out without establishing the amount of ammonia remained inside the tank | Overfilling of road tanker that could led to catastrophic failures resulting major releases of ammonia | L | H | Operator monitor road tanker content gauge | Training and strictly follow the procedures. |
| | Inappropriate plan executed. | The loading procedure did not included the requirement for leak test | Connection joints integrity cannot be ascertained, and leaks might developed under pumping pressure | H | M | No recovery | To include steps for leak testing for connection joints prior to ammonia pumping to road tanker |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Plan pre-condition ignored | Ammonia filling operation is carried out by inexperienced operator | Delay in filling operation and delivery pressure may result in unsafe loading practice. Unable to respond in effectively during emergency, e.g. sudden releases of ammonia. | L | L | The multi-skilling approach adopted by the site management has produced adequate pool of experienced operators. But this was off-set by high turnover of operator looking for better incentives elsewhere | The site management has to provide better incentives to keep experienced operators, e.g. through profit sharing scheme which could be easily implemented as the site is owned by individuals. |
| 2. PREPARE ROAD TANKER<br>PLAN = Do 1 to 7 in Sequence | | | | | | | |
| **Task Step** | **Error Type (Operation Error)** | **Description** | **Consequences (F, S) F=Frequency , S= Severity Low (L), Medium(M), High(H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | F | S | | |
| 2.1 Drive tanker to weighbridge. | Action too much | Tanker is driven too fast within plant compound. | Meet accident with other vehicles or hit plant piping or cylinder storage area. | M | H | Remind by supervisors or operators | Provide systematic vehicle movement inside the plant and enforce speed limit. |
| 2.2 Park tanker on the bridge and switch off ignition. | Action omitted | Tanker was not properly parked on weighbridge. | Wrong reading for tanker gross weight. | L | L | Operator check tanker position when unusual reading appeared. | Provide clear marking to indicate correct parking position. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Check omitted. | Operator failed to check that tanker was not parked correctly. | Wrong target weight set resulting overfilled. | L | L | Operators notice abnormal tanker gross weight reading. | Supervisor check |
| 2.3 Chock front and rear wheel. | Action omitted | Operator omits to place the wheel chocks. | Tanker could move or driven away with transfer hose still attached to it. | H | M | Check valves at tanker activates when transfer hose rupture hence minimised leaks. | Supervisor checks. |
| | Action incomplete. | Operator only put chocks to prevent forward movement of tanker but the tanker could move backward, sharing transfer hoses. | Ammonia leaks through rupture hose. | H | L | Check valve at tanker activates reduce leaks. | Supervisor or 2nd.operator checks. |
| 2.4 Ensure the tanker is empty by checking the ullage, pressure and temperature. | Check omitted. | Operator failed to establish that the tanker is empty. | Tanker overfilled resulting leaks or rupture of bullet and lead to major release of ammonia. | M | H | No recovery if tanker bullet failed. | Enforce strict procedures. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Check incomplete. | Operator only rely on reading of one gauge e.g ullage gauge which might be faulty. | Tanker might not be empty resulting overfilling. | L | H | Operator notice abnormal empty gross weight based on experienced. | Use checklist and enforced it. |
| | information misinterpreted (wrong information obtained) | Operator takes wrong reading due to too small dial gauge or makes mistakes under hot sun. | Cannot determined whether the tanker is empty. | L | L | Countercheck by other operator | Filling procedures should specify second checks. |
| 2.5 Weight tanker gross weight and record. | Action omitted. | Drive drove straight to loading bay without weighing. | Operator did not know ammonia target filling weight resulting overfill that might rupture tanker. | L | L | Operator observed content gauge on road tanker | Strict procedures where filling operator refused to fill without knowing the target filling weight. |
| | Check omitted. | The operator forgets to weigh tanker and driver unaware of it and drive straight into the loading bay. | Operator does not know target filling weight resulting over/ underfill. | L | L | Filling operator counterchecks with weighbridge. | Strict enforcement of filling authorization permit. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.6 Established ammonia filling weight. | Check omitted | Operator did not check one of the parameter to establish target filling weight, e.g. tare weight of different model of tanker. | Wrong target filling weight being established and resulted in overfilling of tanker | L | H | Operator may realise abnormal reading based on experience. | Provide checklist and training. |
| 2.7 Connect earth clip for grounding | Action omitted. | Operator forgets/ deliberately did not connect earth clip. | Sparks occurred that could ignite ammonia in the air. | L | L | No Recovery. | Supervisor/ buddy checks. |
| | Action mistimed. | Connection only be made during filling operation | Operator only aware improper connection being made at that time and sparks might be generated prior to it. | L | L | Operator rectifies improper connection. | Double checking by operator /buddy. |
| 3 FILLING OF AMMONIA TO ROAD TANKER<br>PLAN = Do in 1 to 9 in sequence, if leak developed do 10 and return to 7 | | | | | | | |
| **Task Step** | **Error Type (Operation Error)** | **Description** | **Consequences (F, S) F=Frequency , S= Severity Low (L), Medium (M), High(H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | **F** | **S** | | |
| 3.1 Operators put on PPE | Action omitted. | Operator omits to put on PPE | Operator not protected and cannot provide proper protection in the event of ammonia leaks. | H | M | - No recovery if violation<br>- Reminded by 2nd.operator | Strict enforcement on wearing of PPE |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Action incomplete | Operator is expected to put on PPE immediately once the tanker is properly parked for filling. | PPE incorrectly put on in a hurry and cannot provide proper protection in the event of ammonia leaks. | H | M | Difficult to detect | Training and spot check by supervisor. |
| 3.2 Release ESV lever for vapour and liquid valves on tanker. | Action omitted. | Operator omits to release ESV lever. | Tanker check valves for vapour and liquid did not open and create back pressure during pumping. | L | L | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |
| | Action incomplete | Operator does not fully pull ESV release lever. | Tanker check valves for vapour and liquid did not fully open resulting back pressure during pumping. | L | L | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |
| 3.3 Connect vapour filling hose to tanker's vapour inlet valve. | Action omitted. | Operator omits to connect vapour filling hose to tanker's vapour inlet valve. | Release of ammonia when pumping commences | L | M | Operator stop the filling operation, but under high stress working inside ammonia cloud. | Use checklist or visual check by 2nd. operator prior filling |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Action incomplete | Operator omits to properly tightened the hose flange tanker. | Significant vapour leaks during transfer. | L | M | Operator stop the filling operation | Pressure/ leak test by slowly cracking opens the filling line. |
| | Right action on wrong object. | Operator connects vapour hose to tanker liquid inlet. | Vapour enters liquid space in tanker. | L | L | Operator cannot make proper connection due to different flange size for liquid and vapour inlet. | Fitted different flange size for liquid and vapour inlet. |
| 3.4 Connect liquid filling hose to tanker's liquid inlet valve. | Action omitted. | Operator omits to connect liquid filling hose to tanker's liquid inlet valve. | Major ammonia releases when pumping commences | L | H | Operator could stop the filling operation, but under high stress working inside ammonia cloud. | Double check by 2nd. operator |
| | Action incomplete | Operator failed to tighten the connection flange joint adequately. | Significant leaks developed during transfer. | L | M | Operator immediately stops the filling operations limiting the amount of gas release. | Need proper leak test procedure as visual check enable to detect error |
| | Right action on wrong object. | Operator connect vapour hose to tanker liquid inlet. | Liquid enters vapour space in tanker. | L | L | Operator cannot make proper connection due to different flange size for liquid and vapour inlet. | Fitted different flange size for liquid and vapour inlet. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.5 Open by pass valve on plant's filling line. | Action too much/ too little. | Operator does not fully open the by pass valve. | Backpressure develop increasing pumping resistance. | L | L | Checks by 2nd. operator | Provide marker to indicate valve position |
| | Right action on wrong object. | Operator may fix vapour hose to liquid inlet. | Hose may burst due to liquid pressure. | L | L | Checks by 2nd. operator | The use of different connecting flange size for vapour and liquid valve. |
| 3.6 Open line valves of the selected pump. | Action omitted. | Operator omits to fix liquid hose to tanker liquid inlet. | Major ammonia release as filling commences. | L | L | Supervisor transfer immediately using ESB. | 2nd. operator using checklist. |
| | Action incomplete | Operator does not fully open line valve of pump. | Reduce pumping flow rate increase filling duration. | L | L | Operator notice during rounds. | Provide marker to indicate valve position |
| | Right action on wrong object. | Operator open line valves of the different pump. | No ammonia flow | L | L | Checks by 2nd. operator | Provide different line valve numbers for each pump |
| 3.7 Switch on pump. | Right action on wrong object. | Operator switch on wrong pump | No transfer take palace | L | L | Operator realised when no flow takes place | 2nd. operator using checklist. |
| 3.8 Observed differential pressure between pump's inlet and outlet | Check omitted. | Operator failed to check the differential pressure which indicated there is flow of ammonia | No ammonia flow | L | L | Operator realised when no flow takes place | 2nd. operator using checklist. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3.9 Ensure there is no leaks. | Check omitted. | Operator failed to check for leaks. | Leak might develop and releases significant amount of ammonia. | H | H | Remind by other when leaks developed from strong ammonia smell and white cloud. | Incorporate proper leak test procedure and equipment to check for leaks. |
| | Check incomplete. | Leak checks only being done on certain part of the system only e.g road tanker only, leaks might develop at plant side. | Failed to notice leaks developing at other part of the system. | L | M | Remind by other when leaks developed from strong ammonia smell and white cloud. | Training. |
| 3.10 Remake joint if leaks developed | Action omitted. | Operator failed to remake joint as the first sign of leak developed | Leak escalated and makes it difficult to repair as ammonia vapour cloud developed | H | H | 2nd. operator noticed or remind by other | Included leak test for connection in filling procedure |
| | Action incomplete | Operator remake joint but not tight enough | Leaks reoccurred when the the pump is switch on again | L | L | 2nd. operator noticed or remind by other | Included leak test for connection in filling procedure |

TASK NO.4 - DECOUPLE TANKER FROM PLANT

PLAN = Do 1 to 5 in sequence, then do 5 and wait for 5 minutes. If no ammonia remains in filling hoses do 9 to 11 in sequence

| Task Step | Error Type (Operation Errors) | Description | Consequences (F, S) F=Frequency , S= Severity Low (L), Medium (M), High (H) | | | Recovery | Error Reduction Strategy |
|---|---|---|---|---|---|---|---|
| | | | | F | S | | |
| 5.1 Operator put on PPE | Action omitted | Operator omits to put on PPE | Operator not protected from hazards (M,L) | M | L | - No recovery if violation<br>- Reminded by sign/ others | Strict enforcement on requirement to wear PPE |
| | Action incomplete | Operator put on PPE but did not secured it to properly covered the face | Operator not protected from hazards (M, L) | M | L | - No recovery, and other operator difficult to detect | Training and spot checks |
| | Action mistimed | Operator put on PPE after filling commences | Operator not protected from hazards at the start filling operation (M,L) | M | L | Reminded by others | Strict enforcement on requirement to wear PPE |
| 5.2 Reset ESV for both road tanker liquid and vapour line | Action omitted | Operator omitted to reset ESV lever. | Tanker check valves for vapour and liquid did not shut and ammonia could leak in the event of tanker's manual filling valve failures. | L | L | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.3 Shut-off liquid inlet manual valve on road tanker | Action omitted | Operator omit to close the manual inlet valve that will isolated ammonia back flow from road tanker | Ammonia flow out from road tanker liquid side during disconnection of flexible hoses | L | M | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |
| | Action incomplete | Operator partially closed manual inlet valves, hence provides partiall isolation | Ammonia leak out from road tanker liquid side during disconnection of flexible hoses | L | L | 2nd.operator detected on valve position. | Provide marker to indicate valve position |
| 5.4 Shut-off vapour inlet manual valves on road tanker | Action omitted | Operator omits to close the manual inlet valves that will isolated ammonia back flow from road tanker | Ammonia flow out from road tanker vapour side during disconnection of flexible hoses | L | M | 2nd.operator detected on valve position. | Provide marker to indicate valve position |
| | Action incomplete | Operator partially closed manual inlet valves, hence provides partial isolation | Ammonia leak out from road tanker vapour side during disconnection of flexible hoses | L | L | 2nd.operator detected on valve position. | Provide marker to indicate valve position |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.5 Shut-off liquid inlet manual valves on filling line | Action omitted | Operator omits to close the liquid manual valve on filling line that will isolated ammonia back flow from road tanker | Ammonia flow out from plant liquid filling line during disconnection of flexible hoses | L | M | 2nd.operator detected on valve position. | Provide marker to indicate valve position |
| | Action incomplete | Operator partially closed manual inlet valves, hence provides partial isolation | Ammonia leak out from plant liquid filling line during disconnection of flexible hoses | L | L | 2nd.operator detected on valve position. | Provide marker to indicate valve position |
| 5.6 Shut-off vapour inlet manual valves on filling line | Action omitted | Operator omits to close the liquid manual valve on filling line that will isolated ammonia back flow from road tanker | Ammonia flow out from plant vapour filling line during disconnection of flexible hoses | L | M | 2nd.operator detected on valve position. | Provide marker to indicate valve position |
| | Action incomplete | Operator partially closed manual inlet valves, hence provides partial isolation | Ammonia leak out from plant vapour filling line during disconnection of flexible hoses | L | L | 2nd.operator detected on valve position. | Provide marker to indicate valve position |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.7 Open vent valve on venting line | Action omitted | Operator omits to open vent valve that will let the remains of ammonia in flexible hose to be vent-off to scrubber through plant venting line | Remains of ammonia in flexible hoses leak during disconnection | L | L | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |
| | Action incomplete | Operator partially open vent valves | Small remains of ammonia in flexible hoses leak during disconnection | L | L | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |
| 5.8 Run suction fan for at least 5 minutes | Action omitted | Operator omits to run suction fan that will suck the remains of ammonia in flexible hose to scrubber through plant venting line | Remains of ammonia in flexible hoses leak during disconnection | L | M | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |
| | Action incomplete | Operator run suction fan less than 5 minutes | Some remains of ammonia still in flexible hoses leak as not enough time allowed it to be suck away and it will leak during disconnection | L | L | 2nd.operator noticed. | Countercheck by 2nd.operator using checklist |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.9 Vent-off vapour return hose | Action omitted | Operator omits to vent off the remains of ammonia in vapour return hose to scrubber through plant venting line | Remains of ammonia in vapour return hose escapes during disconnection | L | L | 2nd.operator noticed. | Counter checks by 2nd.operator using checklist |
| | Action incomplete | Operator partially open vent valves | Some remains of ammonia still in vapour return hose escaped during disconnection | L | L | 2nd.operator noticed. | Counter checks by 2nd.operator using checklist |
| 5.10 Vent-off liquid filling hose | Action omitted | Operator omits to vent off the remains of ammonia in liquid filling hose to scrubber through plant venting line | Remains of ammonia in vapour return hose escapes during disconnection | L | M | 2nd.operator noticed. | Counter checks by 2nd.operator using checklist |
| | Action incomplete | Operator partially open vent valves | Remains of ammonia in liquid filling hose escapes during disconnection | L | L | 2nd.operator noticed. | Counter checks by 2nd.operator using checklist |
| 5.11 Stop suction fan and shut-off vent valves | Action omitted | Operator omits to stop suction fan shut-off vent valves | Ammonia vapour escaped through venting line to scrubber during next tanker filling. Ammonia vapour could escaped to atmosphere when the scrubber overloaded | L | L | Supervisor check | To re run safety checks using checklist before filling the next tanker |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.12 Decouple vapour return hose from road tanker | Action omitted | Operator omits to decouple vapour return hose from road tanker | Hose pull away as the road tanker moves. No ammonia leaks if it has been properly vented | L | L | Driver notice | Counter checks by driver before driving away road tanker |
| 5.13 Decouple liquid filling hose from road tanker | Action omitted | Operator omits to decouple liquid filling hose from road tanker | Hose pull away as the road tanker moves. No ammonia leaks if it has been properly vented | L | L | Driver notice | Counter checks by driver before driving away road tanker |
| 5.14 Blank-off liquid inlet valve on road tanker | Action omitted | Operator omits to blank-off the road tanker liquid filling line. | Liquid ammonia leak from road tanker in the event of inlet valves failures | L | L | 2nd. operator or driver notice | Counter checks by driver or operator using checklist before driving away road tanker |
| 5.15 Blank-off vapour return outlet valve on road tanker | Action omitted | Operator omits to blank-off the road tanker vapour line. | Ammonia vapour leak from road tanker in the event of inlet valves failures | L | L | 2nd. operator or driver notice | Counter checks by driver or operator using checklist before driving away road tanker |

Table A5.2. Predictive Human Error Analysis (PHEA) for Site B

| SYSTEM GOAL = LOADING AMMONIA TO ROAD TANKER<br>PLAN = DO IN SEQUENCE | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Task** | **Error Type (Planning Error)** | **Description** | **Consequences (F, S)<br>F=Frequency , S= Severity<br>Low (L), Medium (M), High (H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | **F** | **S** | | |
| To load Ammonia to road tanker. | Incorrect plan executed. | Filling operation carried out without establishing the amount of ammonia remained inside the tank | Overfilling of road tanker that could led to catastrophic failures resulting major releases of ammonia | L | H | Road tanker content gauge | Training and strictly follow the procedures. |
| | Plan pre-condition ignored | The operator decided to carry out connection and disconnection of tanker for urgent shipment as the maintenance crew is not available. | As the operator does not hand on experience he might do improper connection and resulting leaks during filling | L | H | Strict procedure not to allowed operator to carry out connection and disconnection of tanker to plant | Gradually train the operators to carry out connection and disconnection procedures by the maintenance crew until they are competent to do by themselves as practise at Site A |

| 2. PREPARE ROAD TANKER<br>PLAN = Do in Sequence | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Task Step** | **Error Type (Planning Error)** | **Description** | **Consequences (F, S)<br>F=Frequency , S= Severity<br>Low (L), Medium(M), High(H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | F | S | | |
| 2.1 Drive road tanker to loading bay | Operation too much/ too little. | Tanker is driven too fast in plant compound. | Meet accident with other vehicles or hit plant piping or cylinder storage area. | L | H | Plant Manager Supervisor remind | Provide systematic vehicle movement inside the plant and enforce speed limit. |
| 2.2.1 Switch on weight indicator and printer | Action omitted | Operator omits to switch on weight indicator and printer | No reading made available | L | L | Operator notice | Checklist. |
| 2.2.2 Reset weight indicator to zero, set date and time. | Action omitted | Operator omits to reset weight indicator to zero. | Weight indicators register more weight that it should. | L | L | Operator may notice abnormal weight if unreset weight is significant. | Checklist. |
| | Check omitted | Operator omits to check whether he had reset the weight indicator to zero. | Weight indicator will register wrong empty tanker reading. | L | L | Operator might notice abnormal reading if large difference. | Checklist. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Check mistimed. | Operator resets weight indicator to zero after tanker already parked on the weighbridge. | Wrong reading of tanker filling weight. | L | L | Operator can easily discover due to large abnormal reading. | Training. |
| 2.2.3 Park tanker on weighbridge within markers. | Action omitted. | Tanker driver in a hurry and did park tanker for weighing. | Tanker empty weight could not be established | L | L | Operator notice. | Supervision. |
| | Action incomplete | Driver failed to align the tanker properly within marker of the weghbridge. | Weighbridge register wrong empty tanker weight. | L | L | Operator notice. | Adequate training to driver and close supervision by operator |
| 2.2.4 Switch - off engine, remove key and hand it over to supervisor | Action omitted. | Driver omits to switch-off engine and removes key. | He might inadvertently drive away during filling resulting hose pull-away. | L | M | Wheel chocks prevent drive-away. | Supervisor checks. |
| | Action incomplete | Driver switch-off engine but did not remove key and hand it over to the supervisor. | Driver can drive away during filling resulting to hose pull- away. | L | M | Wheel chocks could prevent tanker from moving. | Supervisor checks. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.2.5 Engage hand brake and driver leave the road tanker | Action omitted. | Driver omits to engage hand brake | Tanker could slide down the ramp | L | L | Wheel chocks could prevent tanker from moving. | Supervisor checks. |
| 2.2.6 Read off gross weight of tanker on weight indicator. | Information not obtained. | Operator omits to read gross weight of tanker. | Cannot determine filling weight. | L | L | Realised when he wants to compute filling weight. | Checklist. |
| | Wrong information obtained. | Operator wrongly read gross weight of tanker. | Use wrong gross weight that resulted in wrong deduction of ammonia content in tanker. | L | L | No recovery. | To incorporate gross weight reading straight into weighbridge computer memory. |
| 2.2.7 Deduce net ammonia content in tanker by deducting tanker's tare weight. | Wrong information obtained. | Operator read/use tare weight of different model/size of tanker. | Wrongly deduced net ammonia content in tanker. | L | L | Relied on experience for common tanker sizes.. | Provide clear table of tare weights of different model/size of tankers or painted them clearly of the respective tanker itself. |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.2.8 Place 4 chocks to front and rear wheels to prevent tanker movement. | Action omitted. | Operator omits to place wheel chocks. | Tanker can be driven away during filling resulting hose pull away and initiating ammonia release. | L | H | Supervisor checks. | Training. |
| | Action incomplete | Operator only put chocks on front wheels only. | Tanker can be moved a little during filling. | L | L | Supervisor checks. | Training |
| 2.2.9 Print tanker tanker filling weight | Action omitted. | Operator omits to print 1st weight. | Operator may set wrong target filling weight, could result in overfilling. | L | H | Could only relied on experience for common tanker sizes. | To incorporate gross weight reading straight into weighbridge computer memory. |
| 2.3 Ensure that ammonia line depressurised prior to tanker's connection, | Check omitted. | Operator omits to check ammonia line has been fully depressurised prior to tanker connection. | Ammonia not depressurised and leaks after during hose connection. | L | M | Reminded by control room operator who notice line valve status. | Warning alarm at control room. |
| | Check incomplete. | Operator did not check all valve status as specified in the procedures. | Ammonia line not fully depressurised. | L | L | Difficult to recover as not all valve status displayed at control panel. | Checklist and double checking. |

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| | Wrong check on right object. | Operator made mistake in ascertaining ammonia line valves status, i.e. open instead of closed. | Ammonia line not fully depressurised. | L | L | Difficult to recover as not all valve status displayed at control panel. | Checklist. |
| 3. CONNECTING PLANT TO ROAD TANKER<br>PLAN = Do in Sequence | | | | | | | |
| **Task Step** | **Error Type (Operation Error)** | **Description** | **Consequences (F, S) F=Frequency, S= Severity Low (L), Medium(M), High(H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | **F** | **S** | | |
| 3.1 Operator dons appropriate PPE (gas hood with air supply) | Operation omitted. | Operator failed to put on gas hood with air supply. | Exposure to ammonia leaks and under worst circumstances incapacitated and unable to take mitigative action. | L | H | Reminded by others/ signs. | Training and strict enforcement on wearing of PPE |
| | Operation incomplete. | Operator dons gas hood incorrectly. | Exposure to ammonia leaks, might be incapacitated and unable to take mitigative action. | L | M | No recovery without close examination. | Training and spot check by supervisor. |
| | Check omitted. | Operator failed to check the condition of gas hood and air supply system that might be faulty. | Gas hood would not offer protection in the event of gas leaks. | L | M | No recovery | Regular checks and servicing of the system. |

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| 3.2 Ensure that maintenance crew and driver wear appropriate PPE (gas masks with face shield). | Check omitted. | Operator failed to check maintenance crew and driver failed to wear of gas masks with face shield. | Gas masks fail to protect them and they cannot take appropriate mitigative action in the event of gas leaks. | L | H | Difficult to recover. | Regular checks and servicing of gas masks, and remove faulty masks from inventory cabinet. |
| 3.3 Check pressure in Chicksan arm is zero. | Check omitted. | Operator omits to ensure that pressure in Chicksan arm is zero. | Ammonia still left in Chicksan arm and would be released during hose connection. | L | L | No recovery. | Checklist |
| | Wrong information obtained. | Operator wrongly read the pressure which actually is not zero. | Ammonia still remains inside and could leaks during connections. | L | L | No recovery as the operator always works unsupervised. | Put clear marks on zero reading. |
| 3.4 Connect flexible pipe liquid drain line to tanker. | Operation omitted. | Maintenance crew omit to connect liquid drain line to tanker. | Ammonia remains in hoses cannot be drained to catch pot | L | L | Reminded by operator. | Close supervision by the operator. |
| | Operation incomplete. | Maintenance crew fixed flexible liquid incorrectly. | Ammonia still remains inside and could leaks during connections. | L | L | Discover during pressure test. | Training. |

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| 3.5 Connect Chicksan arms and flexible hoses to tanker. | Operation omitted. | Maintenance crew omit to connect flexible hose to tanker. | Major ammonia releases when pumping commences | L | H | Remind by operator | Counter check by operator before transfer commences. |
| | Operation incomplete. | Maintenance crew connects flexible hose incorrectly. | Ammonia leaks through untightened flange connection. | L | M | Leak test will showed. | Conduct proper leak test as prescribed in procedure |
| 3.6 Do leak test on joint to ensure connection integrity. | Operation omitted. | Maintenance crew omit to carry out leak test under time pressure. | Integrity of joint is not known, might leaks when transfer commences. | L | M | Procedure and remind by the operator. | Training/ Checklist. |
| | Operation incomplete. | Maintenance crew only carry out leak test on some connection joints under time pressure. | Leaks might develop on untested joints during filling. | L | M | Difficult for the operator to realise unless he observed the whole testing | Training. |
| 3.7 Set weight trip setting | Operation omitted. | Operator omits to set trip setting at weight indicator. | Filling operations would not be automatically trip, no alarm sounded and could result in overfilling. | L | H | No recovery as the operator works alone inside an enclosed work cabin. | Checklist. |

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| | Operation incomplete. | Operator only set 1st trip for target weight but not for overweight (2nd. trip) and overfill (3rd.trip) setting. | If 1st. trip failed no recovery for 2nd. and 3rd.trip which could resulted to overfill. | L | M | Discover at trip verification stage. | Closely follow the procedures. |
| 3.8 Commences filling by pressing pump start button | Operation omitted. | Operator omits to press button to start pumping. | No flow of ammonia | L | L | Operator realise no filling takes place | Checklist. |
| 3.9 Ensure there are no leaks. | Check omitted | Operator omits checking for leaks. | Leak might develop and releases significant amount of ammonia. | L | H | Remind by other when leaks developed from strong ammonia smell and white cloud. | Spot checks by supervisor during filling |
| | Check incomplete | Leak checks only being done on certain part of the system only, e.g. road tanker only, leaks might develop at plant side. | Failed to notice leaks developing at other part of the system. | L | M | Remind by other when leaks developed from strong ammonia smell and white cloud. | Spot checks by supervisor during filling |

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| 3.10 Rectify leaks | Action omitted | Operator omits to rectify leaks. | Leak escalated and releases significant amount of ammonia. | L | H | Remind by other when leaks developed | Spot checks by supervisor during filling |
| 5. DISCONNECTING ROAD TANKER FROM PLANT<br>PLAN = Do 1 to 9 in Sequence | | | | | | | |
| **Task Step** | **Error Type (Operation Error)** | **Description** | **Consequences (F, S)<br>F=Frequency, S= Severity<br>Low (L), Medium(M), High(H)** | | | **Recovery** | **Error Reduction Strategy** |
| | | | | **F** | **S** | | |
| 5.1 Operator dons gas hood with air supply. | Operation omitted. | Operator omits to put on gas hood with air supply. | Exposure to ammonia leaks and under worst circumstances incapacitated and unable to take mitigative action. | L | H | Reminded by others/ signs. | Training and strict enforcement on wearing of PPE |
| | Operation incomplete. | Operator dons gas hood incorrectly. | Exposure to ammonia leaks, might be incapacitated and unable to take mitigative action. | L | L | Difficult to recover without close examination. | Training and spot check by supervisor |
| 5.2 Ensure that driver wears appropriate gas masks. | Check omitted. | Operator omits to check driver failed to wear gas masks with face shield. | Gas masks fail to protect them and they cannot take appropriate mitigative action in the event of gas leaks. | L | H | Difficult to recover. | Spot checks and servicing of gas masks , and remove faulty masks from inventory cabinet. |

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| 5.3 Depressurise the Chiksan arms by draining remaining ammonia to the catchpot. | Operation omitted. | Operator omits to depressurise Chiksan arm and flexible hoses | Ammonia remains inside Chiksan arm and flexible hoses that will result in ammonia release during disconnection. | L | L | Counter check by maintenance crew who will carry out disconnecting. | Use appropriate checklist for disconnection |
| | Operation too short. | Sufficient time must be given to allow liquid ammonia entrapped in flexible pipe and Chiksan arm to be drain out to catch pot. | Insufficient draining leave certain amount of ammonia insisde and will resulted in ammonia release during disconnection. | L | L | Countercheck by maintenance crew who will carry out diconnecting. | Training. |
| 5.4 Park the disconnected Chiksan arm | Operation omitted . | Operator omits to park Chiksan arm to its resting position | Chiksan arm could be hit by incoming tanker | L | L | Noticed by the driver of oncoming tanker | Supervisor check prior to each filling. |
| 5.5 Print 2nd weight on weight ticket and deduces net filling weight. | Operation omitted. | Operator omits to print 2nd. weight and deduces net weight of ammonia being filled | Operator cannot compare the actual filling weight with target weight and the tanker could be overfilled | L | L | Operator or driver checked content gauge fitted on tanker. | Included checking of content gauge in procedure. |

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| 5.6 Remove wheel chocks and drive tanker away | Operation omitted. | Operator omits to remove wheel chock | Tanker cannot move | L | L | Driver notice | Closely follow the procedures. |
| 5.7 Switch off printer and lock cabin | Operation omitted. | Operator omits to switch-off printer and lock cabin | Printer may be wrongly adjusted/damaged by foul play | L | L | Spot check by supervisor | Closely follow the procedures. |
| 5.8 Close BCV 10 and it's downstream valve V106. | Operation omitted | Operator omits to close the two valves that will isolated ammonia flow to road tanker filling bay | In case of piping rupture at filling bay ammonia from stock tank could escape | L | L | Control room operator noticed | Checklist |
| | Wrong selection made. | Operator closed wrong valves, hence filling bay piping was not isolated | In case of piping rupture at filling bay ammonia from stock tank could escape | L | L | Control room operator noticed | Clearly labelled the valves and provided line diagram with checklist |
| 5.9 Open vent valve V 105 to vent-off catch pot to scrubber for next tanker filling. | Operation omitted. | Operator omits to vent off ammonia in catch pot to scrubber. | Ammonia in catch pot could enter drained line during next tanker filling. | L | L | Control room operator noticed and operator check prior to next filling | Checklist |
| | Operation incomplete. | Operator opens vent valve too short a time to allow ammonia be fully vented from catch pot to scrubber | Ammonia in catch pot could enter drained line during next tanker filling. | L | L | - as above - | Training and spot check by supervisor |

# *Appendix 6*

## Performance Influencing Factors (PIFs) Analysis

Table A6.1. Performance Influencing Factors (PIFs) Analysis for Site A

| PIF Topics | Findings of Analysis |
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| **1. EXPERIENCE** | |
| 4.1 Experience | Majority of the workers have no experience working on ammonia plant before. They were recruited fresh when the plant started operation in 1985. They were trained from scratch on the aspects of the plant operation by two supervisors who have considerable experience working in ammonia production plant at one of the multinational operations. The Managing Director also has some operational experience in fertiliser plant that use ammonia as feedstock. These three personnel provided on -job training for the new recruits which basically with the equivalent of the U.K O level qualifications. These trainees become the core operators for the plant operation. However the company lose a considerable number of these core operators to the newly built plants in the surrounding area. Such plants especially the electronic companies normally offer attractive wages and better working conditions e.g. fully air-conditioning workplace. |
| 4.2 Physical conditions and age | Majority of the worker are in their late twenty or early thirties and in good physical condition that the job demand. The hot tropical weather could reach to 32 degree centigrade in mid-day. As the road tanker loading operations in done in the open without any form of solar shading such hot conditions require the operator to be in good physical condition. |
| 4.3 Personality | Most of the workers were observed to have good personality. However being relatively young workforce they have more tendency to take risk or horse plays especially at the cylinder filling area. In the ammonia filling operation they are more likely to not don the PPE when carrying out a hazardous task such as during the connecting and disconnecting the flexible filling hose. However the more senior operators are more disciplined since they have experienced a major ammonia release before. The management half hearted approaches on the workers discipline |

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| 4.4 Training | As mentioned earlier most of the worker joined the company fresh after school and without working experience. They will be trained on the job training by senior operator for certain of period of time. The training does not followed any written procedures or standard but will cover all aspect of plant operation and maintenance i.e. cylinder filling, road tanker and skid tanks filling, as well ship to shore loading of ammonia. Length of training depended on individual capability. The adequacy of training will be assessed by the supervisor and the Plant Manager through work observation and interview. Emphasis is on the ability to perform specific tasks in safe and efficient manner Continuous training for operators is rare and only given in the case of introducing new task or modifying existing task. It also being conducted for specific purposes such for emergency response in the event of fire or ammonia releases. |
| 4.5 Timing | Timing of training for new operator is appropriate as they have to successfully complete their training before carrying out any task. |
| 4.6 Frequency of personnel involvement | There is high degree of personnel involvement with the process which allowed necessary skills and experience be developed to ensure safe operations. Nevertheless the implementation of job rotation (from maintenance to operation, vice versa) over 3 months period tends to reduce operator skill a bit. But this probably will offset the advantage of reducing the effect of boredom to stay in one section over a long period of time and provide better promotion opportunity to all personnel from this multi-skilling approach |
| **2. PROCEDURES** | |
| 2.1 Job Aid and Procedures | Job aids and procedures at this plant are not adequate at all. The management and the operator both seem to be in the opinion that the process is very straight forward and simple that it does not require procedures. Through interviews and observations the workers hardly referred to procedures in carrying out their tasks even for those considered critical. While agreeing the process is fairly simple the use of procedure is still necessary for critical task such as in checking leaks and establishing the target weight for filling |
| 2.2 Clarity of instruction | The instructions are mainly written in English despite the fact that fairly large numbers of workers are not proficient in English and most of the time has to rely on the plant engineer and supervisor for clarification. |

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| 2.3 Level of description | Level of description of procedures is quite adequate but sometimes does not correspond to the way the job is actually done. Identification of equipment such as valves' number on procedures does not correspond to one installed(most are not labelled or numbered). No flow diagram comes with the procedures. |
| 2.4 Specification of entry/exit conditions | No problem in this area as the process of cylinder filling quite separate from the road tanker filling apart from preparing the bulk tanks. Each process could be isolated individually without putting the other process in danger. |
| 2.5 Quality of checks and warning | Checks and warning in the procedures were not highlighted |
| 2.6 Degree of fault diagnosis support | Fault diagnosis support in procedures included ERP is the very minimum. Operator has to rely heavily on his experience to make judgement in diagnosing faults and takes appropriate mitigative actions. |
| 2.7 Compatibility with operational experience | Low degree of procedure compatibility with operational experiences. Procedures are written by the plant manufacture with little input from workers. |
| 2.8 Frequency of updating | ERP was last updated about 4 years ago after major ammonia release incident. Other operating procedures were not updated since the commissioning of the plant. |
| 2.9 Safe System of Work | Available for critical tasks only such as ship tanker unloading, ammonia road tanker filling, and ammonia bulk tanks internal inspections. However the systems lack transparency. |
| **3. STRESS** | |
| 3.1 Complexity of process | Ammonia bulking activities is a fairly straight forward process that involved the storage of large quantity of toxic gas under pressure, filling of ammonia into bullet tanks (road tanker and skids tanks) and cylinders bottling operations. On this site the process is fairly automated but there is still a lot of human interactions with the plant hardware. |

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| 3.2 PPE | Since ammonia is a highly toxic gas the use of PPE is very important. For bulk filling operation the operators are provided with cartridge type gas mask with face shield. For emergency gas tight body suit is provided with air supply. Feedback from interview with operators and through observation indicated that those PPE are not comfortable to be used in hot and humid weather. It becomes the practice for the operator to put on PPE on for short period during critical tasks only such as filling hose connection and disconnection. In the event of major leaks e.g. hose rupture its difficult to response quickly. From the interview operator complaints about uncomfortable feeling using the equipment |
| 3.3 Perceived Danger | Bulking operations tend to release a small amount of ammonia into the plant atmosphere and its pungent smell and white cloud always presents a positive sign of the existence of hazards to the operators. But the same sign overtime could make workers fall into complacency since unable to differentiate between operational release and possible leaks. Major release of ammonia at the plant that had resulted in ammonia releases has increased the management and workers' awareness of perceived danger of the operations. |
| 3.4 Time Pressure | The task with the greatest time pressure is the unloading of ammonia for ship tanker. As the window available for berthing at the multipurpose jetty is limited the unloading has to be carryout as quickly as possible. And as the unloading time takes up to about 12 hours most of the time it's will extend until night.<br>Time pressure also exists in carrying out the bottling of ammonia. Demand for this type of product is high especially from the small end user which are at scattered locations. Some are for overseas customers. Road tanker filling is carried out on average about 2 times per days hence the time pressure is not high. |
| 3.4 Suddenness onset of event | There is high possibility of the suddenness of events from major releases of ammonia, e.g. rupture of hose due to pull-away. As liquefied gas under pressure this sudden releases flash the ammonia and create large pool of vapour cloud. Such cloud engulfs quite a big area and incapacitated the operator preventing him quickly isolating the leak. |
| 3.6 Noise | Noise problem is limited to impact sound of cylinder stacking and lorry engine noise. Pump noise is almost negligible |

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| 3.7 Lighting | Lighting during daylight is good as the process is carried out in the open. Cylinder and road tanker filling are only done in day shift. Unloading ammonia from ship tanker where it may carried out at nights that is riskier than daytime operation due to inadequate lighting. Accidental releases at night especially from pipework will be difficult to detect. |
| 3.8 Thermal conditions | The process does not produces significant heat |
| 3.9 Atmospheric conditions | Of major concern is the heat effect on operator while loading or filling of ammonia to road and rail tankers carried out in the open shed. Temperature up to 30 degree Celsius will make the wearing off PPE become very uncomfortable and increasing the tendency of operator to stay inside the control room which is air conditioned, away from filling bays and unable to notice quickly abnormal conditions |
| 3.10 Working hours and rest pause | Filling of ammonia into cylinders, skid tanks and road tankers are only done during daytime as the plant has the capacity to meet demands during that period. There are 3 breaks during day time shift for morning tea, lunch and afternoon tea and their duration seem to be adequate. Ammonia loading from ship tanker and rail tanker filling may take place at night depending on the availability of berthing time and rail stock tanks. Works hours for this task are limited to the shift duration meaning that the next shift will takes over if shift loading passed through between shifts. |
| 3.11 Shift rotation and Night Work | Shift work for rail and ship tanker unloading. The shift rotates every week with a day off in between shift. Ship-tanker unload ammonia depends on demand but on average at 2 weeks interval. |

| 4. FEEDBACK | |
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| 4.1 Plant Layout | Plant layout is adequate where each working section is independent and spacious. However the traffic movement inside the factory is a quite haphazard without proper lane marking and tight turning areas. The road tanker loading bay is next to the traffic lane and without impact protection, e.g. in the form of bollard poles. So chances of the road tanker being hit by moving lorry during filling operation is quite high. Location of valves and control panel are within workers height reach. Critical information about the plant status is displayed on control panel. Pipework runs at heights at plant wall or on pipe rack at road crossing and does not obstruct people or vehicle movement. Most of the plant instrument and gauges are easy to read. Access to emergency stop buttons is good as the emergency shut down system could be initiated from the control and at respective section, i.e. cylinder filling, road tanker loading bay and administrative office. |
| 4.2 Location and access | Location of valves for ammonia filling majority is within worker's height reach but pipework hindered lateral movement and no elevated walkway is provided. Most of the plant instrument and gauges are easy to read. However making hose connection to skid tanks has to be done at height using ladder. Use of work platform is not practical due to different size of skid tanks. Access to emergency stop button is good as the emergency shut down system could be initiated at three different locations, two which are well away from the filling bays |
| 4.3 Labelling | Inadequate labelling and identification scheme on critical equipment, valves and piping system are of major concern. No systematic labelling or identification number to match the numbering scheme provided by the PI&D diagrams and work procedures. Workers rely on experience and checking by supervisors |
| 4.4 Control Panel Design | The plant has minimum remote control. Control panel mainly consist of start and stop button for pneumatically operated valves, pumps, suction fan and water spray curtain |
| 4.5 Content and relevant of information | Most of display elements such as content gauges, pressure gauges, temperature gauges are not connected to control panel and have to be checked individually for reading |
| 4.6 Identification of display and control | Poor identification of start/stop button for equipment (too small) beside the ESB which is red in colour |

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| 4.7 Compatibility with user expectation | Too few to check for compatibility |
| 4.8 Grouping of information | Too few to check for compatibility |
| 4.9 Overview of critical alarm and information | Only two types of alarm, i.e. fire and gas leak alarm. From the interview operator seem not very sure the difference between the two alarm indicating insufficient drills conducted for both situations |

Table A6.2. Performance Influencing Factors (PIFs) Analysis for Site B

| PIF Topics | Human Error Audit Findings |
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| **1. EXPERIENCE** | |
| 1.1 Plant personnel experience | Most of the workers have long experience in working with ammonia either at this plant or the sister plant or both except for the Plant engineer who has less than 4 years experience in working with ammonia. Workers turnover is low due to the stability of the company with proven business track record for nearly 20 years. However recent demand for experienced workers and supervisors by newly built large chemical plant may change the situation in the very near future. |
| 1.2 Personality | Majority of workers are above 30 years of age which in a way reduce the degree of risk taking in carrying out hazardous task, i.e. not wearing PPE. Worker's motivation seems to be on the lower side as the new management in the process of carrying out task rationalisation to increase efficiency. Another point of disagreement is lack of promotion opportunity of maintenance worker as compared to the process operator due to job compartmentalisation. |
| 1.3 Physical conditions and age | Majority of the workers in good physical condition, and couple with considerable amount of process automation enable them to do fairly heavy physical job, i.e. cylinder filling, to work under hot sun, i.e. for road tanker filling as well at night for rail tanker and ship tanker unloading. However small number of workers at about retirement age and under the management of job rationalisation will have to do extra work that might affect their performance |
| 1.4 Operator Training | In general training for new workers was conducted through on the job method where they learn through observation and hands on under the supervision of experience workers and supervisors. For new workers and outside contractors there are compulsory safety and emergency training. After that the workers will be assigned to specific task, i.e. operations, maintenance or services that becomes their long term career with the company. The plant manager and supervisor will assess whether they are ready to do certain jobs through observations and interview. Only those rank as supervisors and above given post employment training in courses related to their work i.e. HAZOP, Quality Control and Management |

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| 1.5 Design and development of training method | Design and development of training method based on ICI U.K. As it has been developed about 15 years ago it is not clear whether specific technique such as job and task analysis were utilised. As is it, the training seems to be adequate judging from workers' response. |
| 1.6 Task specific training | Existed in the form of ERP drill which included mitigation of ammonia release and fire and evacuation. |
| 1.7 The timing of training | Timing for training of new workers and outside contractors is suitable, i.e. before they are allowed to do specific task on their own. |
| 1.8 Frequency of operator involvement | There is high degree of personnel involvement with rail-tanker and cylinder filling process that allowed necessary skills and experience be developed to ensure safe operations. Nevertheless the road tanker filling only takes place on,average about 3 times a week. But as the company has distinct job categorisation where operation and maintenance are life time job allowed the skill to specific job to be retained by specialise group such as maintenance. But this introduced the need to stay in one section over a long period of time and provide less chance for promotion opportunity to certain group of personnel especially from maintenance section. |
| **2. PROCEDURES** | |
| 2.1 Job Aid and Procedures | Job aids and procedures at this plant are following the standard set by ICI Group. Procedures available for most operations, maintenance and modification works. This supplemented by job aids in the form of permit to work, job checklist and manuals. The management and the operator both felt strongly about the benefits of using the job aid and procedures. However the activity of revising the procedures seems to have lost its urgency under the new management. |
| 2.21 Clarity of instruction | The instructions are mainly written in English despite the fact that fairly large number of workers is not proficient in English and most of the time has to rely on the plant engineer and supervisor for clarification. But this situation is probably being off-set by a long experience most of the worker s had doing the same routine job. |
| 2.22 Level of description | Level of description of procedures is quite comprehensive and most of the times correspond to the way the job is actually done. Identifications of equipment such as valve's number on procedures do correspond to one installed (most are not labelled or numbered). Relevant flow diagram comes with the procedures. |

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| 2.23 Specification of entry/exit conditions | Problem might arise during the ship tanker unloading activities where close co-ordination requires to off-load ammonia to the rail tankers in order to make room for the remaining of ammonia from the tanker, but the control room is quite capable to handle it safely. |
| 2.23 Quality of checks and warning | Checks and warning in the procedures are included and highlighted in most cases |
| 2.24 Degree of fault diagnosis support | Fault diagnosis support in procedures included ERP is quite adequate. Operator can refer to it to assist in making judgement or taking appropriate mitigative actions. |
| 2.25 Compatibility with operational experience | Fairly high degree of procedures compatibility with operational experiences of ICI plant world-wide. However those procedures are written by the plant manufacture with little input from local workers. |
| 2.27 Frequency of updating | The operating manual calls for the procedures to be reviewed yearly. This was found out not to be carried out under the new management As the plant now independent of the sister company those initiatives which normally driven by the Safety Department located at the former now missing. |
| 2.8 Emergency Response Plan (ERP) | Media attention of complaints of minor ammonia releases from people lives in the surrounding few years ago have made ERP of the plant becomes very prominent. Concern for incident such as Bhopal by the Port Authority also prompted the company to conduct regular drills by simulating a number of release scenarios, some involving the local fire service. However off-site ERP still lacking since it involved surrounding factories and local population where co-ordination by the site authority is required. |
| 2.9 Safe System of Work | Generally safe system of work of most activities of the plant is sufficient for safe operation. For example rail-tanker are provided with remotely controlled pneumatic operated wheel interlock system to prevent Chiksan arm pull away. However the road tanker loading bay that was designed for top loading using Chiksan arm had to be modified to suit most tankers that fixed with bottom loading facilities defeating the reliability of Chiksan arm. Interlock system similar to the rail tanker loading should be fitted to prevent hose pull away. Another area of weakness is the solution filling to small containers that has to be carried out manually using makeshift rubber hose. |

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| 2.10 Shift Rotation and Night Work | Shift work for rail and ship tanker unloading. The shift rotates every week with a day off in between shift. Ship-tanker unload ammonia depends on demand but on average at 2 weeks interval. |
| **3. STRESS** | |
| 3.1 Complexity of process | Ammonia bulking activities is a fairly straight forward process which involved the storage of large quantity of toxic gas under pressure, filling of ammonia into bullet tanks(road tanker and skids tanks) and cylinders bottling operations. On this site the process is fairly automated but there is still a lot of human interactions with the plant hardware. |
| 3.2 PPE | Since ammonia is a highly toxic gas the use of PPE is very important. For bulk filling operation the operators are provided with air supply lines with hood. The maintenance crew who is responsible to connect and disconnect transfer hose is provided with cartridge type gas mask and face shield. For emergency gas tight body suit is provided with air supply. Interview with operators and through observation indicates that those PPE are not comfortable to be used in hot and humid weather. It becomes the practice to put on PPE on for short period during critical tasks only such as filling hose connection and disconnection. In the event of major leaks, e.g. hose rupture its difficult to response quickly. Through interview operator complaints about feeling uncomfortable using the air supply lines due to the 'dryness feeling' of the air supply and restriction of movement due to the lines. |
| 3.3 Perceived danger | Bulking operations tend to release a small amount of ammonia into the plant atmosphere and its pungent smell and white cloud always presents a positive sign of the existence of hazards to the operators. But the same sign over time could make workers fall into complacency since unable to differentiate between operational release and possible leaks. Previous significant release of ammonia at the plant had increased the management and workers' awareness of perceived danger of the operations. Another positive aspect is that most of the plant workers have long experience in working with ammonia at the sister plant when both were under the same management two years ago. |

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| 3.4 Time pressure | Time pressure would come mainly from the activity of discharging of ammonia from ship tanker to the plant's stock tank. The pressure comes first from the limited berthing window and discharging time and secondly from the need to transfer about 400 MT of ammonia from the plant to its sister company using rail tanker due to limited capacity of the on site bulk tanks that could only takes maximum of about 600 MT while the ship tankers normally carry about 1000 MT. This introduces the need to quickly fill the rail tankers to reduce ammonia level from the stock tanks in order to accommodate the remaining amount from the ship tanker. The time pressure to response to an incident is judged to be low road tanker for filling operation while for the rail tanker filling and ship tanker unloading is high |
| 3.5 Suddenness onset of event | There is a high possibility of the sudden onset of events from major releases of ammonia, e.g. rupture of filling hose due to pull out of road and rail tankers. As liquefied gas store under pressure this sudden release will flash the ammonia and create large vapour cloud which could engulf control equipment or incapacitated operator trying to response to such incidents |
| 3.6 Noise | Noise problem is limited to impact sound of cylinder stacking and lorry engine noise. Pump noise is almost negligible |
| 3.7 Lighting | Lighting during daylight is good as the process is carried out in unenclosed shed. Cylinder and road tanker filling are only done in day shift. Rail tanker filling and ship tanker unloading where it may carry out at nights that could be riskier than daytime operation even under adequate lighting. Accidental releases at night especially from pipework will be difficult to detect. |
| 3.8 Thermal conditions | The process does not produces significant heats |
| 3.9 Atmospheric conditions | Of major concern is the heat effect on operator while loading or filling of ammonia to road and rail tankers carried out in the open shed. Temperature up to 30 degree Celsius will make the wearing off PPE become very uncomfortable and increase the tendency of operator to stay inside the control room which is air conditioned, away from filling bays and unable to notice quickly abnormal conditions |

| | |
|---|---|
| 3.10 Work hours and rest pause | Filling of ammonia into cylinders, skid tanks and road tanker is only done during daytime as the plant has the capacity to meet demands during that period. There 3 breaks during day time shift for morning tea, lunch and afternoon tea and their duration seem to be adequate. Ammonia loading from ship tanker and rail tanker filling may take place at night depending on the availability of berthing time and rail stock tanks. Working hours for this task is limited to the shift duration meaning that the next shift will takes over if shift loading passed through between shifts. |
| 3.11 Shift Rotation and Night Work | Shift work for rail and ship tanker unloading. The shift rotates every week with a day off in between shift. Ship-tanker unload ammonia depends on demand but on average at 2 weeks interval. |
| **4. FEEDBACK** | |
| 4.1 Plant Layout | Plant layout was good where each working section is independent and spacious. Location of valves and other display instrument majority is within worker's height reach. Critical information about the plant status is displayed on control panel. Pipework runs at heights at plant wall or on pipe rack at road crossing and does not obstruct people or vehicle movement. Most of the plant instrument and gauges are easy to read. However making hose connection to road tankers has to be done in restricted area as the weighbridge platform area is higher than ground level at both sides. Access to emergency stop buttons is good as the emergency shut down system could be initiated from the control and at respective section, i.e. cylinder filling, road and rail tanker filling. |
| 4.2 Labelling | Labelling and identification scheme on critical equipment, valves and piping system is quite adequate. Systematic labelling and identification number match the numbering scheme provided by the PI D diagram and work procedures. The extensive use of permit to work requires positive identifications of equipment, valves and pipework. |
| 4.3 Control Panel Design | The plant has a central control room that is manned around the clock. Control panel design follows ICI standard with a mixture of analogue and digital display. Display of critical information such stock tank level, temperature and pressure, remote control main valve's status, gas leak detectors and emergency alarms. Recent addition of continuos monitoring display of ammonia in water discharge for pollution control |

| | |
|---|---|
| 4.4 Content and relevant of information | The content and relevant of information for the plant are considered to be adequate as most of the critical information for the overall plant status is displayed at the control panel. However road tanker and rail tanker filling are more a 'stand alone' operations where apart from the gas leak alarm the only feedback to the control room is through the reduction of tank level and the status of corresponding valves from stock tank to the filling lines. |
| 4.5 Identification of display and control | Good identification of display and control with colour coding (e.g. green-on, red-off for stop/start button), legible reading and marking. Mimic display of the process operation help to assess the status of operation |
| 4.6 Compatibility with user expectation | Through interview control panel operators they seem to think that the control panel was adequate and easy to understand and to operate. |
| 4.7 Grouping of information | Information grouping was properly laid out. Display of information for stock tank is clustered in one corner while for the alarm system at different corner. |
| 4.8 Overview of critical information and alarm | Overview of critical information could be gathered at a glance on the control panel. The availability of plant layout chart with status light made the overview and interpretation of information easier. Only two types of alarm, e.g. fire and gas leak alarm. From the interview operator seem to be quite well versed about the response to the alarms indicating sufficient drills conducted for both situations |

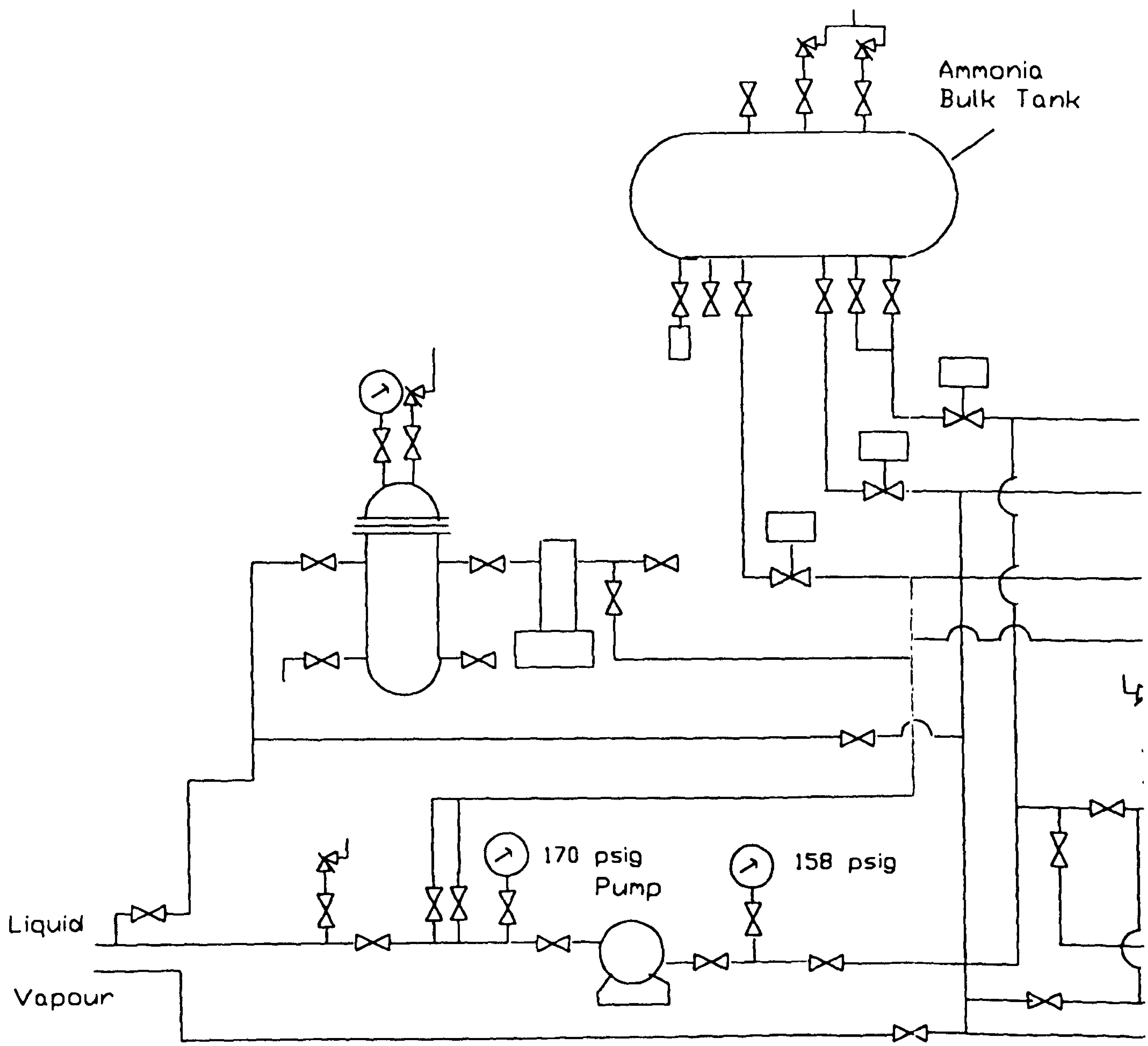
CONTAINS PULLOUTS

# *Appendix 7*

**Simplified PI&D for Ammonia Road Tanker Loading System**

**for Site A and Site B**

Figure A7.1 : Simplified PI & D of Ammonia Roao



Ammonia Road Tanker Loading System for Site A

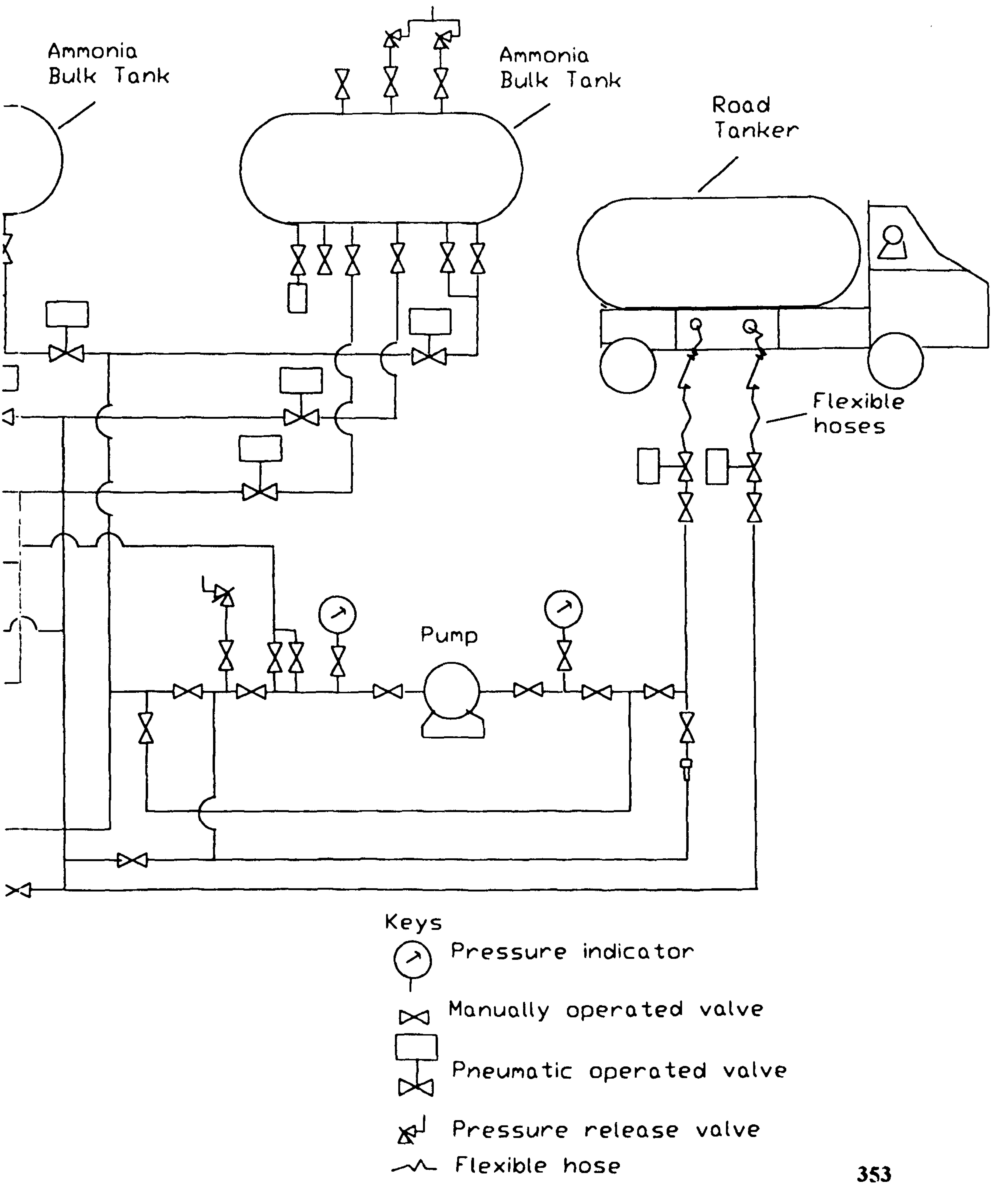
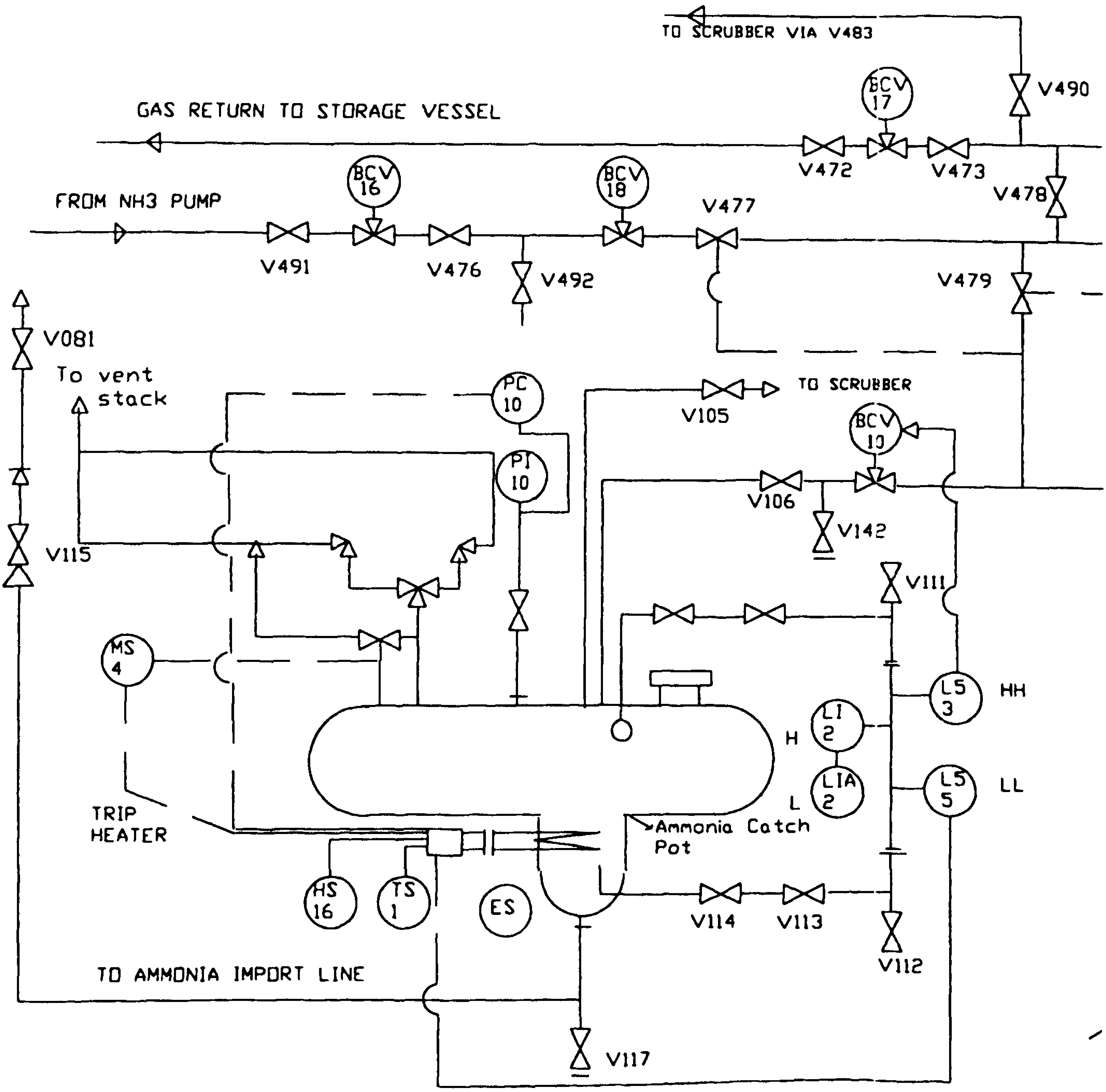
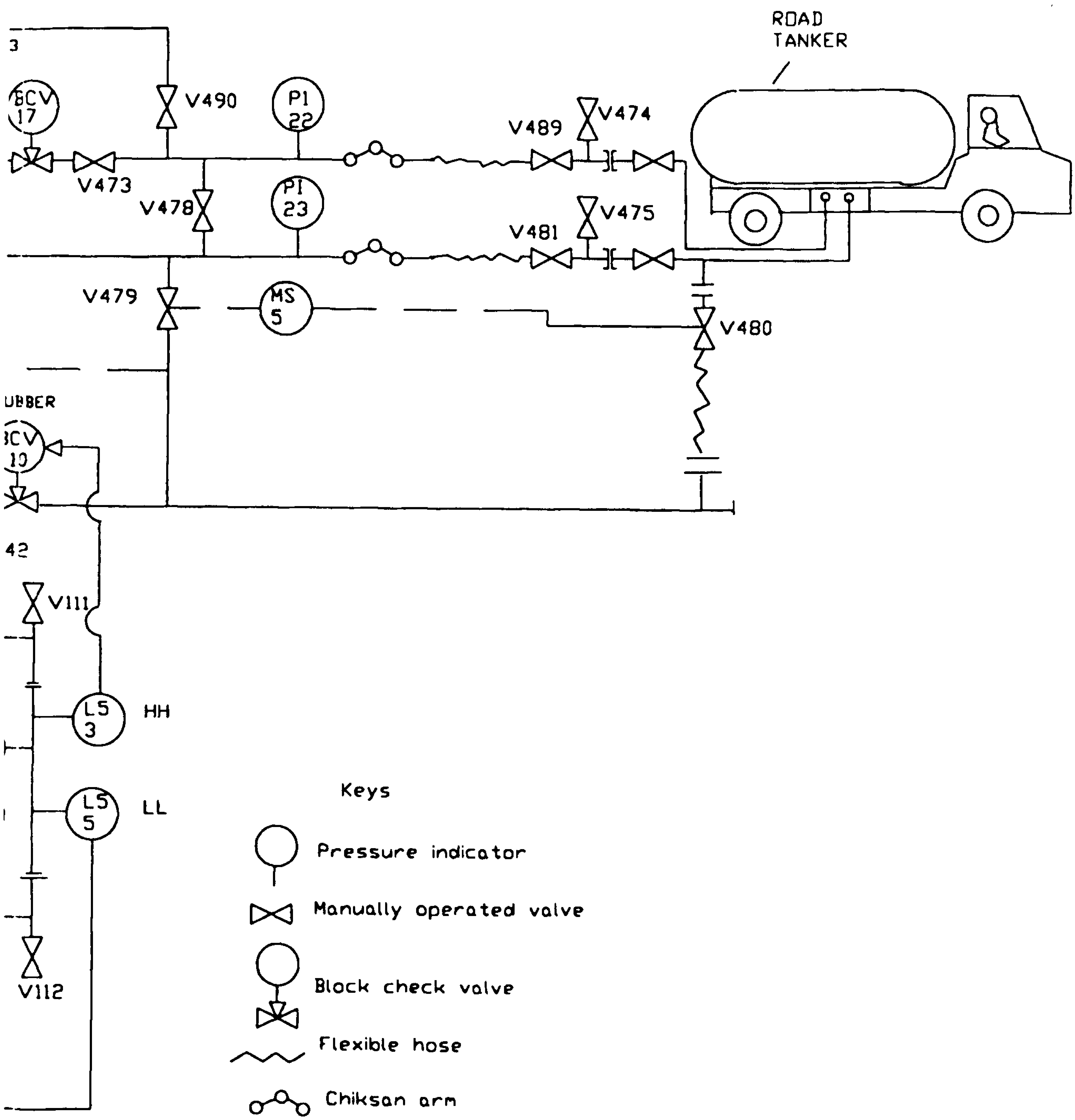


Figure A7.2 : Simplified PI & D of Ammonia Road



Ammonia Road Tanker Loading System for Site B



# *Appendix 8*

**Photographs Showing Ammonia Road Tanker Loading Facilities at Site A and Site B**

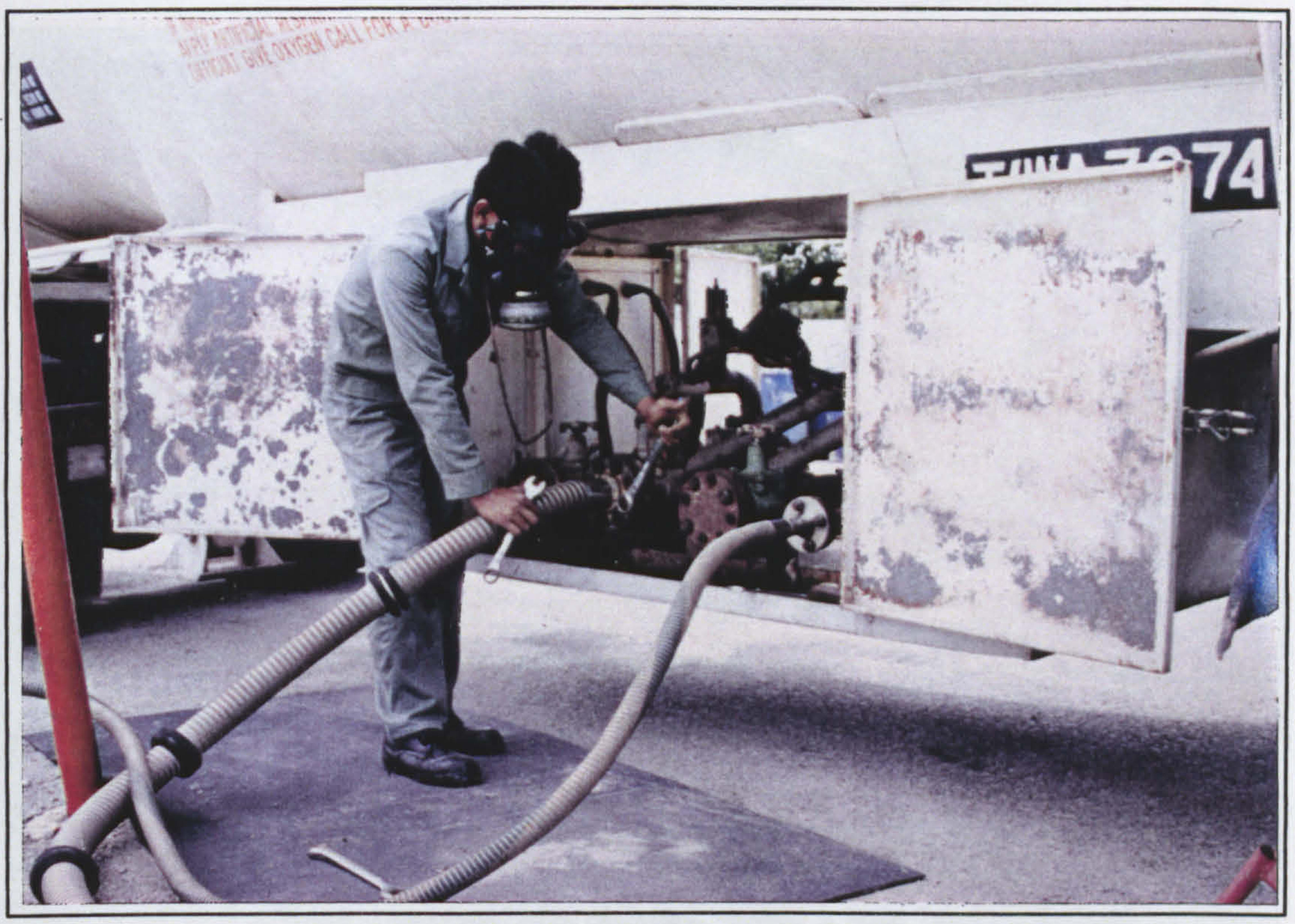


Figure A8.1. Connecting flexible hoses for ammonia road tanker loading at Site A

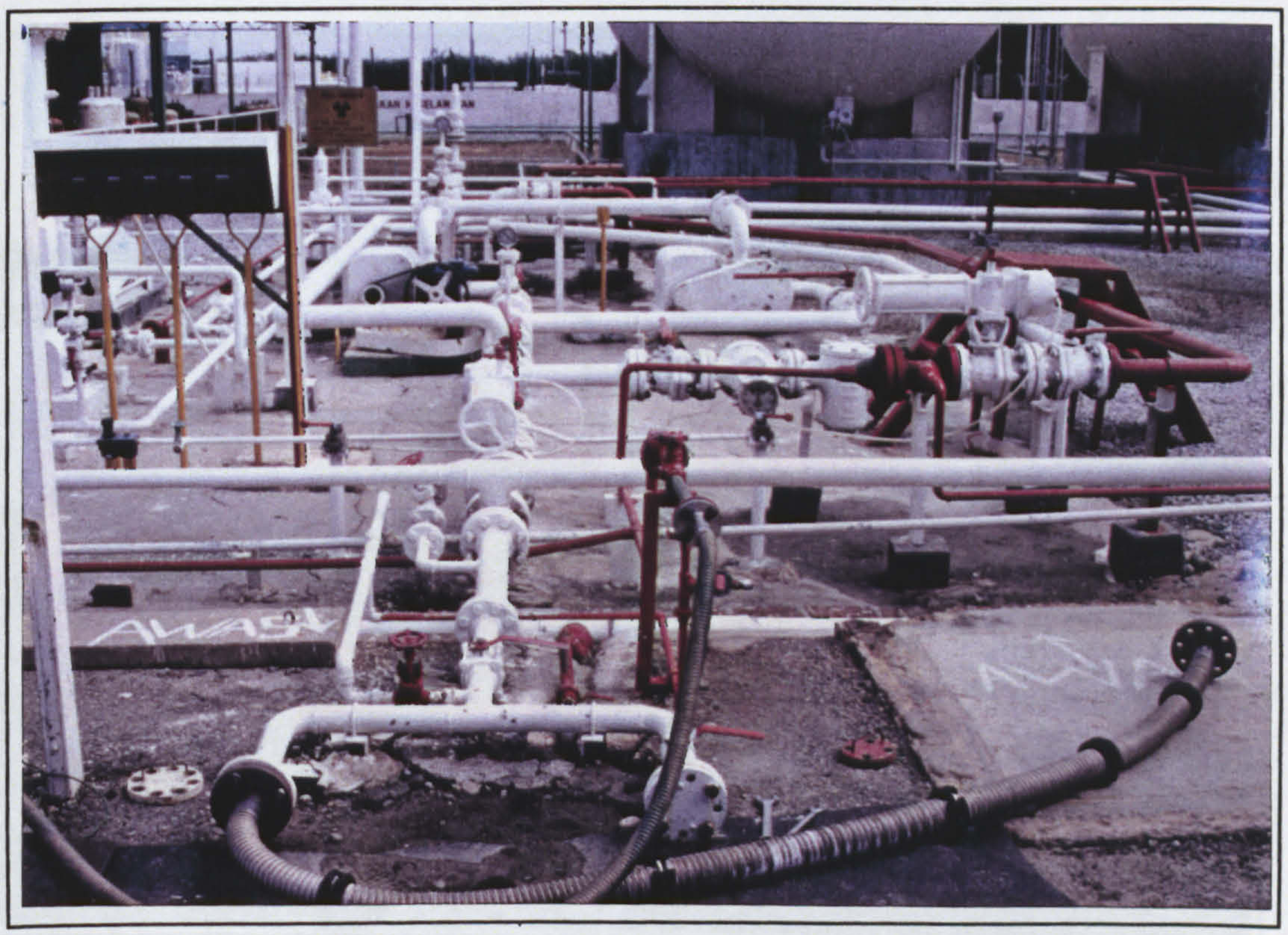



Figure A8.2. Piping arrangement for ammonia road tanker loading at Site A

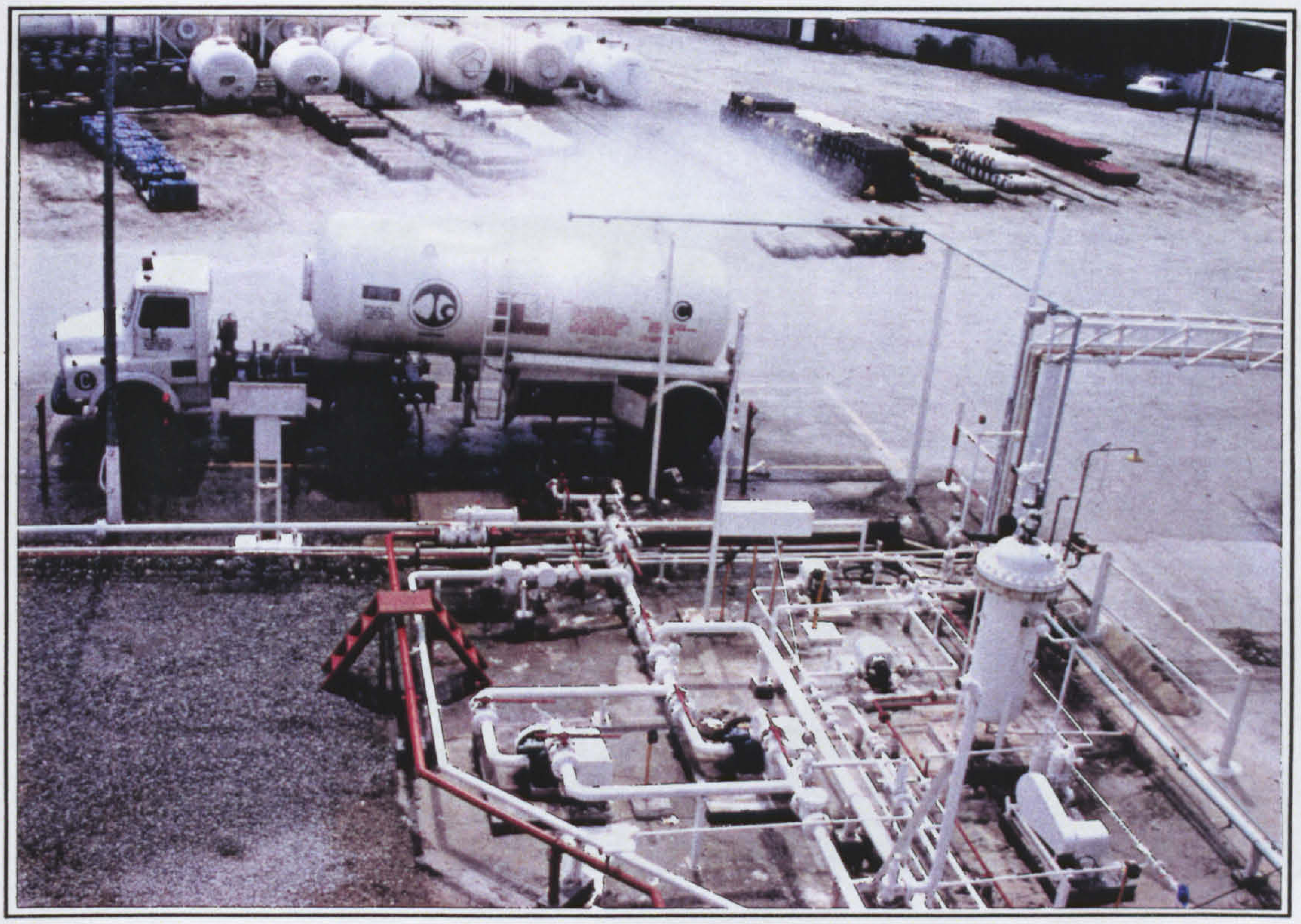


Figure A8.3. Ammonia road tanker loading in progress at Site A

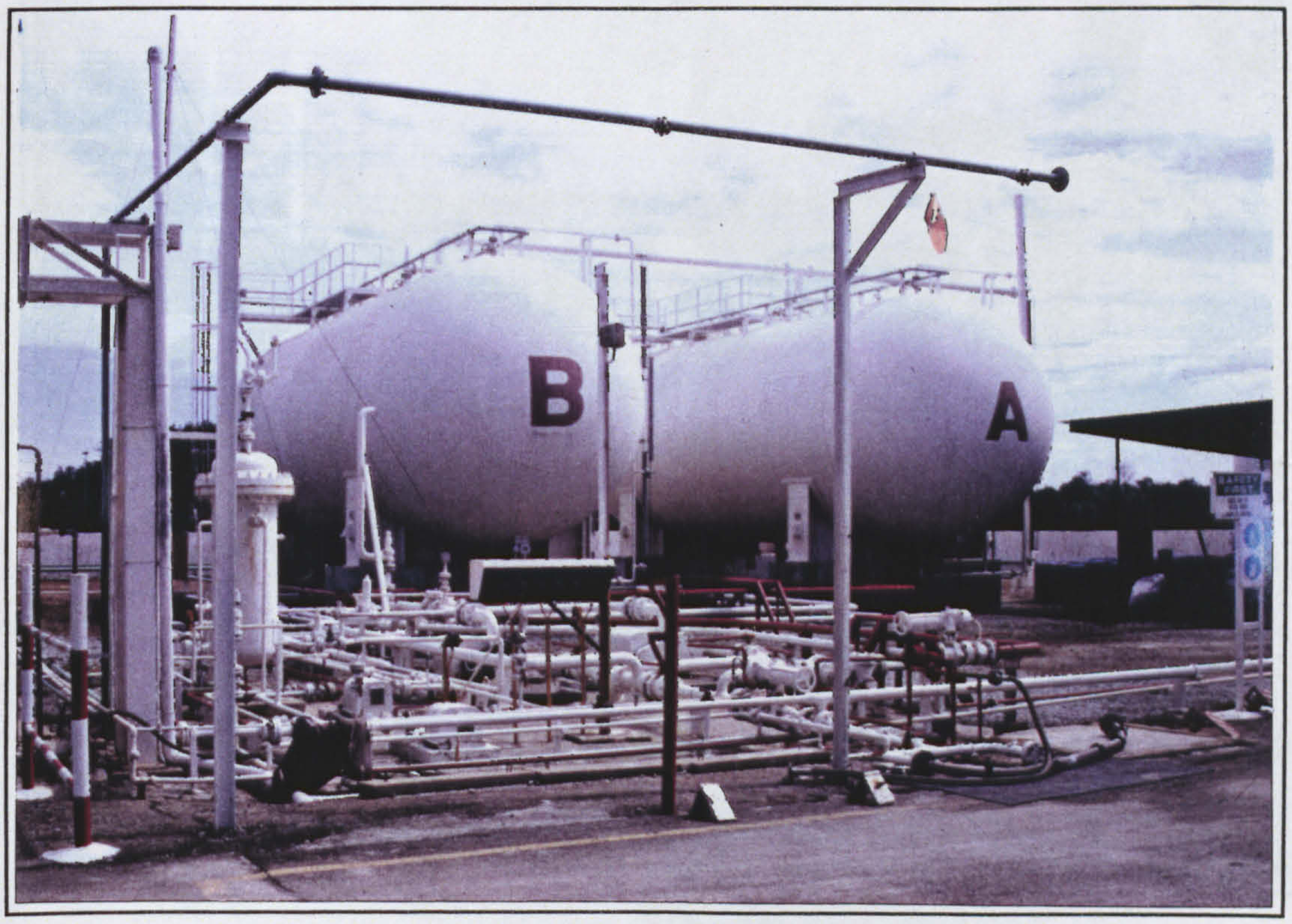



Figure A8.4. Ammonia bulk storage tanks at Site A


Figure A8.5. Maintenance fitter connecting flexible hoses for ammonia road tanker loading at Site B

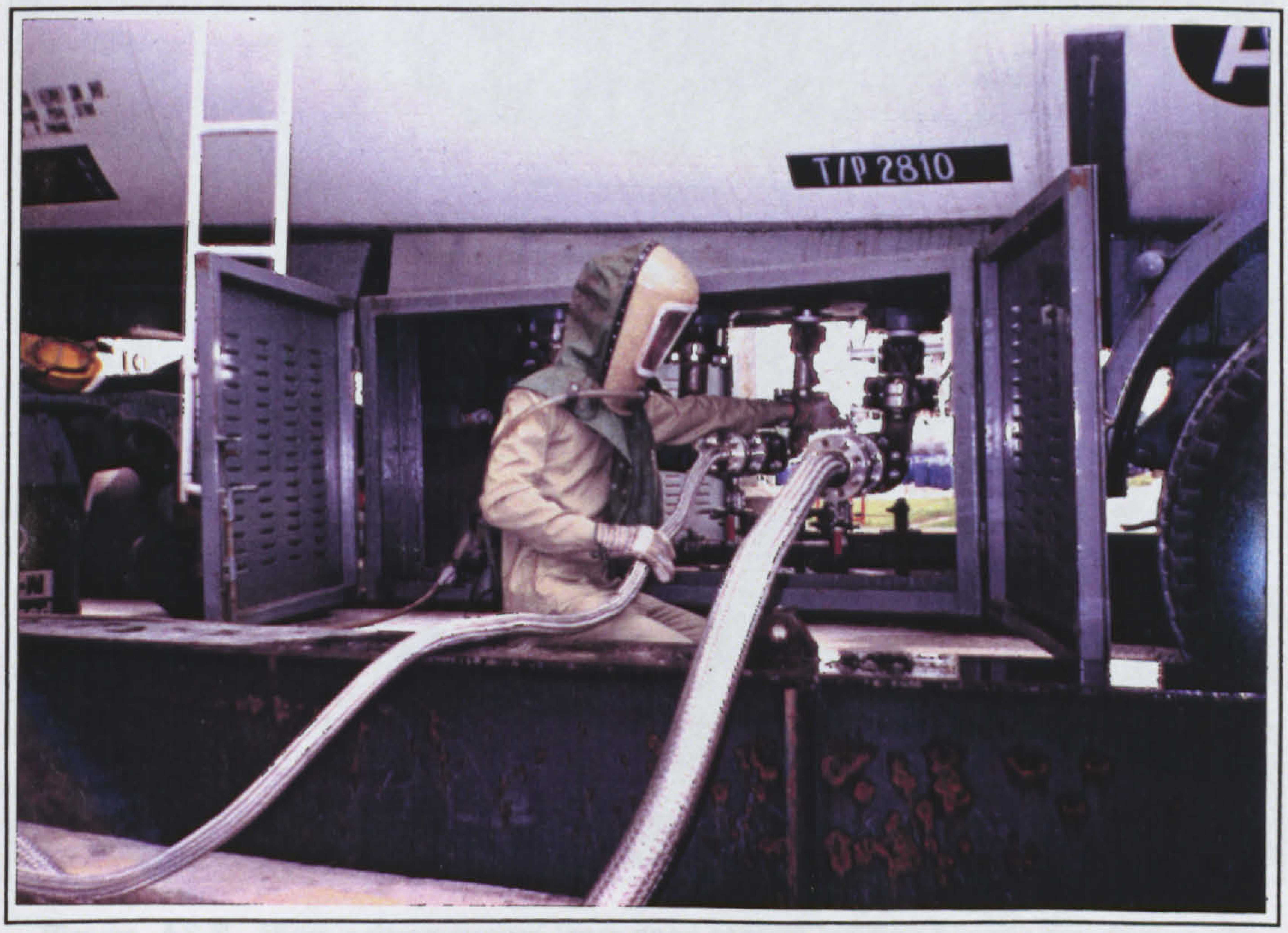



Figure A8.6. Operator opens road tanker filling valves to commence ammonia filling at Site B

Figure A8.7. Chiksan arm s and flexible hoses connection at Site B

Figure A8.8. Piping arrangement from road tanker loading bay to ammonia bulk tanks at Site B

**Meteorological data used as input for QRA for Site A and Site B**

Table A9.1. Combination of 10 Years Meterological Data for Alor Star Airport (Total and normalised data)

| Directional sectors | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 73.51 | 41.17 | 10.94 | 2.59 | 0.00 | 0.00 | 128.21 |
| NNE | 21.90 | 38.35 | 14.19 | 3.68 | 0.04 | 0.00 | 78.15 |
| NE | 19.53 | 58.19 | 45.98 | 16.20 | 0.27 | 0.00 | 140.16 |
| ENE | 15.42 | 28.21 | 26.78 | 12.71 | 0.17 | 0.00 | 83.29 |
| E | 18.67 | 21.74 | 3.89 | 1.86 | 0.00 | 0.00 | 46.16 |
| ESE | 10.32 | 15.15 | 1.51 | 0.14 | 0.06 | 0.02 | 27.20 |
| SE | 8.66 | 17.22 | 2.81 | 0.35 | 0.02 | 0.00 | 29.06 |
| SSE | 6.81 | 17.87 | 3.75 | 0.71 | 0.04 | 0.00 | 29.18 |
| S | 9.58 | 24.39 | 10.57 | 3.03 | 0.14 | 0.00 | 47.71 |
| SSW | 5.90 | 14.31 | 9.62 | 3.15 | 0.10 | 0.00 | 33.08 |
| SW | 9.05 | 25.40 | 21.95 | 6.10 | 0.25 | 0.00 | 62.74 |
| WSW | 10.23 | 36.16 | 34.96 | 11.43 | 0.45 | 0.00 | 93.22 |
| W | 16.43 | 47.68 | 37.19 | 10.67 | 0.28 | 0.00 | 112.24 |
| WNW | 8.32 | 19.55 | 8.58 | 2.35 | 0.08 | 0.00 | 38.88 |
| NW | 7.65 | 13.57 | 4.15 | 0.77 | 0.00 | 0.00 | 26.14 |
| NNW | 8.90 | 12.93 | 2.35 | 0.40 | 0.00 | 0.00 | 24.58 |
| TOTAL | 250.88 | 431.86 | 239.21 | 76.14 | 1.90 | 0.02 | 1000.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 2.84 | 0.00 | 180.48 | 180.48 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 131.40 | 131.40 |
| NE | 0.00 | 0.00 | 0.00 | 0.51 | 0.00 | 262.86 | 262.86 |
| ENE | 0.00 | 0.00 | 0.00 | 2.38 | 0.00 | 95.01 | 95.01 |
| E | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 34.85 | 34.85 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 39.96 | 39.96 |
| SE | 0.00 | 0.00 | 0.00 | 1.62 | 0.00 | 43.27 | 43.27 |
| SSE | 0.00 | 0.00 | 0.00 | 1.45 | 0.00 | 31.65 | 31.65 |
| S | 0.00 | 0.00 | 0.00 | 1.04 | 0.00 | 26.48 | 26.48 |
| SSW | 0.00 | 0.00 | 0.00 | 0.99 | 0.22 | 7.34 | 7.34 |
| SW | 0.00 | 0.00 | 0.00 | 1.75 | 0.00 | 10.32 | 10.32 |
| WSW | 0.00 | 0.00 | 0.00 | 1.59 | 0.00 | 13.32 | 13.32 |
| W | 0.00 | 0.00 | 0.00 | 2.59 | 0.31 | 23.09 | 23.09 |
| WNW | 0.00 | 0.00 | 0.00 | 0.62 | 0.00 | 21.30 | 21.30 |
| NW | 0.00 | 0.00 | 0.00 | 0.79 | 0.00 | 29.32 | 29.32 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.38 | 30.38 |
| TOTAL | 0.00 | 0.00 | 0.00 | 18.45 | 0.53 | 981.02 | 1000.00 |

| Directional sectors | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 7.35 | 4.12 | 1.09 | 0.26 | 0.00 | 0.00 | 12.82 |
| NNE | 2.19 | 3.83 | 1.42 | 0.37 | 0.00 | 0.00 | 7.82 |
| NE | 1.95 | 5.82 | 4.60 | 1.62 | 0.03 | 0.00 | 14.02 |
| ENE | 1.54 | 2.82 | 2.68 | 1.27 | 0.02 | 0.00 | 8.33 |
| E | 1.87 | 2.17 | 0.39 | 0.19 | 0.00 | 0.00 | 4.62 |
| ESE | 1.03 | 1.51 | 0.15 | 0.01 | 0.01 | 0.00 | 2.72 |
| SE | 0.87 | 1.72 | 0.28 | 0.03 | 0.00 | 0.00 | 2.91 |
| SSE | 0.68 | 1.79 | 0.37 | 0.07 | 0.00 | 0.00 | 2.92 |
| S | 0.96 | 2.44 | 1.06 | 0.30 | 0.01 | 0.00 | 4.77 |
| SSW | 0.59 | 1.43 | 0.96 | 0.31 | 0.01 | 0.00 | 3.31 |
| SW | 0.90 | 2.54 | 2.19 | 0.61 | 0.02 | 0.00 | 6.27 |
| WSW | 1.02 | 3.62 | 3.50 | 1.14 | 0.04 | 0.00 | 9.32 |
| W | 1.64 | 4.77 | 3.72 | 1.07 | 0.03 | 0.00 | 11.22 |
| WNW | 0.83 | 1.95 | 0.86 | 0.23 | 0.01 | 0.00 | 3.89 |
| NW | 0.76 | 1.36 | 0.41 | 0.08 | 0.00 | 0.00 | 2.61 |
| NNW | 0.89 | 1.29 | 0.23 | 0.04 | 0.00 | 0.00 | 2.46 |
| TOTAL | 25.09 | 43.19 | 23.92 | 7.61 | 0.19 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 18.05 | 18.05 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.14 | 13.14 |
| NE | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 26.29 | 26.29 |
| ENE | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 9.50 | 9.50 |
| E | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 3.49 | 3.49 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 4.00 |
| SE | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 | 4.33 | 4.33 |
| SSE | 0.00 | 0.00 | 0.00 | 0.15 | 0.00 | 3.17 | 3.17 |
| S | 0.00 | 0.00 | 0.00 | 0.10 | 0.00 | 2.65 | 2.65 |
| SSW | 0.00 | 0.00 | 0.00 | 0.10 | 0.02 | 0.73 | 0.73 |
| SW | 0.00 | 0.00 | 0.00 | 0.17 | 0.00 | 1.03 | 1.03 |
| WSW | 0.00 | 0.00 | 0.00 | 0.16 | 0.00 | 1.33 | 1.33 |
| W | 0.00 | 0.00 | 0.00 | 0.26 | 0.03 | 2.31 | 2.31 |
| WNW | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 2.13 | 2.13 |
| NW | 0.00 | 0.00 | 0.00 | 0.08 | 0.00 | 2.93 | 2.93 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.04 | 3.04 |
| TOTAL | 0.00 | 0.00 | 0.00 | 1.84 | 0.05 | 98.10 | 100.00 |

Table A9.2. Meterological Data for Alor Star Airport from 1985 to 1994

YEAR 1985

| Directional sectors | DAYTIME DATA (0700 - 1900) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 9.72 | 3.90 | 0.70 | 0.00 | 0.00 | 0.00 | 14.32 |
| NNE | 1.98 | 3.44 | 0.93 | 0.06 | 0.00 | 0.00 | 6.41 |
| NE | 1.64 | 3.79 | 4.78 | 1.26 | 0.00 | 0.00 | 11.45 |
| ENE | 2.17 | 2.70 | 3.01 | 1.26 | 0.00 | 0.00 | 9.14 |
| E | 1.94 | 1.60 | 0.30 | 0.17 | 0.00 | 0.00 | 4.01 |
| ESE | 1.16 | 0.95 | 0.19 | 0.00 | 0.00 | 0.00 | 2.30 |
| SE | 1.05 | 1.35 | 0.17 | 0.00 | 0.00 | 0.00 | 2.57 |
| SSE | 0.78 | 1.88 | 0.15 | 0.02 | 0.00 | 0.00 | 2.83 |
| S | 0.99 | 2.15 | 0.51 | 0.08 | 0.00 | 0.00 | 3.73 |
| SSW | 0.76 | 1.03 | 0.44 | 0.19 | 0.00 | 0.00 | 2.42 |
| SW | 1.12 | 1.90 | 1.77 | 0.61 | 0.00 | 0.00 | 5.40 |
| WSW | 1.48 | 3.60 | 4.45 | 1.54 | 0.02 | 0.00 | 11.09 |
| W | 2.30 | 5.86 | 5.06 | 1.56 | 0.00 | 0.00 | 14.78 |
| WNW | 0.99 | 2.13 | 1.37 | 0.40 | 0.02 | 0.00 | 4.91 |
| NW | 0.55 | 1.20 | 0.51 | 0.13 | 0.00 | 0.00 | 2.39 |
| NNW | 0.64 | 1.03 | 0.36 | 0.04 | 0.00 | 0.00 | 2.27 |
| TOTAL | 29.46 | 38.50 | 24.68 | 7.32 | 0.04 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.69 | 9.69 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 13.13 | 13.13 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.00 | 30.00 |
| ENE | 0.00 | 0.00 | 0.00 | 0.94 | 0.00 | 14.38 | 15.32 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.75 | 3.75 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.63 | 5.63 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.63 | 5.63 |
| SSE | 0.00 | 0.00 | 0.00 | 0.31 | 0.00 | 1.56 | 1.87 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.56 | 1.56 |
| SSW | 0.00 | 0.00 | 0.00 | 0.31 | 0.00 | 0.31 | 0.62 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.63 | 0.63 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.81 | 2.81 |
| W | 0.00 | 0.00 | 0.00 | 0.31 | 0.31 | 2.81 | 3.43 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.56 | 1.56 |
| NW | 0.00 | 0.00 | 0.00 | 0.31 | 0.00 | 1.88 | 2.19 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.19 | 2.19 |
| TOTAL | 0.00 | 0.00 | 0.00 | 2.18 | 0.31 | 97.51 | 100.00 |

YEAR 1986

| Directional sectors | DAYTIME DATA (0700 - 1900) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 6.70 | 4.99 | 0.99 | 0.04 | 0.00 | 0.00 | 12.72 |
| NNE | 1.35 | 3.39 | 3.52 | 0.76 | 0.00 | 0.00 | 9.02 |
| NE | 1.52 | 3.01 | 5.35 | 3.65 | 0.27 | 0.00 | 13.80 |
| ENE | 1.05 | 1.26 | 0.86 | 0.91 | 0.11 | 0.00 | 4.19 |
| E | 1.39 | 1.75 | 0.25 | 0.08 | 0.00 | 0.00 | 3.47 |
| ESE | 0.89 | 1.85 | 0.23 | 0.02 | 0.00 | 0.00 | 2.99 |
| SE | 0.48 | 1.75 | 0.38 | 0.13 | 0.02 | 0.00 | 2.76 |
| SSE | 0.42 | 1.52 | 0.38 | 0.02 | 0.00 | 0.00 | 2.34 |
| S | 0.72 | 1.90 | 0.74 | 0.19 | 0.02 | 0.00 | 3.57 |
| SSW | 0.57 | 1.73 | 1.18 | 0.48 | 0.06 | 0.00 | 4.02 |
| SW | 0.91 | 3.77 | 3.39 | 1.83 | 0.11 | 0.00 | 10.01 |
| WSW | 0.86 | 3.65 | 4.64 | 1.90 | 0.11 | 0.00 | 11.16 |
| W | 1.37 | 4.19 | 3.88 | 1.96 | 0.02 | 0.00 | 11.42 |
| WNW | 0.78 | 1.58 | 0.61 | 0.21 | 0.02 | 0.00 | 3.20 |
| NW | 0.48 | 1.18 | 0.40 | 0.04 | 0.00 | 0.00 | 2.10 |
| NNW | 0.89 | 1.94 | 0.38 | 0.04 | 0.00 | 0.00 | 3.25 |
| TOTAL | 20.38 | 39.45 | 27.17 | 12.26 | 0.74 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 1.42 | 0.00 | 40.52 | 41.94 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.45 | 5.45 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.11 | 7.11 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.74 | 4.74 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.79 | 3.79 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.08 | 3.08 |
| SE | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 3.79 | 4.03 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.27 | 4.27 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.37 | 2.37 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.47 | 0.47 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 | 0.24 |
| WSW | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 0.24 | 0.48 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.66 | 1.66 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.50 | 4.50 |
| NW | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 7.35 | 7.59 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.29 | 8.29 |
| TOTAL | 0.00 | 0.00 | 0.00 | 2.14 | 0.00 | 97.86 | 100.00 |

. ......Table A9.2 Meterological Data for Alor Star Airport from 1985 to 1994

YEAR 1987

| Directional sectors | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 4.36 | 5.73 | 4.55 | 1.79 | 0.00 | 0.00 | 0.00 |
| NNE | 1.90 | 3.23 | 2.28 | 1.64 | 0.00 | 0.00 | 0.00 |
| NE | 1.83 | 2.57 | 1.64 | 0.38 | 0.00 | 0.00 | 0.00 |
| ENE | 1.69 | 2.17 | 1.69 | 0.57 | 0.00 | 0.00 | 0.00 |
| E | 1.83 | 2.17 | 0.25 | 0.04 | 0.00 | 0.00 | 0.00 |
| ESE | 1.20 | 1.33 | 0.19 | 0.02 | 0.00 | 0.00 | 0.00 |
| SE | 1.05 | 2.04 | 0.30 | 0.02 | 0.00 | 0.00 | 0.00 |
| SSE | 0.72 | 1.79 | 0.38 | 0.02 | 0.00 | 0.00 | 0.00 |
| S | 0.95 | 3.10 | 1.64 | 0.72 | 0.00 | 0.00 | 0.00 |
| SSW | 0.61 | 1.54 | 1.64 | 0.89 | 0.00 | 0.00 | 0.00 |
| SW | 0.65 | 2.28 | 2.57 | 0.55 | 0.00 | 0.00 | 0.00 |
| WSW | 0.59 | 3.12 | 3.29 | 0.74 | 0.00 | 0.00 | 0.00 |
| W | 1.20 | 4.49 | 3.84 | 1.26 | 0.02 | 0.00 | 0.00 |
| WNW | 1.08 | 2.09 | 0.93 | 0.23 | 0.00 | 0.00 | 0.00 |
| NW | 1.16 | 2.80 | 0.86 | 0.11 | 0.00 | 0.00 | 0.00 |
| NNW | 0.97 | 2.23 | 0.42 | 0.04 | 0.00 | 0.00 | 0.00 |
| TOTAL | 21.79 | 42.69 | 26.48 | 9.02 | 0.02 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 1.42 | 0.00 | 40.52 | 40.52 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.45 | 5.45 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.11 | 7.11 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.74 | 4.74 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.79 | 3.79 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.08 | 3.08 |
| SE | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 3.79 | 3.79 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.27 | 4.27 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.37 | 2.37 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.47 | 0.47 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 | 0.24 |
| WSW | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 0.24 | 0.24 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.66 | 1.66 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.50 | 4.50 |
| NW | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 7.35 | 7.35 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.29 | 8.29 |
| TOTAL | 0.00 | 0.00 | 0.00 | 2.14 | 0.00 | 97.86 | 100.00 |

YEAR 1988

| Directional sectors | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 6.65 | 4.10 | 0.76 | 0.21 | 0.00 | 0.00 | 11.72 |
| NNE | 2.15 | 4.42 | 0.36 | 0.04 | 0.00 | 0.00 | 6.97 |
| NE | 1.58 | 5.81 | 7.07 | 1.43 | 0.00 | 0.00 | 15.89 |
| ENE | 1.56 | 2.53 | 3.62 | 1.73 | 0.00 | 0.00 | 9.44 |
| E | 1.75 | 1.77 | 0.72 | 0.13 | 0.00 | 0.00 | 4.37 |
| ESE | 0.86 | 1.07 | 0.08 | 0.02 | 0.00 | 0.00 | 2.03 |
| SE | 1.18 | 1.47 | 0.15 | 0.04 | 0.00 | 0.00 | 2.84 |
| SSE | 0.84 | 1.85 | 0.25 | 0.04 | 0.00 | 0.00 | 2.98 |
| S | 1.12 | 2.67 | 0.51 | 0.19 | 0.00 | 0.00 | 4.49 |
| SSW | 0.48 | 1.12 | 0.40 | 0.08 | 0.02 | 0.00 | 2.10 |
| SW | 0.55 | 1.54 | 1.52 | 0.29 | 0.00 | 0.00 | 3.90 |
| WSW | 0.67 | 3.03 | 3.22 | 0.63 | 0.04 | 0.00 | 7.59 |
| W | 1.39 | 5.09 | 5.18 | 1.20 | 0.04 | 0.00 | 12.90 |
| WNW | 0.86 | 3.03 | 1.81 | 0.63 | 0.02 | 0.00 | 6.35 |
| NW | 0.90 | 1.83 | 0.93 | 0.25 | 0.00 | 0.00 | 3.91 |
| NNW | 1.05 | 1.14 | 0.27 | 0.06 | 0.00 | 0.00 | 2.52 |
| TOTAL | 23.59 | 42.47 | 26.85 | 6.97 | 0.12 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.52 | 7.52 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.02 | 9.02 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 43.17 | 43.17 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.88 | 9.88 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.65 | 3.65 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.58 | 2.58 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.39 | 4.39 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.72 | 4.72 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.65 | 3.65 |
| SSW | 0.00 | 0.00 | 0.00 | 0.22 | 0.22 | 1.08 | 1.52 |
| SW | 0.00 | 0.00 | 0.00 | 0.43 | 0.00 | 0.86 | 1.29 |
| WSW | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 | 0.43 | 0.65 |
| W | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 | 1.51 | 1.73 |
| WNW | 0.00 | 0.00 | 0.00 | 0.22 | 0.00 | 1.29 | 1.51 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.44 | 3.44 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.29 | 1.29 |
| TOTAL | 0.00 | 0.00 | 0.00 | 1.31 | 0.22 | 98.47 | 100.00 |

......Table A9.2 Meterological Data for Alor Star Airport from 1985 to 1994

YEAR 1989

| Directional | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| sectors | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 4.76 | 5.86 | 2.13 | 0.36 | 0.00 | 0.00 | 13.11 |
| NNE | 1.45 | 5.27 | 2.76 | 0.40 | 0.00 | 0.00 | 9.88 |
| NE | 1.12 | 4.83 | 7.02 | 2.30 | 0.00 | 0.00 | 15.27 |
| ENE | 0.76 | 2.09 | 1.58 | 0.95 | 0.02 | 0.00 | 5.40 |
| E | 0.93 | 2.53 | 0.40 | 0.11 | 0.00 | 0.00 | 3.97 |
| ESE | 0.72 | 1.88 | 0.36 | 0.08 | 0.00 | 0.00 | 3.04 |
| SE | 0.59 | 2.34 | 0.97 | 0.08 | 0.00 | 0.00 | 3.98 |
| SSE | 0.61 | 2.85 | 1.52 | 0.42 | 0.00 | 0.00 | 5.40 |
| S | 0.78 | 4.20 | 4.01 | 1.29 | 0.02 | 0.00 | 10.30 |
| SSW | 0.21 | 2.02 | 1.90 | 0.44 | 0.00 | 0.00 | 4.57 |
| SW | 0.53 | 1.88 | 2.38 | 0.59 | 0.04 | 0.00 | 5.42 |
| WSW | 0.44 | 1.98 | 1.98 | 0.72 | 0.04 | 0.00 | 5.16 |
| W | 0.65 | 2.76 | 2.23 | 0.61 | 0.00 | 0.00 | 6.25 |
| WNW | 0.46 | 1.33 | 0.57 | 0.17 | 0.00 | 0.00 | 2.53 |
| NW | 0.84 | 1.54 | 0.21 | 0.00 | 0.00 | 0.00 | 2.59 |
| NNW | 0.99 | 1.67 | 0.36 | 0.11 | 0.00 | 0.00 | 3.13 |
| TOTAL | 15.84 | 45.03 | 30.38 | 8.63 | 0.12 | 0.00 | 100.00 |

| Directional | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| sectors | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 21.14 | 21.14 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.38 | 20.38 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 24.38 | 24.38 |
| ENE | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 4.57 | 4.57 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.05 | 3.05 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.24 | 3.24 |
| SE | 0.00 | 0.00 | 0.00 | 0.57 | 0.00 | 4.00 | 4.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.29 | 2.29 |
| S | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 3.24 | 3.24 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.76 | 0.76 |
| SW | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 1.71 | 1.71 |
| WSW | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 1.90 | 1.90 |
| W | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 2.29 | 2.29 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.33 | 1.33 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.10 | 2.10 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.52 | 1.52 |
| TOTAL | 0.00 | 0.00 | 0.00 | 2.09 | 0.00 | 97.91 | 100.00 |

YEAR 1990

| Directional | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| sectors | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 6.19 | 3.48 | 0.59 | 0.11 | 0.00 | 0.00 | 10.37 |
| NNE | 2.24 | 4.12 | 2.68 | 0.51 | 0.00 | 0.00 | 9.55 |
| NE | 1.86 | 5.87 | 4.94 | 2.77 | 0.00 | 0.00 | 15.44 |
| ENE | 1.39 | 2.87 | 2.39 | 1.08 | 0.00 | 0.00 | 7.73 |
| E | 2.07 | 1.90 | 0.11 | 0.02 | 0.00 | 0.00 | 4.10 |
| ESE | 1.18 | 1.94 | 0.13 | 0.00 | 0.02 | 0.00 | 3.27 |
| SE | 0.74 | 1.73 | 0.17 | 0.02 | 0.00 | 0.00 | 2.66 |
| SSE | 0.57 | 1.08 | 0.34 | 0.04 | 0.00 | 0.00 | 2.03 |
| S | 1.03 | 2.22 | 1.44 | 0.19 | 0.00 | 0.00 | 4.88 |
| SSW | 0.95 | 2.28 | 1.71 | 0.68 | 0.02 | 0.00 | 5.64 |
| SW | 1.18 | 3.78 | 2.91 | 0.44 | 0.02 | 0.00 | 8.33 |
| WSW | 1.20 | 3.72 | 3.25 | 0.80 | 0.02 | 0.00 | 8.99 |
| W | 1.20 | 3.59 | 2.62 | 0.95 | 0.06 | 0.00 | 8.42 |
| WNW | 0.49 | 1.73 | 1.10 | 0.19 | 0.00 | 0.00 | 3.51 |
| NW | 0.78 | 1.27 | 0.46 | 0.13 | 0.00 | 0.00 | 2.64 |
| NNW | 0.93 | 1.29 | 0.23 | 0.02 | 0.00 | 0.00 | 2.47 |
| TOTAL | 23.99 | 42.86 | 25.06 | 7.95 | 0.14 | 0.00 | 100.00 |

| Directional | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| sectors | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.45 | 14.45 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 25.22 | 25.22 |
| NE | 0.00 | 0.00 | 0.00 | 0.23 | 0.00 | 29.12 | 29.12 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.01 | 11.01 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.52 | 2.52 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.52 | 2.52 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.38 | 1.38 |
| SSE | 0.00 | 0.00 | 0.00 | 0.46 | 0.00 | 1.15 | 1.15 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.83 | 1.83 |
| SSW | 0.00 | 0.00 | 0.00 | 0.46 | 0.00 | 0.92 | 0.92 |
| SW | 0.00 | 0.00 | 0.00 | 0.23 | 0.00 | 0.23 | 0.23 |
| WSW | 0.00 | 0.00 | 0.00 | 0.23 | 0.00 | 0.92 | 0.92 |
| W | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.61 | 1.61 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.61 | 1.61 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.15 | 1.15 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.75 | 2.75 |
| TOTAL | 0.00 | 0.00 | 0.00 | 1.61 | 0.00 | 98.39 | 100.00 |

.......Table A9.2 Meterological Data for Alor Star Airport from 1985 to 1994

YEAR 1991

| Directional sectors | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 7.47 | 3.59 | 0.27 | 0.00 | 0.00 | 0.00 | 11.33 |
| NNE | 2.91 | 3.86 | 0.51 | 0.13 | 0.00 | 0.00 | 7.41 |
| NE | 2.76 | 7.41 | 3.31 | 0.97 | 0.00 | 0.00 | 14.45 |
| ENE | 1.92 | 4.60 | 4.26 | 2.51 | 0.00 | 0.00 | 13.29 |
| E | 3.04 | 2.05 | 0.40 | 0.27 | 0.00 | 0.00 | 5.76 |
| ESE | 1.41 | 0.80 | 0.02 | 0.00 | 0.00 | 0.00 | 2.23 |
| SE | 1.54 | 1.31 | 0.15 | 0.00 | 0.00 | 0.00 | 3.00 |
| SSE | 1.18 | 1.56 | 0.19 | 0.06 | 0.00 | 0.00 | 2.99 |
| S | 1.41 | 2.28 | 0.42 | 0.06 | 0.00 | 0.00 | 4.17 |
| SSW | 0.78 | 0.76 | 0.42 | 0.11 | 0.00 | 0.00 | 2.07 |
| SW | 1.20 | 1.81 | 1.14 | 0.23 | 0.02 | 0.00 | 4.40 |
| WSW | 1.84 | 3.67 | 2.26 | 0.74 | 0.02 | 0.00 | 8.53 |
| W | 2.87 | 6.03 | 3.23 | 0.68 | 0.00 | 0.00 | 12.81 |
| WNW | 1.01 | 1.84 | 0.53 | 0.02 | 0.00 | 0.00 | 3.40 |
| NW | 0.93 | 0.91 | 0.17 | 0.00 | 0.00 | 0.00 | 2.01 |
| NNW | 1.03 | 1.01 | 0.08 | 0.02 | 0.00 | 0.00 | 2.14 |
| TOTAL | 33.30 | 43.49 | 17.36 | 5.80 | 0.04 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.48 | 6.48 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.88 | 6.88 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 32.81 | 32.81 |
| ENE | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 26.74 | 26.74 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.02 | 2.02 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.83 | 2.83 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.43 | 2.43 |
| SSE | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 3.64 | 3.64 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.02 | 2.02 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.81 | 0.81 |
| SW | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 1.21 | 1.21 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.21 | 1.21 |
| W | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 2.83 | 2.83 |
| WNW | 0.00 | 0.00 | 0.00 | 0.40 | 0.00 | 2.83 | 2.83 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.02 | 2.02 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.21 | 1.21 |
| TOTAL | 0.00 | 0.00 | 0.00 | 2.00 | 0.00 | 98.00 | 100 00 |

YEAR 1992

| Directional sectors | DAYTIME DATA (0700 - 1900) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 9.55 | 2.66 | 0.36 | 0.04 | 0.00 | 0.00 | 0.00 |
| NNE | 3.02 | 2.62 | 0.20 | 0.00 | 0.02 | 0.00 | 0.00 |
| NE | 2.93 | 7.96 | 3.02 | 0.96 | 0.00 | 0.00 | 0.00 |
| ENE | 1.86 | 3.67 | 3.80 | 1.52 | 0.02 | 0.00 | 0.00 |
| E | 2.01 | 2.93 | 0.63 | 0.43 | 0.00 | 0.00 | 0.00 |
| ESE | 1.03 | 1.59 | 0.13 | 0.00 | 0.02 | 0.00 | 0.00 |
| SE | 0.72 | 1.39 | 0.18 | 0.02 | 0.00 | 0.00 | 0.00 |
| SSE | 0.54 | 1.57 | 0.18 | 0.02 | 0.02 | 0.00 | 0.00 |
| S | 0.87 | 1.86 | 0.40 | 0.13 | 0.04 | 0.00 | 0.00 |
| SSW | 0.51 | 1.28 | 0.60 | 0.07 | 0.00 | 0.00 | 0.00 |
| SW | 1.07 | 2.71 | 2.15 | 0.51 | 0.02 | 0.00 | 0.00 |
| WSW | 1.01 | 4.36 | 4.12 | 1.77 | 0.09 | 0.00 | 0.00 |
| W | 1.83 | 5.17 | 3.85 | 1.01 | 0.07 | 0.00 | 0.00 |
| WNW | 0.96 | 1.99 | 0.65 | 0.18 | 0.00 | 0.00 | 0.00 |
| NW | 0.63 | 0.81 | 0.25 | 0.02 | 0.00 | 0.00 | 0.00 |
| NNW | 0.67 | 0.65 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| TOTAL | 29.21 | 43.22 | 20.59 | 6.68 | 0.30 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 21.14 | 21.14 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 20.38 | 20.38 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 24.38 | 24.38 |
| ENE | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 4.57 | 4.57 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.05 | 3.05 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.24 | 3.24 |
| SE | 0.00 | 0.00 | 0.00 | 0.57 | 0.00 | 4.00 | 4.00 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.29 | 2.29 |
| S | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 3.24 | 3.24 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.76 | 0.76 |
| SW | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 1.71 | 1.71 |
| WSW | 0.00 | 0.00 | 0.00 | 0.19 | 0.00 | 1.90 | 1.90 |
| W | 0.00 | 0.00 | 0.00 | 0.38 | 0.00 | 2.29 | 2.29 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.33 | 1.33 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.10 | 2.10 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.52 | 1.52 |
| TOTAL | 0.00 | 0.00 | 0.00 | 2.09 | 0.00 | 97.91 | 100.00 |

........Table A9.2 Meterological Data for Alor Star Airport from 1985 to 1994

YEAR 1993

| Directional sectors | DAYTIME DATA (0700 - 1900) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 9.55 | 2.66 | 0.36 | 0.04 | 0.00 | 0.00 | 0.00 |
| NNE | 3.02 | 2.62 | 0.20 | 0.00 | 0.02 | 0.00 | 0.00 |
| NE | 2.93 | 7.96 | 3.02 | 0.96 | 0.00 | 0.00 | 0.00 |
| ENE | 1.86 | 3.67 | 3.80 | 1.52 | 0.02 | 0.00 | 0.00 |
| E | 2.01 | 2.93 | 0.63 | 0.43 | 0.00 | 0.00 | 0.00 |
| ESE | 1.03 | 1.59 | 0.13 | 0.00 | 0.02 | 0.00 | 0.00 |
| SE | 0.72 | 1.39 | 0.18 | 0.02 | 0.00 | 0.00 | 0.00 |
| SSE | 0.54 | 1.57 | 0.18 | 0.02 | 0.02 | 0.00 | 0.00 |
| S | 0.87 | 1.86 | 0.40 | 0.13 | 0.04 | 0.00 | 0.00 |
| SSW | 0.51 | 1.28 | 0.60 | 0.07 | 0.00 | 0.00 | 0.00 |
| SW | 1.07 | 2.71 | 2.15 | 0.51 | 0.02 | 0.00 | 0.00 |
| WSW | 1.01 | 4.36 | 4.12 | 1.77 | 0.09 | 0.00 | 0.00 |
| W | 1.83 | 5.17 | 3.85 | 1.01 | 0.07 | 0.00 | 0.00 |
| WNW | 0.96 | 1.99 | 0.65 | 0.18 | 0.00 | 0.00 | 0.00 |
| NW | 0.63 | 0.81 | 0.25 | 0.02 | 0.00 | 0.00 | 0.00 |
| NNW | 0.67 | 0.65 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| TOTAL | 29.21 | 43.22 | 20.59 | 6.68 | 0.30 | 0.00 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.18 | 7.18 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.22 | 10.22 |
| NE | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 34.25 | 34.25 |
| ENE | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 6.91 | 6.91 |
| E | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 5.80 | 5.80 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.91 | 6.91 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 8.56 | 8.56 |
| SSE | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 4.97 | 4.97 |
| S | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 2.76 | 2.76 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.83 | 0.83 |
| SW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.93 | 1.93 |
| WSW | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 0.55 | 0.55 |
| W | 0.00 | 0.00 | 0.00 | 0.28 | 0.00 | 3.31 | 3.31 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.10 | 1.10 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.93 | 1.93 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.83 | 0.83 |
| TOTAL | 0.00 | 0.00 | 0.00 | 1.96 | 0.00 | 98.04 | 100.00 |

YEAR 1994

| Directional sectors | DAYTIME DATA (0700 - 1900) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 8.57 | 4.20 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNE | 1.88 | 5.38 | 0.75 | 0.14 | 0.00 | 0.00 | 0.00 |
| NE | 1.36 | 8.98 | 5.85 | 1.52 | 0.00 | 0.00 | 0.00 |
| ENE | 1.16 | 2.65 | 1.77 | 0.66 | 0.00 | 0.00 | 0.00 |
| E | 1.70 | 2.11 | 0.20 | 0.18 | 0.00 | 0.00 | 0.00 |
| ESE | 0.84 | 2.15 | 0.05 | 0.00 | 0.00 | 0.02 | 0.02 |
| SE | 0.59 | 2.45 | 0.16 | 0.02 | 0.00 | 0.00 | 0.00 |
| SSE | 0.61 | 2.20 | 0.18 | 0.05 | 0.00 | 0.00 | 0.00 |
| S | 0.84 | 2.15 | 0.50 | 0.05 | 0.02 | 0.00 | 0.00 |
| SSW | 0.52 | 1.27 | 0.73 | 0.14 | 0.00 | 0.00 | 0.00 |
| SW | 0.77 | 3.02 | 1.97 | 0.54 | 0.02 | 0.00 | 0.00 |
| WSW | 1.13 | 4.67 | 3.63 | 0.82 | 0.02 | 0.00 | 0.00 |
| W | 1.79 | 5.33 | 3.45 | 0.43 | 0.00 | 0.00 | 0.00 |
| WNW | 0.73 | 1.84 | 0.36 | 0.14 | 0.02 | 0.00 | 0.00 |
| NW | 0.75 | 1.22 | 0.11 | 0.07 | 0.00 | 0.00 | 0.00 |
| NNW | 0.86 | 1.32 | 0.11 | 0.07 | 0.00 | 0.00 | 0.00 |
| TOTAL | 24.10 | 50.93 | 20.05 | 4.83 | 0.08 | 0.02 | 100.00 |

| Directional sectors | NIGHTTIME DATA (2000 - 0600) A 1m/s | A 2m/s | B 3m/s | D 5m/s | D 7m/s | F 2m/s | TOTAL |
|---|---|---|---|---|---|---|---|
| N | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 11.84 | 11.84 |
| NNE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15.26 | 15.26 |
| NE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 30.53 | 30.53 |
| ENE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 7.48 | 7.48 |
| E | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.43 | 3.43 |
| ESE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.85 | 6.85 |
| SE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.30 | 5.30 |
| SSE | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.49 | 2.49 |
| S | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.43 | 3.43 |
| SSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.93 | 0.93 |
| SW | 0.00 | 0.00 | 0.00 | 0.31 | 0.00 | 1.56 | 1.56 |
| WSW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.12 | 3.12 |
| W | 0.00 | 0.00 | 0.00 | 0.62 | 0.00 | 3.12 | 3.12 |
| WNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.25 | 1.25 |
| NW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNW | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.49 | 2.49 |
| TOTAL | 0.00 | 0.00 | 0.00 | 0.93 | 0.00 | 99.07 | 100.00 |

**Atmospheric Stability Classification Brief description of Pasquill - Gifford Weather Stability categories**

Pasquill - Gifford (Gifford, 1976) weather categories emphasised the importance of utilising data on wind-direction fluctuation and wind-inclination fluctuation. They are used in RISKAT for the risk calculations which require directional frequencies for each combination of wind speed and stability used. It describes the stability of the lowest layers of the atmosphere which facilitates the estimation of dispersion of materials at the ground level or higher elevation. Brief description of categories illustrative of the range involved is given as follows;

Category A - Very Unstable

Occurs typically on a warm, sunny, summer afternoon with light winds and cloudless skies. This mean there is strong solar heating (strong insolation) of the ground and hence the air immediately above the surface. Bubbles of warm air rise from the ground in thermals. The rate of change of temperature with heights known as 'lapse rate' is very high.

Category D - Neutral

Occurs in cloudy conditions or whenever there is a strong surface wind to cause rigorous mechanical mixing of the lower atmosphere. D stability occurs both during day time and at night. The period immediately after sunrise and immediately before sunset are usually considered neutral.

Category G - Very Stable

Occurs typically on a cold, clear, calm night when there is strong cooling of the ground, and lowest layers of the atmosphere, by long wave radiation. There is a strong inversion of temperature (i.e. warm air over cold air) and effect only occurs at night time.

Intermediate categories of B and C are used to describe weather conditions between Very Stable (A) to Neutral (D). While the intermediate categories of E and F are used to describe weather conditions form Neutral (D) to Very Stable (G), where slight or moderate inversion of temperature exists.

# *Appendix 10*

**Population Data used for QRA for Site A and Site B**

Table A10.1. Population and Housing Census According to Zones for Melaka Tengah, 1991 - Site A
(Bilangan Penduduk Kawasan Kajian Mengikut Zone Banci Penduduk dan Perumahan Malaysia, 1991)

| **Area/ Zone** | **Population** | **Area / Zone** | **Population** |
|---|---|---|---|
| **Tanjung Bruas** | | **Tanjung Kling** | |
| ZONE A | 1171 | ZONE A | 1004 |
| ZONE B | 1415 | ZONE B | 997 |
| ZONE C | 1649 | ZONE C | 1544 |
| ZONE E | 1467 | ZONE D | 1391 |
| ZONE F | 1132 | ZONE E | 692 |
| | 698 | ZONE F | 1195 |
| TOTAL ( GRID A-F ) | 7532 | TOTAL ( GRID A-F ) | 66832 |

Table A10. 2. Population and Housing Census According to Zones for Kelang, 1991 - Site B

(Bilangan Penduduk Kawasan Kajian Mengikut Zone Banci Penduduk dan Perumahan Malaysia, 1991 )

| Area / Zone | Population | Area / Zone | Population | Area / Zone | Population | Area / Zone | Population | Area / Zone | Population |
|---|---|---|---|---|---|---|---|---|---|
| ZONE A | 1722 | ZONE N | 2194 | ZONE AA | 2284 | ZONE AN | 1062 | ZONE BA | 2546 |
| ZONE B | 1570 | ZONE O | 1698 | ZONE AB | 1658 | ZONE AO | 1482 | ZONE BB | 2324 |
| ZONE C | 1932 | ZONE P | 664 | ZONE AC | 1624 | ZONE AP | 928 | ZONE BC | 2245 |
| ZONE D | 1130 | ZONE Q | 0 | ZONE AD | 1334 | ZONE AQ | 2122 | ZONE BD | 1419 |
| ZONE E | 2786 | ZONE R | 0 | ZONE AE | 1539 | ZONE AR | 1862 | ZONE BE | 1251 |
| ZONE F | 1163 | ZONE S | 0 | ZONE AF | 1363 | ZONE AS | 1946 | ZONE BF | 1613 |
| ZONE G | 1611 | ZONE T | 962 | ZONE AG | 1287 | ZONE AT | 1848 | ZONE BG | 2610 |
| ZONE H | 1782 | ZONE U | 970 | ZONE AH | 1708 | ZONE AU | 1979 | | |
| ZONE I | 1629 | ZONE V | 759 | ZONE AI | 1553 | ZONE AV | 1468 | | |
| ZONE J | 1680 | ZONE W | 1255 | ZONE AJ | 1382 | ZONE AW | 1963 | | |
| ZONE K | 1407 | ZONE X | 1389 | ZONE AK | 1617 | ZONE AX | 1320 | | |
| ZONE L | 2407 | ZONE Y | 1735 | ZONE AL | 1440 | ZONE AY | 1530 | TOTAL | 91850 |
| ZONE M | 2361 | ZONE Z | 2034 | ZONE AM | 1541 | ZONE AZ | 1162 | ( ZON A - BG ) | |

**Department of Occupational Safety and Health Malaysia**

**Failure Rate Data used for QRA**

Table A11.1. Department of Occupational Safety and Health Malaysia Failure Rate Data

| Component Type | Hole Size (Range/Normal) | Frequency (per year) |
|---|---|---|
| Pressure Vessel | 5-10mm/5mm | 3.7E-5 |
| | 10-50mm/25mm | 9.6E-5 |
| | 50-150mm/100mm | 9.7E-6 |
| | Rupture | 6.5E-6 |
| Distillation Column | 5-10mm/5mm | 7.4E-5 |
| | 10-50mm/25mm | 1.9E-4 |
| | 50-150mm/100mm | 6.5E-6 |
| | Rupture | 6.5E-6 |
| Plate Heat Exchanger | 5mm | 5.8E-3 |
| | 25mm | 1.0E-3 |
| | 100mm | N/A |
| | Rupture | 6.0E-6 |
| Shell and Tube Heat Exchanger (Total External Leaks) | 5mm | 4.3E-5 |
| | 25mm | 1.1E-4 |
| | 100mm | 1.1E-5 |
| | Rupture | 7.5E-6 |
| Condenser | 5mm | 3.7E-5 |
| | 25mm | 9.6E-5 |
| | 100mm | 9.7E-6 |
| | Rupture | 6.5E-6 |
| Fin Fan cooler (Header Leaks) | 5mm | 3.7E-5 |

| | | |
|---|---|---|
| Reciprocating Compressor | 5mm | Not Evaluated |
| | 25mm | 6.5E-3 |
| | 100mm | 6.5E-4 |
| Single Seal Centrifugal Pump | 5mm | 75E-3 |
| | 25mm | 1.0E-3 |
| | 100mm3 | 1.0E-4 |
| | Rupture | 1.0E-3 |
| Flange | 5mm | 3.6E-4 |
| | 25mm | 4.0E-5 |
| Gasket | 5mm | 0.0045 |
| | 25mm | 0.0005 |
| Filter | 5mm | 8.5E-4 |
| | 25mm | 1.0E-4 |
| | 100mm | 5.0E-5 |
| | Rupture | 1.0E-5 |
| Fin Fan Cooler (Tube Leaks) | 5mm | 1.6E-2 |
| | 25mm | 2.7E-3 |
| Atmospheric Storage Tank | Catastrophic Failure | 2.0E-5 |
| Rail Car | 5mm | 3.7E-5 |
| | 25mm | 9.6E-5 |
| | 100mm | 9.7E-6 |
| | Rupture | 6.5E-6 |
| Tank Truck (Conditional probability of release in the event of an accident) | 5mm | 2.0E-2 |
| | 100mm | 1.0E-2 |
| | Rupture | 4.0E-3 |

| | | |
|---|---|---|
| Flexible Loading Arm | 5mm | 7.8E-3 |
| | 25mm | 1.8E-2 |
| | 100mm | 7.1E-3 |
| | Rupture | 1.4E-3 |
| Unloading Hose | 5mm | 3.3E-2 |
| | Rupture | 1.0E-3 |
| Centrifugal Compressor | 5mm | 0.013 |
| | 25mm | 8.6E-4 |
| | 100mm | 8.6E-5 |
| ESD Valve (On demand failure probabilities) | Automatically Activated | 3.9E-3 |
| | Manual and Remote Activated | 3.8E-3 |
| | ESDValve sticks open | 4.1E-4 |
| Excess Flow Valve (On demand failure probabilities) | | 0.013 |
| Flow Control Valve (On demand failure probabilities) | | 5.5E-3 |
| Check (Non Return) Valve | Per demand | 5.5E-3 |
| | Per hour | 3.0E-6 |

| Pipe Diameter | | Hole Size Category | Frequency |
|---|---|---|---|
| (mm) | (in) | (mm) | (per m year) |
| 0.5 | 12 | 5 (0-10) | 3.6E-05 |
| | | Full bore (10-12.7) | 7.8E-07 |
| 0.75 | 20 | 5 (0-10) | 2.4E-05 |
| | | Full bore(10-19.1) | 1.1E-06 |
| 1 | 25 | 5 (0-10) | 1.7E-05 |
| | | Full bore (10+) | 1.4E-06 |
| 1.5 | 38 | 5 (0-10) | 1.1E-05 |
| | | Full bore (10+) | 1.5E-06 |
| 2 | 50 | 5 (0-10) | 7.5E-06 |
| | | Full bore (10+) | 1.7E-06 |
| 3 | 75 | 5 (0-10) | 4.2E-06 |
| | | 25(10-50) | 1.7E-06 |
| | | Full bore(50-75) | 2.0E-07 |
| 4 | 100 | 5 (0-10) | 2.8E-06 |
| | | 25 (10-50) | 1.7E-06 |
| | | Full bore (50+) | 2.2E-07 |
| 6 | 150 | 5 (0-10) | 1.4E-06 |
| | | 25(10-50) | 1.4E-06 |
| | | Full bore (50+) | 2.4E-07 |
| 8 | 200 | 5 (0-10) | 9.0E-07 |
| | | 25(10-50) | 1.1E-06 |
| | | 100(50-150) | 2.5E-07 |
| | | Full bore (150+) | 5.6E-07 |

| | | | |
|---|---|---|---|
| 10 | 250 | 5 (0-10) | 5.9E-07 |
| | | 25(10-50) | 9.2E-07 |
| | | 100(50-150) | 2.7E-07 |
| | | Full bore (150+) | 7.2E-08 |
| 12 | 300 | 5 (0-10) | 3.8E-07 |
| | | 25(10-50) | 1.0E-06 |
| | | 100(50-150) | 1.0E-07 |
| | | Full bore(150+) | 9.7E-08 |
| 14 | 350 | 5(0-10) | 3.3E-07 |
| | | 25(10-50) | 8.5E-07 |
| | | 100(50-150) | 8.7E-08 |
| | | Full bore (150+) | 5.8E-08 |
| 16 | 400 | 5(0-10) | 2.9E-07 |
| | | 25(10-50) | 7.5E-07 |
| | | 100(50-150) | 7.6E-08 |
| | | Full bore(150+) | 5.0E-08 |

# Input for QRA using Representative Failures Approach

Table A12.1. Input for QRA Using Representative Failures Approach for Site A

| SCENARIOS | Hole Size ( mm) | Release Rate kg/s) | Duration of Release (min) | Generic Failure Rate | Poor Modification Factor (MF) | Modified Failure Rate |
|---|---|---|---|---|---|---|
| 1. Liquid releases from road tanker failure below liquid line | 100 | 169 | 30 | 9.7E-06 | Vessel MF=4.6 | 4.5E-05 |
| 2. Vapour releases from road tanker above liquid line | 100 | 8.5 | 30 | 9.7E-06 | Vessel MF=4.6 | 4.5E-05 |
| 3. 2-phase release due guillotine failures of 2 in. liquid flexible hose | 50 | 18.97 | 20 | 1.0E-03 | Hoses MF=4.9 | 4.9E-03 |
| 4. Vapour release due to guillotine failures of 1 in. vapour return flexible hose | 25 | 0.39 | 20 | 1.03-03 | Hoses MF=4.9 | 4.9E-03 |
| 5. 2-phase release due to guillotine failures of 3 in. liquid supply line(10m length) | 75 | 37 | 20 | 2.0E-05 | Pipework MF=4.0 | 8.0E-05 |
| 6. Vapour release from guillotine failure of 2 in. vapour return line(10m length) | 50 | 0.7 | 20 | 1.7E-05 | Paperwork MF=4.0 | 6.8E-05 |

Table 12A.2. Input for QRA Using Representative Failure Approach for Site B

| SCENARIOS | Hole Size ( mm) | Release Rate (kg/s) | Duration of Release (min) | Generic Failure Rate | Good Modification Factor (MF) | Modified Failure Rate |
|---|---|---|---|---|---|---|
| 1. Liquid releases from road tanker failure below liquid line | 100 | 169 | 30 | 9.76E-06 | Vessel MF=0.45 | 4.4E-07 |
| 2. Vapour releases from road tanker above liquid line | 100 | 8.5 | 30 | 9.76E-06 | Vessel MF=0.45 | 4.4E-07 |
| 3. 2-phase release due guillotine failures of 3 in. liquid flexible hose | 75 | 70.7 | 20 | 1.0E-03 | Hoses MF=0.46 | 4.6E-04 |
| 4. Vapour release due to guillotine failures of 2 in. vapour return flexible hose | 50 | 0.94 | 20 | 1.0E-03 | Hoses MF=0.46 | 4.6E-04 |
| 5. 2-phase release due to guillotine failures of 4 in. liquid supply line | 100 | 37 | 20 | 2.2E-06 | Pipework MF=0.45 | 9.9E-07 |
| 6. Vapour release from guillotine failure of 3 in. vapour return line | 75 | 0.7 | 20 | 2.0E-06 | Pipework MF=0.45 | 9.0E-07 |

## HEPs Nominal Data from THERP and HEART Data base

Table A13.1. HEPS Nominal Data for Site A and Site B from THERP Data Base (Swain and Guttman, 1983)

| Base Event No. | Description | THERP nominal data | Error Factor | THERP Ref.Table/ Item No. |
|---|---|---|---|---|
| HL121b | Drivers moves tanker while filling operation. is in progress | 3E-03 | 3 | Table 20-13 Item No.4 |
| HL122b | Operator failed to put on wheel chocks. | 3E-03 | 3 | Table 20-13 Item No.4 |
| HL14111b | Operator failed to open tanker inlet valve . | 8E-03 | 3 | Table 20-13 Item No.4 |
| HL14121b | Operator failed to open tanker vapour outlet valve. | 8E-03 | 3 | Table 20-13 Item No.4 |
| HL15b | Operator disconnect liquid hose while filling operation is in progress. | 1E-03 | 3 | Table 20-11 Item No.2 |
| HL21b | Operator failed to isolate leak. | 8E-03 | 3 | Table 20-13 Item No.4 |
| HV121b | Driver moves tanker while filling operation. | 3E-03 | 3 | Table 20-13 Item No.4 |
| HV122b | Operator failed to put wheel chocks | 3E-03 | 3 | Table 20-13 Item No.4 |
| HV1411b | Operator failed to closed plant vapour return | 8E-03 | 3 | Table 20-13 Item No.4 |
| HV15b | Operator disconnect hose while filling operation is in progress | 1E-03 | 3 | Table 20-11 Item No.2 |
| PL1212b | Operator failed to open liquid line valves | 3E-03 | 3 | Table 20-13 Item No.4 |
| PL14b | Operator commences filling without connecting filling hose to tanker | 3E-03 | 3 | Table 20-13 Item No.4 |
| PL211b | Remote operator failed to isolate leak | 1E-03 | 3 | Table 20-11 Item No.2 |
| PL221b | Local operator failed to isolate leak | 8E-03 | 3 | Table 20-13 Item No.4 |
| PV122b | Operator failed to open vapour return piping valves | 3E-03 | 3 | Table 20-13 Item No.4 |
| PV14b | Operator commences filling without properly connecting vapour return hose to tanker | 3E-03 | 3 | Table 20-13 Item No.4 |
| TL2112b | Operator read wrong tanker gross weight | 3E-03 | 3 | Table 20-10 Item No.1 |
| TL2121b | Operator failed to monitor tanker content gauge | 1E-03 | 3 | Table 20-11 Item No.2 |
| TL2211b | Operator failed to establish tanker empty weigh | 3E-03 | 3 | Table 20-10 Item No.1 |
| TV2211b | Operator failed to established tanker empty weight | 3E-03 | 3 | Table 20-10 Item No.1 |
| TV2212b | Operator read wrong tanker gross weight | 1E-02 | 3 | Table 20-10 Item No.5 |
| TV2221b | Operator failed to monitor tanker content gauge | 1E-03 | 3 | Table 20-11 Item No.2 |

Table A13.2. HEPS Nominal Data for Site A and Site B
from HEART Data Base (Williams, 1984)

| Base Event No. | Description | Generic Task | Nominal Human Unreliability | Uncertainty Bounds L - Lower (5%) U - Upper (95%) |
|---|---|---|---|---|
| HL121b | Drivers moves tanker while filling operation. is in progress | E | 2E-02 | L- 0.007 U - 0.045 |
| HL122b | Operator failed to put on wheel chocks. | E | 2E-02 | L- 0.007 U - 0.045 |
| HL14111b | Operator failed to open tanker inlet valve . | E | 2E-02 | L- 0.007 U - 0.045 |
| HL14121b | Operator failed to open tanker vapour outlet valve. | E | 2E-02 | L- 0.007 U - 0.045 |
| HL15b | Operator disconnect liquid hose while filling operation is in progress. | F | 3E-03 | L- 0.0008 U - 0.009 |
| HL21b | Operator failed to isolate leak. | E | 2E-02 | L- 0.007 U - 0.045 |
| HV121b | Driver moves tanker while filling operation. | E | 2E-02 | L- 0.007 U - 0.045 |
| HV122b | Operator failed to put wheel chocks | E | 2E-02 | L- 0.007 U - 0.045 |
| HV1411b | Operator failed to closed plant vapour return | E | 2E-02 | L- 0.007 U - 0.045 |
| HV15b | Operator disconnect hose while filling operation is in progress | F | 3E-03 | L- 0.0008 U - 0.009 |
| PL1212b | Operator failed to open liquid line valves | E | 2E-02 | L- 0.007 U - 0.045 |
| PL14b | Operator commences filling without connecting filling hose to tanker | F | 3E-03 | L- 0.0008 U - 0.009 |
| PL211b | Remote operator failed to isolate leak | F | 3E-03 | L- 0.0008 U - 0.009 |
| PL221b | Local operator failed to isolate leak | E | 2E-02 | L- 0.007 U - 0.045 |
| PV122b | Operator failed to open vapour return piping valves | E | 2E-02 | L- 0.007 U - 0.045 |
| PV14b | Operator failed properly connecting vapour return hose to tanker | F | 3E-03 | L- 0.0008 U - 0.009 |
| TL2112b | Operator read wrong tanker gross weight | E | 2E-02 | L- 0.007 U - 0.045 |
| TL2121b | Operator failed to monitor tanker content gauge | E | 2E-02 | L- 0.007 U - 0.045 |
| TL2211b | Operator failed to establish tanker empty weigh | F | 3E-03 | L- 0.0008 U - 0.009 |
| TV2212b | Operator read wrong tanker gross weight | E | 2E-02 | L- 0.007 U - 0.045 |
| TV2221b | Operator failed to monitor tanker content gauge | E | 2E-02 | L- 0.007 U - 0.045 |

## Fault Tree Diagrams for Site A and Site B

Diagram A14.1. Fault Tree Diagrams of System Failure (R) Using Hardware Failure Rates and HEPs for Site A

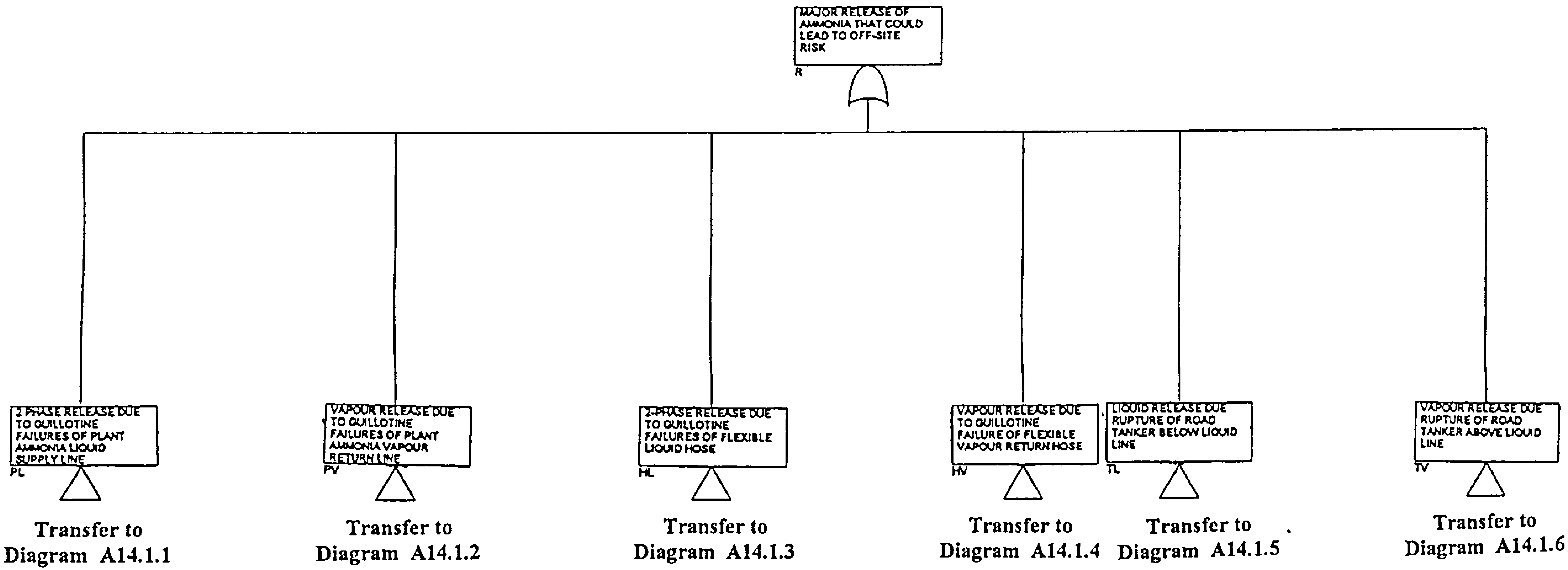


Diagram A14.1.1. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Piping (PL) for Site A (Hardware Failure Rates and HEPs)

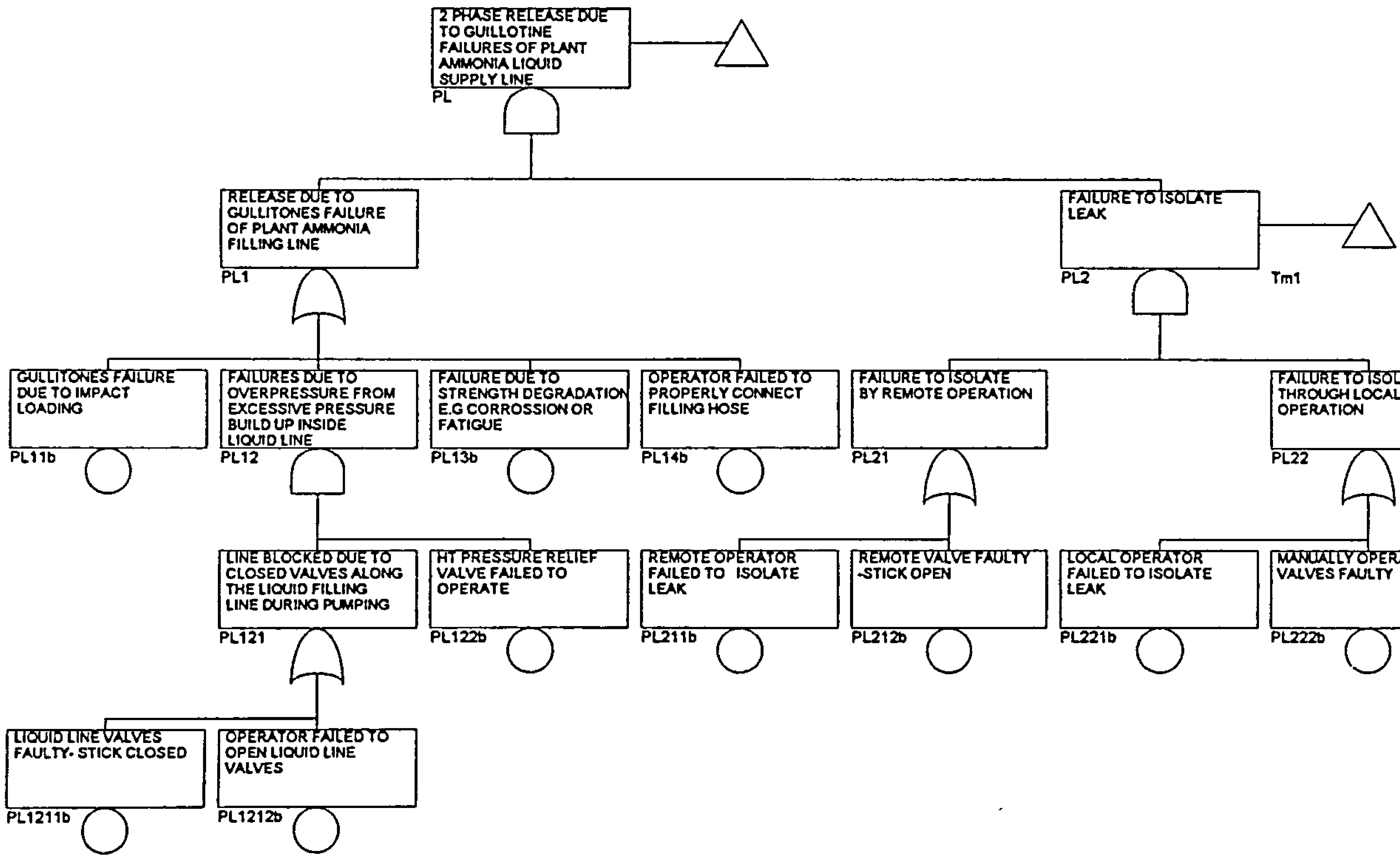


Diagram A14.1.2. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Piping (PV) for Site A (Hardware Failure Rates and HEPs)

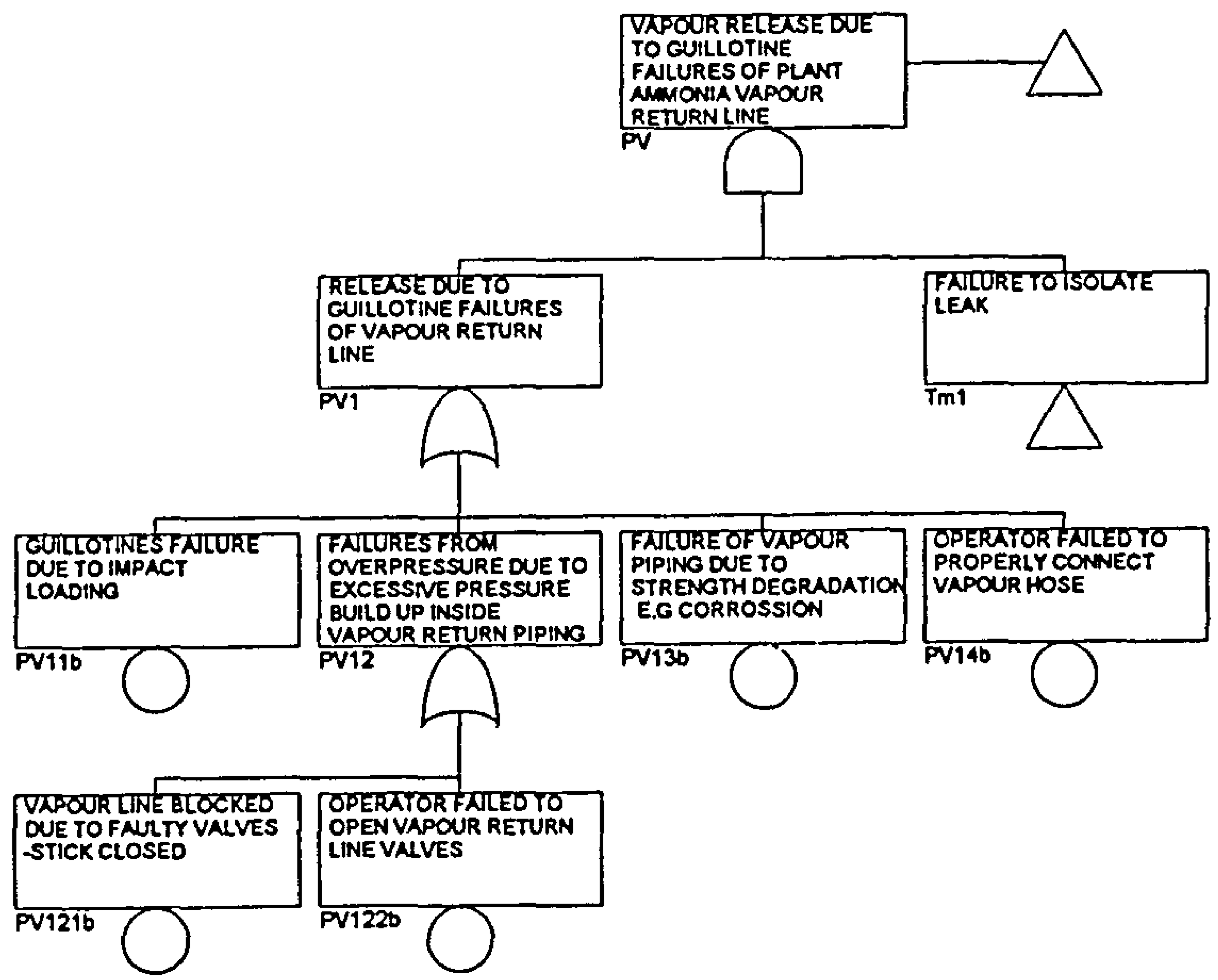


Diagram A14.1.3. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Hose (HL) for Site A (Hardware Failure Rates and HEPs)

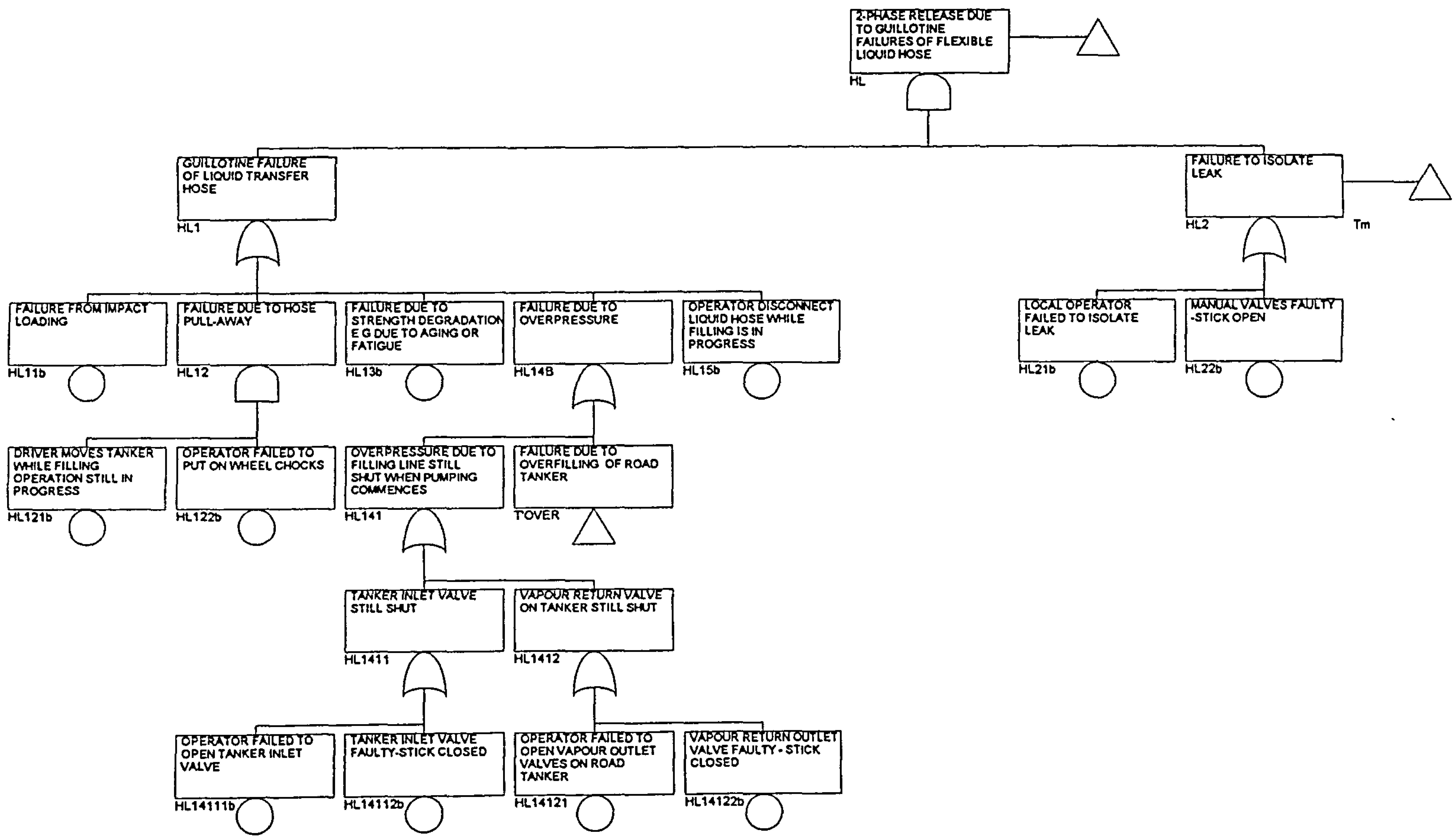


Diagram A14.1.4. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Return Hose (HV) for Site A (Hardware Failure Rates and HEPs)

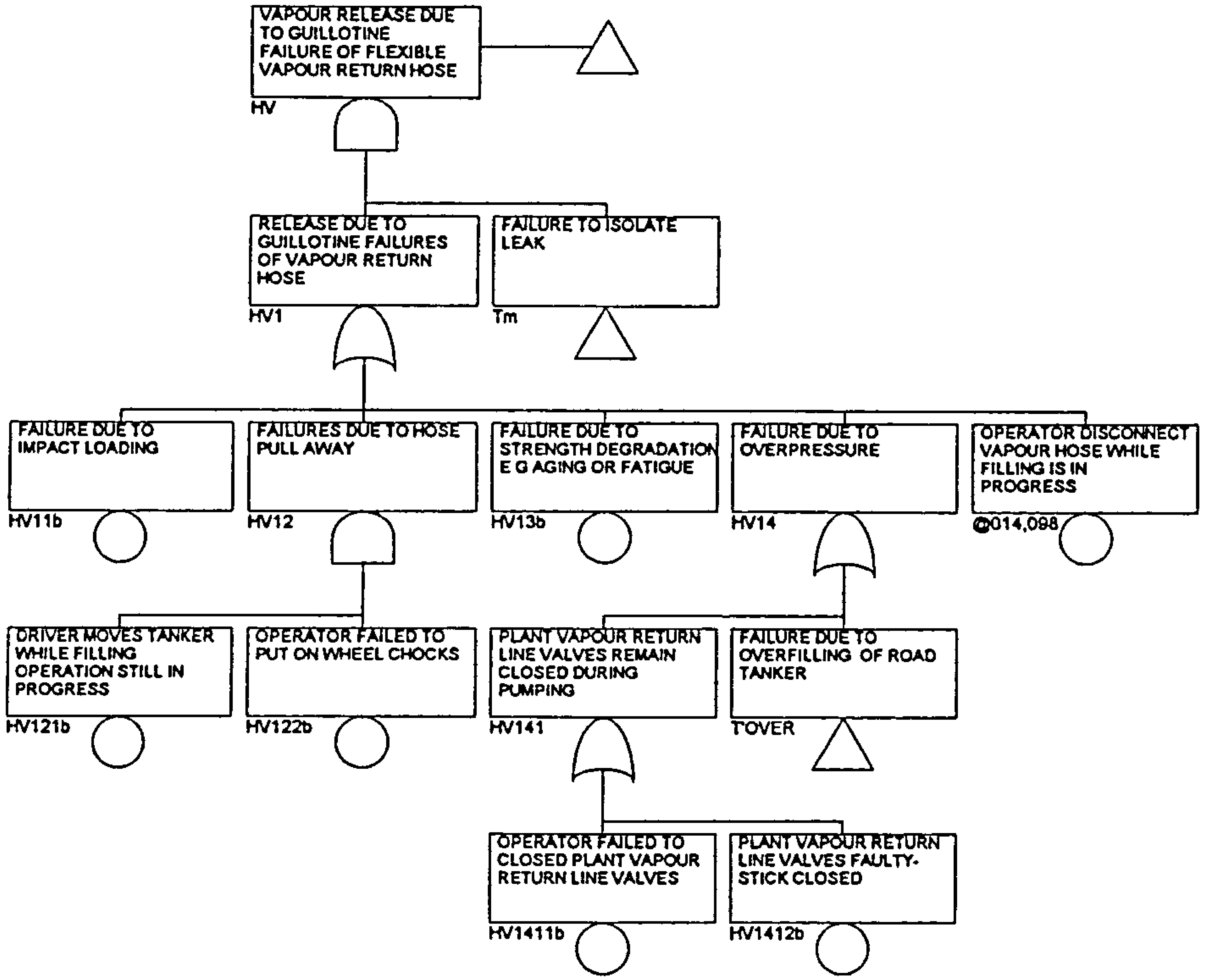


Diagram A14.1.5. Fault Tree Diagram of Road Tanker Bullet Rupture Below Liquid Line (TL) for Site A (Hardware Failure Rates and HEPs)

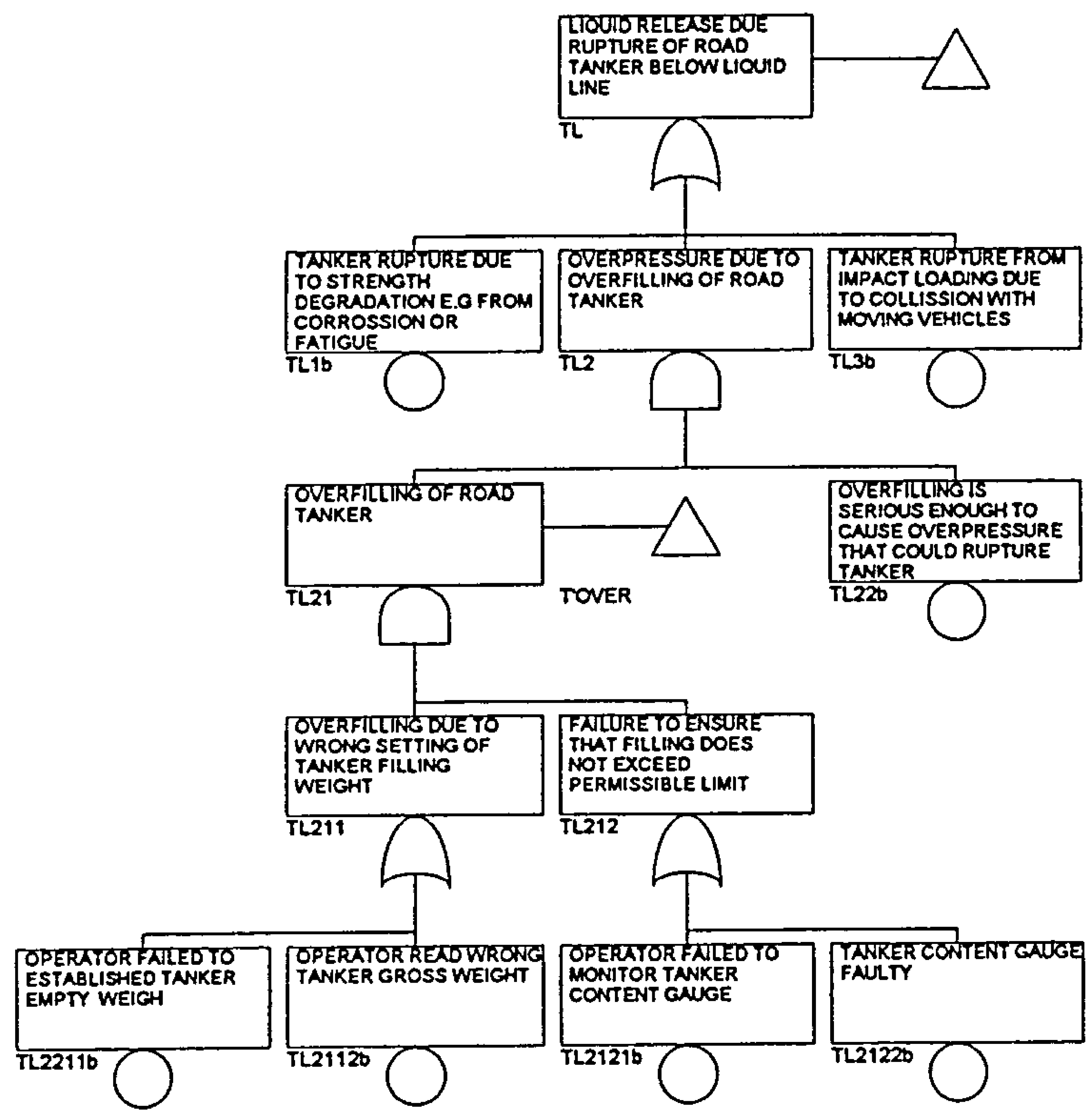


Diagram A14.1.6. Fault Tree Diagram of Road Tanker Bullet Rupture Above Liquid Line (TV) for Site A (Hardware Failure Rates and HEPs)

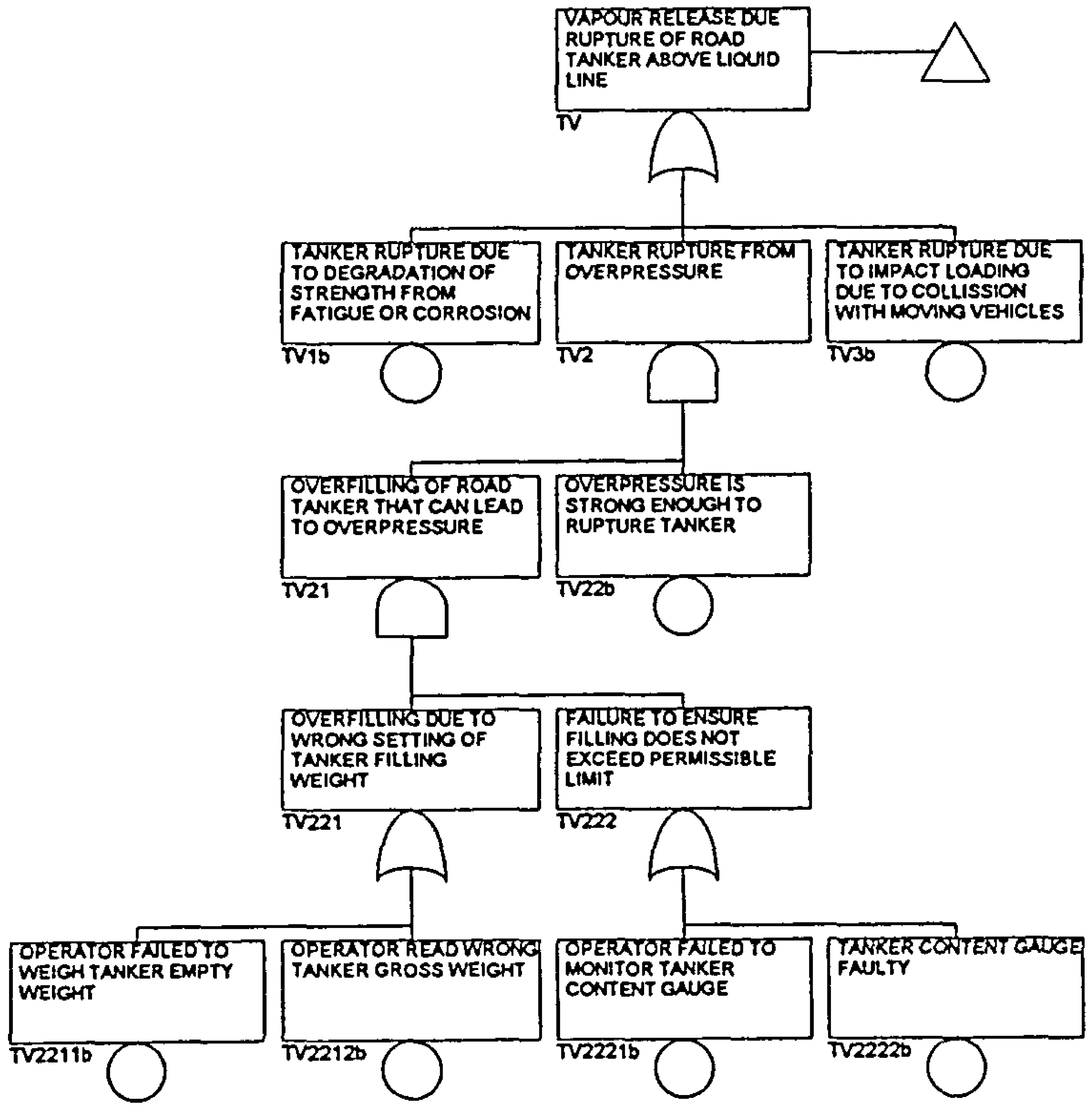


Diagram A14.2. Fault Tree Diagrams of System Failure (R) Using Hardware Failure Rates only for Site A

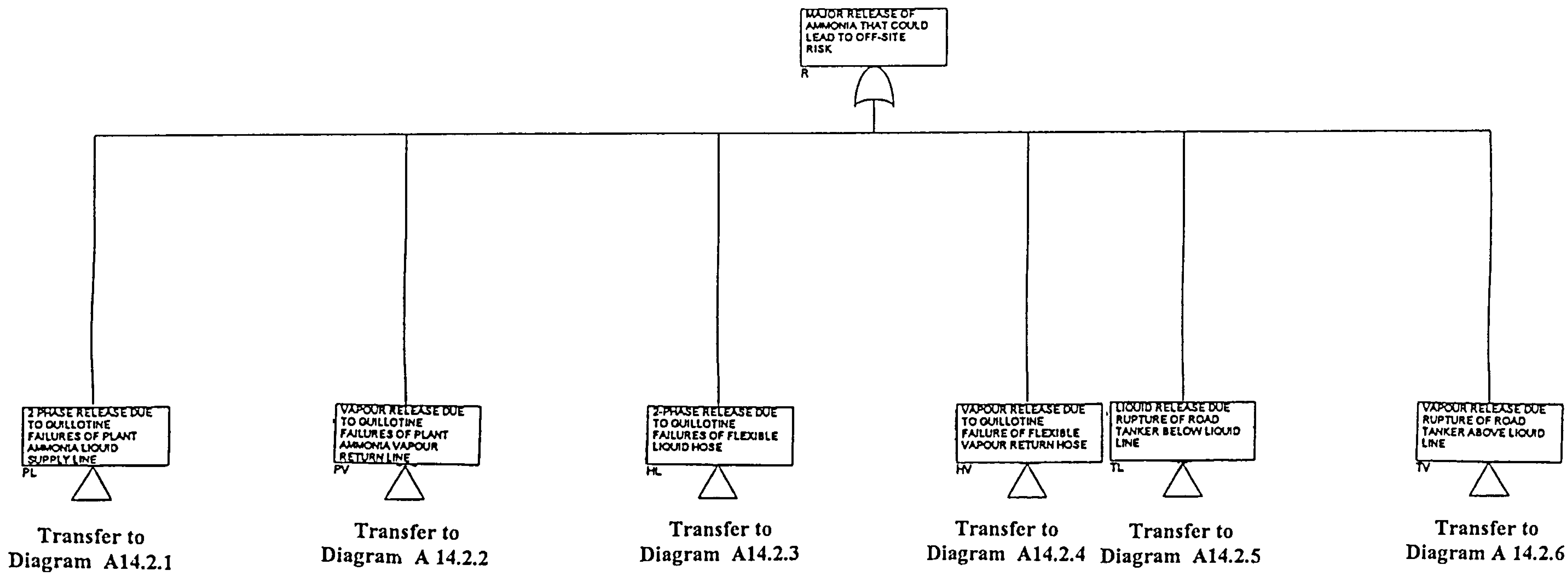


Diagram A14.2.1. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Piping (PL) for Site A (Hardware Failure Rates Only )

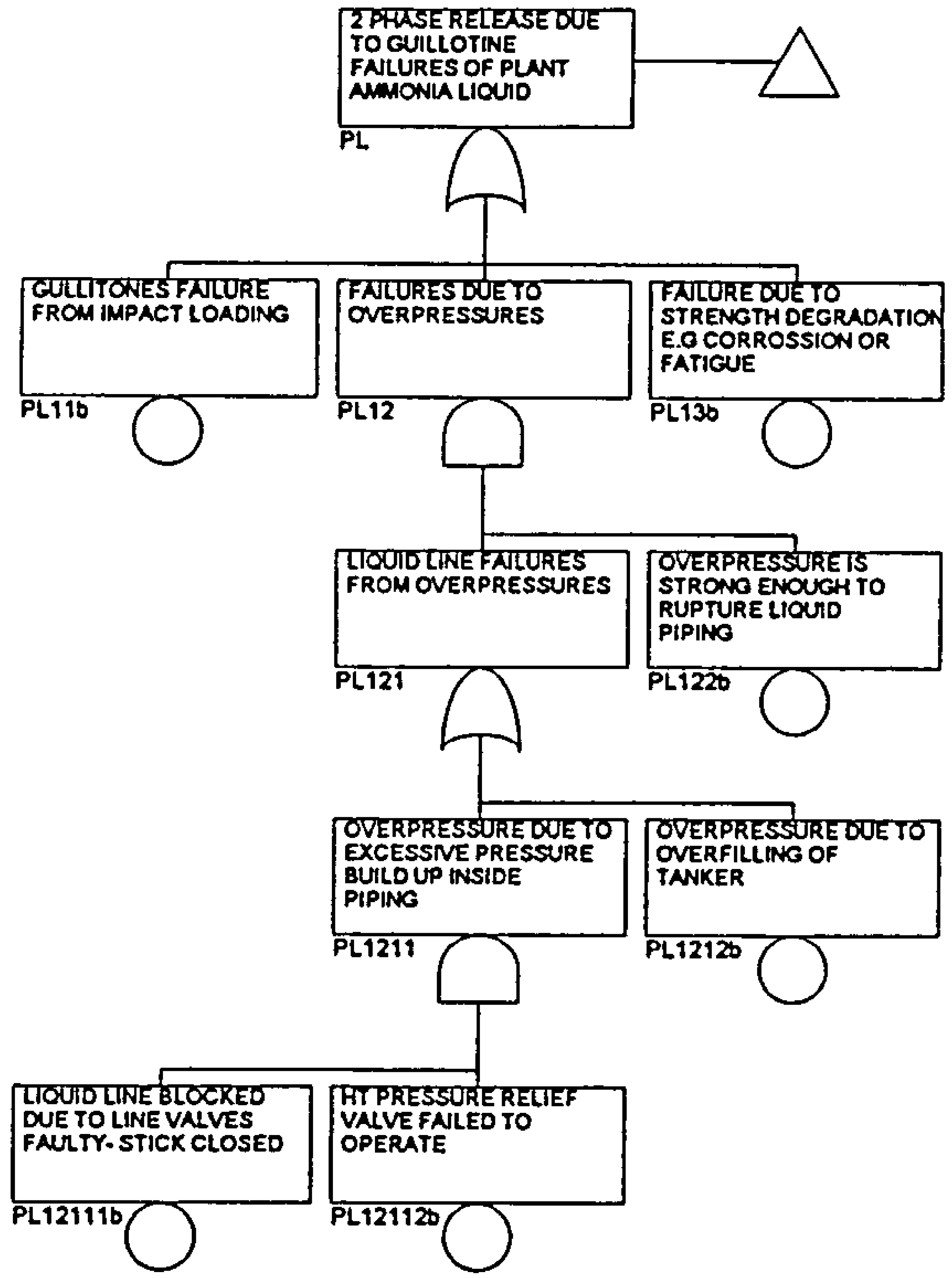


Diagram A14.2.2. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Piping (PV) for Site A (Hardware Failure Rates Only)

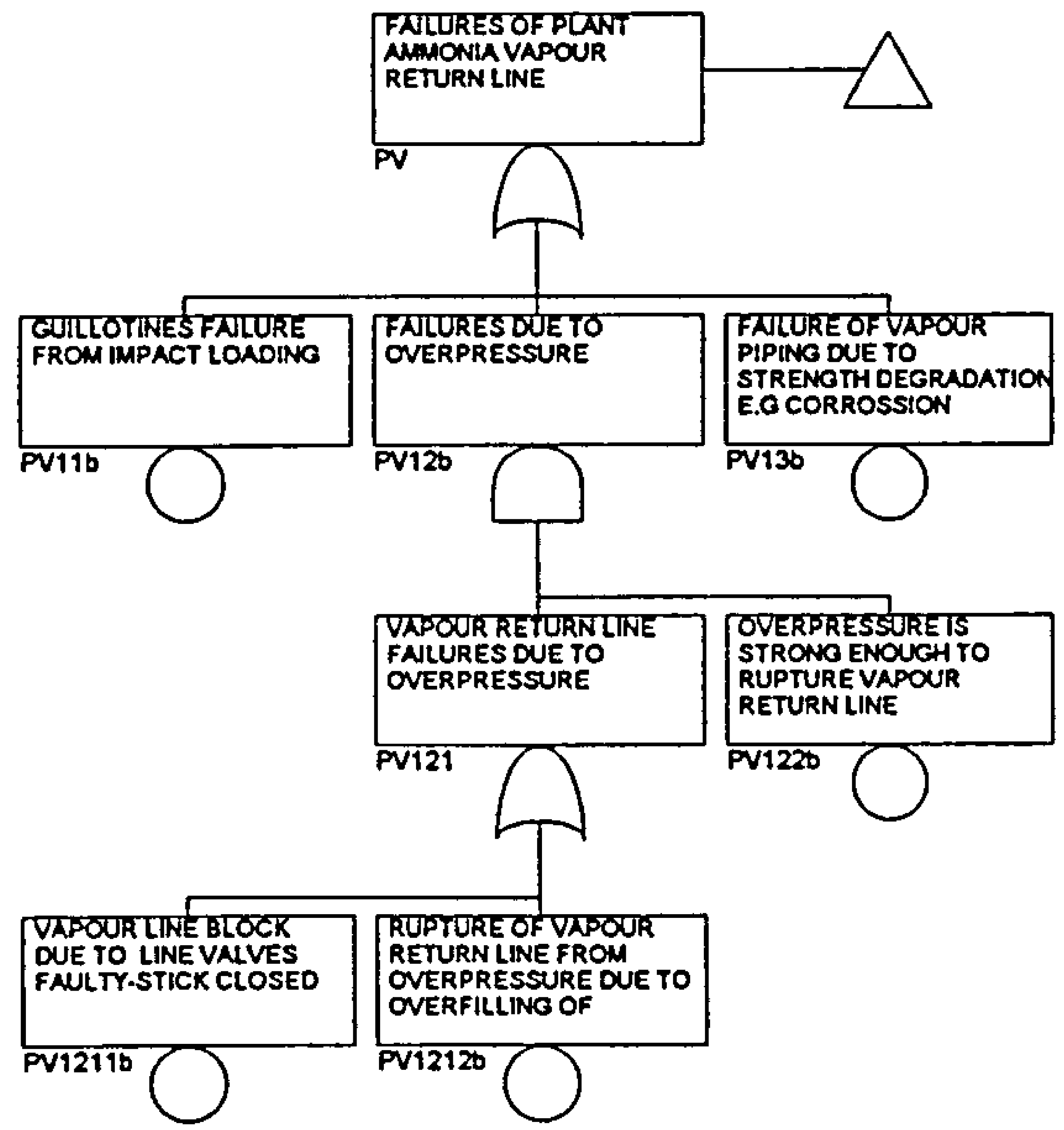


Diagram A14.2.3. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Hoses (HL) for Site A (Hardware Failure Rates Only)

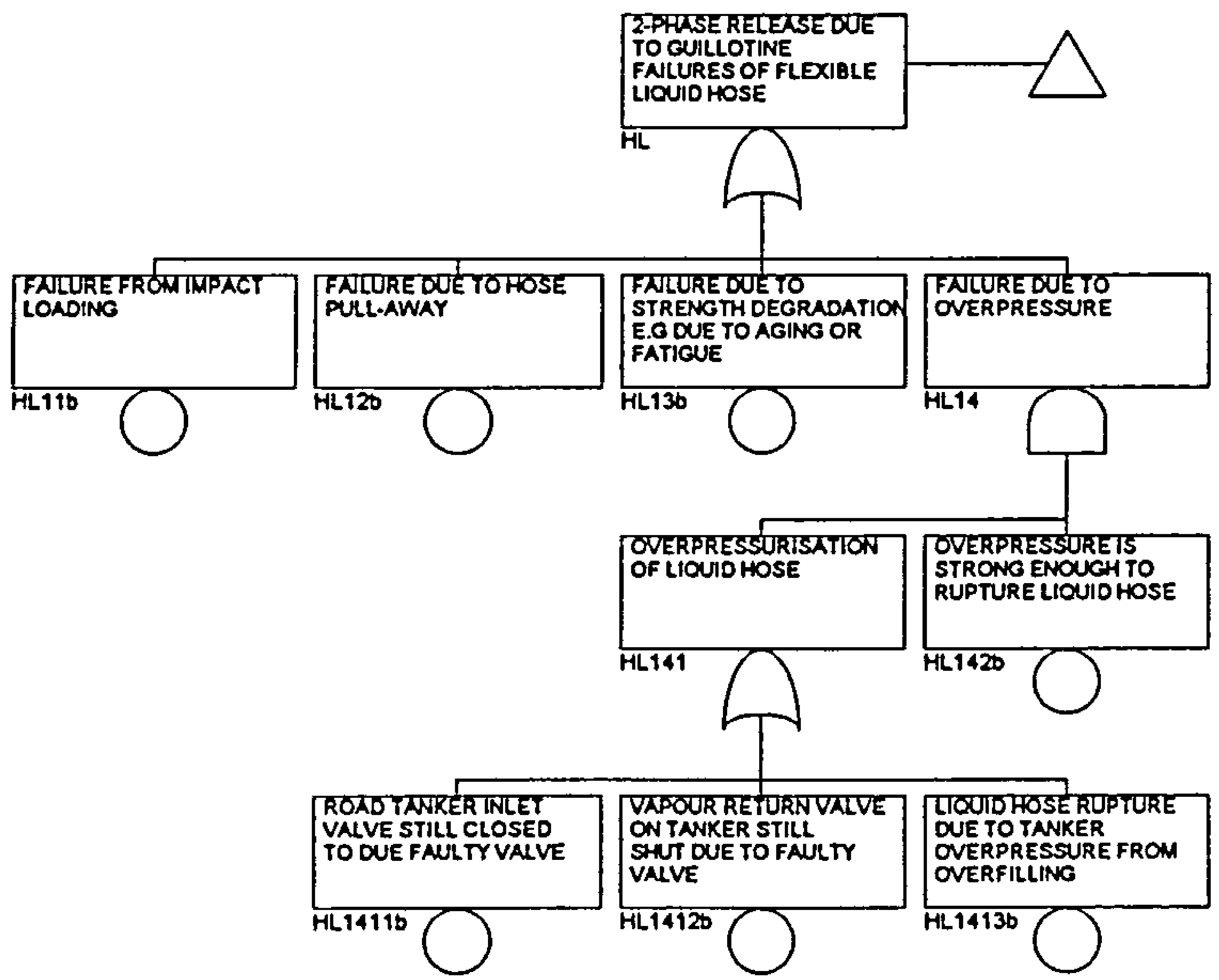


Diagram A14.2.4. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Return Hose (HV) for Site A (Hardware Failure Rates Only)

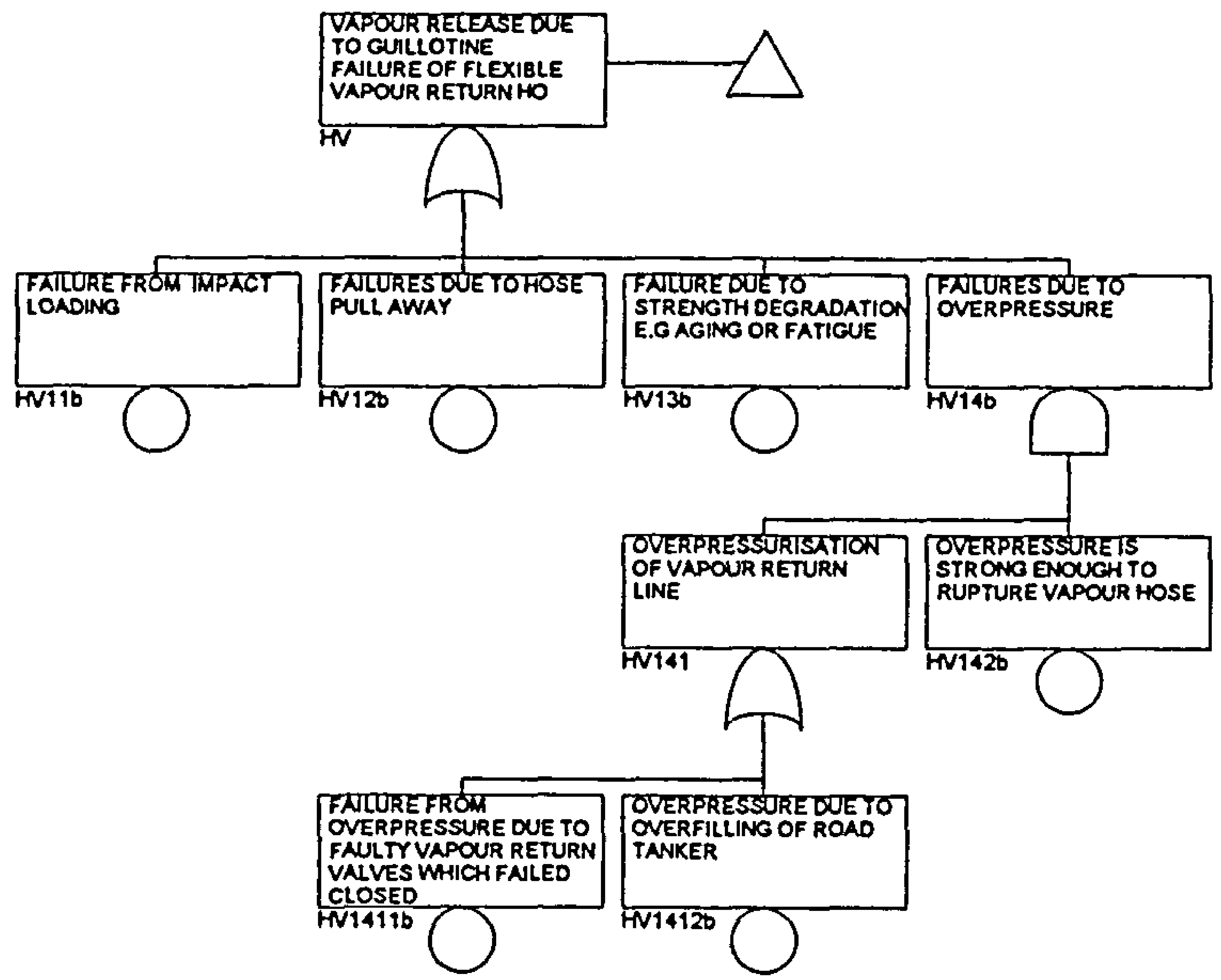


Diagram A14.2.5. Fault Tree Diagram of Road Tanker Bullet Rupture Below Liquid Line (TL) for Site A (Hardware Failure Rates Only)

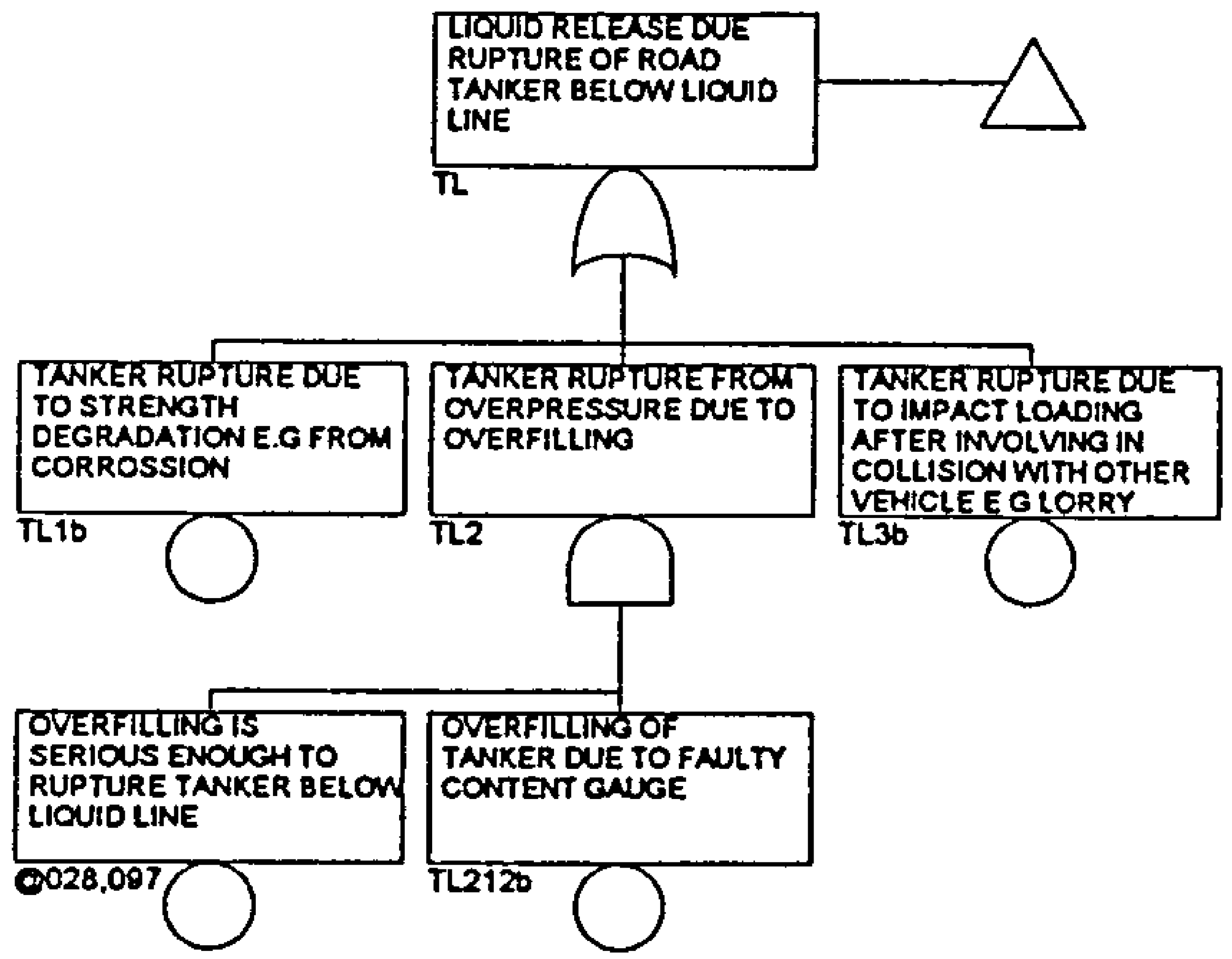


Diagram A14.2.6. Fault Tree Diagram of Road Tanker Bullet Rupture Above Liquid Line (TV) for Site A (Hardware Failure Rates Only)

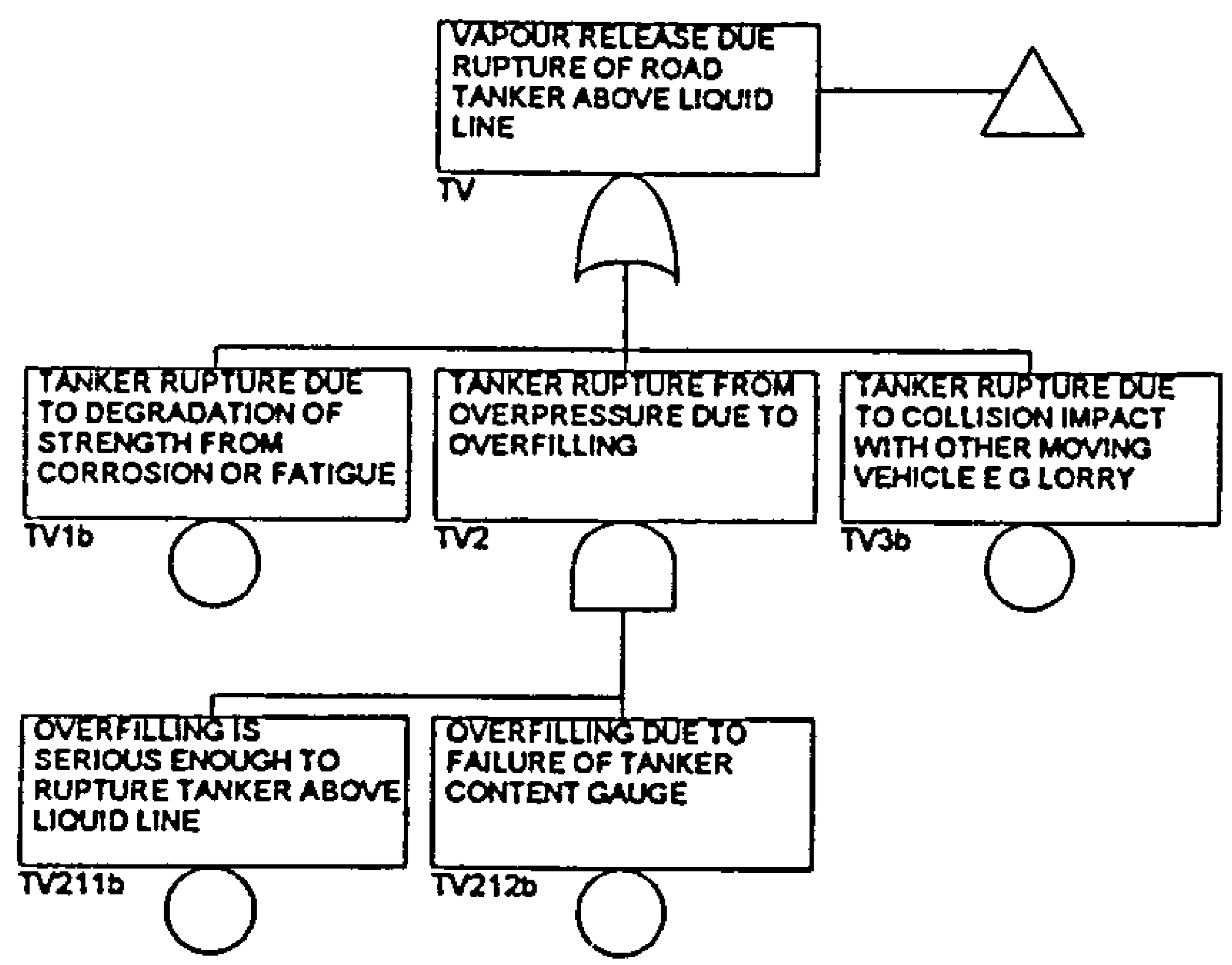


Diagram A14.3. Fault Tree Diagrams of System Failure (R) Using Hardware Failure Rates and HEPs for Site B

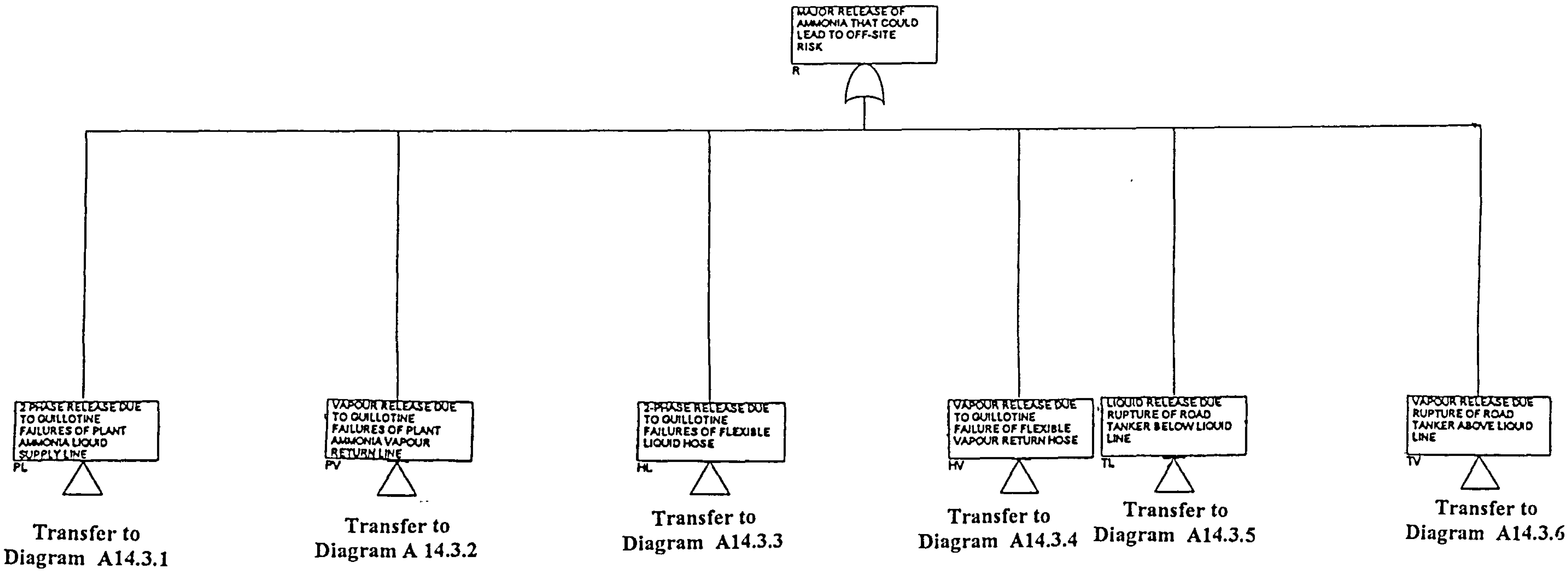


Diagram A14.3.1. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Piping (PL) for Site B
(Hardware Failure Rates and HEPs)

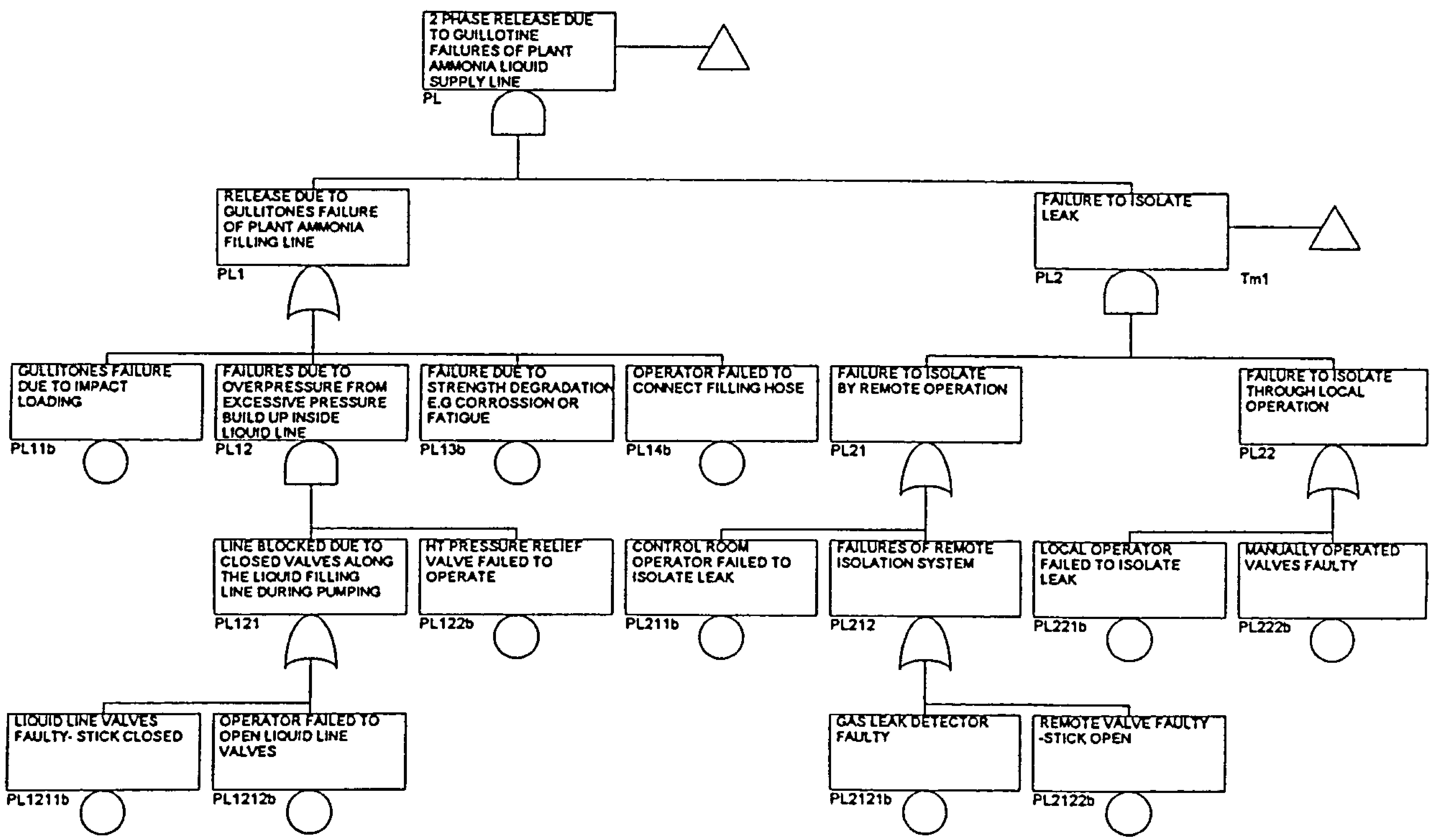


Diagram A14.3.2. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Piping (PV) for Site B (Hardware Failure Rates and HEPs)

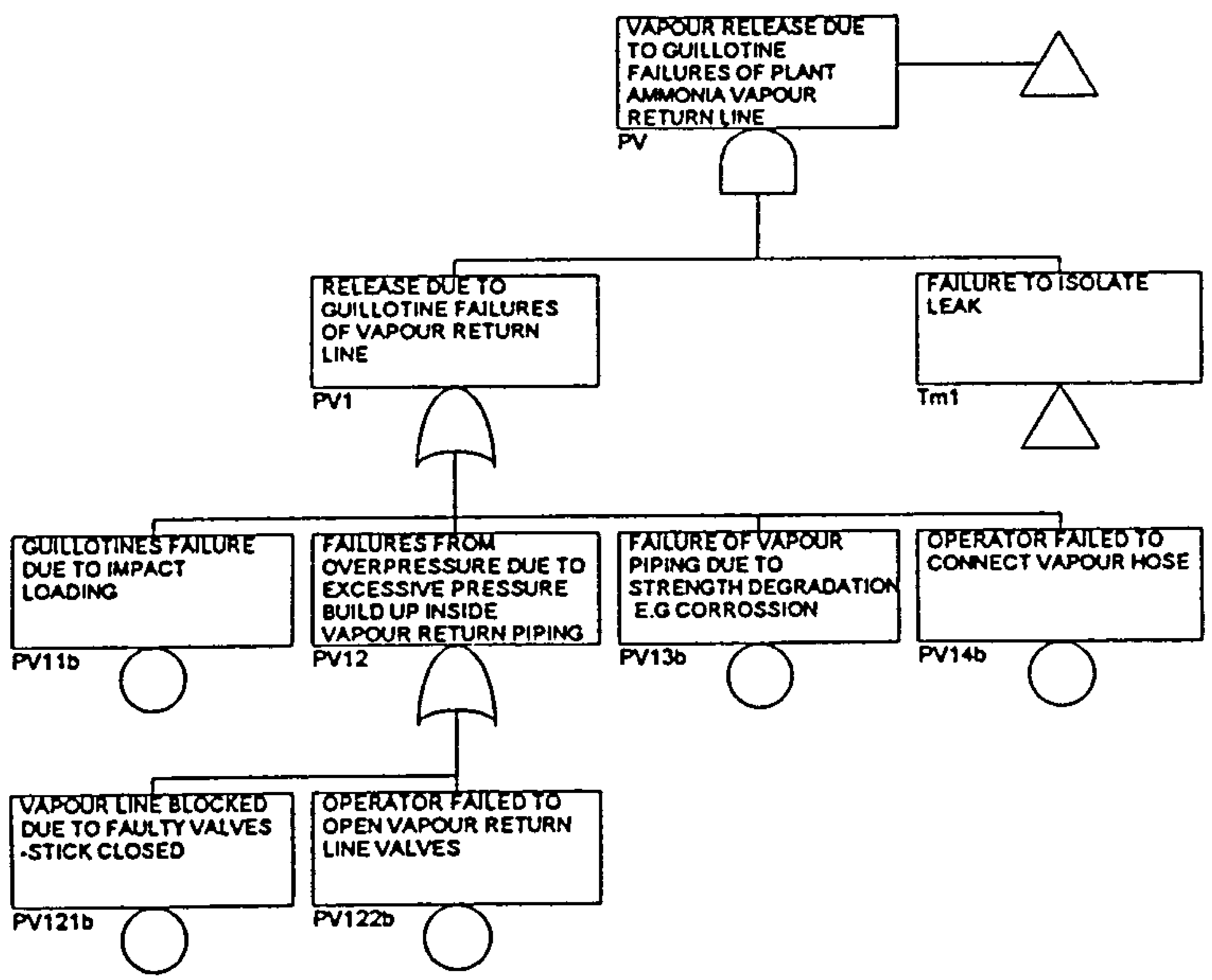


Diagram A14.3.3. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Hose (HL) for Site B
(Hardware Failure Rates and HEPs)

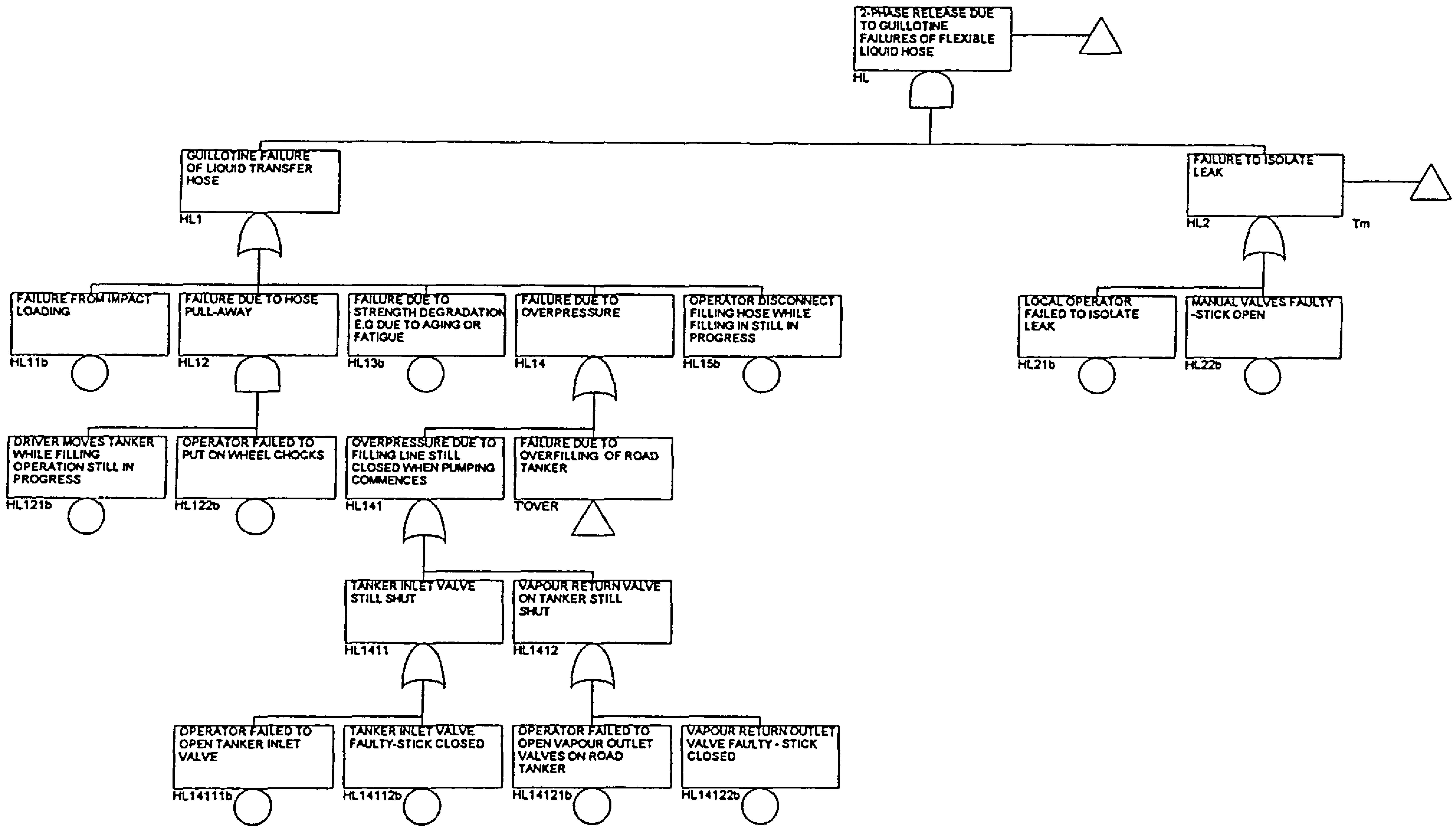


Diagram A14.3.4. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Return Hose (HV) for Site B (Hardware Failure Rates and HEPs)

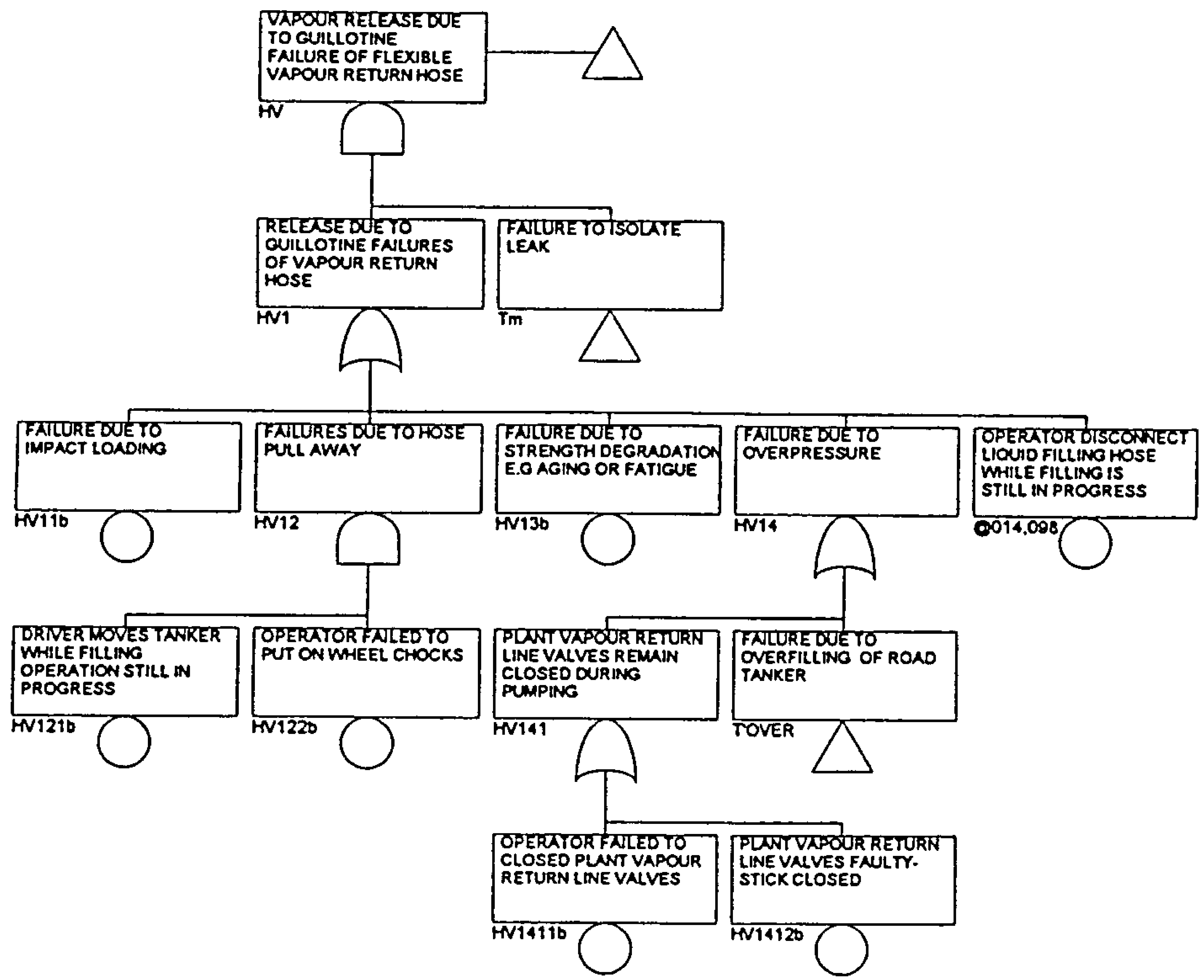


Diagram A14.3.5. Fault Tree Diagram of Road Tanker Bullet Rupture Below Liquid Line (TL) for Site B (Hardware Failure Rates and HEPs)

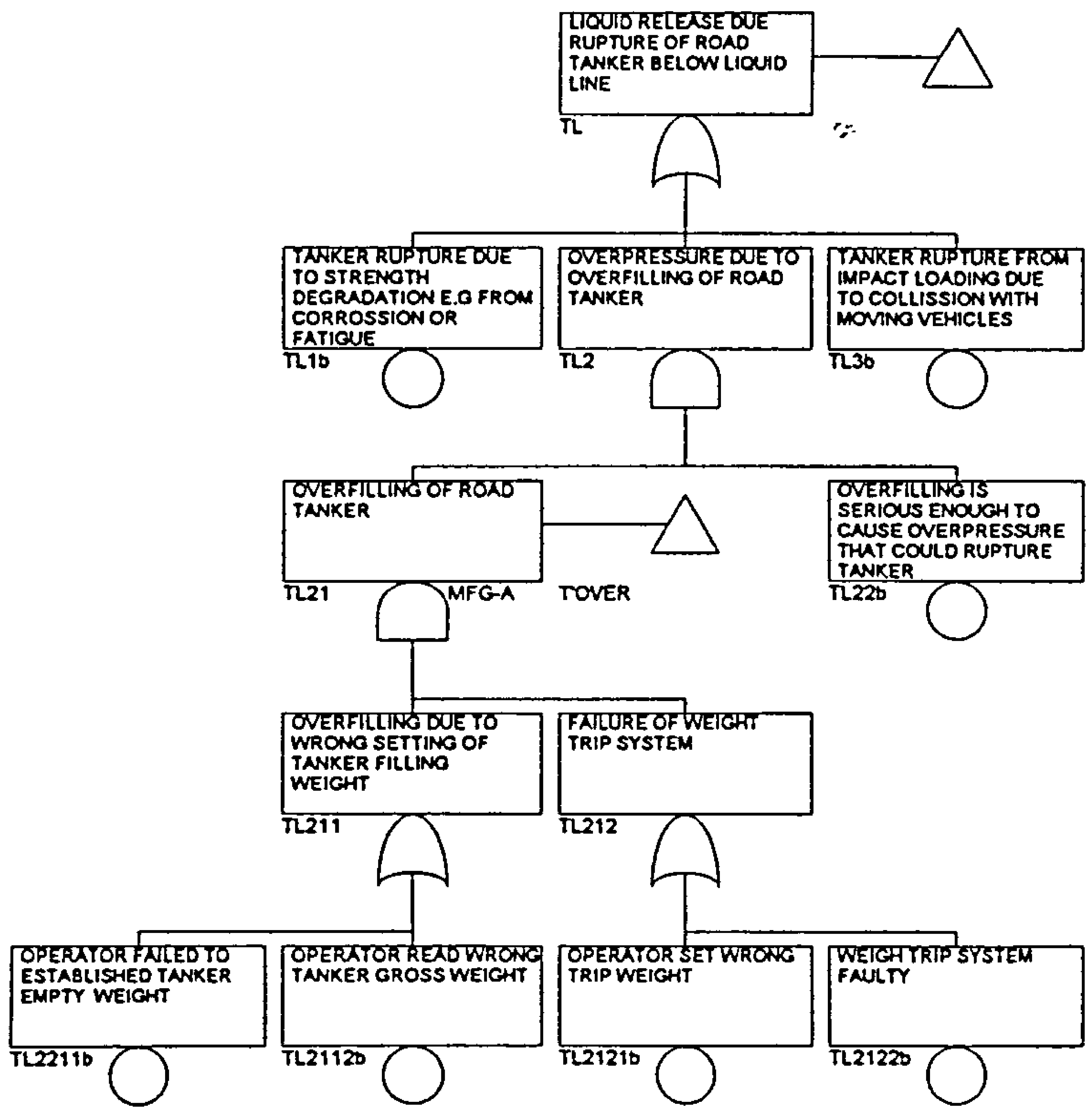


Diagram A14.3.6. Fault Tree Diagram of Road Tanker Bullet Rupture Above Liquid Line (TV) for Site B (Hardware Failure Rates and HEPs)

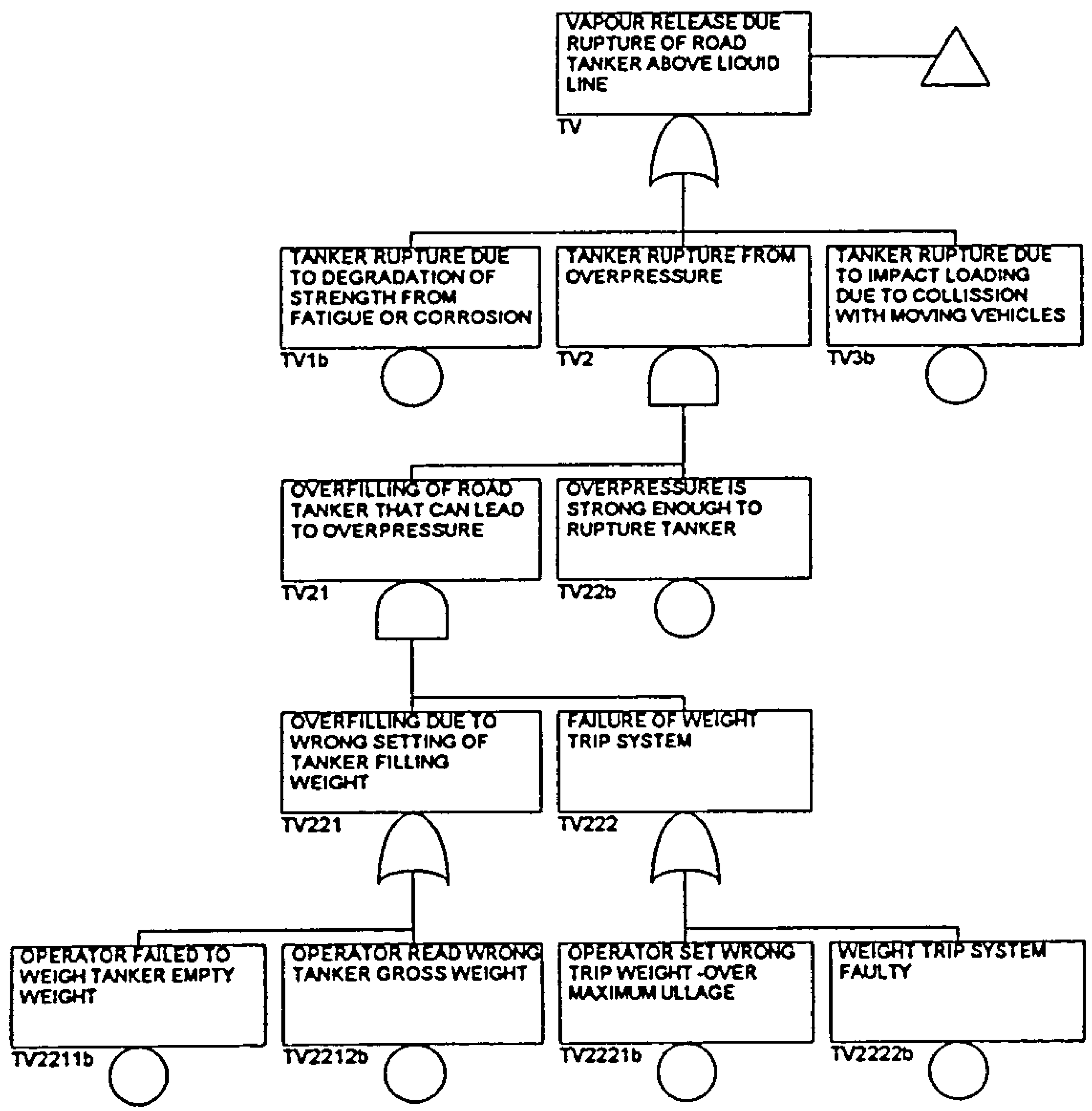


Diagram A14.4. Fault Tree Diagrams of System Failure (R) for Site B (Hardware Failure Rates Only)

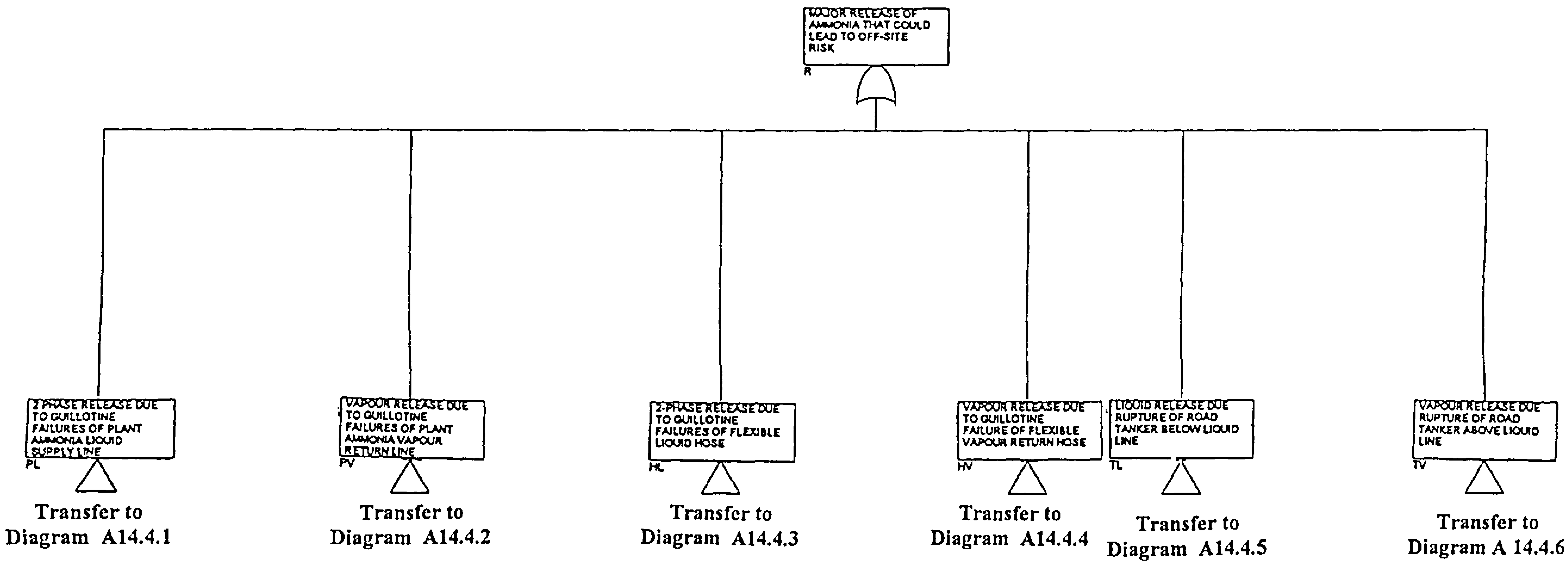


Diagram A14.4.1. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Piping (PL) for Site B (Hardware Failure Rates Only )

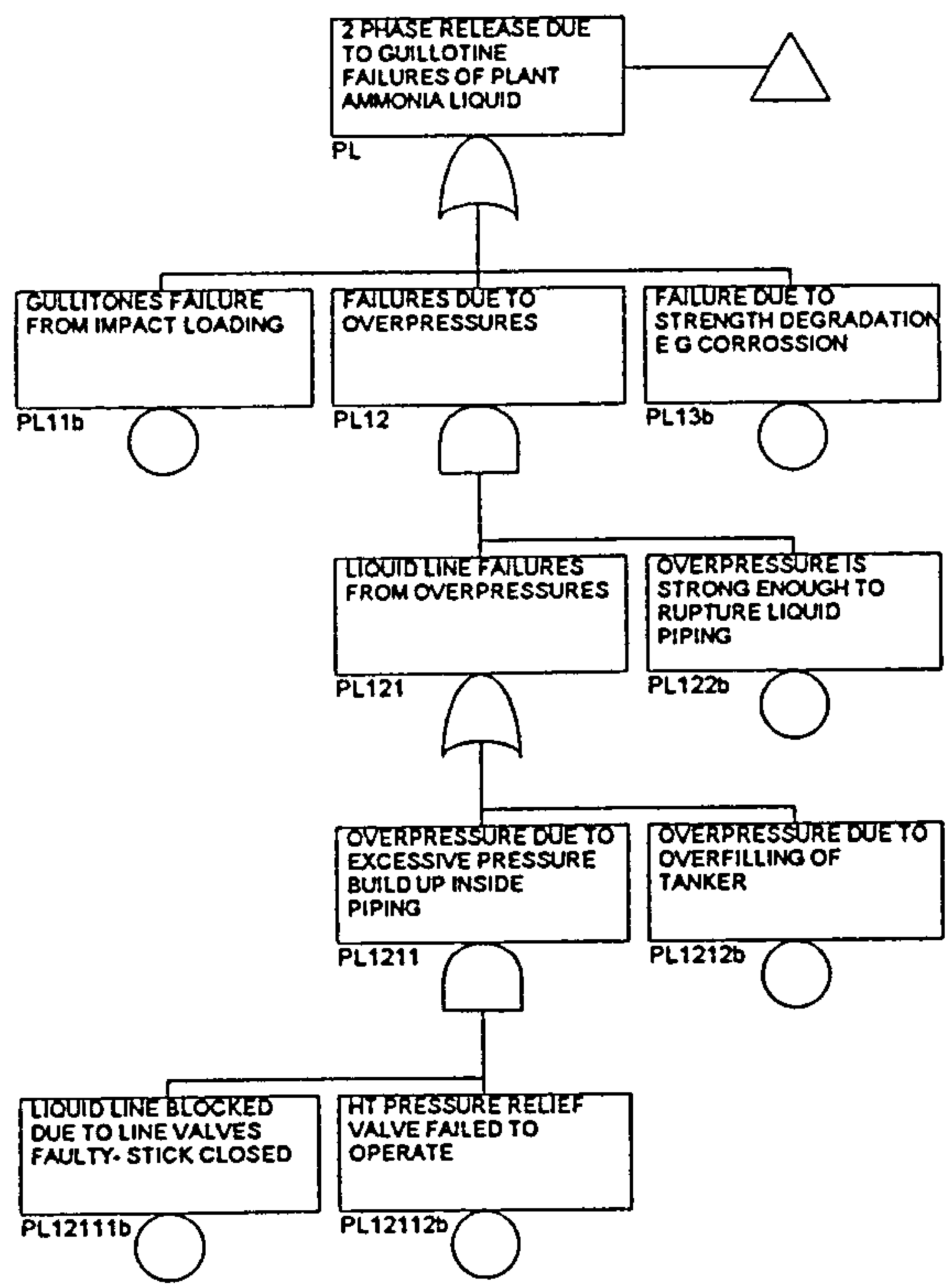


Diagram A14.4.2. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Piping (PV) for Site B (Hardware Failure Rates Only)

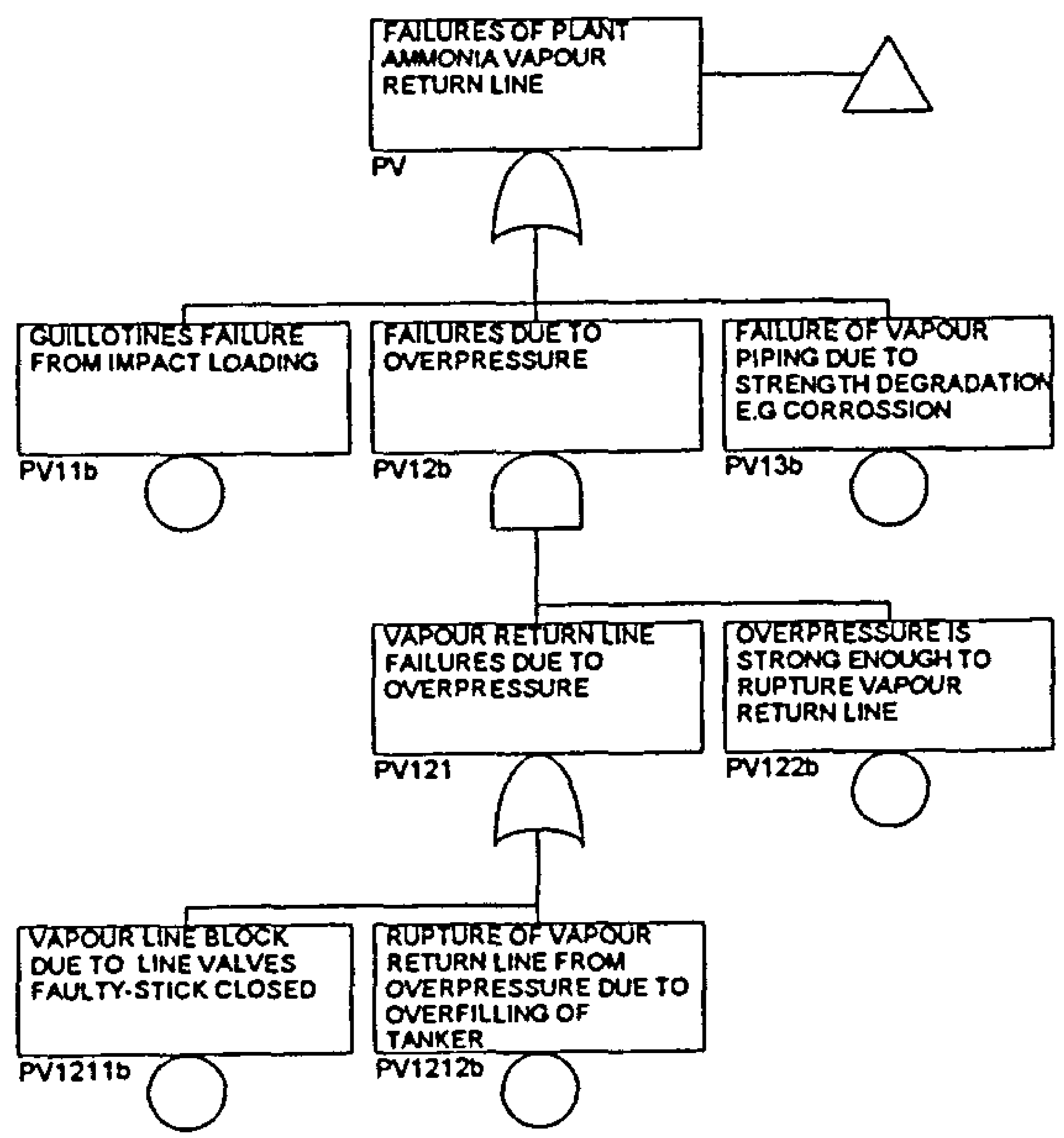


Diagram A14.4.3. Fault Tree Diagram of Guillotine Failures of Ammonia Liquid Hoses (HL) for Site B
(Hardware Failure Rates Only)

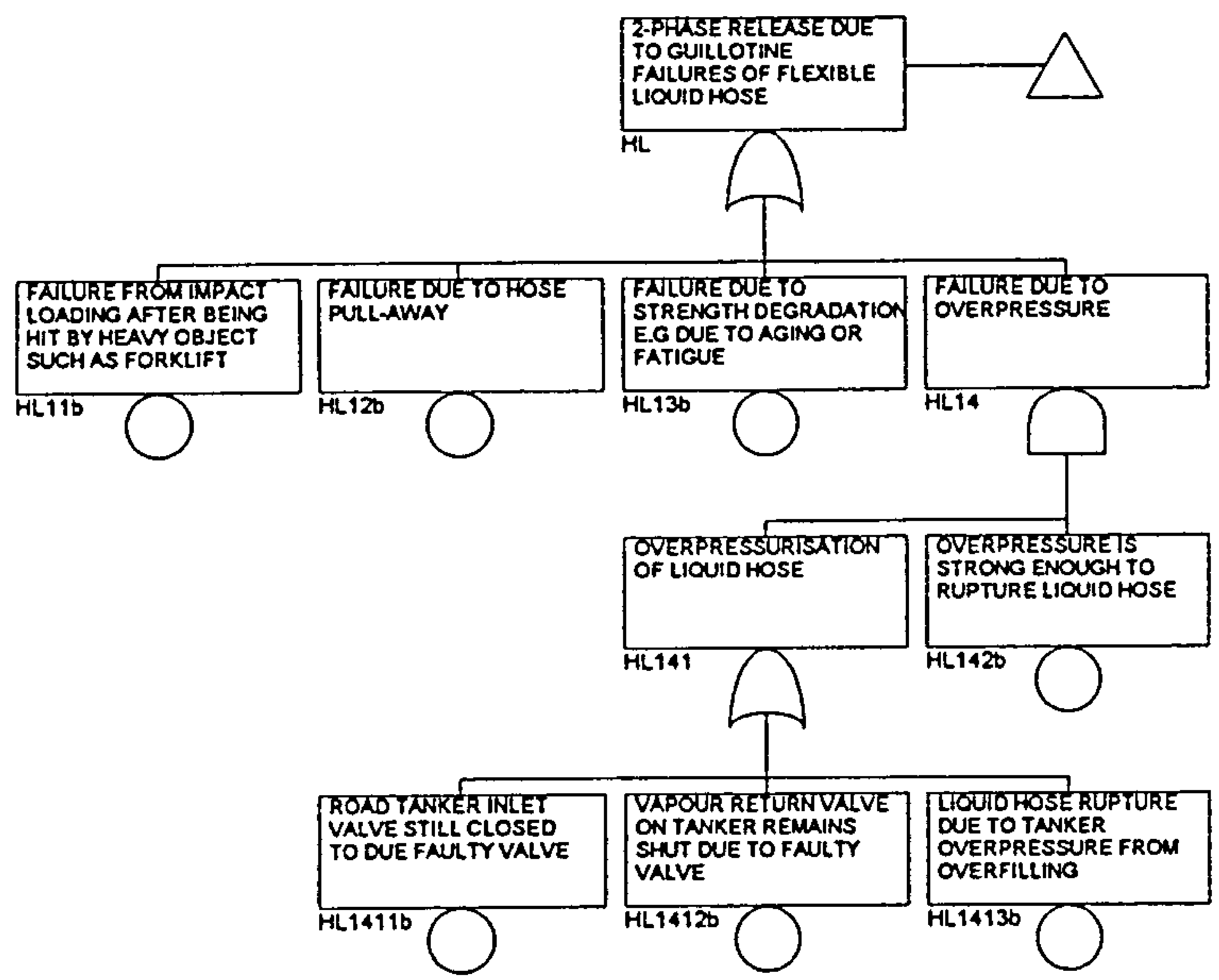


Diagram A14.4.4. Fault Tree Diagram of Guillotine Failures of Ammonia Vapour Return Hose (HV) for Site B (Hardware Failure Rates Only)

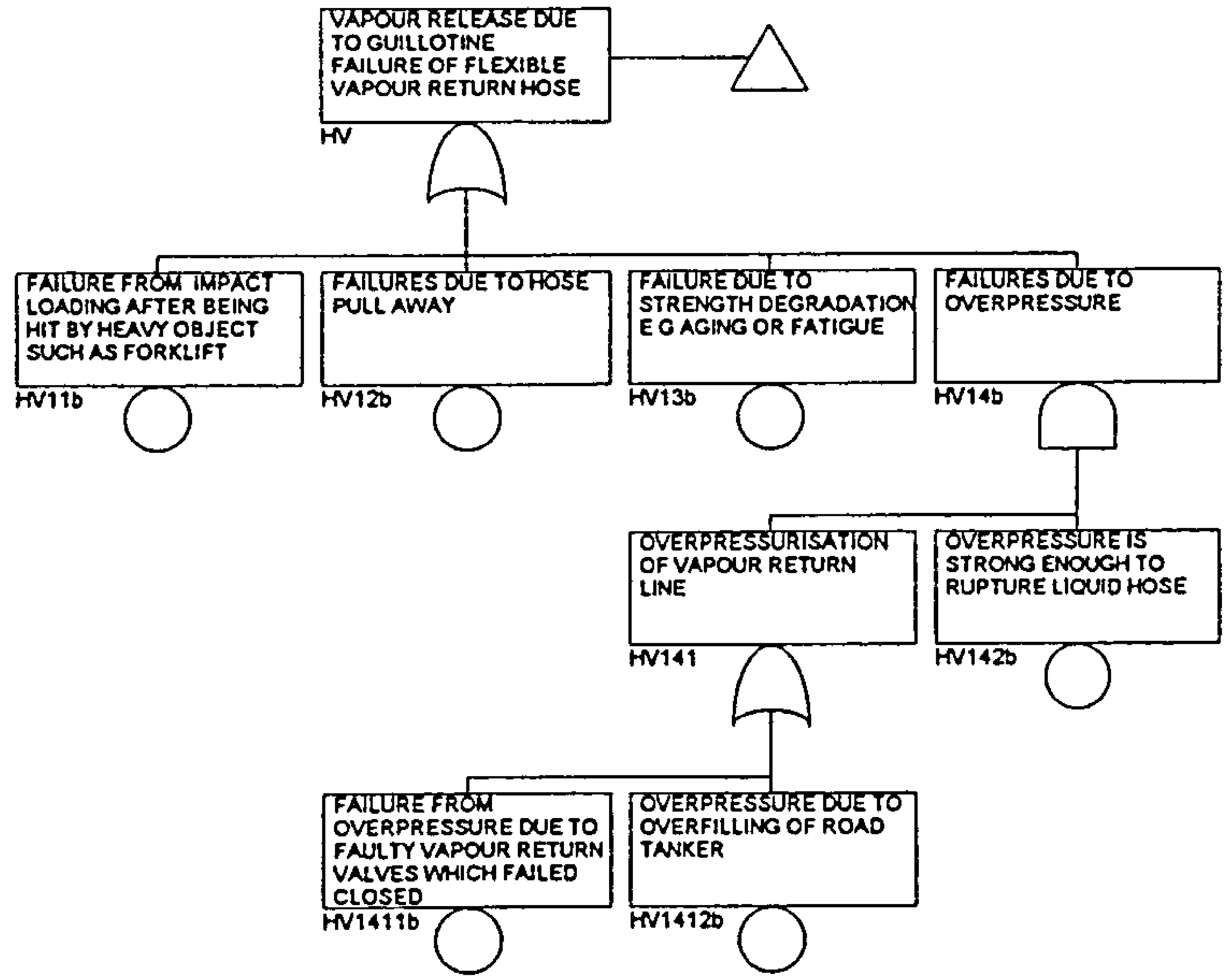


Diagram A14.4.5. Fault Tree Diagram of Road Tanker Bullet Rupture Below Liquid Line (TL) for Site A (Hardware Failure Rates Only)

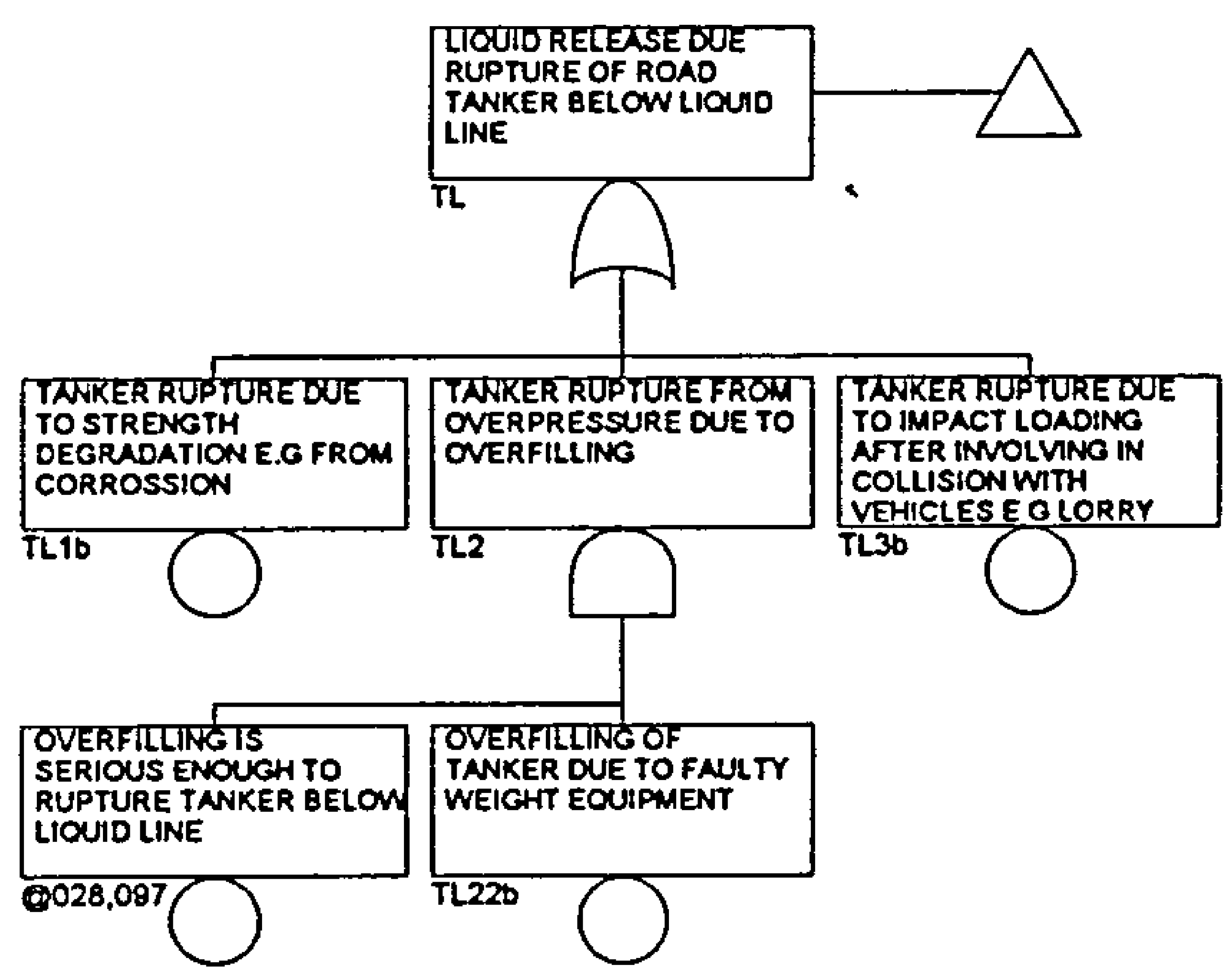
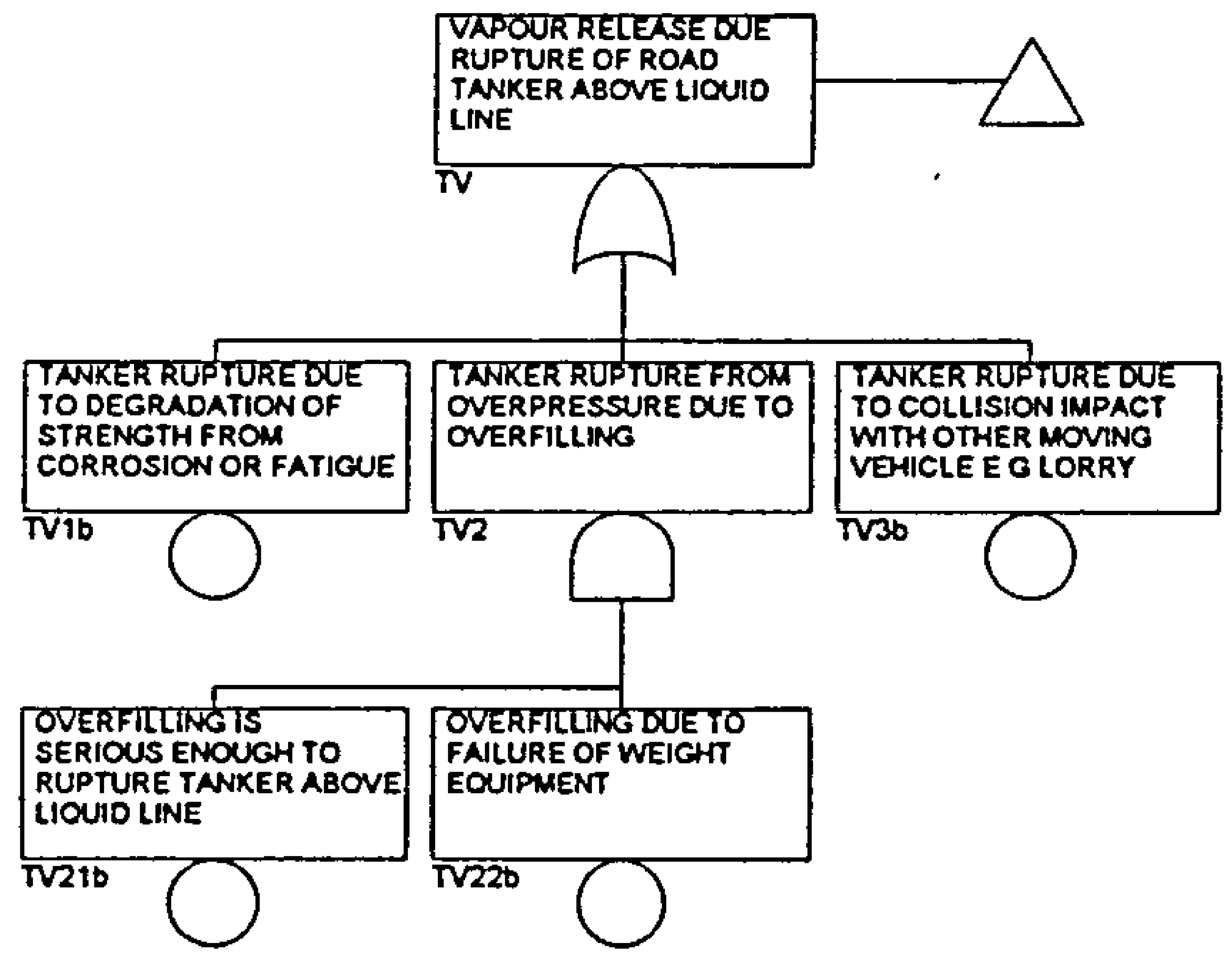


Diagram A14.4.6. Fault Tree Diagram of Road Tanker Bullet Rupture Above Liquid Line (TV) for Site A (Hardware Failure Rates Only)



# *Appendix 15*

**Input for QRA using Fault Tree Approach -**

**Generic Failure Rates and HEPs**

Table A15.1. Input for Fault Tree Analysis to determine frequency of system failure using generic failure rates and HEPs for Site A

| Base Event No. | Description | Generic Failure Rate | HEPs using APJ- Equal Weight | HEPs using APJ- Weighted | HEPs using APJ-Same Calibration Points | HEPs using APJ- 3 Calibration Points | HEPs using HSE (1989) Calibration Points | HEPs from HEART (Nominal HEPs) | HEPs from THERP (Nominal HEPs) |
|---|---|---|---|---|---|---|---|---|---|
| HL 11b | Liquid hose rupture impact loading | 4.3E-07 | | | | | | | |
| HL121b | Drivers moves tanker while filling operation. is in progress | | 1.8E-02 | 2.6E-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 3E-03 |
| HL122b | Operator failed to put on wheel chocks. | | 2.6E-02 | 2.2E-02 | 5.3E-03 | 2.7E-02 | 8.9E-02 | 2E-02 | 3E-03 |
| HL13b | Failure due to strength degradation. e.g fatigue | 1E-05 | | | | | | | |
| HL14111b | Operator failed to open tanker inlet valve . | | 1.8E-02 | 2.6E-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 8E-03 |
| HL14112b | Tanker inlet valves faulty - failed closed | 3.8E-06 | | | | | | | |
| HL14121b | Operator failed to open tanker vapour outlet valve. | | 1.8E-02 | 2.6E-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 8E-03 |
| HL14122b | Vapour return outlet valve faulty - stick closed | 3.8E-06 | | | | | | | |
| HL15b | Operator disconnect liquid hose while filling operation is in progress. | | 3.9E-04 | 9.7E-04 | 4.1E-05 | 4.3E-07 | 3E-05 | 3E-03 | 1E-03 |
| HL21b | Operator failed to isolate leak. | | 7.3E-03 | 1.5E-02 | 1E-03 | 1.6E-02 | 3.8E-03 | 2E-02 | 8E-03 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| HL22b | Manual valve faulty stick open. | 3.8E-06 | | | | | | | |
| HV11b | Hose rupture failure due to impact loading | 4.3E-07 | | | | | | | |
| HV121b | Driver moves tanker while filling operation. | | 1.8E-02 | 2.6E-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 3E-03 |
| HV122b | Operator failed to put wheel chocks | | 2.6e-02 | 2.2e-02 | 5.3E-03 | 2.7E-02 | 8.9E-02 | 2E-02 | 3E-03 |
| HV13b | Failure due to strength degradation e.g. fatigue | 1E-05 | | | | | | | |
| HV1411b | Operator failed to closed plant vapour return | | 1.8E-02 | 2.6E-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 8E-03 |
| HV 1412b | Plant vapour return line valve faulty- stick | 3.8E-06 | | | | | | | |
| HV15b | Operator disconnect hose while filling operation is in progress | | 3.9E-04 | 9.7E-04 | 3.6E-03 | 2E-02 | 3E-05 | 3E-03 | 1E-03 |
| PL11b | Liquid piping rupture failure due to impact loading | 2.3e-08 | | | | | | | |
| PL1211b | Liquid line valves faulty -stick closed | 3.8E-06 | | | | | | | |
| PL1212b | Operator failed to open liquid line valves | | 1.8E-02 | 2.6E-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 3E-03 |
| PL122b | HT pressure relief valve failed to operator | 1E-06 | | | | | | | |
| PL13b | Liquid piping failure due to strength degradation | 2E-09 | | | | | | | |
| PL14b | Operator commences filling without connecting filling hose to tanker | | 2.6E-03 | 5E-03 | 1.5E-04 | 4.3E-03 | 1E-04 | 3E-03 | 3E-03 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| PL211b | Remote operator failed to isolate leak | | 1.8E-03 | 9.7E-03 | 2.8E-04 | 9.7E-03 | 3.4E-03 | 3E-03 | 1E-03 |
| PL212b | Remote isolation valve faulty - stick open | 3.8E-06 | | | | | | | |
| PL221b | Local operator failed to isolate leak | | 1.4E-02 | 1.5E-02 | 1E-03 | 1.6E-02 | 3.8E-03 | 2E-02 | 8E-03 |
| PL222b | Manual isolation valve faulty | 3.8E-06 | | | | | | | |
| PV11b | Vapour return piping failure due to impact loading | 9.4e-08 | | | | | | | |
| PV121b | Vapour line valves blocked due to faulty valves- stick closed. | 3.8E-06 | | | | | | | |
| PV122b | Operator failed to open vapour return piping valves | | 1.8E-02 | 2.6e-02 | 3.6E-03 | 2E-02 | 4.3E-02 | 2E-02 | 3E-03 |
| PV13b | Failure of vapour piping due to strength degradation e.g. corrosion | 1.7E-08 | | | | | | | |
| PV14b | Operator commences filling without properly connecting vapour return hose to tanker | | 2.6e-03 | 5E-03 | 1.5E-04 | 4.3E-03 | 1E-04 | 3E-03 | 3E-03 |
| TL1b | Tanker rupture due to strength degradation | 9.7E-09 | | | | | | | |
| TL2112b | Operator read wrong tanker gross weight | | 5.3e-02 | 3.3E-03 | 5.3E-03 | 2.7E-02 | 8.9E-02 | 2E-02 | 3E-03 |
| TL2121b | Operator failed to monitor tanker content gauge | | 5.3e-04 | 5E-04 | 5.3E-04 | 4.3E-03 | 1.1E-03 | 2E-02 | 1E-03 |
| TL2122b | Tanker content gauge faulty | 1.01E-03 | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TL2211b | Operator failed to establish tanker empty weigh | | 5.3e-02 | 3.3E-03 | 5.3E-03 | 2.7E-02 | | 3E-03 | 3E-03 |
| TL22b | Overpressure is strong enough to rupture tanker below liquid line | 3.2E-04 | | | | | | | |
| TL3b | Tanker rupture due to collision with moving vehicles e.g. lorry | 3.7E-08 | | | | | | | |
| TV1b | Tanker rupture due to the strength degradation e.g. corrosion | 9.7E-09 | | | | | | | |
| TV2211b | Operator failed to established tanker empty weight | | 5.3e-02 | 3.3E-03 | 5.3E-03 | 2.7E-02 | 8.9E-02 | 3E-03 | 3E-03 |
| TV2212b | Operator read wrong tanker gross weight | | 5.3e-02 | 3.3E-03 | 5.3E-03 | 2.7E-02 | 8.9E-02 | 2E-02 | 1E-02 |
| TV2221b | Operator failed to monitor tanker content gauge | | 5.3e-04 | 5E-04 | 5.3E-04 | 4.3E-03 | 1.1E-03 | 2E-02 | 1E-03 |
| TV2222b | Tanker content gauge faulty | 1.01E-03 | | | | | | | |
| TV22b | Overpressure is strong enough to rupture tanker above liquid line | 6.6 E-03 | | | | | | | |
| TV3b | Tanker rupture due to collision with moving vehicle e.g. lorry | 3.7E-08 | | | | | | | |

Table A15.2. Input for QRA scenarios using Fault Tree Approach - Site A

| Scenarios | Hole Size ( mm) | Release Rate (kg/s) | Duration of Release(min) | Failure Rate (Hardware and Human Error) | Failure Rate (Hardware Only) |
|---|---|---|---|---|---|
| 1. Liquid releases from road tanker failure below liquid line | 100 | 169 | 30 | 4.7E-08/loading 2.3E-05/year | 1.8E-05/loading 8.6E-02/year |
| 2. Vapour releases from road tanker above liquid line | 100 | 8.5 | 30 | 4.7E-08/loading 2.3E-05/year | 1.8E-08/loading 8.6E-02/year |
| 3. 2-phase release due guillotine failures of 2 in. liquid flexible hose | 50 | 70.7 | 20 | 3.7e-08/loading 1.8E-05/year | 2.1E-05/loading 1.0E-02/year |
| 4. Vapour release due to guillotine failures of 1 in. vapour return flexible hose | 25 | 0.94 | 20 | 9.5E-09/loading 4.6E-06/year | 1.4E-05/loading 6.7E-03/year |
| 5. 2-phase release due to guillotine failures of 4 in. liquid supply line | 75 | 37 | 20 | 4.7E-09/loading 2.3E-06/year | 2.2E-05/loading 1.1E-02/year |
| 6. Vapour release from guillotine failure of 3 in. vapour return line | 50 | 0.7 | 20 | 9.5E-09/loading 4.6E-05/year | 1.8E-05/loading 8.6E-03/year |

Table A15.3. Input for Fault Tree Analysis to determine frequency of system failure using generic failure rates and HEPs for Site B

| Base Event No. | Description | Generic Failure Rate | HEPs using APJ- Equal Weight | HEPs using APJ- Weighted | HEPs using APJ - 3 Calibration Points | HEPs using APJ - HSE(1989) Calibration Points | HEPs from HEART (Nominal Data) | HEPs from THERP (Nominal Data) |
|---|---|---|---|---|---|---|---|---|
| HL 11b | Liquid hose rupture impact loading | 4.3E-07 | | | | | | |
| HL121b | Drivers moves tanker while filling operation. | | 1E-03 | 5.2E-03 | 1.2E-03 | 5E-03 | 2E-02 | 3E-03 |
| HL122b | Operator failed to put on wheel chocks | | 1E-03 | 1E-03 | 1.2E-03 | 5E-03 | 2E-02 | 3E-03 |
| HL13b | Failure due to strength degradation. e.g. fatigue | 7.3E-06 | | | | | | |
| HL14111b | Operator failed to open tanker inlet valve . | | 5.8E-04 | 5.8E-04 | 7.2E-04 | 1.9E-03 | 2E-02 | 8E-03 |
| HL14112b | Tanker inlet valves faulty - failed closed | 1.9E-05 | | | | | | |
| HL14121b | Operator failed to open tanker vapour outlet valve. | | 5.8E-04 | 5.8E-04 | 7.2E-04 | 1.9E-03 | 2E-02 | 8E-03 |
| HL14122b | Vapour return outlet valve faulty -stick closed | 1.95E-05 | | | | | | |
| HL15b | Operator failed to connect hose to plant liquid filling line. | | 3.7E-05 | 3.7E-05 | 2.6E-04 | 1.4E-04 | 3E-03 | 3E-03 |
| HL21b | Operator failed to isolate leak. | | 1.1E-03 | 4.6E-04 | 1.3E-03 | 2.3E-03 | 2E-02 | 8E-03 |
| HL22b | Manual valve faulty stick open. | 1.95E-05 | | | | | | |
| HV11b | Hose rupture failure due to impact loading | 4.3E-07 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| HV121b | Driver moves tanker while filling operation. | | 1E-03 | 5E-03 | 1.2E-03 | 5E-03 | 2E-02 | 3E-03 |
| HV122b | Operator failed to put wheel chocks | | 1E-03 | 1E-03 | 1.2E-03 | 5E-03 | 2E-02 | 3E-03 |
| HV13b | Failure due to strength degradation e.g. fatigue | 7.3E-06 | | | | | | |
| HV1411b | Operator failed to closed plant vapour return | | 5.8E-04 | 5.8E-04 | 7.2E-04 | 1.4E-05 | 2E-02 | 8E-03 |
| HV 1412b | Plant vapour return line valve faulty-stick | 1.9E-05 | | | | | | |
| HV15b | Operator disconnect hose while filling operation is in progress | | 3.7E-05 | 3.7E-05 | 7.2E-04 | 1E-04 | 3E-03 | 3E-03 |
| PL11b | Liquid piping rupture failure due to impact loading | 2.3e-08 | | | | | | |
| PL1211b | Liquid line valves faulty -stick closed | 1.9E-05 | | | | | | |
| PL1212b | Operator failed to open liquid line valves | | 5.8E-04 | 5.8E-04 | 7.2E-04 | 1.9E-03 | 2E-02 | 8E-03 |
| PL122b | HT pressure relief valve failed to operator | 5.2E-06 | | | | | | |
| PL13b | Liquid piping failure due to strength degradation | 1.2E-08 | | | | | | |
| PL14b | Operator commences filling without connecting plant to tanker | | 1.9E-04 | 1.9E-04 | 2.6E-04 | 1E--04 | 3E-03 | 3E-03 |
| PL211b | Control room operator failed to isolate leak | | 4.6E-04 | 4.6E-04 | 5.8E-04 | 4.8E-04 | 3E-03 | 1E-03 |
| PL2121b | Gas leak detector faulty | 4.1E-06 | | | | | | |
| PL2122b | Remote valve faulty - stick open | 1.9E-05 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PL221b | Local operator failed to isolate leak | | 1.1E-03 | 1.1E-03 | 1.3E-03 | 2.3E-03 | 2E-02 | 8E-03 |
| PL222b | Manual isolation valve faulty | 1.9E-05 | | | | | | |
| PV11b | Vapour return piping failure due to impact loading | 9.4e-08 | | | | | | |
| PV121b | Vapour line valves blocked due to faulty valves- stick closed. | 1.9E-05 | | | | | | |
| PV122b | Operator failed to open vapour return piping valves | | 5.8E-04 | 5.8E-04 | 7.2E-04 | 1.9E-03 | 2E-02 | 3E-03 |
| PV13b | Failure of vapour piping due to strength degradation e.g. corrosion | 1.04E-08 | | | | | | |
| PV14b | Operator commences filling without connecting vapour return hose to tanker | | 1.9E-04 | 1.9E-04 | 2.6E-04 | 1E-04 | 3E-03 | 3E-03 |
| TL1b | Tanker rupture due to strength degradation | 4.9E-08 | | | | | | |
| TL2112b | Operator read wrong tanker gross weight | | 1.4E-03 | 1.4E-03 | 1.6E-03 | 8.9E-03 | 2E-02 | 1E-02 |
| TL2121b | Operator set wrong trip weight -over maximum ullage | | 1.4E-03 | 1.4E-03 | 1.6E-03 | 8.9E-03 | 3E-03 | 1E-02 |
| TL2122b | Weight trip system faulty | 1.1E-03 | | | | | | |
| TL2211b | Operator failed to establish tanker empty weigh | | 1.4E-03 | 1.4E-03 | 1.6E-03 | 8.9E-03 | 3E-03 | 3E-03 |
| TL22b | Overpressure is strong enough to rupture tanker below liquid line | 3.2E-04 | | | | | | |
| TL3b | Tanker rupture due to collision with moving vehicles e.g. lorry | 3.7E-08 | | | | | | |
| TV1b | Tanker rupture due to the strength degradation e.g. corrosion | 4.9E-08 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| TV2211b | Operator failed to weigh tanker empty weight | | 1.4E-03 | 1.4E-03 | 1.6E-03 | 8.9E-03 | 3E-03 | 3E-03 |
| TV2212b | Operator read wrong tanker gross weight | | 1.4E-04 | 1.4E-03 | 1.6E-03 | 8.9E-03 | 2E-02 | 1E-02 |
| TV2221b | Operator set wrong trip weigh above maximum | | 1.4E-04 | 1.4E-03 | 1.6E-03 | 8.9E-03 | 3E-03 | 1E-02 |
| TV2222b | Weigh trip system faulty | 1.1E-03 | | | | | | |
| TV22b | Overpressure is strong enough to rupture tanker above liquid line | 6.6 E-03 | | | | | | |
| TV3b | Tanker rupture due to collision with moving vehicle e.g. lorry | 3.7E-08 | | | | | | |

Table A15.4. Input for QRA scenarios using Fault Tree Approach - Site B

| Scenarios | Hole Size ( mm) | Release Rate (kg/s) | Duration of Release (min) | Failure Rate (Hardware and Human Error) | Failure Rate (Hardware Only) |
|---|---|---|---|---|---|
| 1. Liquid releases from road tanker failure below liquid line | 100 | 169 | 30 | 7.7E-08/loading<br>7.4E-06 /year | 1.1E-06/loading<br>1.1E-04/year |
| 2. Vapour releases from road tanker above liquid line | 100 | 8.5 | 30 | 7.7E-08/loading<br>7.4E-06/year | 1.1E-06/loading<br>1.1E-04/year |
| 3. 2-phase release due guillotine failures of 3 in. liquid flexible hose | 75 | 70.7 | 20 | 5.8E-09/loading<br>5.6E-07/year | 5.3E-05/loading<br>5.1E-03/year |
| 4. Vapour release due to guillotine failures of 2 in. vapour return flexible hose | 50 | 0.94 | 20 | 2.9E-09/loading<br>2.8E-07/year | 3.4E-05/loading<br>3.3E-03/year |
| 5. 2-phase release due to guillotine failures of 4 in. liquid supply line | 100 | 37 | 20 | 2.9E-09/loading<br>2.8E-07/year | 2.6E-05/loading<br>2.5E-03/year |
| 6. Vapour release from guillotine failure of 3 in. vapour return line | 75 | 0.7 | 20 | 2.9E-09/loading<br>2.8E-07/year | 2.0E-05/loading<br>1.9E-03/year |

# *Appendix 16*

## Fault Tree Minimum Cut Set (MCS) Importance

Table A16.1. Fault Tree Minimum Cut Set (MCS) Importance for Site A

| MCS No | Minimal Cut Set (MCS) | MCS Values | MCS Importance (%) | Base Event Description |
|---|---|---|---|---|
| 11 | HL1411bHL21b | 2.5E-04 | 32.1 | HL1411b- Operator failed to open tanker inlet valve<br>HL21b- Operator failed to isolate leak |
| 7 | HL1412bHL21b | 2.5E-04 | 32.1 | HL1412b- Vapour valve on tanker remain shut<br>HL21b- Operator failed to isolate leak |
| 25 | HV1412bHL21b | 2.5E-04 | 32.1 | HL1412b- Vapour valve on tanker remain shut<br>HL21b- Operator failed to isolate leak |
| 59 | HV121bHV122bHL21b | 6.5E-08 | 6.8 | HV121b- Operator failed to close vapour return line<br>HV122b - Operator failed to put wheel chocks<br>HL21b- Operator failed to isolate leak |
| 21 | HL121bHV122bHL21b | 6.5E-08 | 6.8 | HL12Ib - Driver moves tanker while filling in progress<br>HV122b - Operator failed to put wheel chocks<br>HL21b - Operator failed to isolate leak |

Table A16.2. Fault Tree Minimum Cut Set (MCS) Importance for Site B

| MCS No | Minimal Cut Set (MCS) | MCS Values | MCS Importance(%) | Base Event Description |
|---|---|---|---|---|
| 11 | HL1411bHL21b | 6.38E-07 | 27.7 | HL1411b- Operator failed to open tanker inlet valve<br>HL21b- Operator failed to isolate leak |
| 7 | HL1412bHL21b | 6.38E-07 | 27.7 | HL1412b- Vapour valve on tanker remain shut<br>HL21b- Operator failed to isolate leak |
| 25 | HV1411bHL21b | 6.38E-07 | 27.7 | HV1411b- Operator failed to close vapour return line<br>HL21b- Operator failed to isolate leak |
| 2 | TL1b | 4.9E-08 | 2.1 | TL1b - Road tanker rupture due to strength degradation |
| 21 | HV15bHL21b | 4.07E-08 | 1.8 | HV15b - Operator disconnect hose while filling in progress<br>HL21b - Operator failed to isolate leak |
| 15 | HL15bHL21b | 4.07E-08 | 1.8 | HL15b - Operator failed to connect hose to plant<br>HL21b - Operator failed to isolate leak |

# Appendix 17

## Base Events Contribution to System Failure and Suggestions for Improvements

Table A17.1. Base Events contribution to system failure and suggestions for error reduction for Site A

| Base Event Number | Description of Event | Contribution to system failure (%) | Suggestions for error reduction |
|---|---|---|---|
| HL21b | Operator failed to isolate leak in the event of liquid hose rupture | 49% | 1. Hardware Modification<br>• Installing separate outlet for tanker filling fitted with non-return and excess flow valve to prevent outflow of ammonia inside the road tanker during filling.<br>• Protecting road tanker loading bays that situated next to vehicle route inside the plant with physical barrier, e.g. bollard poles to prevent moving vehicles from accidentally hit the loading system during filling.<br>2. Human Error Improvements<br>• Ensuring that operator wear the right PPE during filling operation that would enable him to isolate the leak in the event of hose rupture. The current practice of wearing gas mask is not sufficient to deal with major releases of ammonia.<br>• Ensuring adequate training and drill to deal with major ammonia releases are conducted regularly |
| HL14111b | Operator failed to open tanker inlet valve but commences pumping | 14% | 1. Hardware Modification<br>• Improve inlet valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior disconnection |

| | | | |
|---|---|---|---|
| HL14111b | Operator failed to open tanker inlet valve but commences pumping | 16% | 1. Hardware Modification<br>• Improve tanker inlet valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior commences filling. |
| HL 14121b | Operator failed to open tanker vapour outlet valve | 16% | 1. Hardware Modification<br>• Improve outlet valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior starting the filling pump |
| HV1411b | Operator failed to closed plant vapour return line when filling commences | 16% | 1. Hardware Modification<br>• Improve vapour return valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior starting the pump filling |

Table A17.2. Base Events contribution to system failure and suggestions for error reduction for Site B

| Base Event Number | Description of Event | Contribution to system failure (%) | Suggestions for error reduction |
|---|---|---|---|
| HL21b | Operator failed to isolate leak in the event of liquid hose rupture | 47% | 1. Hardware Modification<br>Installing separate outlet for tanker filling fitted with non-return and excess flow valve to prevent outflow of ammonia inside the road tanker during filling<br><br>2. Human Error Improvements<br>• Ensuring that operator wear the right PPE during filling operation that would enable him to isolate the leak in the event of hose rupture.<br>• Ensuring adequate training and drill to deal with major ammonia releases are conducted regularly |
| HV15b | Operator disconnect hose while filling operation is in progress | 11% | 1. Human Error Improvements<br>• Improving the disconnecting procedures by adding checklist of critical steps to be taken prior disconnection<br>Introducing compulsory checking by a supervisor or second operator prior to hose disconnection |

| | | | |
|---|---|---|---|
| HL14111b | Operator failed to open tanker inlet valve but commences pumping | 14% | 1. Hardware Modification<br>• Improve inlet valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior disconnection |
| HL14121b | Operator failed to open tanker vapour outlet valve | 14% | 1. Hardware Modification<br>• Improve outlet valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior starting the filling pump |
| HV14111b | Operator failed to closed plant vapour return line when filling commences | 14% | 1. Hardware Modification<br>• Improve vapour return valve position indicator using easily to read mark<br>2. Human Error Improvements<br>• Improving the connecting procedures by adding checklist of critical steps to be taken prior starting the pump filling |
| TL1b | Tanker rupture due to strength degradation | 1% | 1. Hardware Modification<br>• Provides higher corrosion allowance for tanker design<br>2. Human Error Improvements<br>Improving inspecting procedures by adding the requirements of using NDT to detect possible failures, e.g. cracks due to stress corrosion cracking (scc) |

# *Appendix 18*

**Eliciting PIFs Rating from PRIMA Audit -**
**Samples for PIF of Experience at Site A and Site B**

Table A18.1 Eliciting PIFs Rating from PRIMA Audit results for PIF of Experience at Site A

| PIF (Performance Influencing Factors) | THEME A (Procedures and Process to do the Job) | THEME B (Standards to do the Job) | THEME C ( Other Pressures Interfere with the Job) | THEME D (Resources to do the Job) |
|---|---|---|---|---|
| **EXPERIENCE** | Level 5 - System Climate<br>A.5.1- Forum to access industry guidance on managing human error<br>(No specific forums to access experience to industry guidance and corporate expertise expect from bit and pieces from general aspect of PSMS from seminar and workshop) | Level 5 - System Climate<br>B.5.1- Industry guidance, regulations and code of practice (c.o.p) used to develop criteria for management of human error in operation i.e. for operator selection, training and assessment<br>(No specific guidance except to fulfil the country regulation on general requirement of SMS) | Level 5 - System Climate<br>C.5.1- Pressures in managing potential operator error i.e.,<br>-allocation of qualified person to operation<br>-level of training<br>(Shortage of worker in that area, stiff wages competition and high worker turnover limit the level of training and availability of qualified person for operation | Level 5 - System Climate<br>D.5.1- Access to trained and experienced operator<br>(Shortage of worker in that area, stiff wages competition and high worker turnover limit the level of training and availability of qualified person for operation- rely on existing worker where few of them have more than 5 years experience |
| | Level 4 - Organisational Process d Structure<br>A.4.4-Ensuring sufficiency of operator training and promotion criteria<br>(The Plant Manager on advice of supervisor decides on sufficiency of operator training and this factor used as one of the criteria for promotion<br>A.4.6-Requirements of technical skill training of operation personnel<br>(No specific policy but personnel is required to have technical skill | Level 4 - Organisational Process and Structure<br>B.4.1- Integration of external guidance and standard on operator error<br>(No external or internal standard used, only through experience deciding whether an error made is serious that need to be highlighted and corrected)<br>B.4.2- Auditing and assessing standard on the management of operator error<br>(No audit or assessment made, | Level 4 - Organisational Process and Structure<br>(None) | Level 4 - Organisational Process and Structure<br>D.4.4-Responsibility to identify and implement training need for operation personnel<br>(Plant Manager and supervisor identify and implement training need-but seldom go beyond day to day operational need)<br>D.4.6-Assessing competency of employees<br>(No formal system to access competency only through observation by supervisor and plant manager and length of |

| | | | | |
|---|---|---|---|---|
| | to know how to carry out job assigned to them safely and efficiently)A.4.11-Revising training of operations personnel in light of experience<br>(Ad-hoc manner only when the experience shows that urgent revisions need to be done) | rely on limited management knowledge and experience on managing operator error) | | service) |
| | Level 3 - Communication Control and Feedback<br>A.3.2- Documentation on the training of operation personnel<br>(No documentation for the on the job training)<br>A.3.3- Documentation on operator competency requirement<br>(No documentation on the requirement of operator competency) | Level 3 - Communication Control and Feedback<br>(None) | Level 3 - Communication Control and Feedback<br>(None) | Level 3 - Communication Control and Feedback<br>D.3.2- Programme of technical skill training for operators.<br>(On the job training cover the basic requirement for efficient and safely execution of operational task. Job rotation provides training in other section, i.e. maintenance and special task (ship loading) |
| | Level 2 - Operator Reliability<br>(None) | Level 2 - Operator Reliability<br>(None) | Level 2 - Operator Reliability<br>C.2.2- Improving training after accident or incident<br>(Improvement of training from lesson learnt through serious incident/accident)<br>C.2.5- Type of training received when starting and further training received<br>(On the job training when | Level 2 - Operator Reliability<br>D.2.3- Assessing competency of worker before assigning duty<br>(Only through observation and interview)<br>D.2.5- Familiarisation with plant equipment, piping and vessel interfaces such as gauges, valve and display<br>(Operator is observed quite |

| | | | | |
|---|---|---|---|---|
| | | | starting and further training only on emergency response and fire fighting) | familiar with plant item due to relatively simple process hardware and layout)<br>D.2.7- Experience with other plant<br>(Only the MEd and one supervisor had some experience working in ammonia plant before) |

Table A18.1 Eliciting PIFs Rating from PRIMA Audit results for PIF of Experience at Site B

| PIF (Performance Influencing Factors) | THEME A (Procedures and Process to do the Job) | THEME B (Standards to do the Job) | THEME C (Other Pressures Interfere with the Job) | THEME D (Resources to do the Job) |
|---|---|---|---|---|
| **EXPERIENCE** | Level 5 - System Climate<br>A.5.1- Forum to access industry guidance on managing human error (Industry guidance and corporate expertise obtained from previous multinational owner and from time to time from technical report or bulletin and also from general aspect of PSMS from seminar and workshop) | Level 5 - System Climate<br>B.5.1- Industry guidance, regulations and c.o.p used to develop criteria for management of human error in operation i.e. for operator selection, training and assessment (Guidance laid down by previous multinational owner and the country regulation on general requirement of SMS) | Level 5 - System Climate<br>C.5.1- Pressures in managing potential operator error i.e.,<br>-allocation of qualified person to operation<br>-level of training<br>(Low profit margin due to stiff competition and shrinking market forced the company to carry out cost cutting measures in term of not replacing retired worker and reducing non-essential training) | Level 5 - System Climate<br>D.5.1- Access to trained and experienced operator (Worker mostly has started their career with the parent company and stays with the company ever since so there is no shortage of experienced worker. Good wages and working conditions allowed the company to keep these experienced workers) |

| | | | | |
|---|---|---|---|---|
| | Level 4 - Organisational Process and Structure<br>A.4.4-Ensuring sufficiency of operator training and promotion criteria<br>(Sufficiency of operator training has being laid out in written training document prepared by previous multinational owner and this factor used as one of the criteria for promotion)<br>A.4.6-Requirements of technical skill training of operation personnel<br>(Written policy on operator technical skill most of them undergo compulsory 6 months basic training followed by structured apprenticeship scheme over a number of years)<br>A.4.11-Revising training of operations personnel in light of experience<br>(Ad-hoc manner only when the experience show that urgent revisions need to be done) | Level 4 - Organisational Process and Structure<br>B.4.1- Integration of external guidance and standard on operator error<br>(No specific external or internal standard used, only through guidelines laid down by previous multinational owner and over 20 years experience in handling ammonia in bulk quantities)<br>B.4.2- Auditing and assessing standard on the management of operator error<br>(Audit or assessment used to be carried out but lately was not due to lack of resources since the site is made into separate business entity from its parent fertiliser plant) | Level 4 - Organisational Process and Structure<br>(None) | Level 4 - Organisational Process and Structure<br>D.4.4-Responsibility to identify and implement training need for operation personnel<br>(Plant Manager and supervisor identify and implement training need-but seldom being carried out for operational need now as the worker has long experience. Currently training is given only on areas of emergency response and performance control)<br>D.4.6-Assessing competency of employees<br>(Apprenticeship system to access competency was carried out when the operator start working and on the job assessment through observation by supervisor and plant manager for further promotion) |

| | | | | |
|---|---|---|---|---|
| | Level 3 - Communication Control and Feedback<br>A.3.2- Documentation on the training of operation personnel (Using documentation prepared by previous multinational owner)<br>A.3.3- Documentation on operator competency requirement (Using documentation prepared by previous multinational owner that specify type of training but duration depends on a person ability) | Level 3 - Communication Control and Feedback<br>(None) | Level 3 - Communication Control and Feedback<br>(None) | Level 3 - Communication Control and Feedback<br>D.3.2- Programme of technical skill training for operators.<br>(After basic training workers start their career in the company as either operator or supporting personnel, i.e. maintenance. Technical skill training develops for the two groups of worker will be different. Operator will develop solely operational skill to operate various plants within the work while maintenance will be trained to maintain that plant's equipment) |
| | Level 2 - Operator Reliability<br>(None) | Level 2 - Operator Reliability<br>(None) | Level 2 - Operator Reliability<br>C.2.2- Improving training after accident or incident (Improvement of training made from lesson learnt through serious incident/ accident world wide) | Level 2 - Operator Reliability<br>D.2.3- Assessing competency of worker before assigning duty (Through observation and interview)<br>D.2.5- Familiarisation |

| | | | | |
|---|---|---|---|---|
| | | | C.2.5- Type of training received when starting and further training received (After basic training workers start their career in the company as either operator or supporting personnel, i.e. maintenance. Technical skill training develops for the two groups of worker will be different. Operator will develop solely operational skill to operate various plants within the work while maintenance will be trained to maintain that plant's equipment. Further training mainly for emergency response and performance purposes) | with plant equipment, piping and vessel interfaces such as gauges, valve and display (Operator is observed familiar with plant item due to long working experience and only on operations) D.2.7- Experience with other plant (Most of the operator has more than 10 years experience working with fertiliser plant which use bulk quantities of ammonia as feedstock) |