APPENDIX 7.02 HAZARD TO LIFE ASSESSMENT FOR THE USE OF EXPLOSIVES

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1 INTRODUCTION

1.1 Scope of the Study

1.1.1.1 Drill and blast excavation method is adopted during construction of the cavern for this project. This Appendix addresses, in particular, the followings:

- Transport of explosives from the Delivery Point to the blast faces; and
- Use of explosives during the construction of the cavern, including:
  - Use of cartridged emulsion explosives;
  - Use of bulk emulsion explosives; and
  - Use of blasting accessories includes detonators, detonator cords and surface connectors;

1.2 EIAO TM Risk Criteria

1.2.1.1 Annex 4 of the EIAO-TM specifies the Individual and Societal Risk Guidelines. The Hong Kong Government Risk Guidelines (HKRG) per the EIAO-TM Annex 4 states that the individual risk is the predicted increase in the chance of fatality per year to an individual due to a potential hazard. The individual risk guidelines require that the maximum level of individual risk should not exceed 1 in 100,000 per year i.e. 1 x10^{-5} per year. Societal risk expresses the risks to the whole population. It is expressed in terms of lines plotting the cumulative frequency (F) of N or more deaths in the population from incidents at the installation. Two F-N risk lines are used in the HKRG that demark “Acceptable” or “Unacceptable” societal risks. To avoid major disasters, there is a vertical cut-off line at the 1000 fatality level extending down to a frequency of 1 in a billion years. The intermediate region indicates the acceptability of societal risk is borderline and should be reduced to a level which is “As Low As Reasonably Practicable” (ALARP). It seeks to ensure that all practicable and cost effective measures that can reduce risk are considered. The HKRG is presented graphically in **Figure 1.1**.

1.2.1.2 The risk guidelines specified in the EIAO-TM apply to risk of fatality due to storage, transport and use of explosives. They are only applicable to public outside the boundary of the hazardous installation. Risk to workers on the project construction site, DSD staff and its contractors have not been included in this study as they are considered as voluntary risk takers.

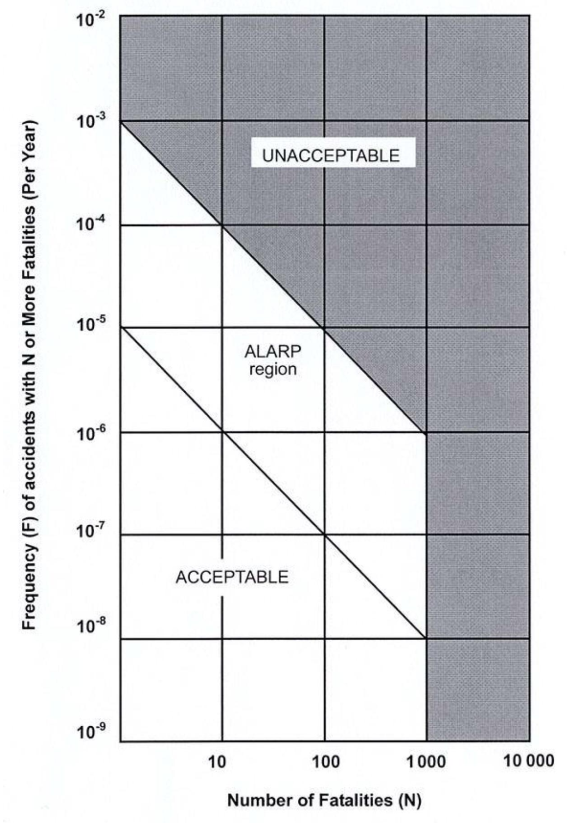


Figure 1.1 Societal Risk Guidelines for Acceptable Risk Levels

2 PROJECT DESCRIPTION

2.1 Project Overview

2.1.1.1 The existing STSTW has been proposed to be relocated to caverns and the location of the caverns is below Nui Po Shan and bounded by Mui Tsz Lam Road to the North and A Kung Kok Street to the West.

2.1.1.2 The layout of the cavern complex has been developed based on considerations of a number of disciplines, especially the sewage treatment process. The footprint consists of a series of parallel caverns aligned along the long axis of the complex. The process caverns have a generally consistent excavated span of around 32m but the height of the caverns varies dependent on the sewage treatment process being undertaken in each cavern.

2.1.1.3 Two access tunnels are proposed to connect to the caverns. One of the tunnel portals is located at the junction of Mui Tsz Lam Road and A Kung Kok Street and the other portal is located close to the current DSD site on Mui Tsz Lam Road.

2.1.1.4 A ventilation shaft is also proposed at the southwest side of the cavern.

2.1.1.5 The proposed Sha Tin Cavern Sewage Treatment Works (CSTW) will be located in caverns excavated within fresh to slightly decomposed granite. Due to the high strength of the rock, the large excavation spans required, the number of access tunnels and connections, drill and blast excavation construction method is the only practical and economical method.

2.1.1.6 Construction of the Project is tentatively scheduled to commence in 2017 for completion in 2027, and the peak cavern excavation year will be around 2020 - 2022. After Year 2022, it is anticipated that civil, E&M, testing and commissioning works will be carried out inside the cavern and some building and landscaping works outside the cavern. Assessment year for construction stage is taken as 2022; no explosive will be used during operation stage of the Project and thus hazard assessment for explosives related issue is not necessary for operation stage.

2.2 Blasting Process

2.2.1 Cavern Blasting Procedure

2.2.1.1 Further to the Section 2.1 to 2.2 of **Appendix 7.01**, the cavern and tunnel excavation works is to start at the site of the main access tunnel portal. After the completion of the tunnel portal, excavation of the main access tunnel would move up to the north-west corner of the relocated STSTW. Then excavation of the western and northern perimeter accesses would follow. Work fronts of blasting would increase along with the progress of caverns excavation. As more work fronts and resources are allowed, blasting at perimeter accesses and caverns for treatment facilities will be carried out simultaneously.

2.2.2 Centralised Blasting System (CBS)

2.2.2.1 Unlike normal tunnelling projects in Hong Kong, multi-face blasting is necessary for the timely completion of this Project. It is expected that up to 8 faces are to be blasted per day during construction.

2.2.2.2 Centralised Blasting System (CBS) is a very effective way to provide high level of safety and reliability for multi-face underground blasting. The typical procedure is: blast faces are prepared and loaded, and once each face is completed, the local area is securely sealed off. Computer controlled firing mechanism and sensors on the security measures ensure that the blast face cannot accidentally initiate, and there will be warning if anyone approaches the sealed off blast area. Other blast faces in the underground works may still be under charging, and these will gradually be completed and the areas sealed off. Once all blast faces are prepared for blasting, then workers are evacuated from the entire underground works, and the blasting is carried out from a centralised computer under strict control and supervision.

2.2.2.3 The advantage of the CBS is:

- Enhance safety
- Improve reliability with real-time availability of information and on-board diagnostics
- Optimise productivity
- Flexibility of expanding or removing blast faces
- Remote access of blasting data

2.2.2.4 The Project is a big challenge in Hong Kong with about 2.4 million m^3 of rock to be excavated from the caverns. CBS is deemed the only effective way to achieve the already tight and long programme.

2.3 Instrumentation and Monitoring

2.3.1 Blasting Monitoring

2.3.1.1 In order to ensure the blasting work is carried out within the specified limits, and also to confirm the design assumptions, blast monitoring is carried out.

2.3.1.2 Blast monitoring sensors are generally located within blasting zone of influence, and concentrated at nearest structures and any particularly sensitive receivers that have low allowable vibration levels. When near tunnel portals, air overpressure monitoring is carried out at the same location as the ground vibration monitoring.

2.3.1.3 Blast vibration monitoring equipment consists of a sensor which is firmly mounted to the ground. On rock, it may be bolted or glued, and in soil it may be buried and/or spiked into the ground. The sensor has three orthogonal axes and the principal axis must be aligned towards the blast source.

2.3.1.4 The trigger level for the sensor should be set to avoid accidental triggering by background vibrations. Typically the trigger level would be 0.5mm/s to 1mm/s. For air overpressure, the trigger level may vary depending on atmospheric conditions, and in many instances it may be necessary to rely solely on the ground vibration to trigger the recording.

2.3.1.5 As the location of blasting progresses along the tunnels, the active sensor locations would be changed in order to provide the most accurate recording of the blast effects.

2.3.2 Instrumentation Monitoring Schedule

2.3.2.1 Blast monitoring is required for every blast carried out. In general, for each blast, a minimum of six sensor locations (including three highest ranked controlling sensitive receivers for that blast; and the locations of another three monitoring points) shall be carried out for each blast. The monitoring points should include various sensitive receivers such as slopes, retaining walls, utilities, buildings etc.

2.3.3 Alert, Action and Alarm Limits for Vibration and Air Overpressure (AOP)

2.3.3.1 Alert, Action and Alarm levels are normally set up for the monitoring of the effect on the concerned sensitive receivers due to the blasting works. The Alert, Action and Alarm levels are typically 90%, 95% and 100% of the allowable maximum permissible blast induced vibration to which the vibration sensitive receiver may be exposed.

2.3.3.2 Alert Level is typically set at 90% of the vibration limit of the sensitive receiver; if exceeded, an agreed suite of remedial measures will be developed for implementation should the “Action” Level criteria be exceeded.

2.3.3.3 Action Level is typically set at 95% of the vibration limit of the sensitive receiver; if exceeded, remedial/ mitigation measures will be instituted as appropriate.

2.3.3.4 Alarm Level is typically set at the vibration limit of the sensitive receiver; if exceeded, blasting works at the site concerned will stop immediately and would only recommence once the blasting works had been revised to ensure that such an event would not reoccur. Alert, Alarm and Action (AAA) levels are assigned to all monitoring locations.

2.3.3.5 For ground vibration, the levels are related to a proportion of the actual limit for the sensor location. Levels and the corresponding control procedures to be carried out are shown in **Table 2.1**.

Table 2.1 Alert, Action and Alarm (AAA) levels for Ground Vibration

Control Level	Vibration Level	Procedures/Requirements
Alert	90% of the specified limit	- Inform the Engineer, Blasting Engineer, Blasting Competent Supervisor (BCS) of occurrence. - Review monitoring data and recording equipment for accuracy. - Check secure placement of transducers. - Review blast pattern and parameters. - Inspect sensitive receivers affected. - Prepare action plan. - Continue blasting.
Action	95% of the specified limit	- Inform the Engineer, Blasting Engineer, BCS, Geotechnical Engineering Office (Mines Division) immediately. - Review / modify blast pattern and blast parameters - Review and implement action plan if necessary. - Detailed inspection of all affected sensitive receivers. - Plan and prepare remedial works if necessary. - Seek approval from the Engineer to resume blasting.
Alarm	100% of the specified limit	- Report occurrence to the Engineer, Blasting Engineer, BCS and GEO Mines Division immediately. - Assess the possible blast related reasons for the vibration exceedance / non-compliance. - Cease blasting works immediately after exceeding the allowable vibration limit and further blasting can only be carried out after approval by relevant site supervision personnel is sought. - Immediate inspection of affected sensitive receivers. - Implement action plan. - Undertake remedial works as necessary.

Control Level	Vibration Level	Procedures/Requirements
		- Blasting Engineer to review and modify the blast design with the Contractor to comply with the limits. - Modify the blast vibration assessment parameters to reduce the PPV and estimated charge weight per delay. - The Engineering Geologist shall review the blast area and the vibration monitoring area and the vibration monitoring area that exceeded the allowable limit and identify whether any geological feature was contributing to the excessive vibration level. - Seek approval from the Engineer and the BCS to resume a period of trial blasting after the various investigations have been carried out.

2.3.3.6 Air overpressure monitoring is carried out at locations where the public has access around the perimeter of the site, nearest to the portals, rather than the blast location itself. Typically, 120dB (Linear) should be considered the maximum permissible level for blasting in the Hong Kong built environment but may be assessed on a case by case basis in case the 120dB (Linear) limit is exceeded. The exceedance may be due to the significant effects that environmental factors such as wind speed and direction, humidity and temperature have on the air overpressure and the transmission of the pressure wave to sensitive receivers.

2.3.3.7 Air overpressure for blasting works is monitored against the following “Alert”, “Alarm” & “Action” Levels and carried out the corresponding control procedures as shown in **Table 2.2**.

Table 2.2 Alert, Action and Alarm (AAA) levels for Air Overpressure

Control Level	AOP Level	Procedures/Requirements
Alert	118dBL	- Review monitoring data and recording equipment for accuracy. - Check placement of microphone. - Check microphone is wind shielded. - Measure background wind DBL level, - Continue blasting.
Action	119dBL	- Carry out all alert actions. - Review / modify blast pattern and blast direction. - Prepare action plan. - Resume blasting.
Alarm	120dBL	- Report occurrence to the Engineer, Blasting Engineer, BCS and GEO Mines Division immediately. - Carry out all alert actions. - Implement action plan if required. - Stop blasting if public complaints are received. - Review / modify blast design and blast direction. - Seek approval from the Engineer and BCS to resume a period of trial blasting.

2.3.4 Blast Monitoring Reporting

2.3.4.1 Prior to carrying out blasting work at any location, the Contractor would provide a report to the Engineer for approval, identifying the blast location, the monitoring points and the controlling sensitive receivers to be monitored, for the agreement of the Engineer. The Blasting Assessment Report would identify the current status of the critical sensitive receivers and their allowable charge weights and any relevant observations that would reduce or constrain the maximum instantaneous charge weights (MIC) for the blast.

2.3.4.2 The Contractor would then follow up after the blast with a report outlining the actual blast design and the monitoring results for vibration and AOP at each agreed monitoring point and any exceedances or anomalies during the blast. Any corrective actions or complaints from the general public would also be provided in the report. In addition, the report would provide reference to the inspections carried out to verify the performance of the existing slopes, boulders and nearby sensitive receivers and any proposed remedial measures necessary to ensure the safety of the works in the surrounding area.

2.3.4.3 The Contractor is to provide examples of the reports to be submitted to the Engineer for agreement prior to commencing the blasting works.

2.3.4.4 Blast vibration response spectra would also be provided with respect to the three axes, comprising frequency, acceleration and displacement.

2.3.4.5 The Contractor is to provide the digital records of the blast vibration and AOP monitoring to the Engineer for his records.

2.3.5 Initial Blast

2.3.5.1 Blasting shall be carried out strictly according to the approved blast design and Blasting Permit. No variation of MIC deviating from the approved design and Blasting Permit shall be allowed during the course of blasting.

2.3.5.2 Field data on ground vibration and AOP will be obtained from the initial blasts to verify the blast design. Regression analyses shall be carried out on monitoring data to obtain site specific constants for the attenuation of ground vibrations and AOP. Should this analysis demonstrate that alternative site specific constants would give a more accurate prediction of the ground vibration or AOP, the Contractor may propose to Mines Division (MD) the adoption of new constants for use in future blast design. If MD agrees to the adoption of alternative site specific constants, the MIC should be increased, if applicable, in a cautious manner, such that the permissible peak particle velocity (PPV) and target AOP at sensitive receivers are not exceeded.

2.4 Explosive Types

2.4.1.1 The proposed explosives including the types, properties, cartridged emulsion, bulk emulsion, blasting explosives and detonating devices have been discussed in the Section 2.3.1 to 2.3.6 of **Appendix 7.01**.

2.5 Statutory/Licensing Requirement and Best Practice

2.5.1 Use of Explosives

2.5.1.1 Bulk emulsions are manufactured at the blast sites and use immediately for rock blasting. A licence is required to manufacture a nitrate mixture outside a factory as Category 1 DG under Regulation 31A of the Dangerous Goods (General) Regulations Cap. 295B.

2.5.1.2 For the manufacturing of bulk emulsion at blast sites, ammonium nitrate (AN), which is classified as Category 7 – Strong Supporters of Combustion under Regulation 3 of the

Dangerous Goods (Application and Exemption) Regulations Cap. 295A, is used. A licence for the storage of Category 7 DGs is required from the Fire Services Department.

2.5.1.3 For the use of explosives, a blasting permit is required from the MD so that the use of explosives at a work site for the carrying out of blasting is allowed; and a Mine Blasting Certification is required so that the shotfirer is permitted to use explosives in blasting.

2.6 Construction Cycle

2.6.1.1 The proposed on site delivery-blasting cycle will consist of the following elements:

- Transfer from the delivery points of the construction areas to the working faces of the excavation; and
- Load and fire the faces to be blasted. Blasts in a particular area will be initiated from a common firing point once all personnel are clear and entry routes to each blast site are secured.

2.7 Concurrent Projects during Construction Phase

2.7.1.1 Apart from construction phase, explosives are not expected to be used, stored or transported, particularly during operation and decommissioning. However, as no other concurrent, planned or committed projects leading to any other hazardous events have been identified at the present stage, it is then reasonable to conclude there will be no potential cumulative impacts expected to arise during the Project cycle.

3 HAZARD IDENTIFICATION

3.1 Features Considered for this Study

3.1.1 General

3.1.1.1 The following features within a distance of 250m were considered as sensitive receivers in this Study. The distance is equivalent to a peak particle velocity value of approximately 25mm/s based on the blasting design. These features were identified by either desktop review or site survey.

3.1.2 Man-made Slopes and Retaining walls

3.1.2.1 These features included cut slopes, fill slopes, retaining walls and a combination of all the above. These slopes are covered with all types of facing, including shotcrete, chunam, stone facing and vegetation.

3.1.3 Natural Terrain Hillside and Boulders

3.1.3.1 As the project site is located within a cavern which is surrounded by natural terrains, natural terrains within the 250m distance are considered in this Study.

3.1.4 Existing Buildings and Structures

3.1.4.1 Buildings and structures within 250m from the project site are considered in this Study.

3.1.5 Utilities

3.1.5.1 The nearest HP underground town gas transmission pipeline is at a distance of around 260m from the project site. Therefore, it is not further considered in this Study.

3.2 Hazardous Scenarios

3.2.1.1 Possible hazardous scenarios associated with the use of explosives are:

- Higher than expected vibration generated by the blast face in the blasting process;
- Higher than expected vibration and air overpressure due to detonation of a full load of explosives whilst transferring explosives from the delivery point to the portals; and
- Higher than expected vibration and air overpressure due to detonation of a full load of explosives within tunnel, cavern and ventilation shaft whilst handling explosives for blasting process.

3.3 Hazards from the Blasting Process

3.3.1.1 Hazards from the blasting process are considered to be the hazards induced by the blasting of a blast face. The design of the blast face is determined by the permitted vibration level of the sensitive receivers which is expected not to cause any damages to the receivers. However, potential hazards may occur when the process is completed with deviation with the designed process. Higher than expected vibration may be induced by such events.

3.3.1.2 According to WIL Study [1], the major hazard from blasting operations is flying debris. Flying debris is identified as a rock that has been propelled beyond the blasting area by the force of an explosion. The cause of flying debris is mismatch of the distribution of explosive energy, type of confinement of the explosive charge, mechanical strength of the rock and lack of security measures at blasting area.

3.3.1.3 In this project, the effect of overpressure and flying debris is not considered as a blast door is in place and closed during the blasting process.

3.4 Hazards from Onsite Transport of Explosives

3.4.1.1 Cartridged emulsions, detonators and detonating cords are onsite transported from the delivery point to portal and then to the blast faces through the access tunnel. The explosives are transported by a licensed diesel vehicle. Potential hazards include higher than expected vibration due to detonation of full load of explosives during onsite transportation.

3.4.1.2 There are also manually transfer of cartridged emulsions, detonators and detonating cords from the magazine site to ventilation shaft through a 20m access road. The cartridged cases and detonating cords delivered to the ventilation shaft will be conveyed to the ventilation shaft blast face using an appropriate and certified lifting system (such as man-cage) through shaft. The lifting system is provided with safety lock to prevent the fall of explosives in case of lifting mechanism failure.

3.4.1.3 The ventilation shaft is 20m away from the magazine. An amount of 28.9kg of explosives is to be delivered from the explosives store to the ventilation shaft by manual transfer without the use of any tools which are susceptible to initiate the explosives.

3.4.1.4 The blast effect distance for 1% fatality probability for indoor population from detonation of 28.9kg of explosives is 29m, which is well covered by the hazard zone of detonation of full load of explosives in an explosives store. The generic failure frequency of storage of explosives has already taken into account the manual transfer of explosives, it is thus considered that the risk from detonation of explosives during the 20m manual transfer from magazine to ventilation shaft has already been covered in the hazard assessment for the storage of explosives.

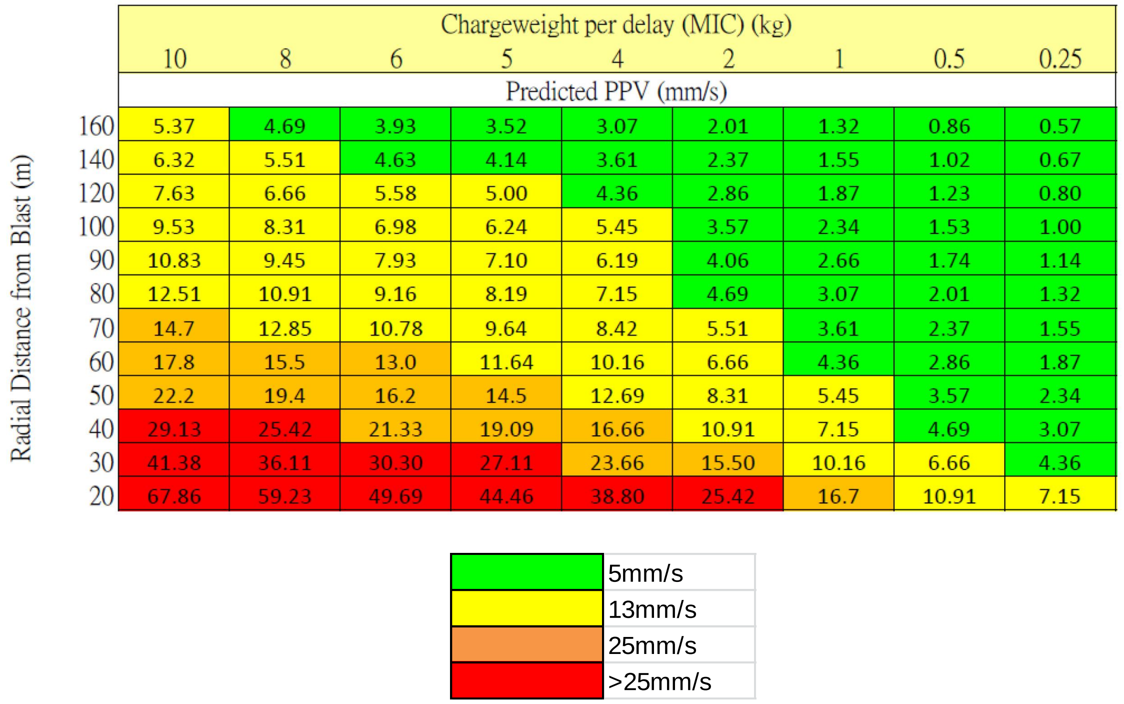
3.4.1.5 Moreover, the blast hazard distance for this transfer of 28.9kg explosives is well confined within the construction site boundary of the ventilation shaft, therefore no offsite impact is expected.

3.4.1.6 The amount of full load for the diesel vehicle is 200kg and that of manual transfer to ventilation shaft from magazine site is 28.9kg under this study.

3.5 Ground Vibration Associated With Use of Explosives

3.5.1.1 During rock excavation, ground vibration is a potential hazard if the stress wave intensity is high enough to induce a high level vibration. Peak particle velocity has been observed to be a good indicator of damage to structures and it is generally considered that reinforced concrete structures in good condition can readily tolerate a peak particle velocity of 50mm/s without any risk of damage. However, it is possible that there will be amplification between the peak ground motion and that experienced by the structure, therefore a peak particle velocity of the ground motion of 25mm/s is used locally and internationally to prevent damage to buildings. This criterion is specified, for example, by the MTR for its structures when subjected to transient vibrations and also by the Hong Kong SAR General Specification for Civil Engineering Works.

3.5.1.2 Ground vibrations induced by this stress wave have a peak velocity that is related to the instantaneous charge weight (MIC) and the distance from the blast source. **Figure 3.1** presents the typical range of charge weights and predicted vibration levels using the MD vibration constants.



Radial Distance from Blast (m)	Chargeweight per delay (MIC) (kg)								
	10	8	6	5	4	2	1	0.5	0.25
	Predicted PPV (mm/s)								
160	5.37	4.69	3.93	3.52	3.07	2.01	1.32	0.86	0.57
140	6.32	5.51	4.63	4.14	3.61	2.37	1.55	1.02	0.67
120	7.63	6.66	5.58	5.00	4.36	2.86	1.87	1.23	0.80
100	9.53	8.31	6.98	6.24	5.45	3.57	2.34	1.53	1.00
90	10.83	9.45	7.93	7.10	6.19	4.06	2.66	1.74	1.14
80	12.51	10.91	9.16	8.19	7.15	4.69	3.07	2.01	1.32
70	14.7	12.85	10.78	9.64	8.42	5.51	3.61	2.37	1.55
60	17.8	15.5	13.0	11.64	10.16	6.66	4.36	2.86	1.87
50	22.2	19.4	16.2	14.5	12.69	8.31	5.45	3.57	2.34
40	29.13	25.42	21.33	19.09	16.66	10.91	7.15	4.69	3.07
30	41.38	36.11	30.30	27.11	23.66	15.50	10.16	6.66	4.36
20	67.86	59.23	49.69	44.46	38.80	25.42	16.7	10.91	7.15

🟩	5mm/s
🟨	13mm/s
🟧	25mm/s
🟥	>25mm/s

Figure 3.1 Charge weight per delay (MIC) versus Distance and PPVc

3.5.1.3 For normal blasting operations, it is considered that structures in vicinity to the blasting site are unlikely to be subjected to PPV levels greater than 5mm/s.

3.5.1.4 Geoguide 4 [2] identifies that there can be various levels of damage considered for structures based upon previous records for ground vibrations and ground frequencies. **Figure 3.2** below outlines the various safe threshold levels that could be expected for different types of buildings.

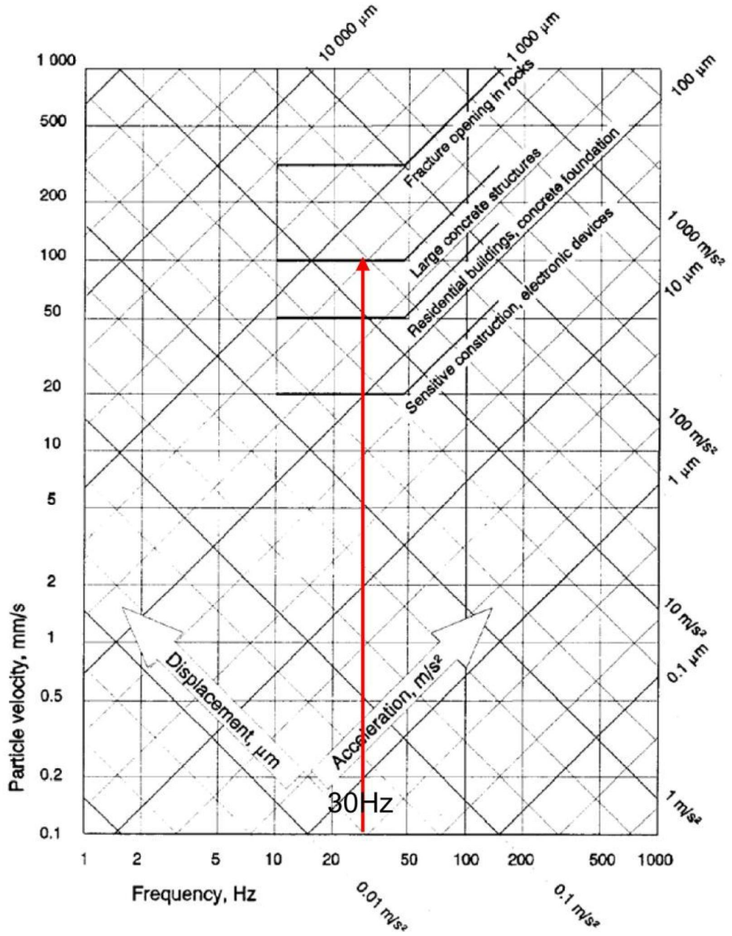


Figure 3.2 Typical Safe Vibration Limits (Geoguide 4) [2]

3.5.1.5 It is worth noting in **Figure 3.2** that the limits are based upon the ground vibration frequencies and the PPV limits. It is widely accepted that the characteristic frequency for ground vibrations from blasting is around 30Hz so the threshold safe limits for the residential buildings and large concrete structures along the alignment should lie well above 50mm/s.

3.5.1.6 Geoguide 4 [2] also identifies that the potential for damage to a structure can be related to the natural frequency of the structure especially if the ground vibration has a similar characteristic frequency to the natural frequency of the building.

3.5.1.7 In general, it is considered that for buildings the formula to determine the approximate natural frequency can be approximated to the following:

Natural Building Frequency = 46 / height of the building (m)

3.5.1.8 This approach is normally applied to earthquake ground motion where the frequencies are much lower and could have a significant effect on the buildings. In addition, earthquake ground motions are also much longer duration than the short duration higher frequency blasts.

3.5.1.9 If the ground motion frequency is similar to the natural building frequency, then amplification could occur leading to larger motion of the building. This usually occurs when low frequency ground motion occurs over a long period of time such as in earthquakes that last maybe 30 seconds to minutes, rather than the usual 4 to 9 seconds for a tunnel blast.

3.5.1.10 Therefore, it is generally considered that buildings can readily tolerate a peak particle velocity of 100mm/sec for any falling objects that cause 1% fatality. Also, buildings are

generally considered to have structure damages when a PPV of 229mm/s is experienced. This criterion is generally used in previous similar studies like WIL Study [1].

4 FREQUENCY ANALYSIS

4.1 Use of Explosives

4.1.1 Introduction

4.1.1.1 The frequency assessment for the use of explosives consists of two parts. The occurrence frequency of higher ground vibration due to errors in the blasting process is the first part while the occurrence frequency of higher than expected vibration and air overpressure due to onsite transport of explosives is the second part.

4.1.1.2 The major causes for all the failure scenarios identified in the failure mode analysis are due to human errors during the blasting process. Errors can be due to design, manufacturing, installation, checking and recovery.

4.1.2 Frequency of higher than expected ground vibration due to errors in the blasting process

4.1.2.1 Fault tree analysis is used to determine the overall occurrence frequencies for the hazardous scenarios stated in Section 3.2 of this Appendix; Human Error Assessment and Reduction Technique (HEART) is carried out to determine the human error probabilities for the events.

4.1.2.2 HEART is a human reliability assessment method based on human performance literature. In this study, HEART is adopted to quantify human error probabilities by assessing the interactions between humans, their specific tasks, performance shaping/ human factors and error producing conditions.

4.1.2.3 Review on fault tree analysis and HEART analysis of WIL Study [1] was carried out. Detail of fault tree analysis and HEART analysis of this Study is presented in **Annex 1** and **Annex 2** of this Appendix. The overall frequencies of failure scenarios leading to higher than expected vibration for this project are estimated based on the analysis in WIL Study [1]. **Table 4.1** summarized the overall frequencies.

4.1.2.4 The probability of 5 and 6 MIC detonated at the same time was assumed to be the same as that of 4 MIC detonated at the same time as conservative. The probability of each additional error for either design or manufacturing of detonator is considered 0.01 for simultaneous detonation of 5 and 6 MIC. The occurrence probability for each additional MIC detonated at the same time will hence be roughly 2 orders of magnitude lower each time. As a result, it is conservatively assumed that the occurrence frequencies of 5 and 6 MIC detonated at the same time will be of the same as that for 4 MIC detonated at the same time.

Table 4.1 The overall frequencies of failure scenarios leading to higher than expected vibration for this project

Sections	**Occurrence Frequency for multiple MIC detonated at the same time (Occurrence per project)**				
	2 MIC	**3 MIC**	**4 MIC**	**5 MIC**	**6 MIC**
Access Tunnels and Ventilation Tunnel	1.09E-02	9.24E-05	9.04E-07	9.40E-07	9.40E-07
Ventilation Shaft	4.05E-04	3.43E-06	3.48E-08	3.48E-08	3.48E-08
Cavern	3.41E-02	2.88E-04	2.93E-06	2.93E-06	2.93E-06

Note:

1. Assume mischarge of explosives only occurs in one blast face.
2. The maximum instantaneous charge weights (MIC) taken in this study is 10kg per blast.

4.1.2.5 However, the frequencies given in **Table 4.1** are slightly lower than some actual blasting scenarios, the derived frequencies are increased by 25% to account for actual scenarios and presented in **Table 4.2**.

Table 4.2 Revised overall frequencies of failure scenarios leading to higher than expected vibration for this project

Sections	**Occurrence Frequency for multiple MIC detonated at the same time (Occurrence per project)**				
	2 MIC	**3 MIC**	**4 MIC**	**5 MIC**	**6 MIC**
Access Tunnels and Ventilation Tunnel	1.36E-02	1.15E-04	1.17E-06	1.17E-06	1.17E-06
Ventilation Shaft	5.06E-04	4.28E-06	4.35E-08	4.35E-08	4.35E-08
Cavern	4.26E-02	3.61E-04	3.67E-06	3.67E-06	3.67E-06

4.1.2.6 For the Worst Case scenario, the overall number of blasts is increased by 20% to account for potential deviation from the proposed construction programme.

4.1.3 Frequency of higher than expected vibration and air overpressure due to onsite transport of explosives

4.1.3.1 The overall frequency of accidental initiation during transportation is 7.69×10^{-10} per truck-km per year as presented in Section 6.2 in **Appendix 7.01**. Such value is considered conservative to assess the onsite transport of explosives of cartridges as there should be speed control within the site. Also, traffic within the construction site is not as heavy as public roads. For the probability of fire following a vehicle crash and impact initiation in crash, no reduction factors will be considered.

4.1.3.2 Since the transport length within the tunnel will vary as the blasting proceeds, the average transport length was assumed as half the total length for all deliveries in accordance with the WIL Study [1]. The calculated frequency for onsite transportation is shown in **Table 4.3**.

Table 4.3 Frequency of higher than expected vibration and air overpressure due to onsite transport of explosives (Base Case)

	Initial Freq. (/year)	**No. of Deliveries**	**Road Length (km)**	**Frequency (/year)**
Main Access Tunnel	7.69E-10	900	0.27	9.34E-08
From Delivery Point to Portal	7.69E-10	900	0.14	4.84E-08
From Ventilation Shaft Portal to Ventilation Shaft Blast Site	7.69E-10	448	0.077	1.33E-08

4.1.3.3 For the Worst Case scenario, the number of deliveries is increased by 20% to account for potential deviation from the proposed construction programme.

Table 4.4 Frequency of higher than expected vibration and air overpressure due to onsite transport of explosives (Worst Case)

	Initial Freq. (/year)	**No. of Deliveries**	**Road Length (km)**	**Frequency (/year)**
Main Access Tunnel	7.69E-10	1080	0.27	1.12E-07
From Delivery Point to Portal	7.69E-10	1080	0.14	6.46E-08

From Ventilation Shaft Portal to Ventilation Shaft Blast Site	7.69E-10	538	0.077	1.59E-08

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5 CONSEQUENCE ANALYSIS

5.1 General

5.1.1.1 Possible outcome from hazardous events associated with the use of explosives include:

- Primary hazards: Ground shock/ vibrations and blast effects;
- Secondary hazards: Effect on buildings, slopes and other sensitive receivers; and
- Tertiary hazards: Landslides and boulders fall.

5.2 Primary Hazards

5.2.1 Ground Shock/ Vibrations Generated by Rock Excavation using Explosives

5.2.1.1 There are some slopes close to the road along the transport route of explosives. It is possible that an accidental detonation of the explosives may trigger a landslide or boulders fall. This is identified as a secondary hazard. The *Landslide Consequence Classification System and Boulder Fall Consequence Analysis* published in GEO Report No.81 will be adopted to evaluate the possible outcomes.

5.2.1.2 In this project, explosives transport and storage is carried out aboveground while explosives usage is carried out underground. Aboveground explosion will result in a lower pressure wave as the explosives are less confined. The consequence is considered less concerned compared to the hazards posed by the overpressure wave and debris generated by the explosion. Ground shock can be calculated by the following equation [9]:

$$\boldsymbol{A = K(R/Q^{d})^{-b}}$$

where A = predicted particle velocity in mm/s
K = a ‘rock constant’
Q = maximum charge weight per delay interval in kilograms
R = distance in meters between the blast and the measuring point
d = charge exponent, assumed to be 0.5 [9]
b = attenuation exponent, assumed to be 1.22 [2]

5.2.1.3 Excessive ground shock may also lead to secondary hazards such as building failure and slope failure. Tertiary hazards such as landslide and rupture of town gas high pressure pipelines may be induced by secondary hazards. These hazards will be discussed in the following sections.

5.2.1.4 In this QRA, the rock constant, K, is considered as 1200 which is the upper limit selected from GEO Guide 4. [2]

5.2.2 Ground Shock/ Vibrations Generated during Transport of Explosives within the Access Tunnel

5.2.2.1 The methodology to access the ground shock due to detonation of full load of explosives within the access tunnel is the same as Section 5.2.1 of this Appendix. Instead, the value of K is considered to be 200 to represent the “decoupling” of explosives during transport in the cavern [4].

5.2.3 Ground Shock/ Vibrations Generated during Transport of Explosives from delivery point to portal

5.2.3.1 Ground shock due to detonation of full load of explosives transported from delivery point to portal is built into the ESTC model. Ground Vibration model is used to evaluate the specific effects of vibrations on the nearby sensitive receivers.

5.2.4 Blast Effects including Air Overpressure and Flying Debris due to Accidental Explosion while Transferring Explosives from Portal to Blast Faces

5.2.4.1 The blast and overpressure effects for detonation of cartridges during transport in the tunnel and shaft can be estimated by the DoD 6055.9-STD equation C9.7-16 [7] and ESTC model. Comparisons were made between the two methods and ESTC was adopted in this Study when assessing the likelihood of fatalities due to blast effects.

5.2.4.2 DoD 6055.9-STD equation C9.7-16 is as follow:

$$R = 220.91\, D_{HYD}\, ((W/V_E)^{0.5} / P_{so})^{1/1.4}$$

Where R is the distance from the opening (m);
D_{HYD} is the effective hydraulic diameter that controls dynamic flow issuing from the opening ($D_{HYD} = 4A/P$ where A is the cross-sectional area of the opening and P is the perimeter);
P_{so} is the overpressure at distance R (kPa);
W is the charge weight for the maximum credible event (kg); and
V_E is the total volume engulfed by the blast wavefront within the tunnel system at the time the wavefront arrives at the point of interest (m^3).

5.2.4.3 If the point of interest is off the centreline axis of the opening at an angle θ, the distance versus overpressure can be evaluated from equation C9.7-17 of DoD 6055.9-STD.

$$R(\theta) = R(\theta = 0)/ (1+(\theta/ 56)^2)^{1/1.4}$$

Where R(θ = 0) is the distance along the centreline axis.

5.2.4.4 Overpressure that is sufficient to cause a fatality is based on that resulting in lung haemorrhage in people located outside. In general, human body is capable of adapting to large changes in pressure which occur gradually. A probit equation based on data relating to death primarily from lung haemorrhage due to peak overpressure was derived by Fugelso, Weiner and Schiffman [8],

$$Pr = -77.1 + 6.91 \ln P^0$$

Where P^0 is the peak overpressure generated by the blast (Pa).

5.2.4.5 The peak overpressures corresponding to a 1%, 3%, 10%, 50%, and 90% fatality level are 103 kPa, 110 kPa, 120 kPa, 144 kPa and 174 kPa respectively.

5.2.4.6 The length of the main access tunnel is 270m with a diameter of about 17.5m. According to DoD 6055.9-STD Table C9.T32, the distance from the opening is the longest when θ = 0. In this assessment, point of interest for overpressure generated by detonation of 200 kg cartridges at main access tunnel is assumed to be along the centreline axis of the opening to obtain a maximum distance. Therefore, the distances calculated by equation C9.7-16 of DoD 6055.9-STD for peak overpressures corresponding to different fatality level are 18m, 17m, 16m, 14m and 12m for 1%, 3%, 10%, 50% and 90% fatality level respectively.

5.2.4.7 The hazard distances calculated by ESTC model for outdoor population are 20m, 19m, 18m, 16m and 15m for 1%, 3%, 10%, 50% and 90% fatality level respectively. It can be seen that the hazard distance estimated by ESTC outdoor model is more conservative than equation C9.7-16 of DoD 6055.9-STD. Therefore, the consequence distances obtained from the ESTC models were used to assess the risk of transporting explosives within main access tunnel during construction.

5.2.4.8 The length of the ventilation shaft is 77m with a diameter of 8m. As the alignment of ventilation shaft is vertical, point of interest for overpressure generated by detonation of 28.9 kg cartridges at ventilation shaft is perpendicular to the centreline axis of the opening to obtain a maximum distance. Therefore, the distances calculated by equation C9.7-16 of DoD 6055.9-STD for peak overpressures corresponding to different fatality level have to be adjusted by C9.7-17 of DoD 6055.9-STD with θ = 90. The adjusted distances are 4.5m, 4.3m, 4m, 3.5m and 3m for 1%, 3%, 10%, 50% and 90% fatality level respectively.

5.2.4.9 The hazard distances calculated by ESTC model for outdoor population are 10m, 10m, 9m, 8m and 8m for 1%, 3%, 10%, 50% and 90% fatality level respectively. It can be seen that the hazard distance estimated by ESTC outdoor model is more conservative than equation C9.7-16 of DoD 6055.9-STD. Therefore, the consequence distances obtained from the ESTC models were used to assess the risk of transporting explosives within ventilation shaft during construction.

5.2.4.10 To be consistent with previous similar studies, during the construction of cavern, an initiation of explosives during transport within the project site is considered as an explosion at the portal of the main access tunnel since no decay factor was considered for a blast wave propagating from the blast face to the portal.

5.2.4.11 Fatality due to flying debris due to above ground explosion is considered in the ESTC model. The ESTC model is a more conservative approach in estimating hazard distances during the construction of cavern, as compared to using the above Ground Vibration Model. Therefore, consequence distances calculated by ESTC model were used to assess the risk of transporting explosives from the portal to blast faces. Details of the ESTC model can be found in **Appendix 7.01**.

5.2.5 Blast Effects including Air Overpressure and Flying Debris due to Accidental Explosion while Transferring Explosives from Delivery Point to Portal

5.2.5.1 The blast effects due to detonation of full load of explosives during transport from delivery point to portal was assessed with the same approach as Sections 5.2.4.10 - 5.2.4.11 of this Appendix.

5.3 Secondary Hazards

5.3.1 Effect on buildings

5.3.1.1 In Hong Kong, the maximum values of peak particle velocity normally accepted by a building to prevent cosmetic damage is 25 mm/s. For the purpose of this study, the peak particle velocity that induces significant structural damage and results in potential fatalities is also required.

5.3.1.2 The US Bureau of Mines (USBoM) Bulletin 656 Blasting vibrations and their effects on structure was reviewed and obtained the damage level of a building with different PPVs. The results are tabulated in **Table 5.1**.

Table 5.1 Damage Level due to Ground Vibration

Damage Level	Peak Particle Velocity, mm/s (in/s)
No noticeable damage	70 (2.8)
Fine cracking and fall of plaster	110 (4.3)
Cracking	160 (6.3)
Serious cracking	231 (9.1)

5.3.1.3 The US Department of Defence Standard DoD 6055.9-STD 2004 DOD Ammunition and explosives safety standards (USDoD, 2004) was also reviewed for the maximum particle velocity induced in the ground at the building site. The maximum particle velocity induced in the ground at the building site shall not exceed 9.0 in/s or 229 mm/s for strong rock.

5.3.1.4 Criteria adopted for building risk assessment were summarized as follow:

- PPV = 229mm/s – Building structural collapse threshold
- PPV = 100mm/s – Object fall threshold

5.3.1.5 It is assumed that a 1% fatality level within a building due to vibration causing falling objects when reaching the object fall threshold 100mm/s, but no major damages to buildings is expected.

5.3.1.6 Therefore, buildings will collapse only when a peak particle velocity is significantly larger than the assumed threshold limit 229 mm/s. The above criteria are considered conservative.

5.3.2 Building Collapse Models for Explosion/ Earthquake

5.3.2.1 A review of previous similar studies such as WIL EIA report was carried out. The approach is to be based on the WIL study [1]. For the types of buildings considered in this study, the objects with the potential to fall are assumed to be 1m^2 large. As the considered buildings are along A Kung Kok Street, the maximum pedestrian density of A Kung Kok Street is 0.000428 person/m^2 (as extracted from **Appendix 7.01**). Therefore, the maximum fatality due to a falling object is conservatively assumed as 1.

5.3.2.2 Building damage vulnerability models for partial collapse/ damage is adopted from the WIL Study [1]. The major causes of fatality due to partial building collapse are collapse of roofs, ceilings and walls. They are considered as the most serious types of falling objects causing fatality which causes more than 1 fatality. The fatality rates calculated from different models for partial collapse of a building vary from 0.01% to 1.5%. Therefore, a fatality rate of 1% is conservatively considered for fatalities resulting from falling objects.

5.3.2.3 The fatality probabilities of buildings receiving PPV values within the range of 100 mm/s and 229 mm/s are interpolated.

5.3.3 Effect on Slopes

5.3.3.1 The vibration limits for registered geotechnical features are different for each individual feature, and the methods of assessment to define the vibration limit for the different geotechnical features are discussed in the following sections.

5.3.3.2 GEO TGN 28 allows the use of prescribed allowable PPV of 25mm/s for soil cut slopes that have been upgraded and are in good condition. With reference to TGN 28, any slope that falls into Consequence-to-Life (CTL) Categories 1 and 2 and meets current standards shall also be considered that an allowable PPV of 25mm/s could be adopted. Furthermore, any slope within Consequence-to-Life category 3 can be assigned an allowable PPV of 25mm/s.

5.3.3.3 PPV of 25mm/s is the standard and prescribed allowable PPV for the existing slopes. As the vibration limits for registered geotechnical features are different for each individual feature, the project specific allowable PPV limit is calculated as 66mm/s.

5.3.3.4 For any slope for which it is proposed to adopt the use of the prescriptive PPV, visual inspection will be carried out to confirm there are no signs of distress or instability, or any other stability concerns.

5.3.3.5 The analysis of the effects of vibration on the stability of slopes is based on the guidelines detailed in GEO Report No. 15 [3]. The critical Peak Particle Velocity (PPVc) corresponding to the maximum vibration is calculated using the following equation:

$$PPVc = K_c g/(\omega Ka)$$

where K_c = the critical acceleration at which the slope has a factor of safety of 1.0 against failure,
g = the acceleration due to gravity (ms^{-2}),
ω = the circular frequency of the ground motion ($2\pi f$), and
Ka = the magnification factor.

5.3.3.6 The value of ω is related to f, the frequency of vibration. The typical range of the frequency is about 30-100Hz for blasting. As recommended in GEO Report No. 15, a frequency of 30Hz is adopted for this assessment.

5.3.3.7 The value of Kc is obtained from stability analysis of the slopes to achieve a minimum of pseudo-static FOS as detailed in **Table 5.2** and corresponding to different Consequences to Life (CTL) category of the slopes which is in line with the current GEO practice.

Table 5.2 Summary of Adopted Pseudo-Static FOS

CTL Category	Adopted Pseudo-Static FOS
Cat 1	1.1
Cat 2	1.0
Cat 3	1.0

5.3.3.8 The values of Ka is different for different S/H and frequency of vibration, where S is the velocity of travelling wave and H is the height of the slope.

5.3.3.9 GEO Report No.15 [3] provided a graphical presentation of the Critical Peak Particle Velocity, PPVc, and the initial static factor of safety for varying joint displacements at peak stress. This is shown in **Figure 5.1** below.

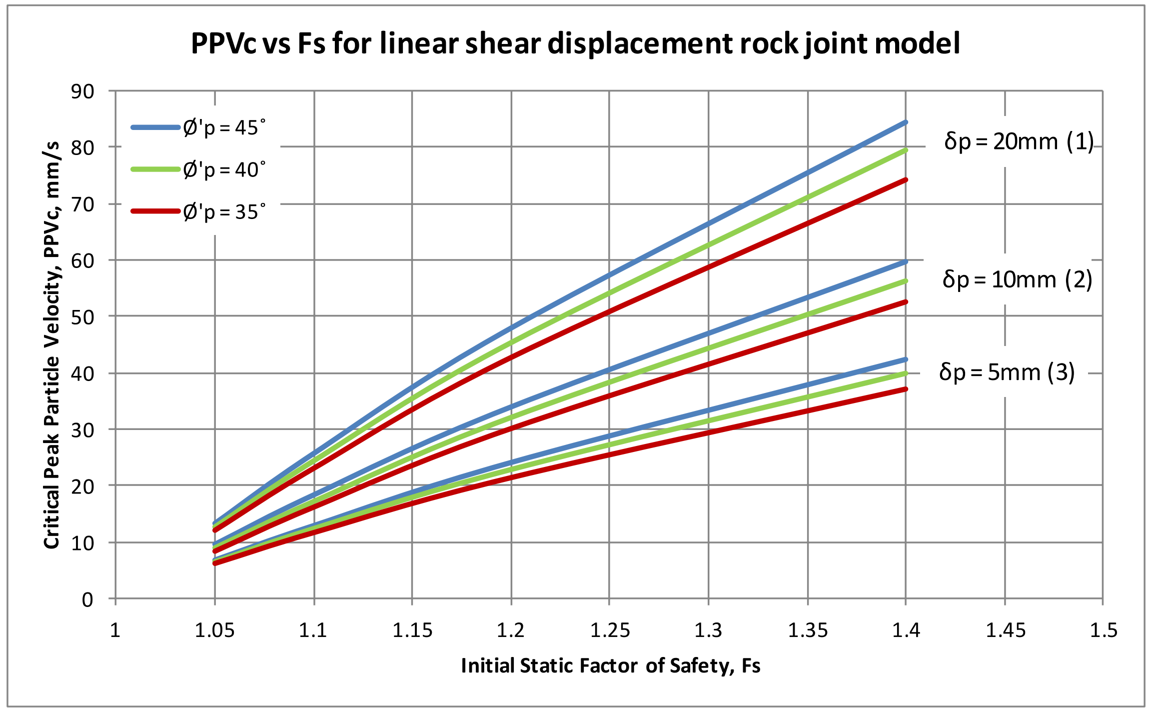

Figure 5.1 Plot of Critical Peak Particle Velocity against Initial Static Factor of Safety

Note:
Ø'p = Peak angle of shearing resistance of rock joint
(1) Corresponds to Joint Roughness Coefficient (JRC) = 5 and L=14.0m
(2) Corresponds to Joint Roughness Coefficient (JRC) = 5 and L=5.0m
(3) Corresponds to Joint Roughness Coefficient (JRC) = 5 and L=1.8m

5.3.3.10 In order to calculate the slope movement due to ground vibration, Sarma 1975 as stated in GEO Report 15 [3]. The formula for slope movement is as follow:

$$Xm = 0.25 * C * Am * T^2 * 10^{(1.07-3.83Ac/Am)}$$

where
Xm = slope movement;
C = function of the slope geometry and generally is a value near unity;
Am = peak acceleration;
T = dominant period of the ground motion; and
Ac = critical acceleration required to cause sliding.

5.3.3.11 According to GEO Report 15, for blast observations, the dominant period (T) is about 1/30 seconds with peak ground acceleration in mm/s^2 is about 670 times the PPV in mm/s. It means that the peak acceleration for a PPV of 60 mm/s is about 4g or $40,000mm/s^2$. Therefore, the above formula can be rewrite as follow:

$$Xm = 0.186 * PPV * 10^{(1.07-3.83PPVc/PPV)}$$

5.3.3.12 However, the formula is derived based on earthquake data, which comprised several low frequency pulses instead of a singular high frequency pulse resulted from explosives detonating. A factor of 0.25 is adopted in order to incorporate the Sarma formula in calculating slope movement due to explosives detonation as typical earthquake consists of at least 4 separate peaks. [3] Therefore, the modified Sarma equation is as below:

$$Xm = 0.0465 * PPV * 10^{(1.07-3.83PPVc/PPV)}$$

5.3.3.13 The criteria for the failure of slopes based on the amount of shear displacement or slope movement are summarized as follows:

- 20mm shear displacement or slope movement = 0.01% chance of slope failure
- 50mm shear displacement or slope movement = 10% chance of slope failure
- 100mm shear displacement or slope movement = 50% chance of slope failure
- 200mm shear displacement or slope movement = 100% chance of slope failure

5.3.4 Effect on Natural Terrains and Boulders

5.3.4.1 During blasting, the induced ground vibration may trigger boulders fall or natural terrain landslide. The Critical Peak Particle Velocity (PPVc) of a boulder will be calculated to estimate the limit of PPV that a boulder can withstand without falling.

5.3.4.2 The PPVc of boulders is calculated based on the Energy Approach with the principle of conservation of energy as shown in GEO Report No.15. The PPVc of a rock block is calculated using the following equation:

$$PPVc = (g/0.91\ (\delta p)\ \sin\beta\ (Fs/2 + 1/(2Fs) - 1)\ )^{1/2}$$

where
g = acceleration due to gravity = $9.81m/s^2$
δp = Joint displacement at peak stress
β = Joint dip angle
Fs = initial static factor of safety

5.3.4.3 Since rock boulders can exist in various locations of the natural terrain, a sensitivity analysis approach is adopted to calculate the PPV limit of boulders that may be resting on the natural terrain. Conservative rock parameters and critical angle of natural terrain are assumed in the analysis. The calculate PPV limit of boulders is 66mm/s.

5.3.4.4 Rock boulders ranging from 500mm to 5m in size are assessed for their critical vibration level to initiate movement. It is found that the smaller boulders result in a lower PPV limit, and this has been adopted for the further analysis. A global factor of safety of 2 is then applied to the calculated vibration limit, to assign the allowable PPV of rock boulder, based on the observed natural terrain slope angle.

5.3.4.5 Boulder survey will be carried out, and assessment of specific boulder hazard will be undertaken, for all areas of natural terrain within the 5mm/s vibration contour zone. For any boulders resting on slope greater than 30˚, the risk of instability will be individually assessed, for those areas where existing boulder survey is available. Those boulders identified as having potential instability, and also on a slope greater than 30˚, will be stabilised or protective measures will be installed, prior to the commencement of blasting.

5.3.4.6 The boulder size used in our calculation is assumed as 5m for the boulders with potential danger around the project site.

5.3.5 Effect on High Pressure Underground Town Gas Transmission Pipelines

5.3.5.1 A higher than expected ground vibration from an accidental explosion or during the blasting process can potentially cause leakage or rupture of a gas pipeline. For this project, the maximum allowable PPV for underground gas pipelines is considered to be 25 mm/s. In previous similar studies, it is conservatively considered 25 mm/s PPV (i.e. damage threshold in blast design) leads to a 1% probability of significant damage to a pipe upon ignition and cause fatality [4].

5.3.5.2 With reference to a previous similar study [4], the following criteria are assumed for vibration effect on gas pipelines:

- 25 mm/s PPV (i.e. damage threshold in blast design) leads to a 1% probability of significant damage to a pipe upon ignition and cause fatality
- 62.5 mm/s PPV (i.e. 2.5 times the 1% probability of damage) leads to a 10% probability of significant damage to a pipe upon ignition and cause fatality
- 125 mm/s PPV (i.e. 5 times the 1% probability of damage) leads to a 50% probability of significant damage to a pipe upon ignition and cause fatality
- 250 mm/s PPV (i.e. 10 times the 1% probability of damage) leads to a 100% probability of significant damage to a pipe upon ignition and cause fatality

5.4 Tertiary Hazards

5.4.1 Landslide Consequence

5.4.1.1 GEO Report No.81 Slope Failures along BRIL Roads: Quantitative Risk Assessment and Ranking [4] was published in 1999 to discuss a landslide consequence classification system. An equation was derived for the estimation of the number of fatalities:

$$\boldsymbol{N} = \frac{\sum \boldsymbol{WFPEA}}{\boldsymbol{V}}\ [\mathbf{4}]$$

where W is the width of the landslide plus an adjustment for effective stopping distance;

F is the frequency of passing passengers, which may be taken as the product of the Annual Average Daily Traffic (AADT) and the average number of people in a vehicle;
P is the probability of death due to being caught in the landslide;
E is the extent of the landslide equivalent to the number of lanes affected;
A is an adjustment factor for proportion of normal road usage at the time of the landslide; and
V is the speed of vehicles.

5.4.1.2 The following assumptions are made for the above equation.

- Average vehicle speed is assumed to be 30 miles/hr (i.e. 48 km/hr) based on the road conditions linking to the magazine and project site. The vehicle speed is not particularly sensitive to the calculation of N since the effect will be largely compensated by the effective stopping distance.
- A stopping distance of 23m is assumed based on UK Highway Code data for a vehicle speed of 30 miles/hr (i.e. 48 km/hr) [5].This stopping distance already included the reaction time.
- The probability of death due to landslides is given in **Table 5.3** below, which is obtained from the GEO Report No.81 [4]. The consequence model has been developed by GEO and papers have been published. Past incidents show that the assumptions are reasonable. This model has been applied to several studies on landslides in Hong Kong.

Table 5.3 Probability of Fatality due to Landslide [4]

Proximity of Slope	Probability of Death
Lane nearest to slope	0.8
2nd lane away from slope	0.6
3rd lane away from slope	0.4

- For failure of retaining wall that causes the collapse of a road, the probability of death is assumed to be 1 for the lanes affected.
- Parameter A can be 0.82 to account for the fact that landslides are most likely to occur during heavy rainfall. However, in this project, as the possible slope failure is caused by detonation of explosives, the value of A is assumed to be 1.
- An adjustment factor should be applied to the calculation to account for the additional risk due to footpath adjacent to the road. It was recommended the value of N should be increased by 25% in the GEO Report No.81 [4]. However, as the footpath along the transportation route in this project is comparatively remote. A lower factor than 25% is considered more appropriate. Therefore, the calculated N value is increased by 10% to account for pedestrians [2].

5.4.1.3 Mechanism of slope failure will affect the travel distance of landslide debris. For example, a landslide induced by rainfall is expected to travel further than one caused by blasting as the soil and rock behave in a more liquid manner. Therefore, the travel distance for rainfall induced landslides may be based on an apparent angle of friction of 15˚ to 30˚. The apparent angle of friction or travel angle is defined as the inclination. The GEO Report No.81 [4] states that the travel angle of a typical rain induced landslide involves a landslide volume less than 2000 m^3 generally ranges from 30˚ to 40˚. It is conservatively assumed that a landslide caused by detonation of explosives will result in a travel angle of 30˚.The relationship of shadow/ travel angle and run out distance is shown in **Figure 5.2**.

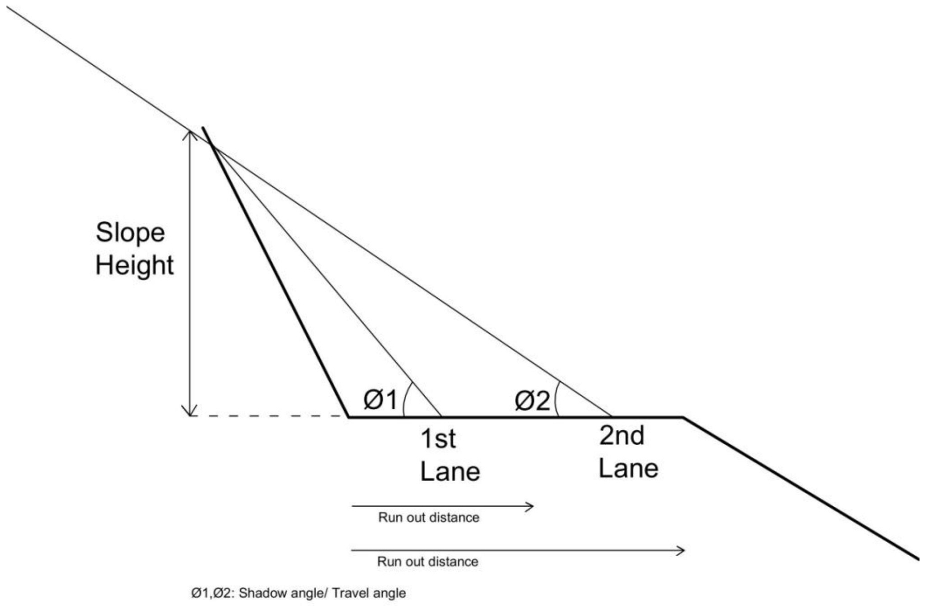

Figure 5.2 Influence zone for Slope Failures [4]

5.4.1.4 Assume the slope is a triangular volume, the run out distance for the landslide can be estimated by the following equation.

$$\boldsymbol{L} = \sqrt{\frac{\boldsymbol{2V}}{\boldsymbol{W}\,\mathbf{tan}(\mathbf{30})}}$$

where L is the run out distance in m;
V is the slip volume in m^3; and
W is the slip width in m.

5.4.2 Boulder Fall Consequence

5.4.2.1 The estimation of boulder fall consequence is based on the methodology introduced in the GEO Report No.81 [4]. The probability of a falling rock of greater than 150mm diameter that hit a moving vehicle can be presented by the fraction of the road occupied by the vehicle, which is defined as the probability of spatial impact given a rock fall.

P(S:H) = (AADT x Length of the vehicle)/ (average vehicle speed x 24,000)

Where AADT is the annual average daily traffic (i.e. the number of vehicles per day);
Length of the vehicle is assumed to be 5m;
Average vehicle speed is assumed to be 30 miles/hr (i.e. 48 km/hr); and
Conversion factor for units is 24,000.

5.4.2.2 The above equation is modified to calculate the probability of a falling rock of greater than 150mm diameter that hit a pedestrian as below:

P(S:H) = (Number of pedestrians per day x Width of a person)/ (average walking speed x 24,000)

Where Number of pedestrians per day is obtained by site survey;
Width of a person is assumed to be 1m;
Average walking speed is assumed to be 5 km/hr; and
Conversion factor for units is 24,000.

5.4.2.3 The probability that a rock hits a vehicle or a pedestrian is then given by:-

$$P(S) = 1-\{1-P(S:H)\}^{Nrf}$$

where Nrf is the frequency of rock fall per year.

5.4.2.4 The probability of loss of life of an occupant given a vehicle is hit by a rock is assumed as 0.2 [1]. Size of the rock, number of occupants inside the vehicle and the protection of the vehicle are already considered in this probability.

5.4.2.5 Similarly, the consequence of a vehicle hitting a falling boulder can also be estimated based on the stopping distance of the vehicle. The value of stopping distance can then be substituted for that of length of vehicle in P(S:H) equation. The probability of an occupant is assumed as 0.1 after collision [4].

5.4.2.6 With reference to WIL Study [1], it was suggested that the fatality of pedestrians hit by falling boulders is 100%.

5.4.2.7 There are several buildings found near potential boulders. The affected populations are calculated by the proportion of the area of a boulder to the floor area of the buildings as shown in the following equation.

$$Affected\ population = \frac{Area\ of\ a\ boulder}{Floor\ Area\ of\ the\ building} \times Population\ per\ floor$$

5.4.2.8 The fatality of an occupant given a building is hit by a rock is assumed to be 20%. This figure is referenced from the probability of loss of life of an occupant inside a New Territories house hit by a boulder given in “Territory Wide Quantitative Risk Assessment of Boulder Fall Hazards: Stage 2 Final Report” [6].

5.4.3 Underground Town Gas High Pressure Transmission Pipeline Rupture Consequence

5.4.3.1 The HP underground town gas transmission pipeline to Sha Tin originates at the Tai Po Gas Production Plant, runs subsea along Tolo Harbour and Shing Mun River to the offtake and pigging station in City One, Sha Tin. The HP underground town gas transmission pipeline continues towards Ma On Shan along Tate’s Cairn Highway and Sai Sha Road, and arrives the downstream Sai O pigging station. The project site is in vicinity of a section of the HP underground town gas transmission pipelines from the Ah Kung Kok Fishermen Village to Chevalier Garden. Separation distance between the project site and the pipelines is around 260m. With underground construction site of this project, the domino effect of High Pressure Town Gas Transmission Pipelines towards the use of explosives is not further considered in this study.

5.5 Results of Consequence Assessment

5.5.1 Ground Vibration Effect on Buildings due to Errors in Blast Face

5.5.1.1 Since both the building structural element collapse threshold (PPV = 229mm/s) and the falling object threshold (PPV = 100mm/s) for accidental explosion up to 6 MIC during the construction of access tunnels and shaft are not received by any of the surrounding buildings. Therefore, no further assessment is required.

5.5.1.2 For the construction of cavern, since both the building structural element collapse threshold (PPV = 229mm/s) and the falling object threshold (PPV = 100mm/s) for accidental explosion up to 6 MIC are not received by any of the surrounding buildings. Therefore, no further assessment is required.

5.5.2 Ground Vibration Effect on Slopes due to Errors in Blast Face

5.5.2.1 Slopes are identified for further assessment based on the screening criteria of PPV = 66 mm/s during the construction of the project. It is a more conservative and site specified limit for the screening criteria than the 90mm/s used in previous similar studies.

5.5.2.2 Some surrounding slope features were identified to receive a PPV level that causes potential failure during construction of access tunnels. The affected slopes are summarised in **Table 5.4**. None of the surrounding slope features was identified to receive a PPV level that would cause potential failure during construction of cavern.

Table 5.4 Slopes affected by Higher than Expected Vibrations Generated by Accidental Initiation during the Construction of Access Tunnels

Scenario/ Slope Number	Occurrence Frequency
4 MIC detonated at the same time	
7SE-A/C 526	3.87E-09
5 MIC detonated at the same time	
7SE-A/C 271	3.87E-09
7SE-A/C 526	5.81E-09
6 MIC detonated at the same time	
7SE-A/C 271	5.81E-09
7SE-A/C 259	1.94E-09
7SE-A/C 526	7.74E-09
7SE-A/C 266	1.94E-09

5.5.3 Ground Vibration Effect due to Accidental Detonation of Explosives during Transport

5.5.3.1 For the transport of explosives within tunnels / cavern, the predicted ground vibrations at the surrounding buildings and slopes features do not exceed their damage thresholds. Therefore, no further assessment is required.

5.5.4 Boulders fall due to Higher than Expected Ground Vibration

5.5.4.1 Boulders are assumed to have 1% chance to fall when it experiences a ground vibration greater than 66mm/s. This potentially exists for the errors of blast faces during the construction of the project or accidental detonation of explosives during transport within tunnels.

<u>Boulders fall due to Errors in Blast Faces</u>

5.5.4.2 The calculated frequencies for boulder fall due to errors in blast faces are summarized in **Table 5.5** below.

Table 5.5 Boulder Fall Frequencies for accidental initiation of explosives from 2 MIC to 6 MIC due to errors in Blast Faces

Work Area	2 MIC	3 MIC	4 MIC	5 MIC	6 MIC
Main Access Tunnel	2.25E-06	3.69E-08	3.87E-10	3.99E-10	3.99E-10
Secondary Access Tunnel	1.69E-06	1.43E-08	1.45E-10	1.45E-10	1.45E-10
Ventilation Tunnel	0	4.76E-09	1.94E-10	2.90E-10	3.02E-10
Ventilation Shaft	5.62E-07	5.95E-09	7.26E-11	8.47E-11	8.47E-11
Cavern	9.84E-07	2.14E-08	3.63E-10	5.20E-10	7.14E-10

5.5.4.3 With consideration of the topography, misblast during construction of main access tunnel, secondary tunnel, cavern, ventilation tunnel and ventilation shaft will result in boulder fall onto A Kung Kok Street, Mui Tsz Lam Road and Magazine Site Access Road respectively as shown in **Table 5.6** to **Table 5.8** below. There is no impact to buildings and hence the scenario for a falling boulder due to misblast hits a building is not further considered.

Table 5.6 Occurrence Frequencies for a falling boulder striking a vehicle for accidental initiation of explosives from 2 MIC to 6 MIC due to errors in Blast Faces

Work Area	**2 MIC**	**3 MIC**	**4 MIC**	**5 MIC**	**6 MIC**
Main Access Tunnel					
A Kung Kok Street	1.01E-08	1.66E-10	1.74E-12	1.79E-12	1.79E-12
Secondary Access Tunnel					
Mui Tsz Lam Road	7.54E-10	6.38E-12	6.49E-14	6.49E-14	6.49E-14
Ventilation Tunnel					
Magazine Access Road	0	0	0	0	0
Ventilation Shaft					
Magazine Access Road	0	0	0	0	0
Cavern					
Mui Tsz Lam Road	4.40E-10	9.57E-12	1.62E-13	2.33E-13	3.19E-13

Table 5.7 Occurrence Frequencies for a vehicle hitting the boulder once it has fallen for accidental initiation of explosives from 2 MIC to 6 MIC due to errors in Blast Faces

Work Area	**2 MIC**	**3 MIC**	**4 MIC**	**5 MIC**	**6 MIC**
Main Access Tunnel					
A Kung Kok Street	4.68E-08	7.68E-10	8.06E-12	8.31E-12	8.31E-12
Secondary Access Tunnel					
Mui Tsz Lam Road	3.47E-09	2.94E-11	2.99E-13	2.99E-13	2.99E-13
Ventilation Tunnel					
Magazine Access Road	0	0	0	0	0
Ventilation Shaft					
Magazine Access Road	0	0	0	0	0
Cavern					
Mui Tsz Lam Road	2.03E-09	4.41E-11	7.47E-13	1.07E-12	1.47E-12

Table 5.8 Occurrence Frequencies for a falling boulder hitting a person for accidental initiation of explosives from 2 MIC to 6 MIC due to errors in Blast Faces

Work Area	**2 MIC**	**3 MIC**	**4 MIC**	**5 MIC**	**6 MIC**
Main Access Tunnel					
A Kung Kok Street	1.45E-10	2.38E-12	2.50E-14	2.58E-14	2.58E-14
Secondary Access Tunnel					
Mui Tsz Lam Road	5.31E-11	4.50E-13	4.55E-15	4.55E-15	4.55E-15
Ventilation Tunnel					
Magazine Access Road	0	0	0	0	0
Ventilation Shaft					
Magazine Access Road	0	0	0	0	0
Cavern					
Mui Tsz Lam Road	3.10E-11	6.74E-13	1.14E-14	1.64E-14	2.25E-14

Boulders fall due to Accidental Detonation of Explosives during Transport within Tunnels

5.5.4.4 The calculated frequencies for boulder fall due to accidental detonation of explosives during transport within tunnels are summarized in **Table 5.9** to **Table 5.12** below.

Table 5.9 Boulder Fall Frequencies for accidental detonation of explosives during transport within tunnels / cavern

Work Area	**Frequency (per year)**
Main Access Tunnel	9.34E-09
Secondary Access Tunnel	5.61E-09
Ventilation Tunnel	0
Ventilation Shaft	2.80E-09
Cavern	0

5.5.4.5 With consideration of the topography, accidental detonation of explosives during transport within main access tunnel, secondary access tunnel and ventilation shaft will result in boulder fall onto A Kung Kok Street, Mui Tsz Lam Road and Magazine Site Access Road respectively as shown in **Table 5.10** to **Table 5.12** below. There is no impact to buildings and hence the scenario for a falling boulder due to accidental detonation of explosives during transport within tunnels hits a building is not further considered.

Table 5.10 Occurrence Frequencies for a falling boulder striking a vehicle for accidental detonation of explosives during transport within tunnels / cavern

Work Area	**Frequency (per year)**
Main Access Tunnel	
A Kung Kok Street	4.19E-11
Secondary Access Tunnel	
Mui Tsz Lam Road	2.51E-12
Ventilation Tunnel	
Magazine Access Road	0
Ventilation Shaft	
Magazine Access Road	0
Cavern	
Mui Tsz Lam Road	0

Table 5.11 Occurrence Frequencies for a vehicle hitting the boulder once it has fallen for accidental detonation of explosives during transport within tunnels / cavern

Work Area	**Frequency (per year)**
Main Access Tunnel	
A Kung Kok Street	1.95E-10
Secondary Access Tunnel	
Mui Tsz Lam Road	1.15E-11
Ventilation Tunnel	
Magazine Access Road	0
Ventilation Shaft	
Magazine Access Road	0
Cavern	
Mui Tsz Lam Road	0

Table 5.12 *Occurrence Frequencies for a falling boulder hitting a person for accidental detonation of explosives during transport within tunnels / cavern*

Work Area	Frequency (per year)
Main Access Tunnel	
A Kung Kok Street	6.03E-13
Secondary Access Tunnel	
Mui Tsz Lam Road	1.77E-13
Ventilation Tunnel	
Magazine Access Road	0
Ventilation Shaft	
Magazine Access Road	0
Cavern	
Mui Tsz Lam Road	0

5.5.5 Blast Effect due to Detonation of Full Load during the Transfer of Explosives from Delivery Point to Portal

5.5.5.1 The blast effect due to detonation of full load of explosives in one contractor truck from Delivery Point to portal is summarized as **Table 5.13**. The event frequency is 4.84×10^{-8} per year.

Table 5.13 *Consequence results of Blast Effect due to Detonation of Full Load during the Transfer of Explosives from Delivery Point to Portal*

No.	Scenario	TNT eqv. kg	Fatality Prob.	Impact Distance (m)	
				Indoor	Outdoor
Onsite Transport of Explosives					
01	Detonation of full load of explosives in one contractor truck from Delivery Point to Portal	227	90%	19	15
			50%	22	16
			10%	33	18
			3%	44	19
			1%	58	20

5.5.6 Blast Effect due to Detonation of Full Load during the Transfer of Explosives from Portal to Blast Site

5.5.6.1 The blast effect due to detonation of full load of explosives in one contractor truck from portal to Blast Site is summarized as **Table 5.14**. The event frequency is 9.34 $\times10^{-8}$ and 1.33×10^{-8} per year for Scenario 02 and 03 respectively.

Table 5.14 *Consequence results of Blast Effect due to Detonation of Full Load during the Transfer of Explosives from Portal to Blast Site*

No.	Scenario	TNT eqv. kg	Fatality Prob.	Impact Distance (m)	
				Indoor	Outdoor
Onsite Transport of Explosives					
02	Detonation of full load of explosives in one contractor truck from Portal to Blast Site	227	90%	19	15
			50%	22	16
			10%	33	18
			3%	44	19
			1%	58	20
03	Detonation of full load of explosives during transport from Ventilation Shaft Portal to Ventilation Shaft Blast Site	32.8	90%	10	8
			50%	12	8
			10%	17	9
			3%	23	10
			1%	30	11

6 RISK EVALUATION

6.1 Risk Results

6.1.1 Ground Vibration Effect on Slopes due to Errors in Blast Face

6.1.1.1 The results of scenario frequencies and expected fatalities for the affected slopes due to ground shock generated because of errors in the blast faces are summarised in **Table 6.1**. The calculated slope movement of all scenarios are much less than 20mm, and it is conservatively assumed that the chance of a slope failure is 0.01%.

Table 6.1 Scenario frequencies and expected fatalities for slope features affected by higher than expected vibrations generated by accidental initiation during construction of tunnels

Scenario/ Slope Number	**Scenario Frequency**	**Expected Fatality (N)**
4 MIC detonated at the same time		
7SE-A/C 526	3.87E-13	1 [3]
5 MIC detonated at the same time		
7SE-A/C 271	3.87E-13	0 [2]
7SE-A/C 526	5.81E-13	1 [3]
6 MIC detonated at the same time		
7SE-A/C 271	5.81E-13	0 [2]
7SE-A/C 259	1.94E-13	0 [1]
7SE-A/C 526	7.74E-13	1 [3]
7SE-A/C 266	1.94E-13	1 [3]

Notes:
[1] Slope runout within construction site boundary, no off-site impact is induced.
[2] Slope runout within DSD Ah Kung Kok Portal access road, no off-site impact is induced.
[3] Minimum of a single fatality is assumed for values less than 1.

6.1.2 Boulders Fall due to Higher than Expected Ground Vibration

6.1.2.1 In **Section 5.5.4**, boulder fall frequency and probability of the falling boulders hitting a vehicle or a person are calculated. The results of the base case scenario frequencies and expected fatalities for boulder fall due to errors in blast faces during the construction of the project or accidental detonation of explosives during transport within tunnels are summarized as **Table 6.2. Table 6.3** shows the overall frequencies for different fatality level for boulder fall due to errors in Blast Faces and accidental detonation of explosives during transport within tunnels for Base Case Scenario. **Table 6.4** shows the worst case scenario frequencies and expected fatalities for boulder fall due to errors in blast faces during the construction of the project or accidental detonation of explosives during transport within tunnels. The overall frequencies for different fatality level for boulder fall due to errors in Blast Faces and accidental detonation of explosives during transport within tunnels for Worst Case Scenario are summarized in **Table 6.5**.

Table 6.2 Scenario frequencies and expected fatalities for boulder fall due to errors in Blast Faces or accidental detonation of explosives during transport within tunnels (Road and pedestrian populations)(Base Case)

Scenario/ Street Name	**Scenario Frequency**	**Expected Fatality (N)** [1]
2 MIC detonated at the same time		
A Kung Kok Street	1.54E-08	1
	2.23E-09	2
	1.28E-10	3
Mui Tsz Lam Road	1.88E-09	1
	2.63E-10	2
	1.50E-11	3
3 MIC detonated at the same time		
A Kung Kok Street	2.52E-10	1
	3.66E-11	2
	2.09E-12	3
Mui Tsz Lam Road	2.51E-11	1
	3.51E-12	2
	2.01E-13	3
4 MIC detonated at the same time		
A Kung Kok Street	2.65E-12	1
	3.84E-13	2
	2.20E-14	3
Mui Tsz Lam Road	3.57E-13	1
	5.01E-14	2
	2.86E-15	3
5 MIC detonated at the same time		
A Kung Kok Street	2.73E-12	1
	3.90E-13	2
	2.24E-14	3
Mui Tsz Lam Road	4.68E-13	1
	6.55E-14	2
	3.75E-15	3
6 MIC detonated at the same time		
A Kung Kok Street	2.73E-12	1
	3.96E-13	2
	2.26E-14	3
Mui Tsz Lam Road	6.04E-13	1
	8.46E-14	2
	4.84E-15	3
Accidental detonation of explosives during transport within tunnels/ caverns		
A Kung Kok Street	6.40E-11	1
	9.28E-12	2
	5.30E-13	3
Mui Tsz Lam Road	3.94E-12	1
	5.52E-13	2
	3.16E-14	3

Notes:
[1] It is assumed that there are no less than 3 passengers in a vehicle.

Table 6.3 Overall frequencies for different fatality level for boulder fall due to errors in Blast Faces or accidental detonation of explosives during transport within tunnels (Road and pedestrian populations) (Base Case)

Scenario/ Street Name	**Scenario Frequency**	**Expected Fatality (N)** [1]
Boulder fall due to errors in Blast Faces or accidental detonation of explosives during transport within tunnels		
A Kung Kok Street	1.81E-08	1
	2.41E-09	2
	1.30E-10	3
Mui Tsz Lam Road	2.19E-09	1
	2.83E-10	2
	1.53E-11	3

Notes:
[1] It is assumed that there are no less than 3 passengers in a vehicle.

Table 6.4 Scenario frequencies and expected fatalities for boulder fall due to errors in Blast Faces or accidental detonation of explosives during transport within tunnels (Road and pedestrian populations) (Worst Case)

Scenario/ Street Name	**Scenario Frequency**	**Expected Fatality (N)** [1]
2 MIC detonated at the same time		
A Kung Kok Street	1.85E-08	1
	2.68E-09	2
	1.53E-10	3
Mui Tsz Lam Road	2.25E-09	1
	3.16E-10	2
	1.81E-11	3
3 MIC detonated at the same time		
A Kung Kok Street	3.03E-10	1
	4.39E-11	2
	2.51E-12	3
Mui Tsz Lam Road	3.01E-11	1
	4.22E-12	2
	2.41E-13	3
4 MIC detonated at the same time		
A Kung Kok Street	3.18E-12	1
	4.61E-13	2
	2.64E-14	3
Mui Tsz Lam Road	4.29E-13	1
	6.01E-14	2
	3.44E-15	3
5 MIC detonated at the same time		
A Kung Kok Street	3.28E-12	1
	4.68E-13	2
	2.69E-14	3
Mui Tsz Lam Road	5.62E-13	1
	7.87E-14	2
	4.50E-15	3
6 MIC detonated at the same time		
A Kung Kok Street	3.28E-12	1
	4.76E-13	2
	2.72E-14	3
Mui Tsz Lam Road	7.25E-13	1
	1.02E-13	2
	5.81E-15	3
Accidental detonation of explosives during transport within tunnels/ caverns		
A Kung Kok Street	7.68E-11	1
	1.11E-11	2
	6.36E-13	3
Mui Tsz Lam Road	4.73E-12	1
	6.63E-13	2
	3.79E-14	3

Notes:
[1] It is assumed that there are no less than 3 passengers in a vehicle.

Table 6.5 Overall frequencies for different fatality level for boulder fall due to errors in Blast Faces or accidental detonation of explosives during transport within tunnels (Road and pedestrian populations) (Worst Case)

Scenario/ Street Name	**Scenario Frequency**	**Expected Fatality (N)** [1]
Boulder fall due to errors in Blast Faces or accidental detonation of explosives during transport within tunnels		
A Kung Kok Street	2.18E-08	1
	2.89E-09	2
	1.56E-10	3
Mui Tsz Lam Road	2.63E-09	1
	3.39E-10	2
	1.83E-11	3

Notes:
[1] It is assumed that there are no less than 3 passengers in a vehicle.

6.2 Risk Evaluation

6.2.1 Introduction

6.2.1.1 Individual risk is a measure of the risk to a chosen individual at a particular location. As such, this is evaluated by summing the contributions to that risk across a spectrum of incidents which could occur at a particular location.

6.2.1.2 Societal risk is a measure of the overall impact of an activity upon the surrounding community. As such, the likelihoods and consequences of the range of incidents postulated for that particular activity are combined to create a cumulative picture of the spectrum of the possible consequences and their frequencies. This is usually presented as an fN curve and the acceptability of the results can be judged against the societal risk criterion under the risk guidelines.

6.2.2 Individual Risk

6.2.2.1 The individual risk (IR) contours for the use of explosives in Main Portal are shown in **Figure 6.1** and **Figure 6.3** for Base Case and Worst Case respectively. The individual risk (IR) contours for the use of explosives in Ventilation Shaft are shown in **Figure 6.2** and **Figure 6.4** for Base Case and Worst Case respectively. The maximum individual risk is 1×10^{-7} per year in main portal while that in ventilation shaft is 1×10^{-8} per year. The difference between the IR contours of Base Case and Worst Case is not significant. It is because the event occur frequency between two cases only has a 20% increase. On this basis, it would appear that the level of individual risk associated with on-site transport of explosives should be acceptable since it meets the Hong Kong Risk Guidelines.

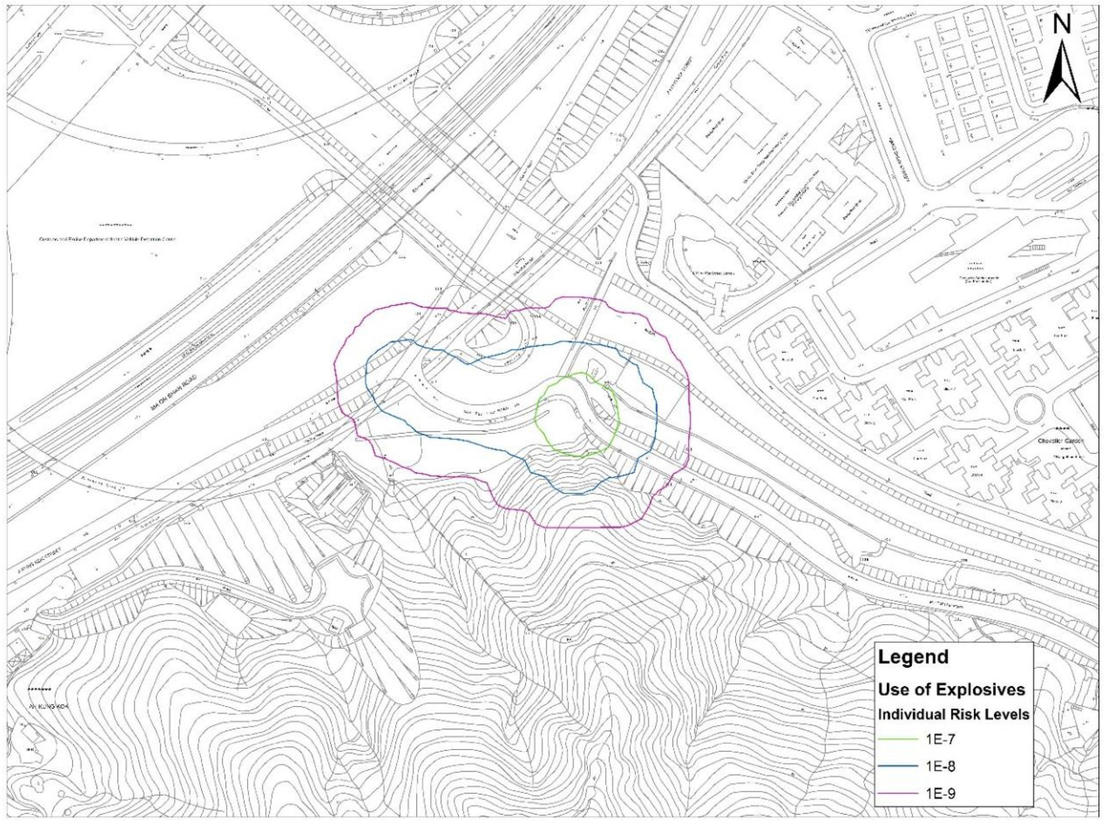

Figure 6.1 Maximum Individual Risk Contours for Use of Explosives in Main Portal (Base Case)

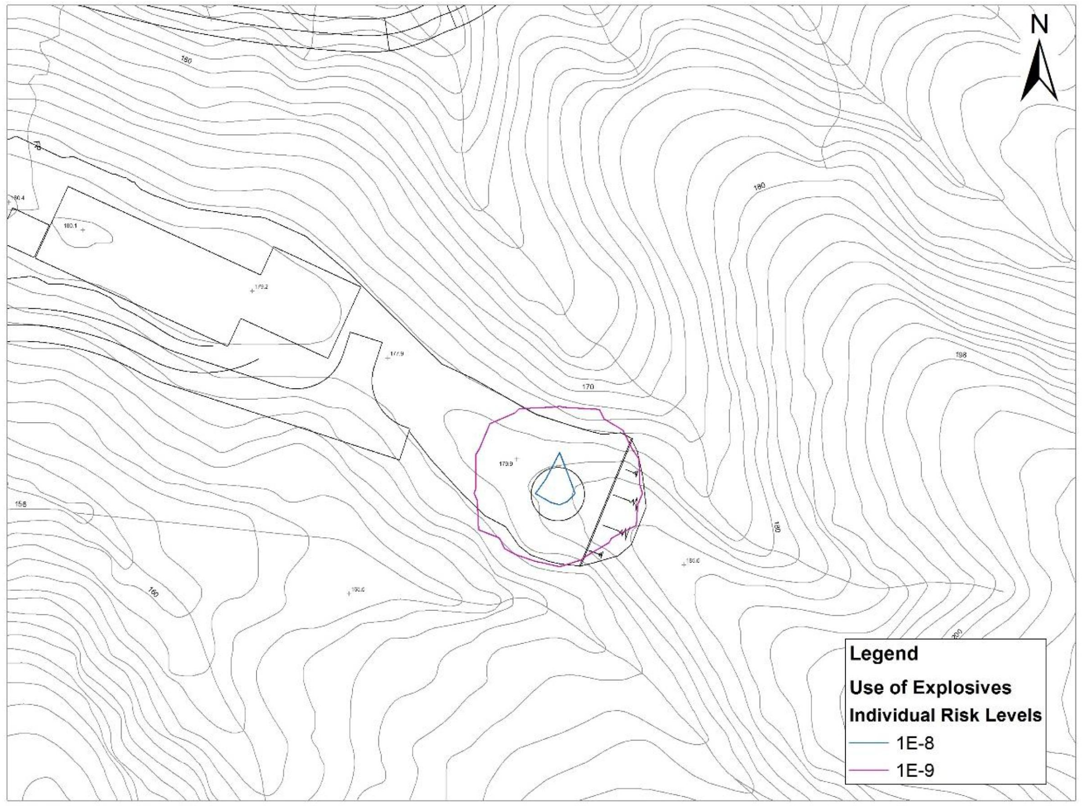

Figure 6.2 Maximum Individual Risk Contours for Use of Explosives in Ventilation Shaft (Base Case)

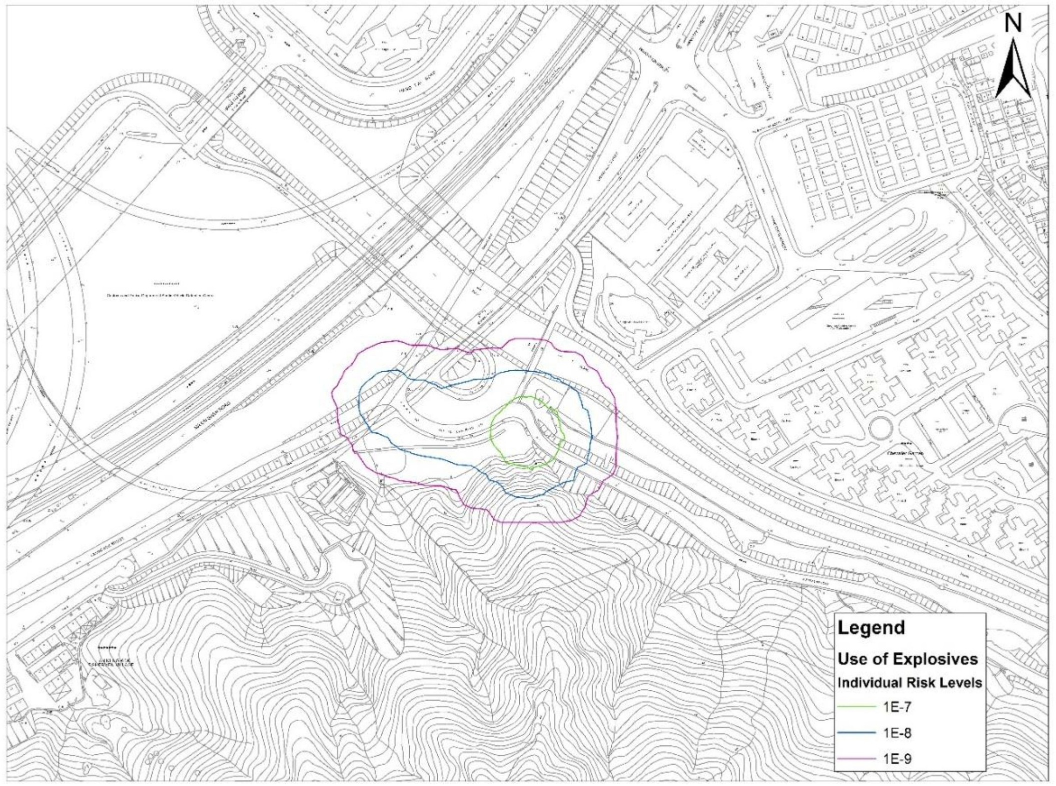

Figure 6.3 Maximum Individual Risk Contours for Use of Explosives in Main Portal (Worst Case)

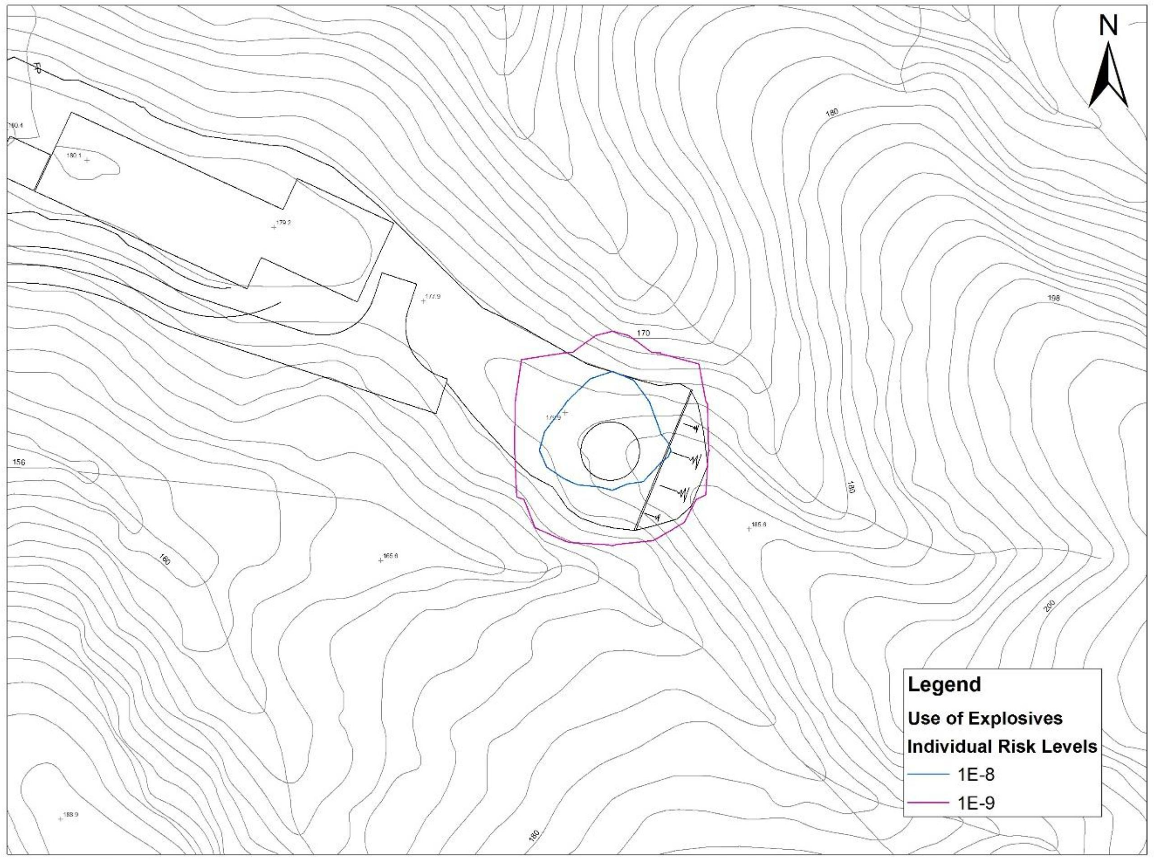

Figure 6.4 Maximum Individual Risk Contours for Use of Explosives in Ventilation Shaft (Worst Case)

6.2.3 Societal Risk

<u>Potential Loss of Life</u>

6.2.3.1 The potential loss of life (PLL) for use of explosives is 7.99×10^{-7} per year for the Base Case. PLL of 9.99×10^{-7} per year is calculated for the Worst Case, which is higher than PLL for the Base Case. For the Detonation of full load of explosives during transport from Ventilation Shaft Portal to Ventilation Shaft Blast Site, only construction workers are present at the construction site of ventilation shaft. Therefore, no societal risk is induced by this scenario. PLL results for Base Case and Worst Case are presented in **Table 6.6** and **Table 6.7** respectively.

Table 6.6 Potential Loss of Life for Base Case

Case: Base Case	PLL (per year)	Contribution (%)
Full load detonation of explosives during transport from delivery point to portal	3.05E-07	38
Full load detonation of explosives during transport from portal to blast face	4.68E-07	59
Higher than expected ground vibration during construction of cavern, tunnels and shaft causing	2.61E-08	3
Total	**7.99E-07**	**100**

Table 6.7 Potential Loss of Life for Worst Case

Case: Base Case	PLL (per year)	Contribution (%)
Full load detonation of explosives during transport from delivery point to portal	4.06E-07	41
Full load detonation of explosives during transport from portal to blast face	5.62E-07	56
Higher than expected ground vibration during construction of cavern, tunnels and shaft causing	3.14E-08	3
Total	**9.99E-07**	**100**

<u>F-N Curve</u>

6.2.3.2 The overall fN curve for the use of explosives is shown in **Figure 6.5**. The Base Case represents the risks associated with the expected blasting programme, while the Worst Case has considered a 20% increase in the number of deliveries to account for any construction uncertainties. It can be seen that the risks lie in Acceptable region.

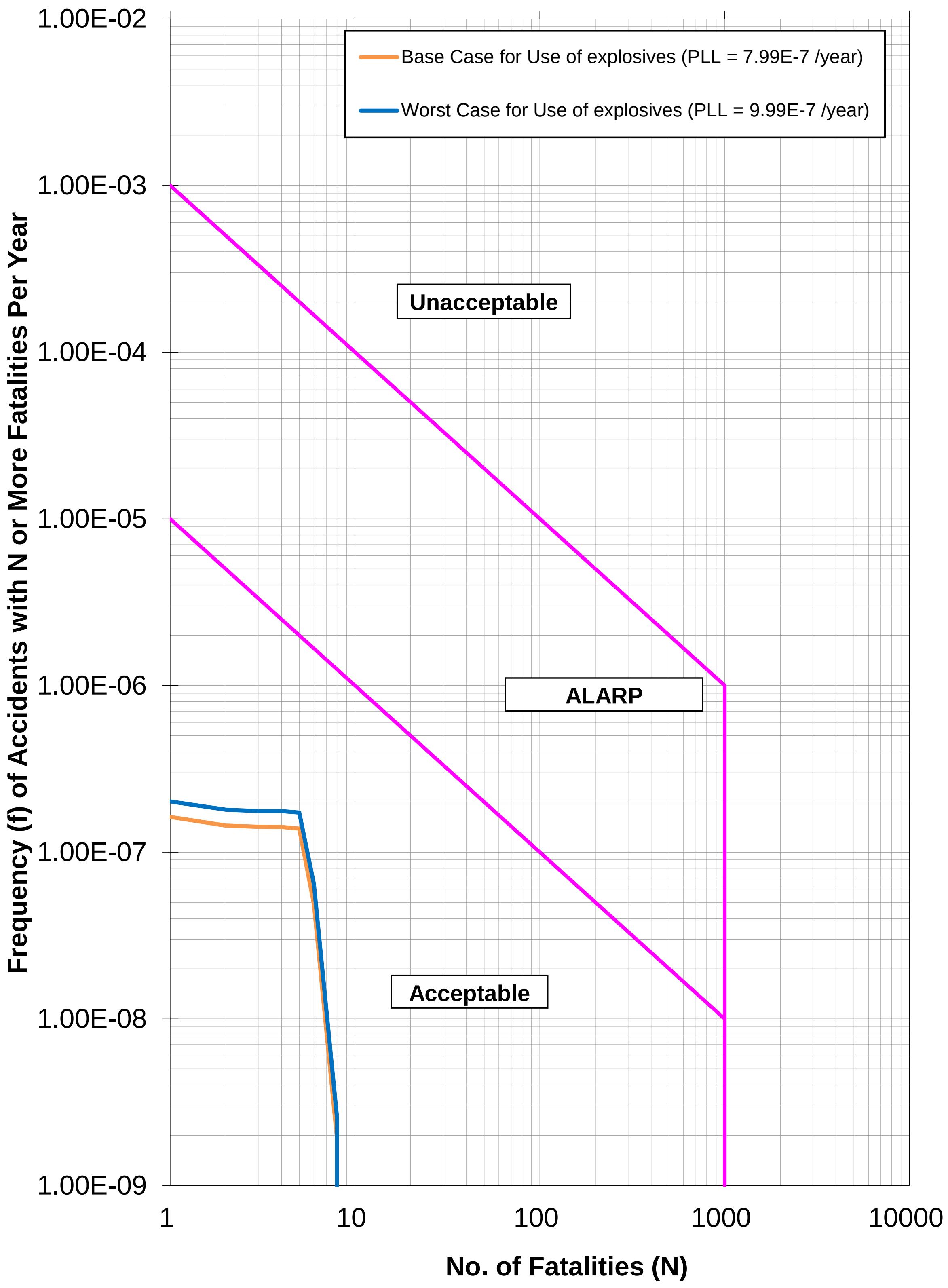

Figure 6.5 F-N Curves for Use of Explosives

6.2.4 Uncertainty Analysis

6.2.4.1 This study is performed based on several assumptions as highlighted in previous sections. A discussion on the uncertainties of the results is given below.

Accident Frequency for Explosives Transfer within Tunnels / Ventilation Shaft and Cavern

6.2.4.2 During transport, explosives are initiated due to crash fire, non-crash fire and crash impact. The crash frequency used for road transport was derived based on accident data on public roads, and the same frequency has been adopted for transport within access tunnel/ ventilation shaft and cavern to the blast faces. However, the crash frequency for transport within the tunnel/ ventilation shaft and cavern is expected to be much lower due to speed restrictions inside the tunnel and the absence of other vehicle movements. Therefore, the adopted frequency in our assessment is considered to be conservative.

Ground Vibration Model

6.2.4.3 When there is more than one blasthole charge being detonated at the same time, it is assumed that the vibration effect will be equivalent to the summation of all charge weight detonated at the same time. However, due to delay scatter within the realms of the manufacturing tolerance, direct summation of charge weight would overestimate the predicted vibration. The consequence assessment has considered the effects to be additive which is conservative.

Frequency of Blast involving more than one MIC

6.2.4.4 The frequency of blasts involving more than one MIC has been estimated from failure mode analysis, fault tree analysis, expert judgment and human error analysis.

6.2.4.5 The frequency of 5MIC and 6MIC detonation occurring simultaneously has been conservatively assumed to be the same as 4MIC.

Impact on Buildings and other Features due to Ground Vibration

6.2.4.6 It has been conservatively assumed that any building subject to vibration of more than 100mm/s will experience some damage to non-structural elements such as brick walls or lead to objects falling off the building including loose ceiling or other unauthorised features. These events can lead to fatality. A fatality level of about 1% of the total population inside the building has been assumed. The maximum PPV affecting any buildings due to six MIC chargeweight is about 30 mm/s which is less than the 100mm/s.

Actual Blasting Scenario

6.2.4.7 The average frequency derived from the Frequency Analysis in Annex 1 will be slightly lower than some actual blasting scenarios in which chargeweight is less than the maximum instantaneous charge, a 25% increase of the derived frequencies was applied in risk assessment to account for actual scenarios.

7 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

7.1.1.1 A Hazard to Life Assessment has been carried out to access the risk issues arising from the use of explosives during the construction of this project.

7.1.1.2 The criterion of Annex 4 of the EIAO-TM for individual risk is fulfilled. The assessment results show that both individual risk and societal risk are within acceptable limits.

7.1.1.3 Nevertheless, there are some recommendations specific to the use of explosives during the construction of the access tunnels, cavern and ventilation shaft to further minimize the risks with best practices.

7.2 Recommendations

7.2.1.1 The following recommendations should be considered for the safe use of explosives:

- Blast Charge Weight should be within maximum MIC as specified for the given blast face.
- Temporary mitigation measures such as blast doors or heavy duty blast curtains should be installed at the portals or shafts and at suitable locations underground to prevent flyrock and control the air overpressure.
- Multiple faces blasting will be carried out for the construction of cavern in this project. Good communication and control will need to be adopted in ensuring that the works are carried out safely.
- It is not intended to carry out complete evacuation of the construction areas and secure refuge areas should be identified to workers in the areas.
- A Chief Shotfirer and a Blasting Engineer shall be employed in addition to the normal blasting personnel to ensure that the works are safe and coordinated between blasting areas.
- Shotfirer to be provided with a lightning detector, and appropriate control measures should be in place.
- Speed limit for the diesel vehicle truck and bulk emulsion truck in the access tunnel and cavern should be imposed. The truck may be escorted while underground to ensure route is clear from hazards and obstructions.
- Hot work should be suspended during passage of the diesel vehicle truck and bulk emulsion truck in the access tunnel and cavern.
- A boulder survey should be undertaken based on the likely PPV values that would result from the blasting process. Those boulders subject to the vibration higher than the allowable limit should be strengthened, removed, or constructed with boulder fence, prior to the commencement of blasting.

8 REFERENCES

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Annex 1 Frequency Analysis for Use of Explosives

1 Estimation of Number of Blasts

1.1.1 A total of about 1,007 blasts has been estimated for the tunnels and shafts and about 3,032 blasts has been estimated for the caverns of the relocation of Sha Tin Sewage Treatment Works to Caverns. The breakdown of different sections is summarized as follows.

Table 1.1 Breakdown of numbers of blasts for different sections of the Project

Sections	No. of sectors per face	No. of Blasts
Single Access Tunnel Top Heading	6	40
Single Access Tunnel Bench	6	40
Full Access Tunnel Top Heading	6	202
Full Access Tunnel Bench	6	101
Secondary Access Tunnel Top Heading	6	81
Secondary Access Tunnel Bench	6	81
Ventilation Shaft	6	36
Ventilation Tunnel	6	198
Branch Tunnel Top Heading	6	114
Branch Tunnel Bench	6	114
	Total for tunnels and shaft	**1,007**
Cavern Top Heading	6	1,516
Cavern Bench	6	1,516
	Total for cavern	**3,032**

2 Frequency Analysis for Scenarios Leading to Higher than Expected Ground Vibration at a Blast Face

2.1 Failure Mode Analysis for Use of Explosives

2.1.1 With reference to the WIL Study [1], the following failure modes were identified and further investigated:

- Face freeze caused by cut failure;
- Two MIC detonated at the same time at a blast face;
- Multiple MIC detonated at the same time at a blast face;
- More cartridges sticks / bulk emulsion explosives loaded into a production hole than required; and
- Unforeseen ground condition

2.1.2 In this project, Blasting Specialist and Human Error Specialist have been deployed to review the Human Error Analysis in **Annex 2** of **Appendix 7.02**.

2.2 Assumptions for Frequency Analysis

2.2.1 The following assumptions are made for performing the frequency analysis:

- Blast faces are typically divided into 1-sector, 4-sector and 6-sector face according to the number of holes per face. [1] In this project, all the blast faces are identified as 6-sector faces as they have 130 or more holes per face.
- For a blast face having more than 1 sector, no more than 4 numbers of same time delay detonators for production holes have been imposed due to design constraints. Having more than one time delay detonators with the same delay time within production holes located in the same sector is not possible unless there has been an erroneous permutation, connection or manufacturer defects. Therefore, it is considered not possible to have more than 4 MIC in any blast with 4 or 6 sectors due to erroneous permutation or connection because of the design constraint.
- Each sector will be detonated in sequence as delay surface connectors will be used to provide external time delay to different sectors. The explosion sequence will stop onwards if an external surface connector fails completely.
- The connection between detonators and bunch blocks (i.e. 0ms surface connector) is to use detonating cord to bundle all detonators in a sector and then connect the detonating cord to a surface connector.
- No failure modes of detonators will result in significant change in time delay unless there are unexpected manufacture defects. Detonation is not expected in case of failure modes other than manufacture defect.
- Each perimeter hole is designed to be loaded with a charge less than a MIC. Multiple perimeter holes will be detonated at the same time and long time delay detonators will be installed at the perimeter holes.
- There are possibilities that a swap of detonators between a perimeter hole and a production hole occurs. For the perimeter hole loaded with a detonator for production holes, the perimeter hole will be blasted out earlier than expected but the effect on vibration is insignificant as the loaded charge is lower than a MIC. For the production

hole loaded with a longer time delay detonator, it will be blasted out when the outer ring comes off and hence the effect is insignificant.

- Putting two or more perimeter detonators of same time delay into the production holes of same sector requires a minimum of two permutations. Multiple MIC blasted off together will be occurred. Perimeter hole detonators requires one further level of error or permutation than production hole detonators to cause multiple MIC detonated at the same time. Therefore, perimeter holes were not further considered in the frequency assessment.

2.3 Face Freeze Caused by Cut Failure

2.3.1 A cut is provided for each blast face to provide a void or relief before other production holes are blasted, this allows the rock to be blasted out in a ring like sequence. Reasons for incorrect size or location of relief holes could be either design error or drilling error. A probability of 0.5 is assumed for such errors that is significantly enough to cause a face freeze.

2.3.2 The human error probabilities associated with the face freeze caused by cut failure were calculated in **Annex 2** and summarized in **Table 2.1**. Since the probabilities calculated in **Annex 2** were derived for each occasion that the task is undertaken, the number of cut holes in a face (i.e. 6 numbers) needs to be considered for deriving the human error probabilities for wrong installation of detonator per face (Event 1.3.1).

Table 2.1 Human Error Probabilities for Cut Hole Error

Event / task no.	Description	Human Error Probability for a face
1.1	**Wrong design of hole diameter/location for cut**	
1.1.1	Design error by Blasting Engineer and failure of design check	1.05E-03
1.1.2	Failure to detect and correct error by Resident Engineer, Mines Division and Shotfirers	3.56E-05
1.2	**Wrong location of drilling or incorrect drill size used**	
1.2.1	Operator fails to drill correctly	2.26E-02
1.2.2	Failure to detect and correct error by Blasting Engineer and Shotfirer	7.61E-05
1.3	**Detonator is installed incorrectly**	
1.3.1	Wrong installation of one detonator by the Shotfirer	3.00E-06
1.3.2	Shotfirer fails to detect and correct that there are holes without detonators left in the face	4.24E-02

2.3.3 The probability of manufacture defect of detonators leading to wrong time delay or no detonation is discussed in Section 2.4.

2.4 Two MIC Detonated at the Same Time at a Blast Face

2.4.1 Detonation of more than one MIC at the same time in a face will result in higher than expected vibration than the design limit. A total of 6 failure modes were identified leading to two MIC detonated at the same time, and were analysed in the following sections:

Wrong design of time delay

2.4.2 The detonators in the same sector will have different time delay while the surface connectors will provide external time delay for different sectors to ensure that no 2 detonators will set off at the same instant of time in a face. For a design error such that 2 detonators with same time delay are provided in the same sector, two MIC may be detonated at the same time.

2.4.3 The human error probabilities associated with the wrong design of time delay were calculated in **Annex 2** and summarized in **Table 2.2**.

Table 2.2 Human Error Probabilities for Wrong Design of Time Delay

Event / task no.	Description	Human Error Probability for a face
2.1	**Wrong design of time delay for a face**	
2.1.1	Design error by Blasting Engineer and failure of design check	1.05E-03
2.1.2	Failure to detect and correct error by Resident Engineer, Mines Division and Shotfirers	1.19E-06

One detonator wrongly put into one sector which contains the same time delay detonator

2.4.4 In case a detonator is wrongly put into a sector contains the same time delay detonator during the blast face set up, 2 MIC will be set off at the same time. Potential causes for this failure mode include the following:

- Incorrect detonators are delivered to site and Shotfirer fails to detect the error during label check before and after the installation;
- The Shotfirer marks the delay number of holes at the face incorrectly;
- The Shotfirer fails to check the detonator labels before and after the installation; and
- The Shotfirer picks up the right detonator but incorrectly puts in an adjacent sector

2.4.5 Generally about 70% pf the holes at a typical blast face 6 sectors are production holes while the rest are perimeter holes. With reference to WIL Study [1], numbers of production holes assumed for a blast face with 6 sectors are summarized in **Table 2.3**.

Table 2.3 Number of Holes per a Blast Face

Sectors per Blast Face	No. of Holes in Face	No. of Production Holes for Frequency Analysis
6	80-130	90

2.4.6 The human error probabilities associated with putting a detonator into a wrong sector on a per face basis were calculated in **Annex 2** and summarized in **Table 2.4**.

Table 2.4 Human Error Probabilities for Detonator put into Wrong Hole

Event / task no.	Description	Human Error Probability for a face
		6-Sector face
2.2	**Detonator put into wrong hole**	
2.2.1	Delivery of incorrect detonators from the magazine to the blast site	7.11E-08
2.2.2	Installation of one detonator by Shotfirer into a sector already containing a detonator of that delay period	4.91E-05
2.2.3	Shotfirer fails to check and correct installation error	1.80E-03

Incorrect timer default of detonators due to manufacturer defect

2.4.7 Detonators with different time delay are produced by the manufacture in batch. Systematic errors such as wrong labeling that affect the whole batch of detonators will be readily detected by the destructive product sample tests. However, for random errors such as individual off-spec detonator exceeding chemical delay tolerance may not be detected in sample tests.

2.4.8 The probability of manufacturer defect of one detonator for a blast face is referred to WIL Study [1] and is shown in **Table 2.5**. The probability of manufacturer defect was assumed as 0.01 for each additional defective detonator.

Table 2.5 Probability of Manufacturer Defect of One Detonator for a Blast Face

Sectors per Blast Face	Probability of Manufacturer Defect of One Detonator for a Blast Face
6	9E-06

Surface connector fails to provide necessary delay

2.4.9 Surface connectors with different time delay will be used. The number of surface connectors required for a blast face with 6 sectors are summarized in **Table 2.6**.

Table 2.6 Number of Surface Connector Per Face

Time Delay of Surface Connector	Sectors per Face
	6 Sectors
0 ms	6
9 ms	1
17 ms	4
42 ms	-

2.4.10 The probability of manufacturer defect of one surface connector for a blast face with 6 sectors is referred to WIL Study [1] and is shown in **Table 2.7**. The probability of manufacturer defect was assumed as 0.01 for each additional defective surface connector.

Table 2.7 Probability of Manufacturer Defect of One Surface Connector for a Blast Face

Sectors per Blast Face	No. of Time Delay (excluding 0 ms) used per face	Probability of Manufacturer Defect of One Surface Connector for a Blast Face
6	5	5E-07

One detonator of a sector connected wrongly to a surface connector of another sector

2.4.11 The detonators of the same sector will be bundled by a detonating cord which will then be connected to a 0ms time delay surface connector. If a detonator of a sector is bundled incorrectly to another sector which contains the same time delay detonator, 2 MIC will be detonated at the same time.

2.4.12 The human error probabilities associated with putting a detonator into a wrong sector on a per face basis were calculated in **Annex 2** and summarized in **Table 2.8**.

Table 2.8 Human Error Probability for Connection of a Detonator to a Wrong Surface

Event / task no.	Description	Human Error Probability for a face
		6-Sector face
2.3	**Detonator of one sector wrongly connected to a surface connector of a different sector**	
2.3.1	Shotfirer misconnects one detonator to the wrong surface connector	1.49E-01
2.3.2	Failure to detect and correct connection error	1.28E-05

Use of a wrong surface connector

2.4.13 Different time delay surface connectors have their unique colour coding. The use of wrong surface connector can be easily spotted during the final hook up checking. WIL Study [1] was referred for identifying the failure modes to be analysed.

2.4.14 The human error probabilities associated with putting a detonator into a wrong sector on a per face basis were calculated in **Annex 2** and summarized in **Table 2.9**. Since the probabilities calculated in **Annex 2** were derived for each occasion that the task is undertaken, the number of surface connector in a face needs to be considered for deriving the human error probabilities for wrong installation of surface connector per face (Event 2.4.1).

Table 2.9 Human Error Probability for Using a Wrong Surface Connector (6-Sector Faces)

Event / task no.	Description	Human Error Probability for a face
		6-Sector face
2.4	**Shot Firer uses a wrong surface connector**	
2.4.1	Wrong installation of surface connector	1.62E-02
2.4.2	Shot firer fails to detect and respond	1.80E-03
2.4.3	Failure to detect and respond during final hook-up check	3.01E-04

2.5 Multiple MIC Detonated at the Same Time at a Blast Face

2.5.1 Failure mode analysis considers simply the multiple failures of the same types of failure modes identified for 2 MIC detonated at the same time as discussed in Section 2.4. These are further analysed in Section 3 with the use of fault tree analysis.

2.5.2 In case there are design errors not readily detected by the robust design check or more number of detonators which have time delay coinciding with the ones already in the face due to manufacturer defect, it is possible to have more than 4 MIC being detonated at the same time.

2.6 More Bulk Emulsion Explosives Loaded into a Production Hole than Required

2.6.1 There are three causes that will lead to more bulk emulsion explosives being loaded into a production hole than required:

- Wrong density check of bulk emulsion;
- Truck Operator, Shotfirer and Blasting Engineer do not realise holes are overloaded; and
- Wrong design of MIC

2.6.2 The human error probabilities associated with more bulk emulsion explosives loaded into a production hole than required were calculated in **Annex 2** and summarized in **Table 2.10**.

Table 2.10 Human Error Probabilities for Excess Emulsion Loaded into a Hole

Event / task no.	Description	Human Error Probability for a face
3.1	**Excess emulsion is loaded into a hole**	
3.1.1	Excess emulsion is loaded due to wrong density	1.11E-12
3.1.2	Shotfirer does not realise hole is overloaded	1.35E-06
3.2	**Wrong design of MIC**	
3.2.1	Design error by Blasting Engineer	2.11E-05
3.2.2	Failure to detect and correct design error	3.70E-05

2.7 More Cartridged Sticks Loaded into a Production Hole than Required

2.7.1 There are four causes that will lead to more cartridged sticks being loaded into a production hole than required:

- Shotfirer does not count number of cartridges picked up and loads too many into a hole;
- Cartridges left over from blocked holes may be disposed of incorrectly;
- Shotfirer may not realise holes are overloaded in case there are excess amount of cartridges delivered to site; and
- Wrong design of MIC

2.7.2 The human error probabilities associated with more cartridged sticks loaded into a production hole than required were calculated in **Annex 2** and summarized in **Table 2.12**.

Table 2.11 Human Error Probabilities for Excess Cartridges Loaded into a Hole

Event / task no.	Description	Human Error Probability for a face
		6-Sector face
4.1	**Too many cartridges are inserted in holes**	
4.1.1	SF does not count correctly and load excess cartridges into holes	6.64E-02
4.1.2	Cartridges from blocked holes are not disposed of correctly	8.13E-03
4.1.3	Shotfirers/Blasting Engineer do not realise holes are overloaded	2.45E-05
4.1.4	Shotfirers/Blasting Engineer do not realise blocked holes are not disposed of	1.78E-08
4.2	**Wrong design of MIC**	
4.2.1	Design error by Blasting Engineer	8.52E-05
4.2.2	Failure to detect and correct design error	1.06E-03

2.8 Unforeseen Ground Conditions

2.8.1 The MIC values derived in the Blast Assessment Report are based on site surveys carried out for sensitive receivers in vicinity, and the values will be refined based on trial blast results prior to full scale blast process of the Project. A 3-As (Alert-Alarm-Action) monitoring programme will be implemented to continuously monitor any potential exceedance of 25 mm/s for every blast. All potential causes leading to increase in ground vibration level will be investigated, it is thus assumed that any unforeseen ground conditions between the blast faces and the sensitive receivers will be detected by the 3-As monitoring programme.

3 Fault Tree Analysis

3.1 Overview

3.1.1 Fault Tree Analysis (FTA) permits the hazardous incident (“Significant Failure Events”) frequency to be estimated from a logical model of the failure mechanisms of a system. The model is based on the combinations of failures of more basic components, safety systems and human errors.

3.1.2 FTA is the use of a combination of simple logic gates, “AND” and “OR” gates, to synthesize a failure model of the hazardous installation. The “Significant Failure Events” frequency is calculated from failure data of more simple events.

3.1.3 A basic assumption in FTA is that all failures in a system are binary in nature, a component or operator either performs successfully or fails completely. In addition, the system is assumed to be functioning if all sub-components are operating properly.

3.2 Fault Tree Models

3.2.1 Fault tree models were developed for the following failure scenarios associated with use of explosives. Details of the fault tree models are presented in **Attachment 1** for this annex.

- Higher vibration due to 2 MIC detonated at the same time.
- Higher vibration due to 3 MIC detonated at the same time.
- Higher vibration due to 4 MIC detonated at the same time.
- Higher vibration due to cut hole error (not applicable for blast faces with 1 sector)

<u>Modelling of Overcharge of Emulsion more than required</u>

3.2.2 Fault tree models were also developed for the following failure scenarios concerning about overcharge. The higher failure probability between bulk and cartridged emulsion was considered as an integral part of the above models as either one of the two emulsions will be used for a blast face. The overload was considered as one of the causes leading to a maximum of 2MIC detonated at the same time as mentioned in **Section 3.2.1**.

- More bulk emulsion explosives loaded into a production hole than required.
- More cartridged sticks loaded into a production hole than required.

3.2.3 The following failure cases have been considered since the overload could be a maximum of 1MIC or less than that.

- For 3 MIC case, charge overload with one error other than overload (i.e. design error in time delay, detonator put into a wrong sector, manufacture defect for a detonator, manufacture defect for a surface connector, incorrect connection of surface connector) will lead to 3MIC detonated at the same time.
- For 4 MIC case, charge overload with two errors other than overload will lead to 4MIC detonated at the same time.

Configuration of Fault Tree Models

3.2.4 The numbers of failure modes required and their combinations were considered as shown below.

- 2 MIC detonated at the same time is caused by one error.
- 3 MIC detonated at the same time is caused by two errors.
- 4 MIC detonated at the same time is caused by three errors.

3.2.5 As a result, the fault trees have been constructed in such a way that:

- For 3 MIC case, the two errors combination could be same type of error occurred two times or two different types of error.
- For 4 MIC case, the three errors combination could be same type of error occurred three times, same type of error occurred two times with one other type of error or three different types of error.

Potential Dependency of Human Errors

3.2.6 The probability of the second human error of the same type was conservatively assumed as 0.01 to account for the potential dependency of human errors. Taking **Event 2.2** as an example, the human error probability for installation of a detonator into a wrong hole is 4.94E-05 for a 6-Sector face. The human error probability for installation of another one detonator into a wrong hole is hence 0.01 by the above assumption.

3.3 Modelling Results

3.3.1 The modelling results are summarised in **Table 3.1**.

Table 3.1 Probability of Occurrence per Blast Face

Probability of Occurrence Per Blast Face	
Scenarios	**6 Sectors**
Higher vibration due to 2 MIC detonated at the same time	1.12E-05
Higher vibration due to 3 MIC detonated at the same time	9.51E-08
Higher vibration due to 4 MIC detonated at the same time	9.68E-10
Higher vibration due to cut hole error	8.80E-07
Others	
More cartridged sticks loaded into a production hole than required	1.73E-06
More bulk emulsion explosives loaded into a production hole than required	1.41E-06

3.3.2 As shown in **Table 3.1**, the probability of occurrence for overload of cartridged sticks into holes for 6 sectors blast face is higher than that for overload of bulk emulsion into holes. Since the blast faces of this project are in 6 sectors, the probability of occurrence for overload of cartridged sticks was considered in the models for the failure scenarios of more than 1MIC detonated at the same time.

3.3.3 The probabilities of occurrence of multiple MIC detonated at the same time shown in **Table 3.1** generally reduce as additional error is required to result in one more MIC blasting off together.

3.3.4 As mentioned in **Section 2.5** above, in case there are design errors not readily detected by the robust design check or more number of detonators which have time delay coinciding with the ones already in the face due to manufacturer defect, it is possible to have more than 4 MIC being detonated at the same time. The occurrence probability for each additional MIC detonated at the same time is roughly two orders of magnitude lower each time as the probability of each additional error for either design or manufacturing of detonator is conservatively assumed as 0.01. Hence, the occurrence probability for 5MIC and 6MIC detonated at the same time will be of 10^{-11} and 10^{-13} per blast face respectively.

3.3.5 It was conservatively assumed that the occurrence probability of 5 and 6 MIC detonated at the same time will be the same as that for 4 MIC detonated at the same time for hazard assessment purpose.

3.3.6 For detonation of more than 6 MIC at the same time, the derived frequency will be of 10^{-15} which is very low and will not be further considered.

3.4 Overall Frequency for Failure Scenarios

3.4.1 The overall frequencies of failure scenarios leading to higher vibration for this project are summarised as below. It is noted that blasting will be spread over a few years.

Table 3.2 Overall frequencies of failure scenarios leading to higher vibration for this project

Sections	Occurrence Frequency for multiple MIC detonated at the same time (Occurrence per project)				
	2 MIC	**3 MIC**	**4 MIC**	**5 MIC**	**6 MIC**
Access Tunnels and Ventilation Tunnel	1.09E-02	9.24E-05	9.40E-07	9.40E-07	9.40E-07
Ventilation Shaft	4.05E-04	3.43E-06	3.48E-08	3.48E-08	3.48E-08
Cavern	3.41E-02	2.88E-04	2.93E-06	2.93E-06	2.93E-06

3.5 Conservatism built into the Fault Tree Analysis

3.5.1 The probability of 5 and 6 MIC detonated at the same time was assumed to be the same as that of 4 MIC detonated at the same time.

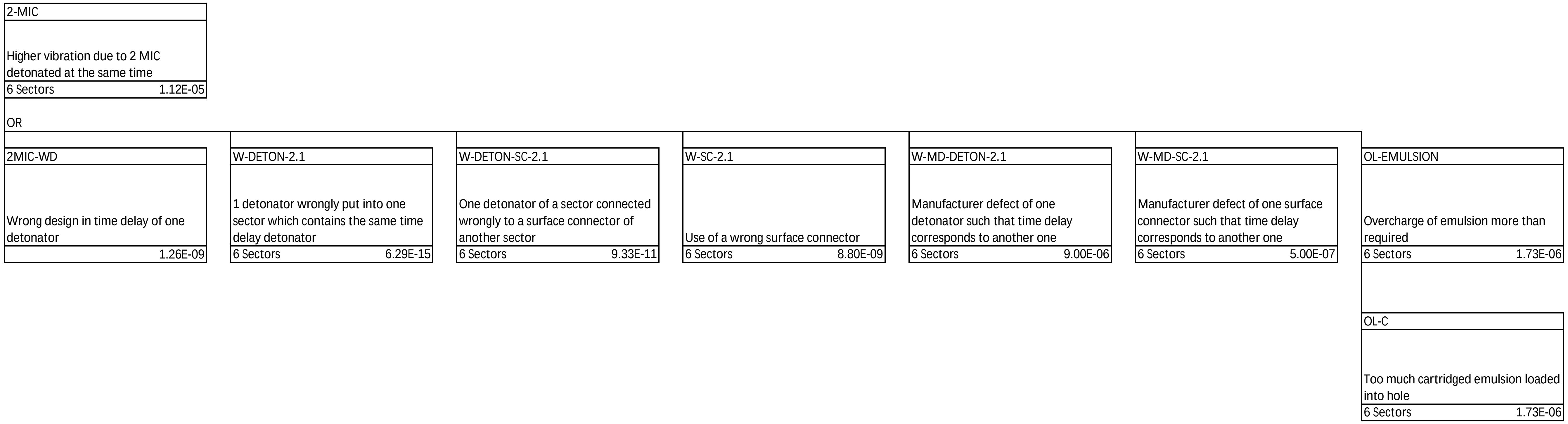
3.5.2 The estimation of the probability of the overload of cartridged sticks into holes considered the amount of over-delivery or number of blocked holes in a face is limited. In addition, the probability of a hole being overloaded and at the same time it has a detonator of same time delay being misplaced is also considered in the fault tree models.

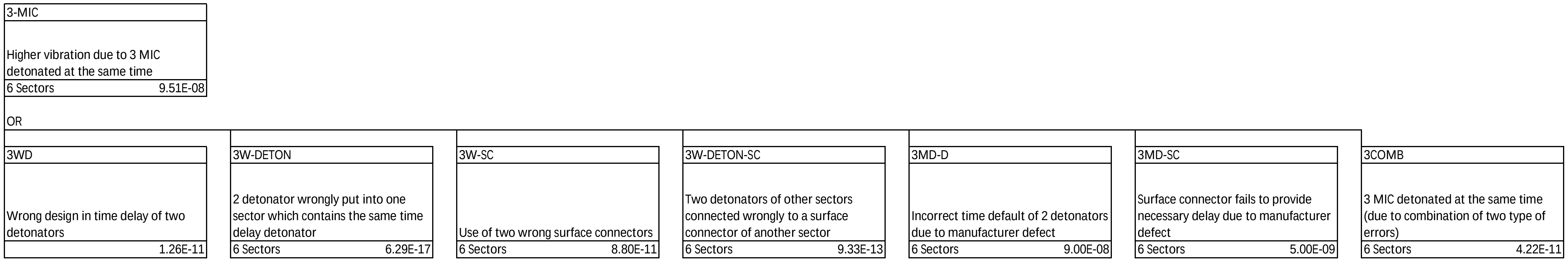
3.5.3 When a surface connector is connected to appropriate detonators/ surface connectors, it will be wrapped by tapes to prevent accidental connection with other detonators / surface connectors. Therefore, it is seldom to have multiple wrong connections to a surface connector at a time. This is not taken into consideration in the fault tree models.

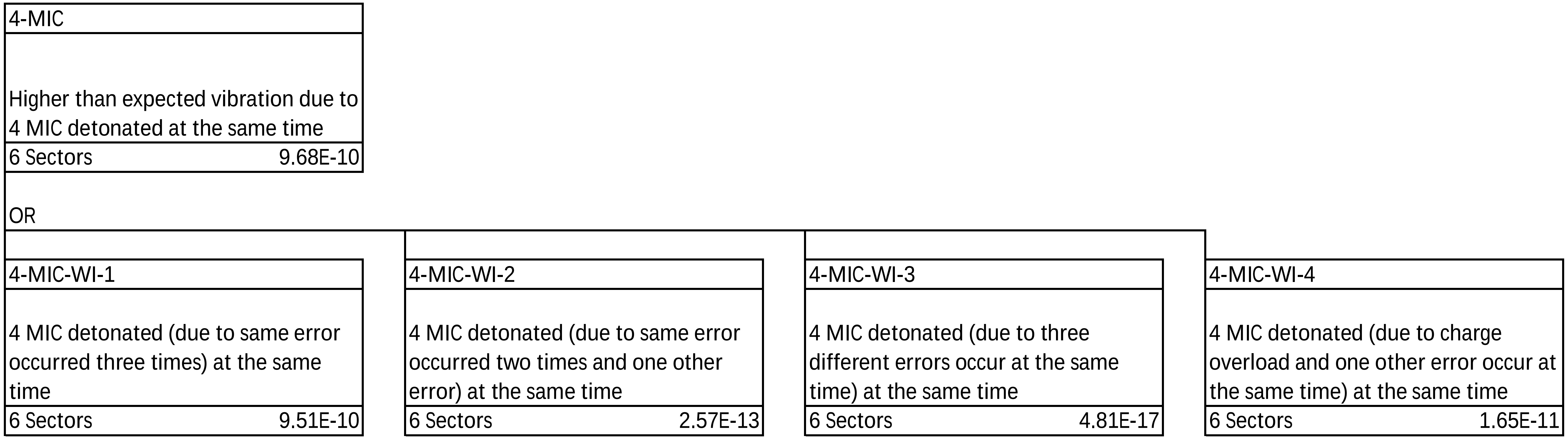
3.5.4 Blast faces were categorised into 6-sector faces. However, the number of the production holes varies depending on the cross-sectional area of a face. The biggest cross-section of the same face category which has the maximum number of production holes was assumed for the study.

4 Reference

[1] ERM, 2008. West Island Line: Hazard to Life Assessment for the Transport, Storage and Use of Explosives.


2-MIC
Higher vibration due to 2 MIC detonated at the same time
6 Sectors 1.12E-05
OR
2MIC-WD
Wrong design in time delay of one detonator
1.26E-09
W-DETON-2.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-DETON-SC-2.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-SC-2.1
Use of a wrong surface connector
6 Sectors 8.80E-09
W-MD-DETON-2.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06
W-MD-SC-2.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


3-MIC
Higher vibration due to 3 MIC detonated at the same time
6 Sectors
9.51E-08
OR
3WD
Wrong design in time delay of two detonators
1.26E-11
3W-DETON
2 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-17
3W-SC
Use of two wrong surface connectors
6 Sectors
8.80E-11
3W-DETON-SC
Two detonators of other sectors connected wrongly to a surface connector of another sector
6 Sectors
9.33E-13
3MD-D
Incorrect time default of 2 detonators due to manufacturer defect
6 Sectors
9.00E-08
3MD-SC
Surface connector fails to provide necessary delay due to manufacturer defect
6 Sectors
5.00E-09
3COMB
3 MIC detonated at the same time (due to combination of two type of errors)
6 Sectors
4.22E-11



4-MIC

Higher than expected vibration due to 4 MIC detonated at the same time

6 Sectors 9.68E-10

OR

4-MIC-WI-1

4 MIC detonated (due to same error occurred three times) at the same time

6 Sectors 9.51E-10

4-MIC-WI-2

4 MIC detonated (due to same error occurred two times and one other error) at the same time

6 Sectors 2.57E-13

4-MIC-WI-3

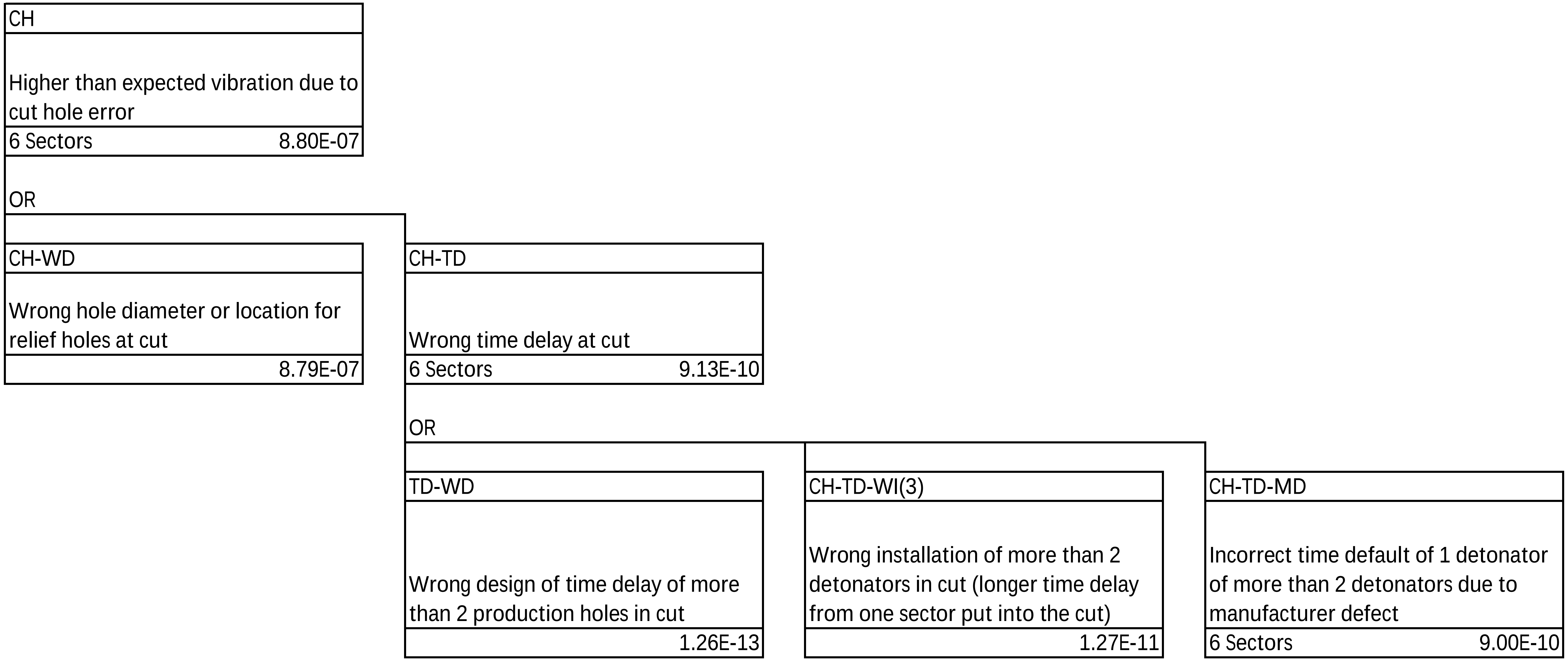
4 MIC detonated (due to three different errors occur at the same time) at the same time

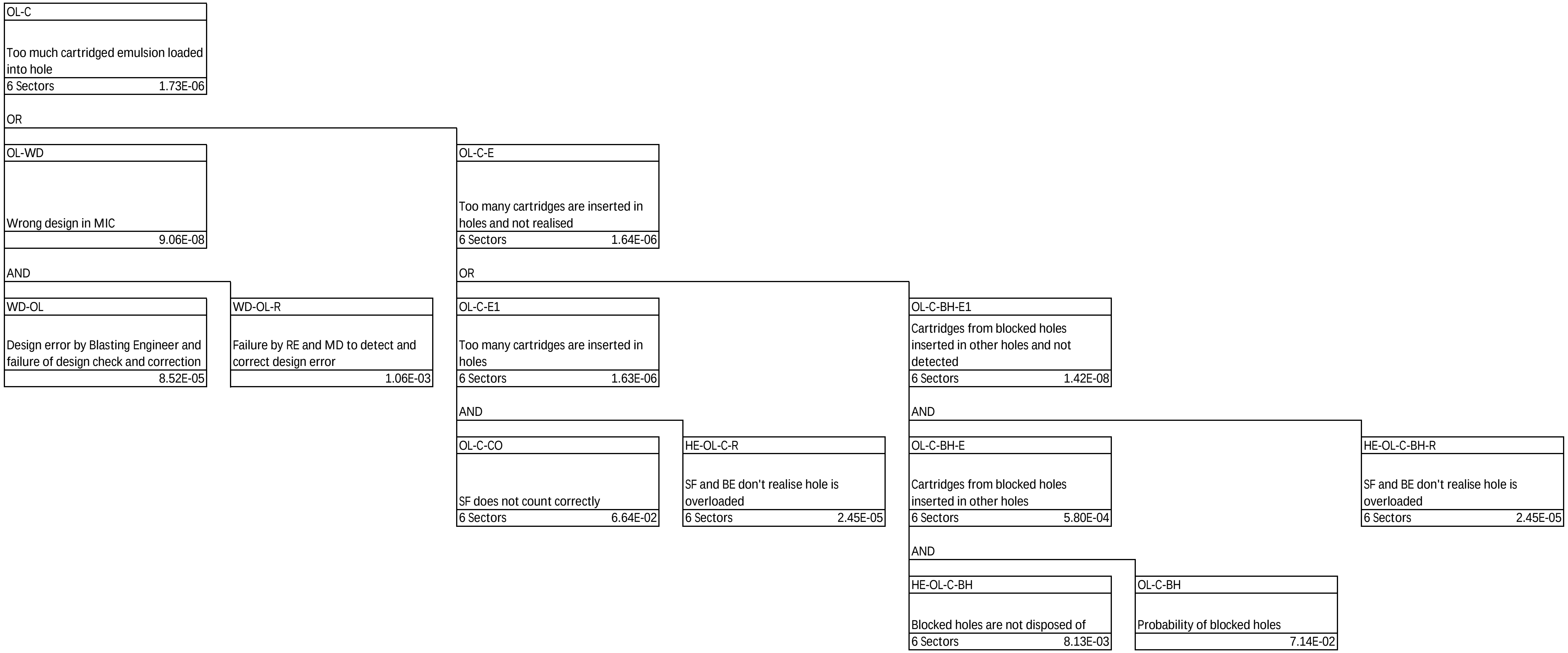
6 Sectors 4.81E-17

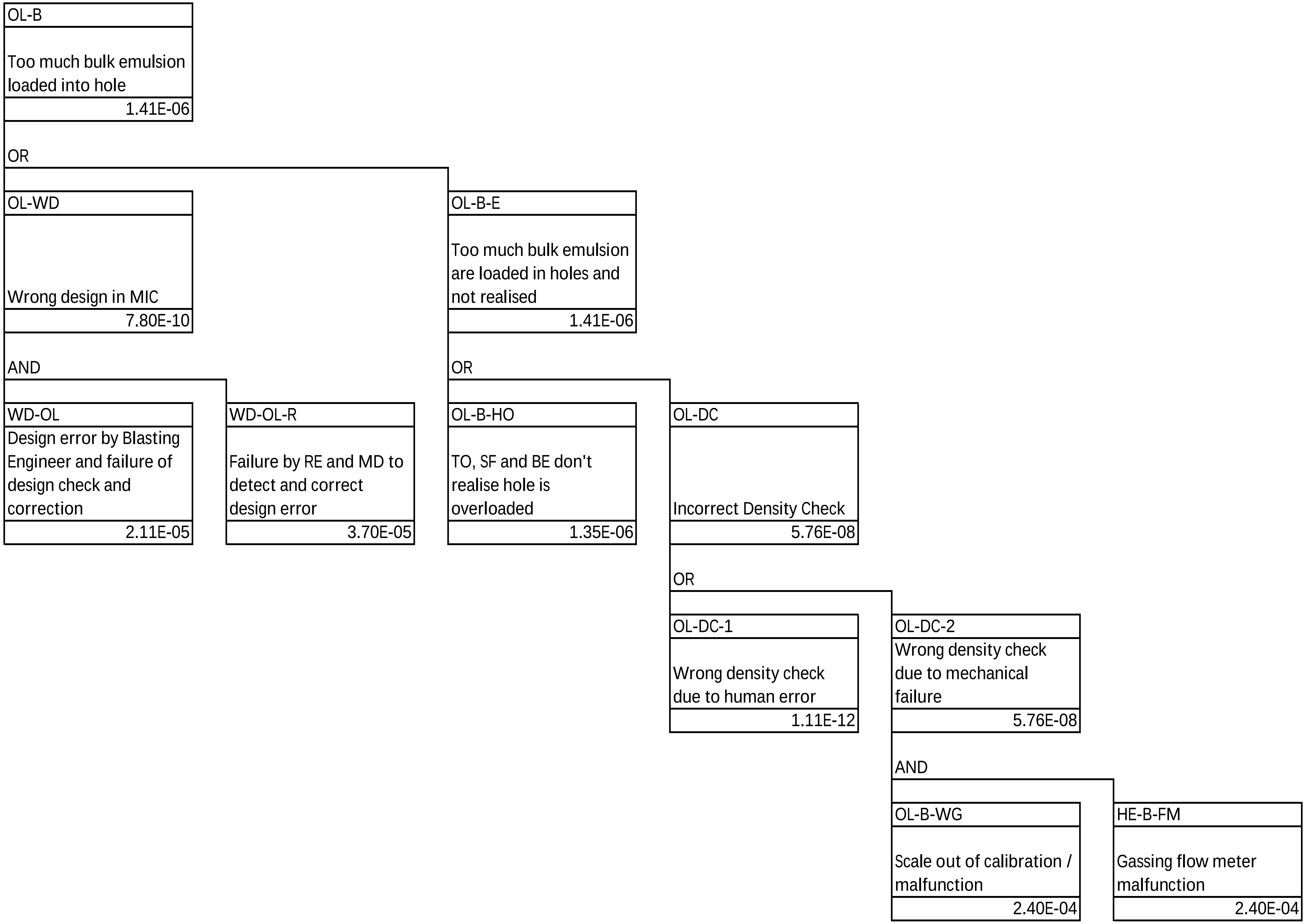
4-MIC-WI-4

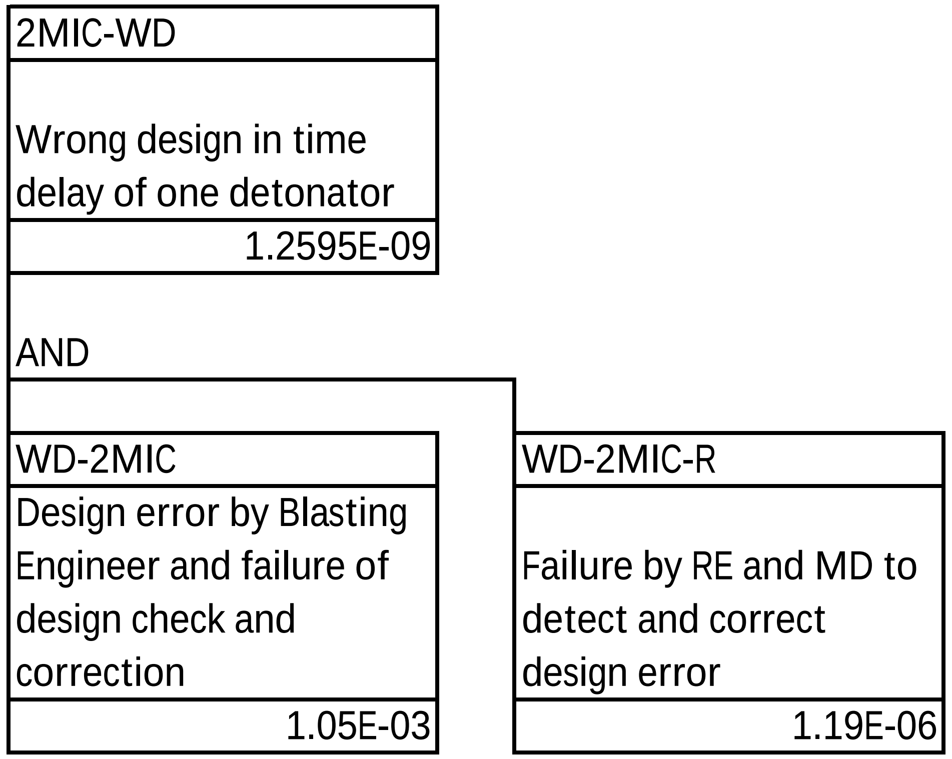
4 MIC detonated (due to charge overload and one other error occur at the same time) at the same time

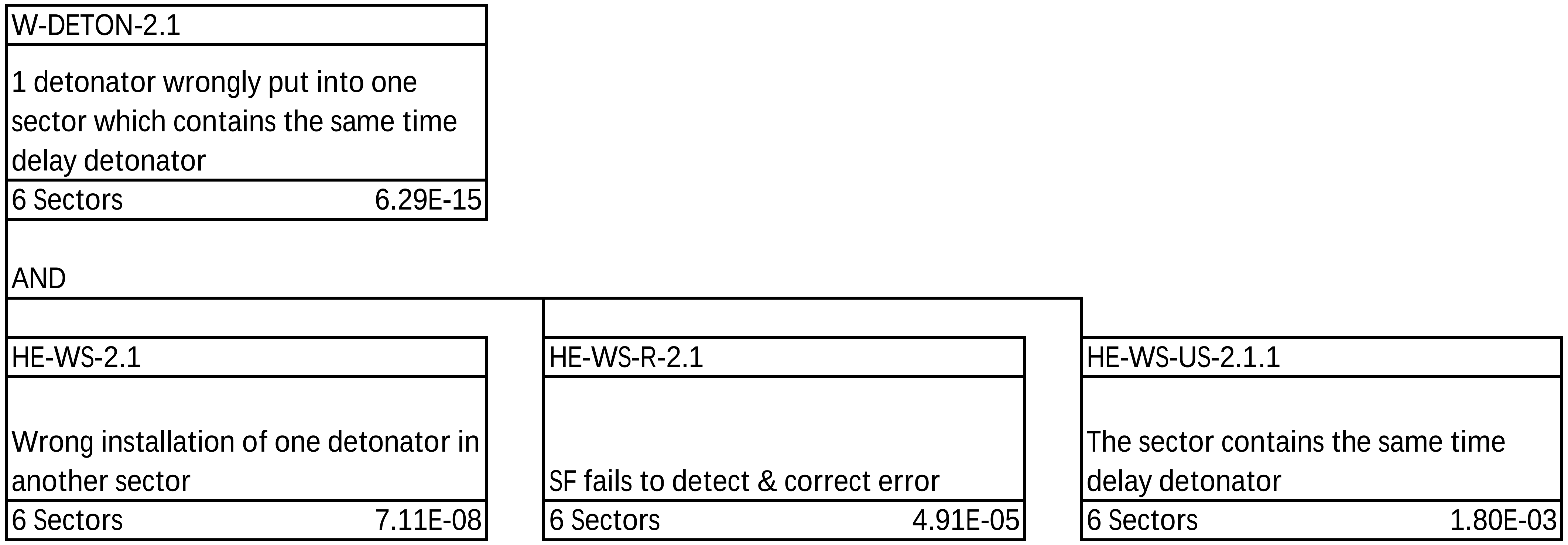
6 Sectors 1.65E-11

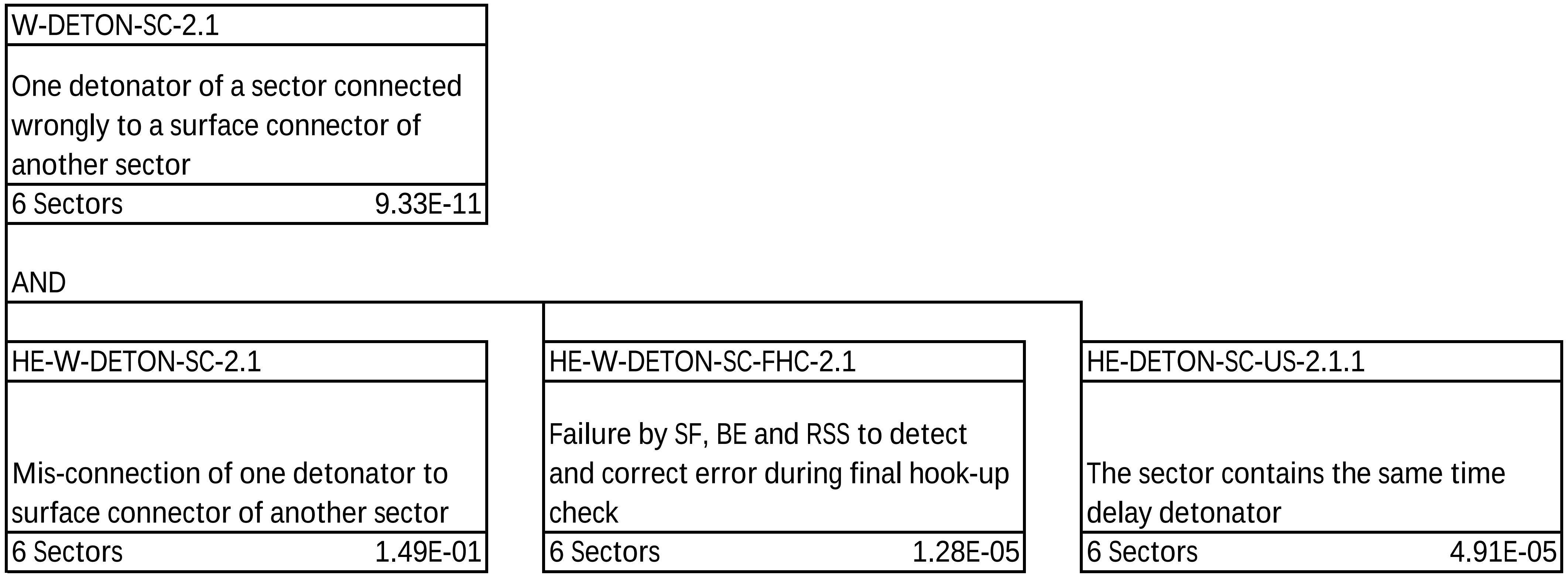

CH
Higher than expected vibration due to cut hole error
6 Sectors
8.80E-07
OR
CH-WD
Wrong hole diameter or location for relief holes at cut
8.79E-07
CH-TD
Wrong time delay at cut
6 Sectors
9.13E-10
OR
TD-WD
Wrong design of time delay of more than 2 production holes in cut
1.26E-13
CH-TD-WI(3)
Wrong installation of more than 2 detonators in cut (longer time delay from one sector put into the cut)
1.27E-11
CH-TD-MD
Incorrect time default of 1 detonator of more than 2 detonators due to manufacturer defect
6 Sectors
9.00E-10

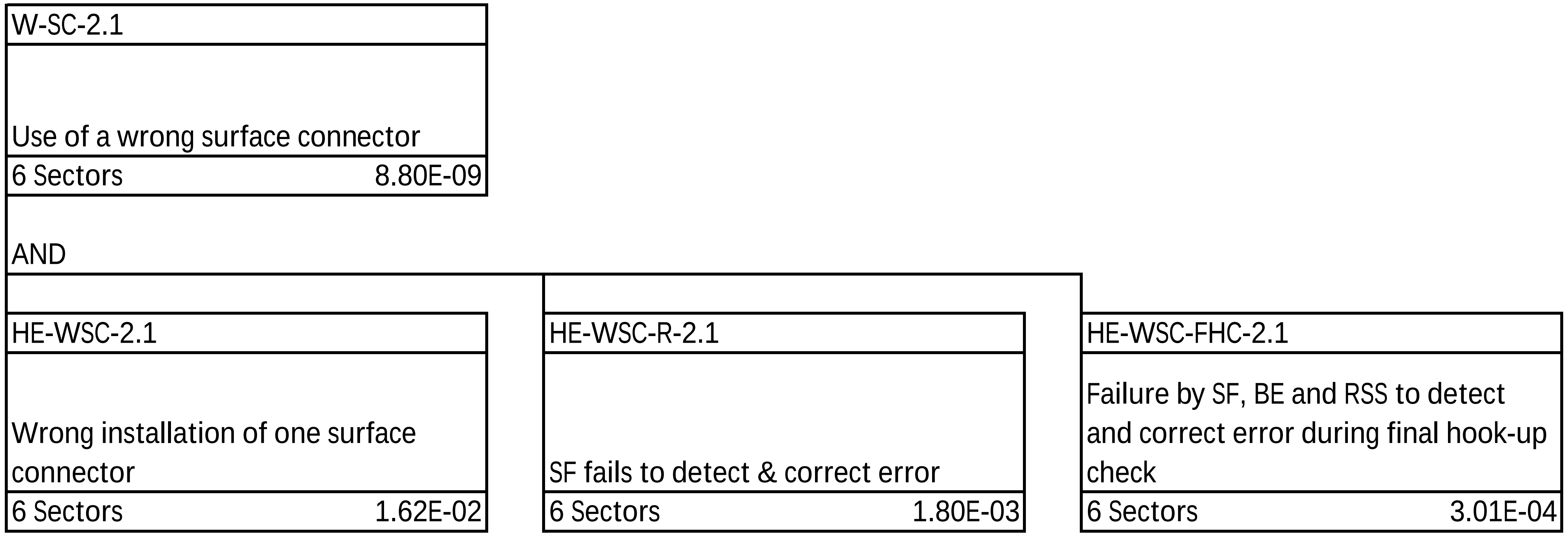

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06
OR
OL-WD
Wrong design in MIC
9.06E-08
AND
WD-OL
Design error by Blasting Engineer and failure of design check and correction
8.52E-05
WD-OL-R
Failure by RE and MD to detect and correct design error
1.06E-03
OL-C-E
Too many cartridges are inserted in holes and not realised
6 Sectors 1.64E-06
OR
OL-C-E1
Too many cartridges are inserted in holes
6 Sectors 1.63E-06
AND
OL-C-CO
SF does not count correctly
6 Sectors 6.64E-02
HE-OL-C-R
SF and BE don't realise hole is overloaded
6 Sectors 2.45E-05
OL-C-BH-E1
Cartridges from blocked holes inserted in other holes and not detected
6 Sectors 1.42E-08
AND
OL-C-BH-E
Cartridges from blocked holes inserted in other holes
6 Sectors 5.80E-04
AND
HE-OL-C-BH
Blocked holes are not disposed of
6 Sectors 8.13E-03
OL-C-BH
Probability of blocked holes
7.14E-02
HE-OL-C-BH-R
SF and BE don't realise hole is overloaded
6 Sectors 2.45E-05

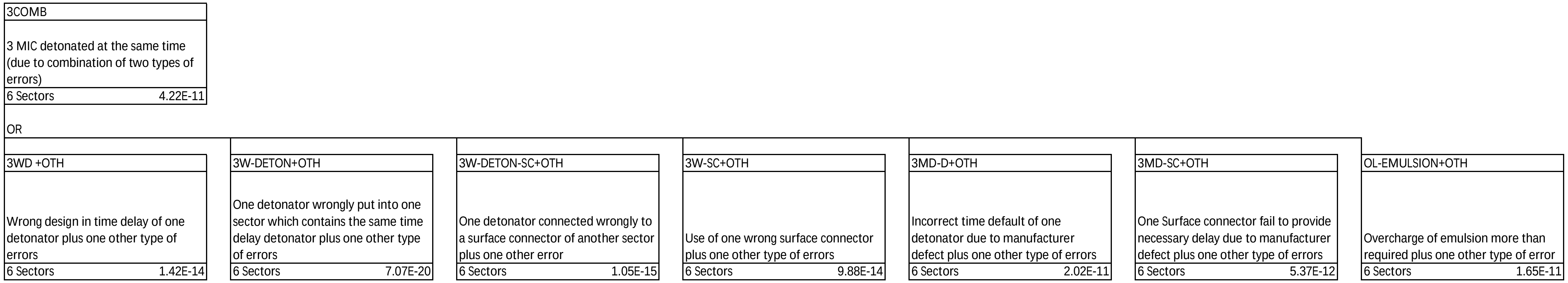

OL-B
Too much bulk emulsion loaded into hole
1.41E-06
OR
OL-WD
Wrong design in MIC
7.80E-10
AND
WD-OL
Design error by Blasting Engineer and failure of design check and correction
2.11E-05
WD-OL-R
Failure by RE and MD to detect and correct design error
3.70E-05
OL-B-E
Too much bulk emulsion are loaded in holes and not realised
1.41E-06
OR
OL-B-HO
TO, SF and BE don't realise hole is overloaded
1.35E-06
OL-DC
Incorrect Density Check
5.76E-08
OR
OL-DC-1
Wrong density check due to human error
1.11E-12
OL-DC-2
Wrong density check due to mechanical failure
5.76E-08
AND
OL-B-WG
Scale out of calibration / malfunction
2.40E-04
HE-B-FM
Gassing flow meter malfunction
2.40E-04


2MIC-WD
Wrong design in time delay of one detonator
1.2595E-09
AND
WD-2MIC
Design error by Blasting Engineer and failure of design check and correction
1.05E-03
WD-2MIC-R
Failure by RE and MD to detect and correct design error
1.19E-06


W-DETON-2.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
AND
HE-WS-2.1
Wrong installation of one detonator in another sector
6 Sectors
7.11E-08
HE-WS-R-2.1
SF fails to detect & correct error
6 Sectors
4.91E-05
HE-WS-US-2.1.1
The sector contains the same time delay detonator
6 Sectors
1.80E-03


W-DETON-SC-2.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
AND
HE-W-DETON-SC-2.1
Mis-connection of one detonator to surface connector of another sector
6 Sectors
1.49E-01
HE-W-DETON-SC-FHC-2.1
Failure by SF, BE and RSS to detect and correct error during final hook-up check
6 Sectors
1.28E-05
HE-DETON-SC-US-2.1.1
The sector contains the same time delay detonator
6 Sectors
4.91E-05


W-SC-2.1
Use of a wrong surface connector
6 Sectors
8.80E-09
AND
HE-WSC-2.1
Wrong installation of one surface connector
6 Sectors
1.62E-02
HE-WSC-R-2.1
SF fails to detect & correct error
6 Sectors
1.80E-03
HE-WSC-FHC-2.1
Failure by SF, BE and RSS to detect and correct error during final hook-up check
6 Sectors
3.01E-04



3COMB
3 MIC detonated at the same time (due to combination of two types of errors)
6 Sectors 4.22E-11

OR

3WD +OTH
Wrong design in time delay of one detonator plus one other type of errors
6 Sectors 1.42E-14

3W-DETON+OTH
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors
6 Sectors 7.07E-20

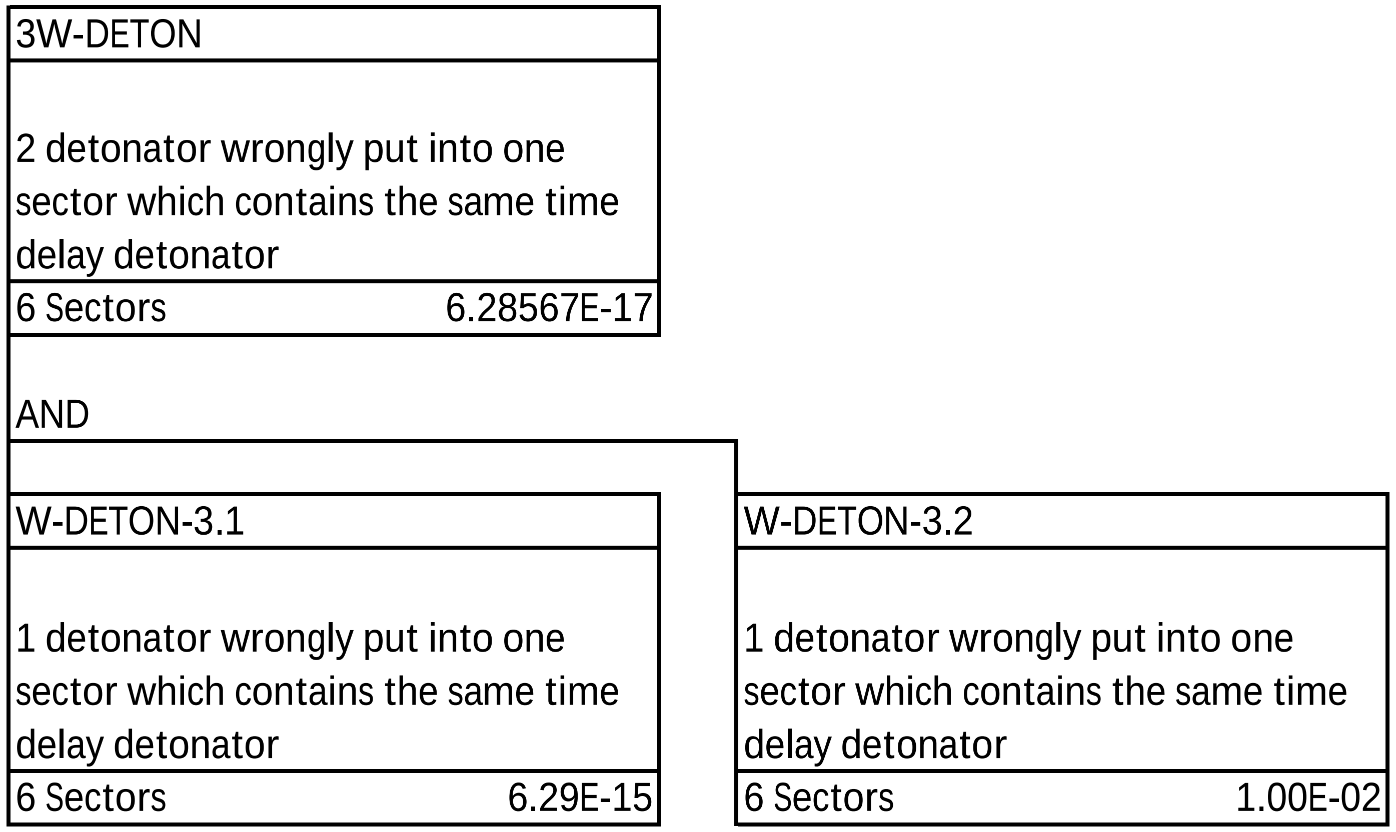
3W-DETON-SC+OTH
One detonator connected wrongly to a surface connector of another sector plus one other error
6 Sectors 1.05E-15

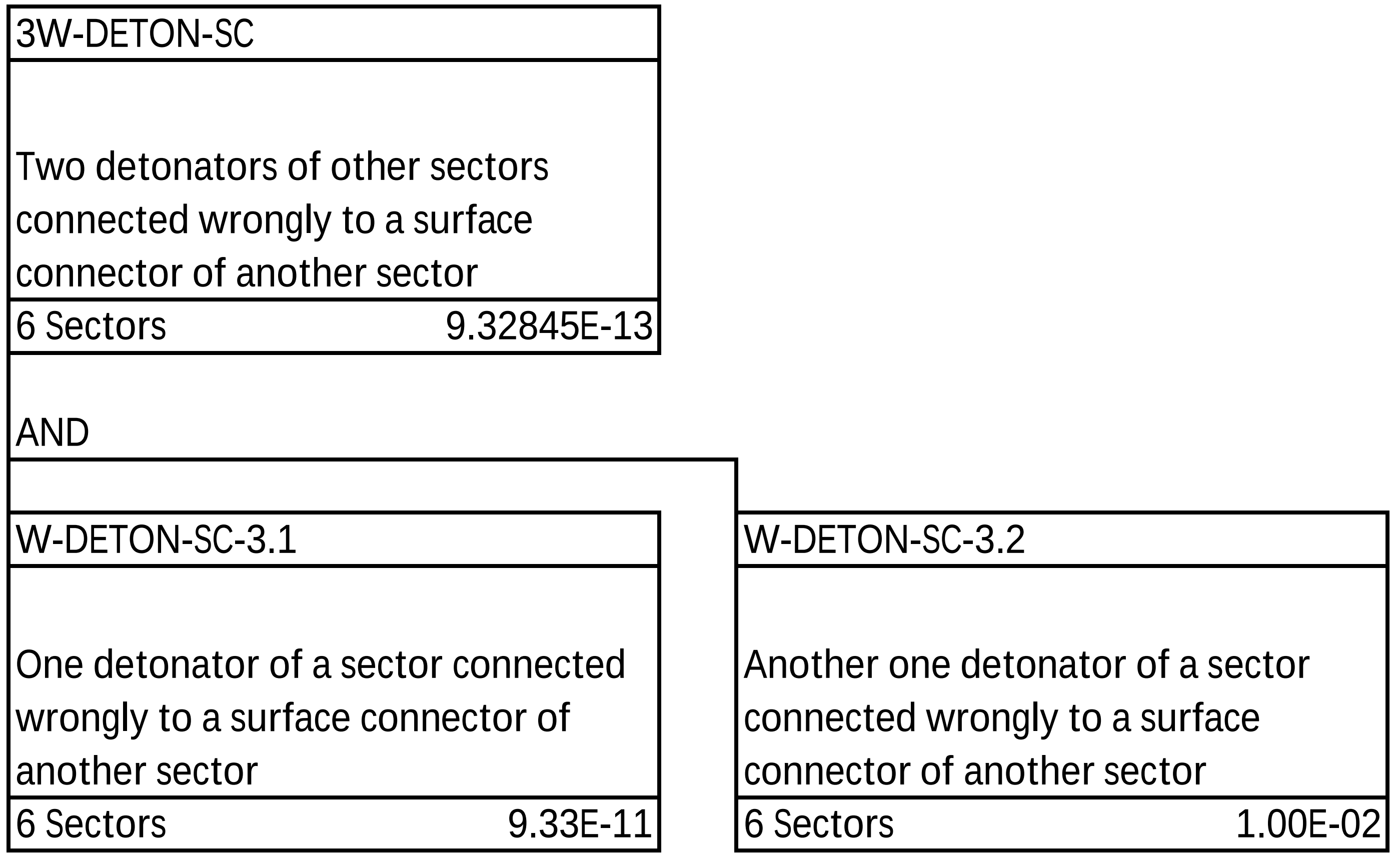
3W-SC+OTH
Use of one wrong surface connector plus one other type of errors
6 Sectors 9.88E-14

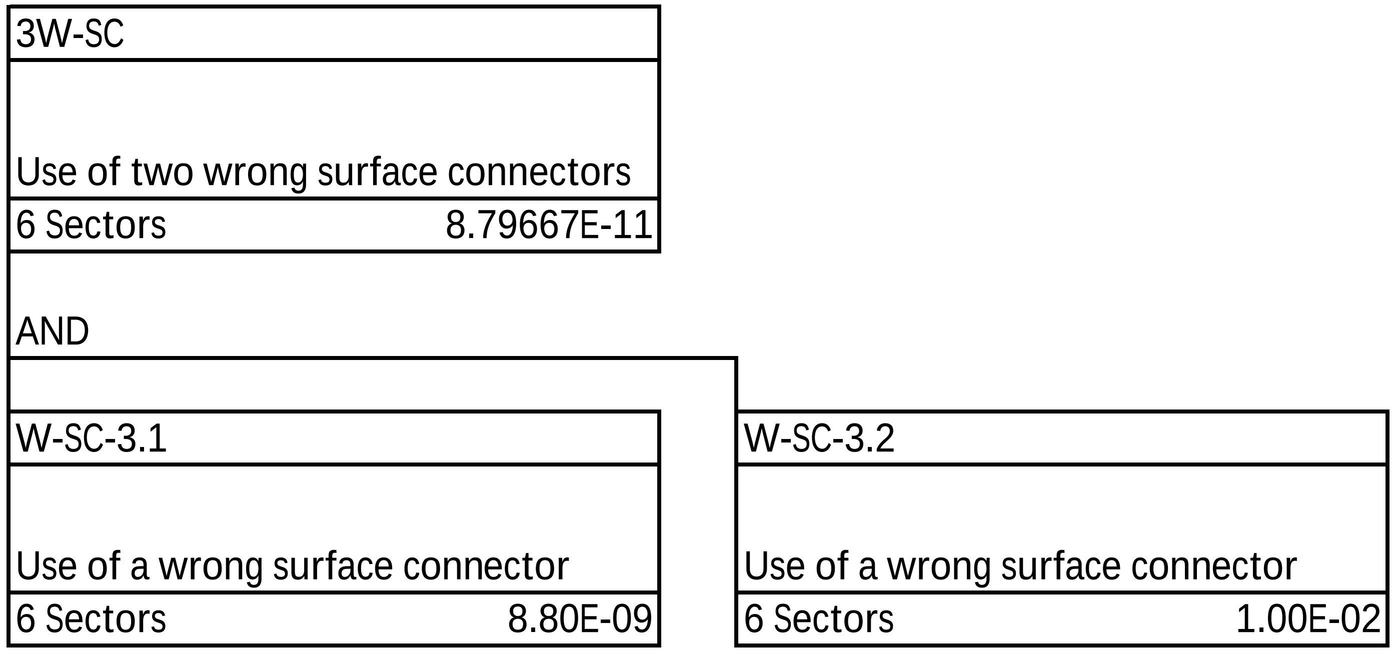
3MD-D+OTH
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors
6 Sectors 2.02E-11

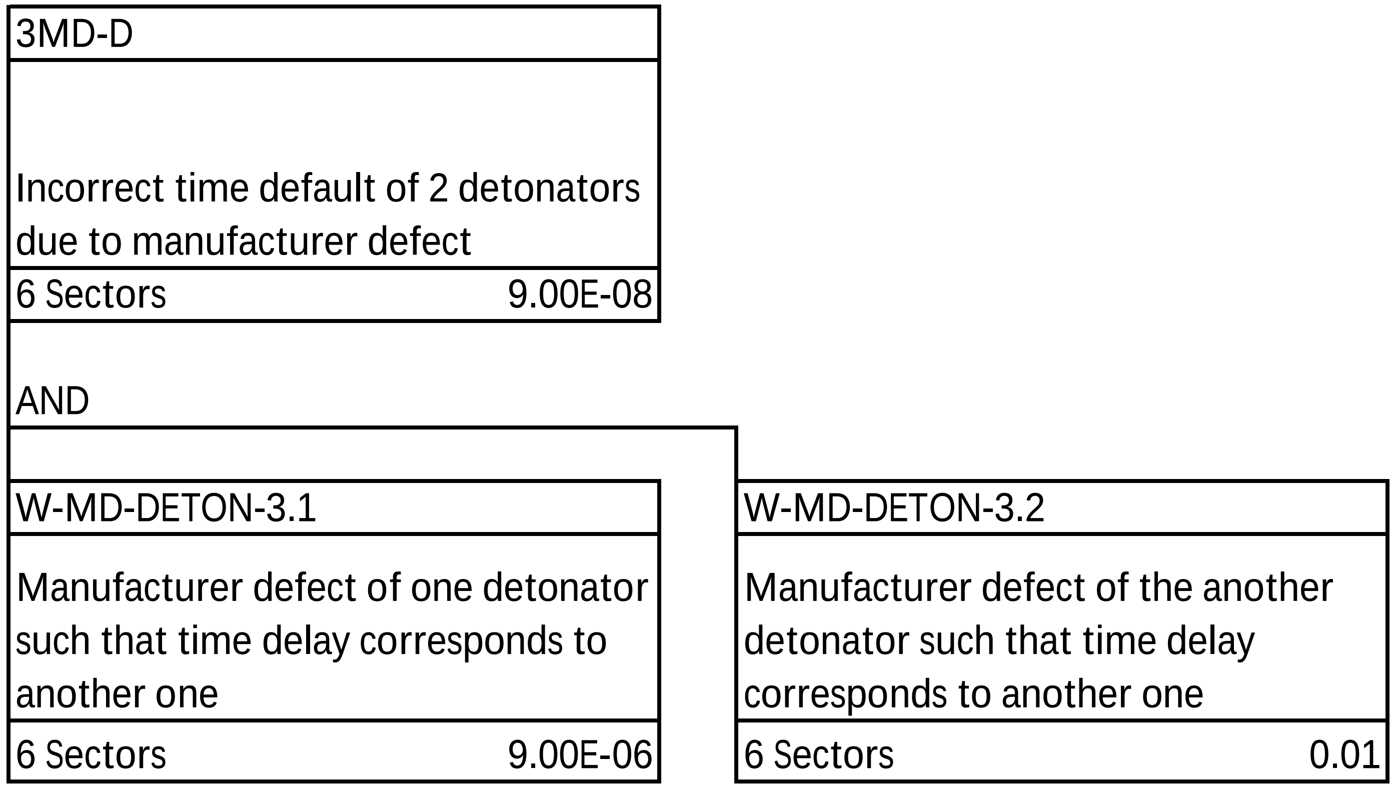
3MD-SC+OTH
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors
6 Sectors 5.37E-12

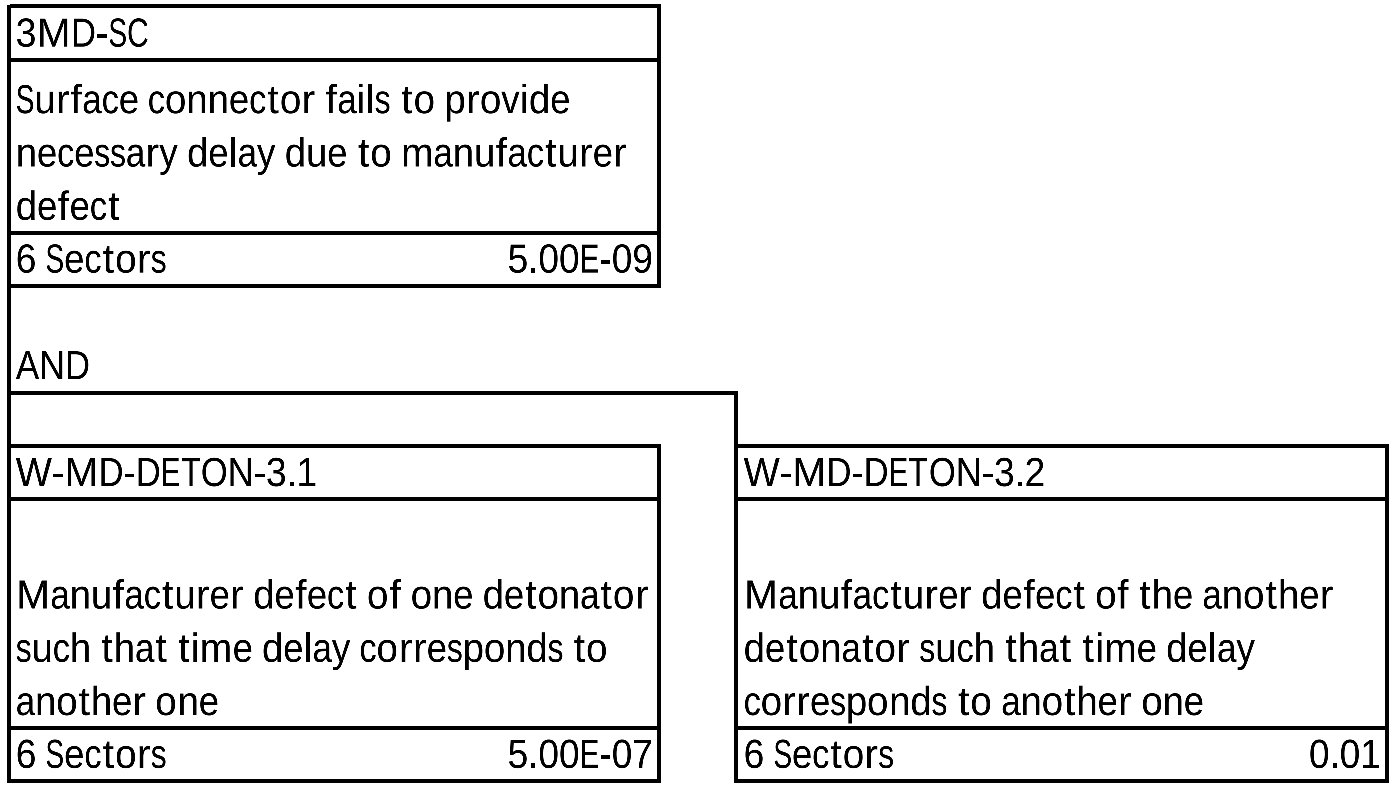
OL-EMULSION+OTH
Overcharge of emulsion more than required plus one other type of error
6 Sectors 1.65E-11

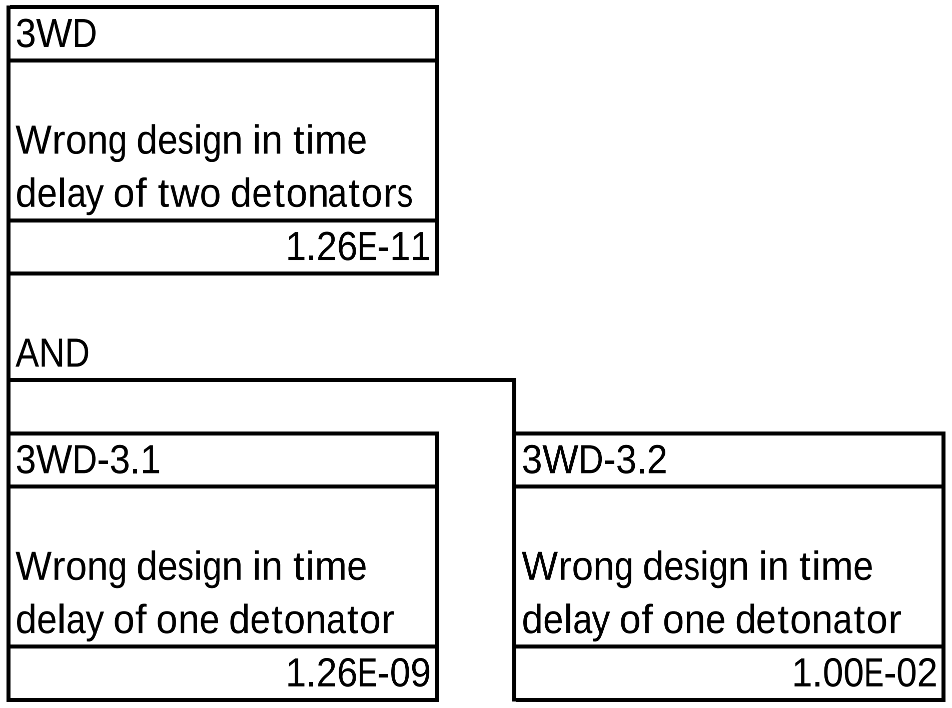

3W-DETON
2 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.28567E-17
AND
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-3.2
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
1.00E-02

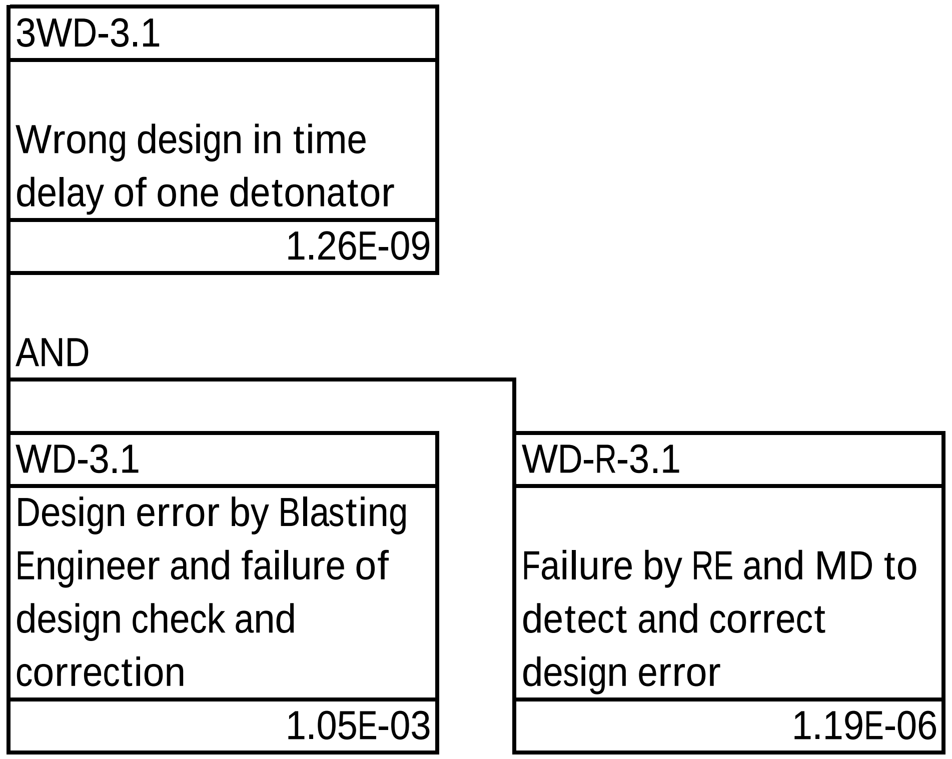

3W-DETON-SC
Two detonators of other sectors connected wrongly to a surface connector of another sector
6 Sectors
9.32845E-13
AND
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-DETON-SC-3.2
Another one detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
1.00E-02

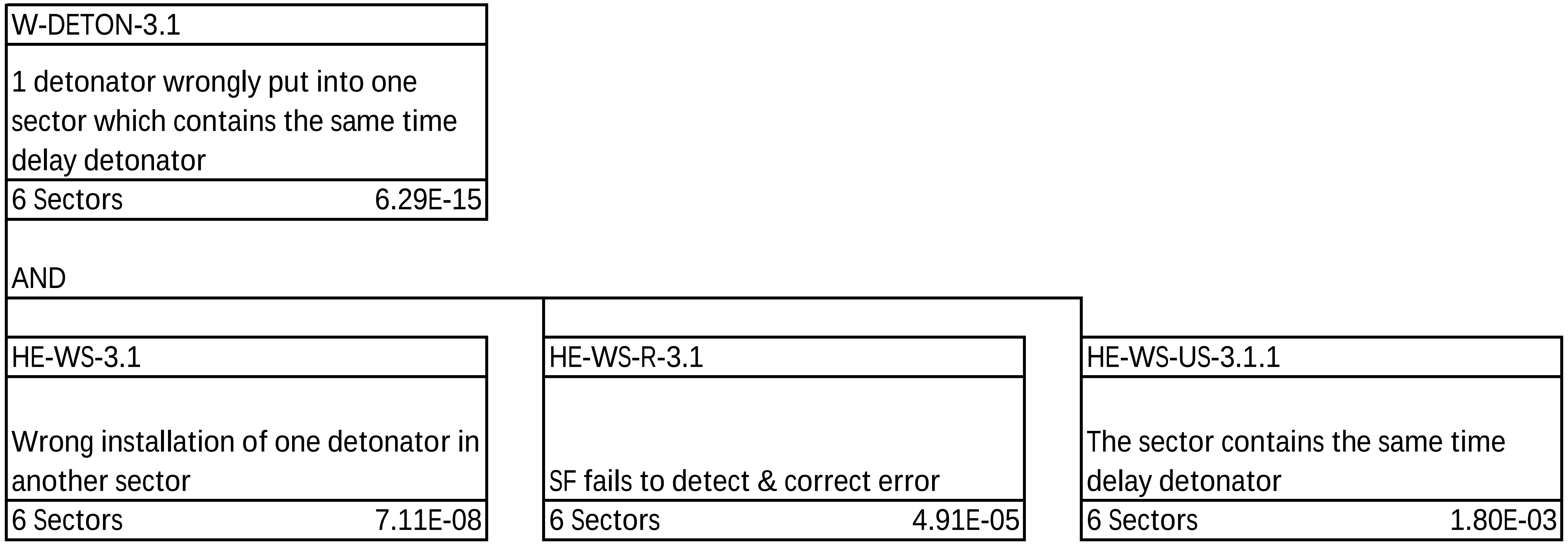

3W-SC
Use of two wrong surface connectors
6 Sectors
8.79667E-11
AND
W-SC-3.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-SC-3.2
Use of a wrong surface connector
6 Sectors
1.00E-02

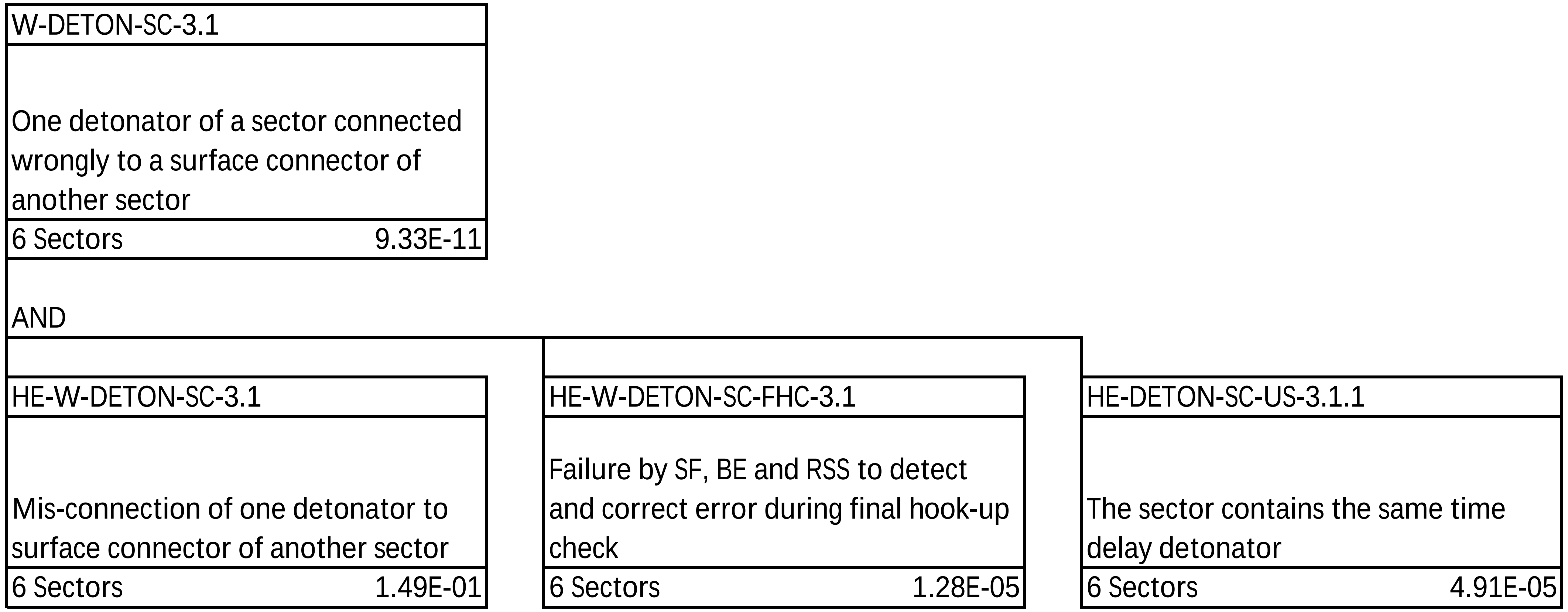

3MD-D
Incorrect time default of 2 detonators due to manufacturer defect
6 Sectors
9.00E-08
AND
W-MD-DETON-3.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-DETON-3.2
Manufacturer defect of the another detonator such that time delay corresponds to another one
6 Sectors
0.01

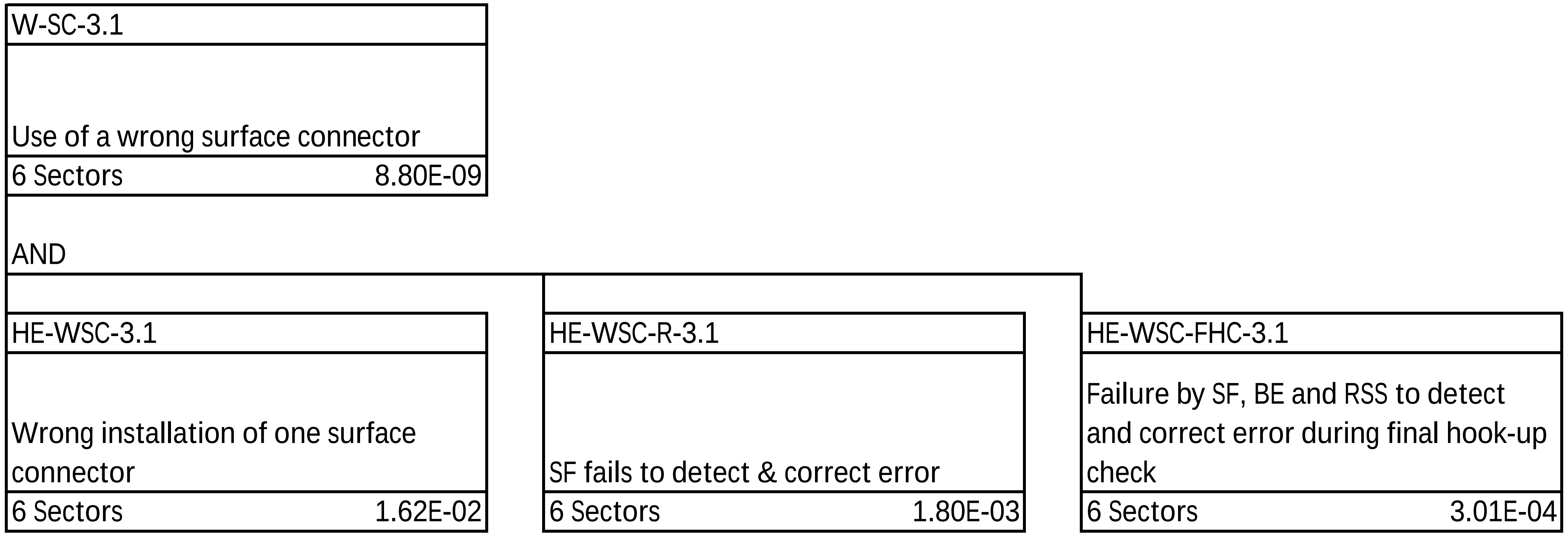

3MD-SC
Surface connector fails to provide necessary delay due to manufacturer defect
6 Sectors
5.00E-09
AND
W-MD-DETON-3.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
5.00E-07
W-MD-DETON-3.2
Manufacturer defect of the another detonator such that time delay corresponds to another one
6 Sectors
0.01

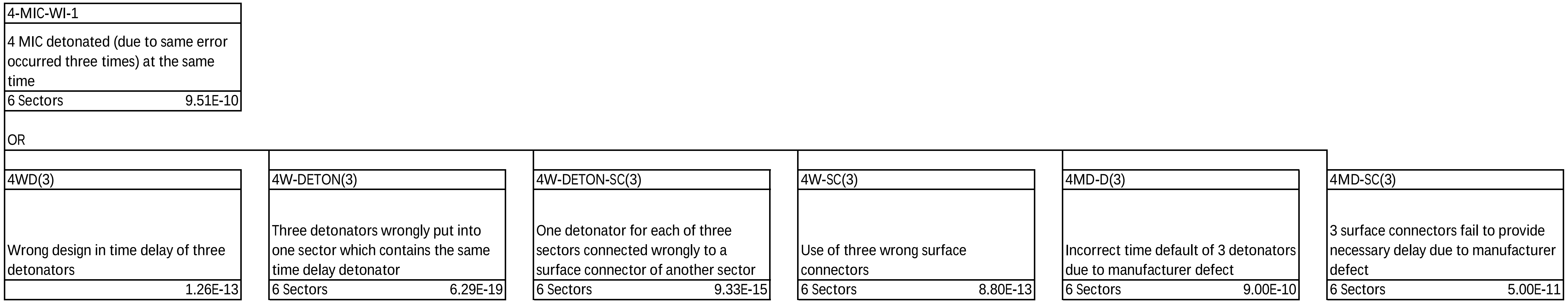

3WD
Wrong design in time delay of two detonators
1.26E-11
AND
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
3WD-3.2
Wrong design in time delay of one detonator
1.00E-02


3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
AND
WD-3.1
Design error by Blasting Engineer and failure of design check and correction
1.05E-03
WD-R-3.1
Failure by RE and MD to detect and correct design error
1.19E-06


W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
AND
HE-WS-3.1
Wrong installation of one detonator in another sector
6 Sectors
7.11E-08
HE-WS-R-3.1
SF fails to detect & correct error
6 Sectors
4.91E-05
HE-WS-US-3.1.1
The sector contains the same time delay detonator
6 Sectors
1.80E-03


W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
AND
HE-W-DETON-SC-3.1
Mis-connection of one detonator to surface connector of another sector
6 Sectors
1.49E-01
HE-W-DETON-SC-FHC-3.1
Failure by SF, BE and RSS to detect and correct error during final hook-up check
6 Sectors
1.28E-05
HE-DETON-SC-US-3.1.1
The sector contains the same time delay detonator
6 Sectors
4.91E-05


W-SC-3.1
Use of a wrong surface connector
6 Sectors
8.80E-09
AND
HE-WSC-3.1
Wrong installation of one surface connector
6 Sectors
1.62E-02
HE-WSC-R-3.1
SF fails to detect & correct error
6 Sectors
1.80E-03
HE-WSC-FHC-3.1
Failure by SF, BE and RSS to detect and correct error during final hook-up check
6 Sectors
3.01E-04



4-MIC-WI-1

4 MIC detonated (due to same error occurred three times) at the same time

6 Sectors 9.51E-10

OR

4WD(3)

Wrong design in time delay of three detonators

1.26E-13

4W-DETON(3)

Three detonators wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-19

4W-DETON-SC(3)

One detonator for each of three sectors connected wrongly to a surface connector of another sector

6 Sectors 9.33E-15

4W-SC(3)

Use of three wrong surface connectors

6 Sectors 8.80E-13

4MD-D(3)

Incorrect time default of 3 detonators due to manufacturer defect

6 Sectors 9.00E-10

4MD-SC(3)

3 surface connectors fail to provide necessary delay due to manufacturer defect

6 Sectors 5.00E-11

4-MIC-WI-2

4 MIC detonated (due to same error occurred two times and one other error) at the same time

6 Sectors 2.57E-13

OR

4WD(2)+OTH

Wrong design in time delay of two detonators plus one other type of errors

6 Sectors 1.42E-16

4W-DETON(2)+OTH

2 detonators wrongly put into one sector which contains the same time delay detonator plus one other type of errors

6 Sectors 7.07E-22

4W-DETON-SC(2)+OTH

One detonator for each of two sectors connected wrongly to a surface connector of another sector plus one other error

6 Sectors 1.05E-17

4W-SC(2)+OTH

Use of two wrong surface connectors plus one other type of errors

6 Sectors 9.88E-16

4MD-D(2)+OTH

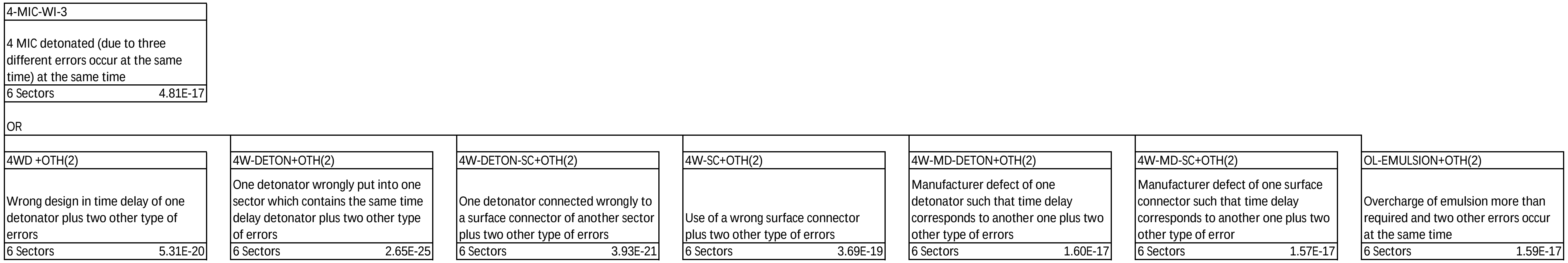
Incorrect time default of 2 detonators due to manufacturer defect plus one other type of errors

6 Sectors 2.02E-13

4MD-SC(2)+OTH

2 Surface connectors fail to provide necessary delay due to manufacturer defect plus one other type of errors

6 Sectors 5.37E-14



4-MIC-WI-3
4 MIC detonated (due to three different errors occur at the same time) at the same time
6 Sectors 4.81E-17

OR

4WD +OTH(2)
Wrong design in time delay of one detonator plus two other type of errors
6 Sectors 5.31E-20

4W-DETON+OTH(2)
One detonator wrongly put into one sector which contains the same time delay detonator plus two other type of errors
6 Sectors 2.65E-25

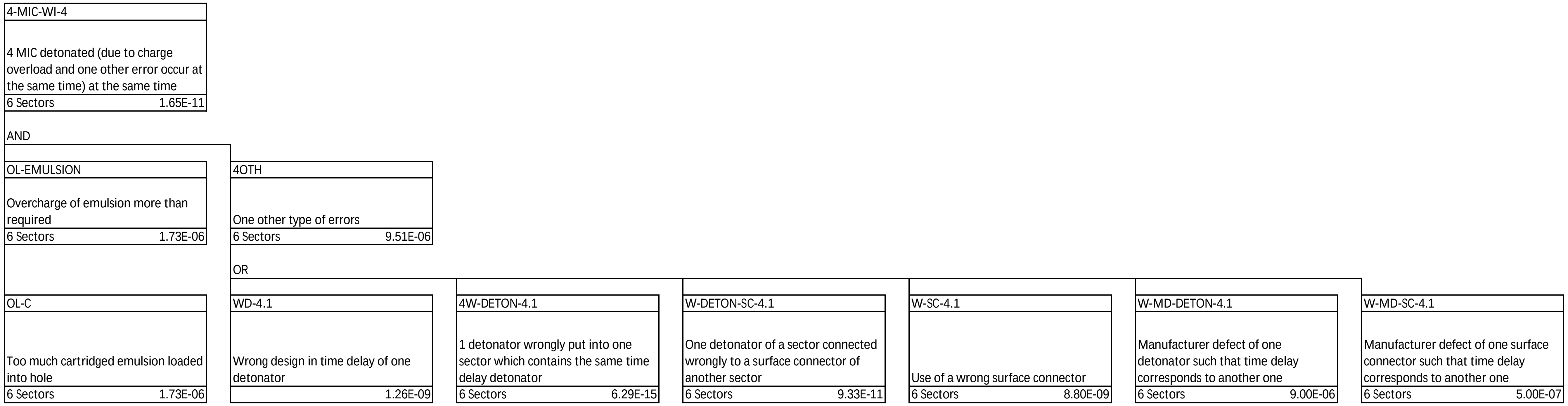
4W-DETON-SC+OTH(2)
One detonator connected wrongly to a surface connector of another sector plus two other type of errors
6 Sectors 3.93E-21

4W-SC+OTH(2)
Use of a wrong surface connector plus two other type of errors
6 Sectors 3.69E-19

4W-MD-DETON+OTH(2)
Manufacturer defect of one detonator such that time delay corresponds to another one plus two other type of errors
6 Sectors 1.60E-17

4W-MD-SC+OTH(2)
Manufacturer defect of one surface connector such that time delay corresponds to another one plus two other type of error
6 Sectors 1.57E-17

OL-EMULSION+OTH(2)
Overcharge of emulsion more than required and two other errors occur at the same time
6 Sectors 1.59E-17



4-MIC-WI-4
4 MIC detonated (due to charge overload and one other error occur at the same time) at the same time
6 Sectors 1.65E-11

AND

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

4OTH
One other type of errors
6 Sectors 9.51E-06

OR

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

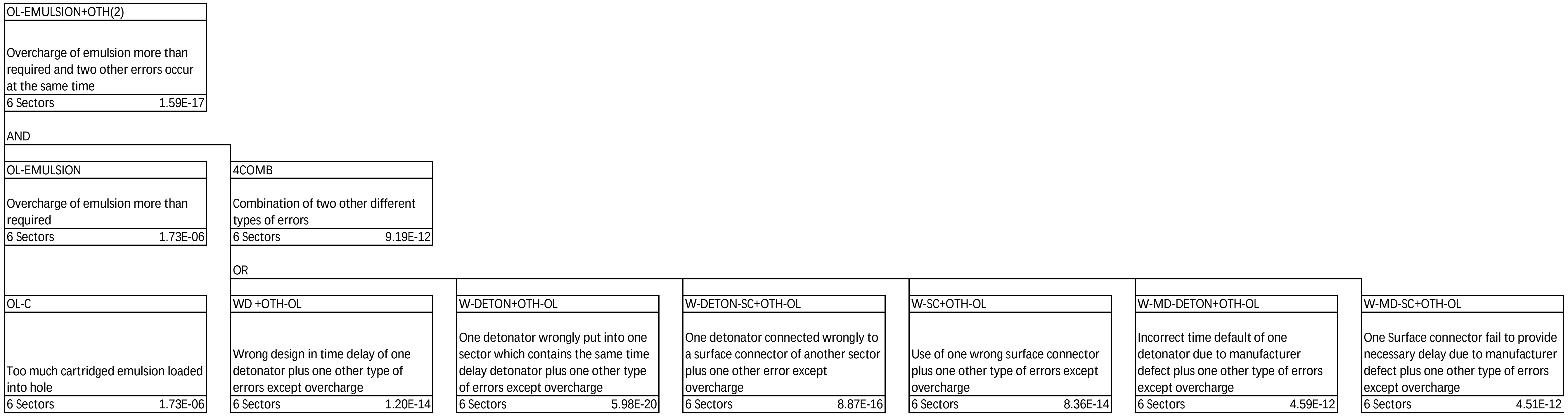
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07



OL-EMULSION+OTH(2)
Overcharge of emulsion more than required and two other errors occur at the same time
6 Sectors 1.59E-17

AND

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

4COMB
Combination of two other different types of errors
6 Sectors 9.19E-12

OR

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

WD +OTH-OL
Wrong design in time delay of one detonator plus one other type of errors except overcharge
6 Sectors 1.20E-14

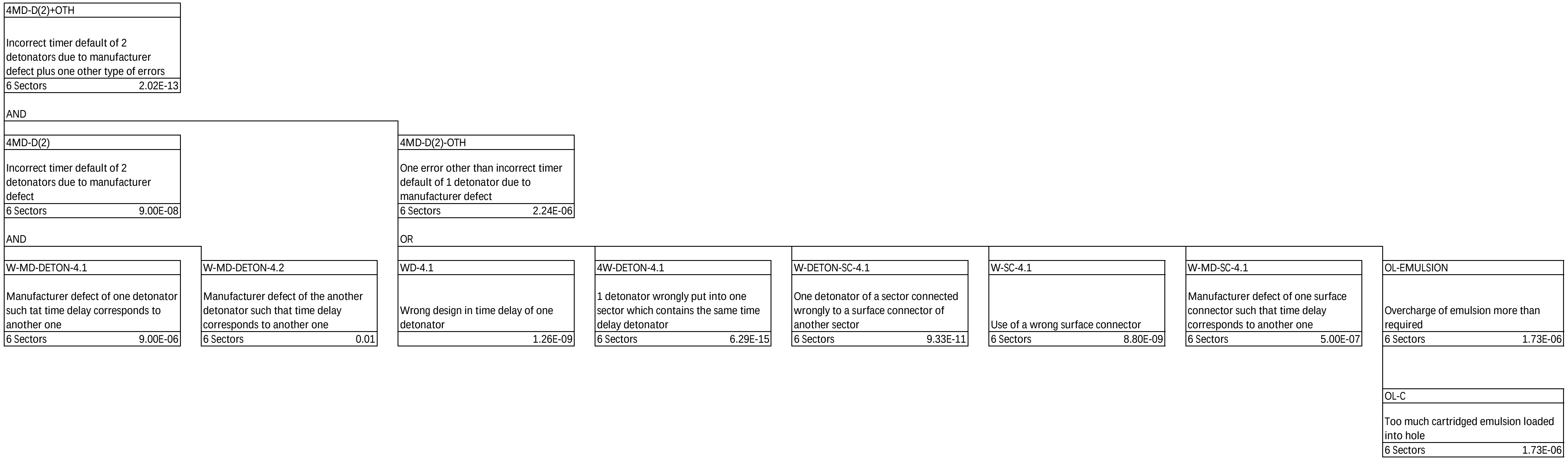
W-DETON+OTH-OL
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except overcharge
6 Sectors 5.98E-20

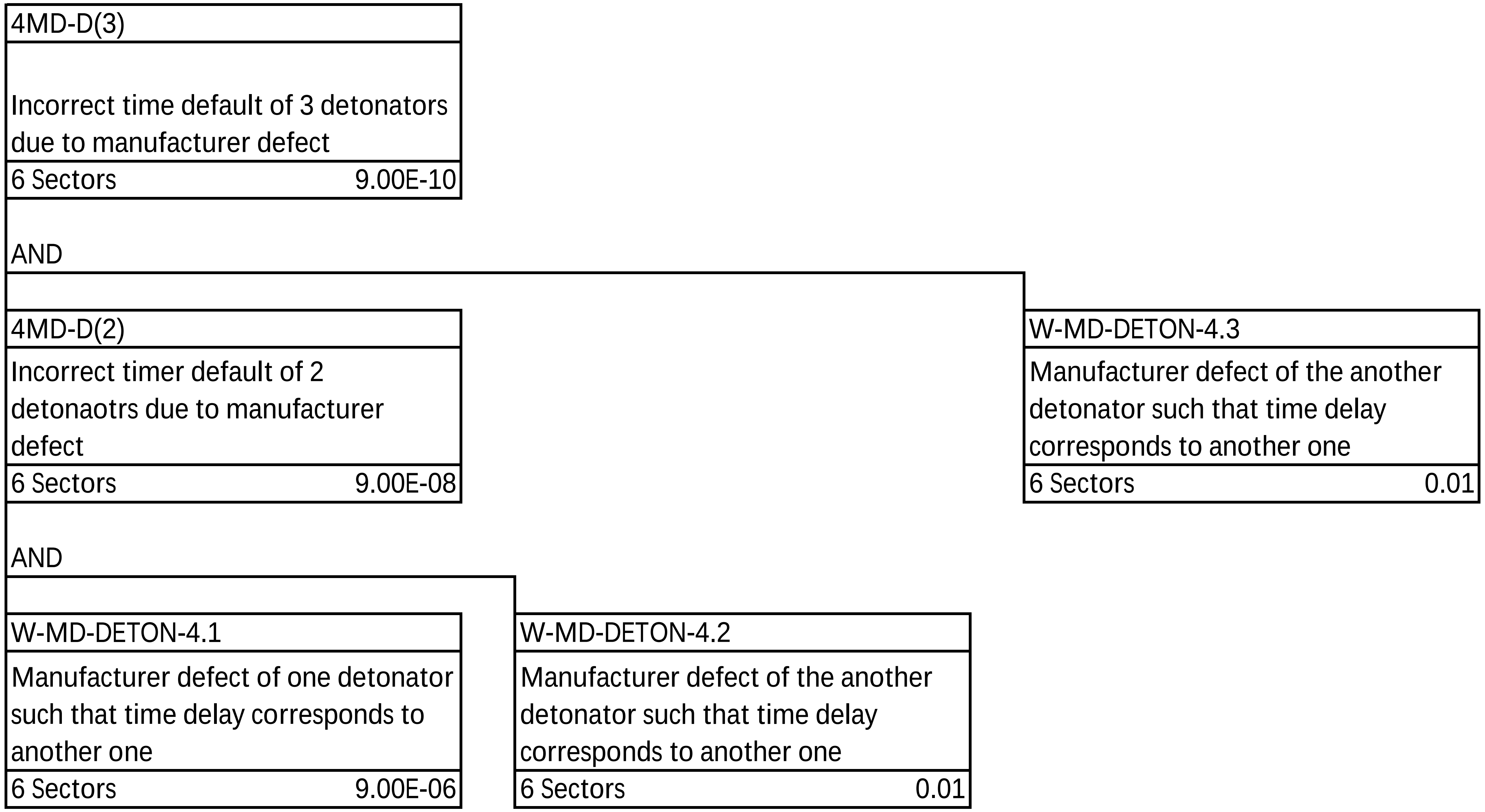
W-DETON-SC+OTH-OL
One detonator connected wrongly to a surface connector of another sector plus one other error except overcharge
6 Sectors 8.87E-16

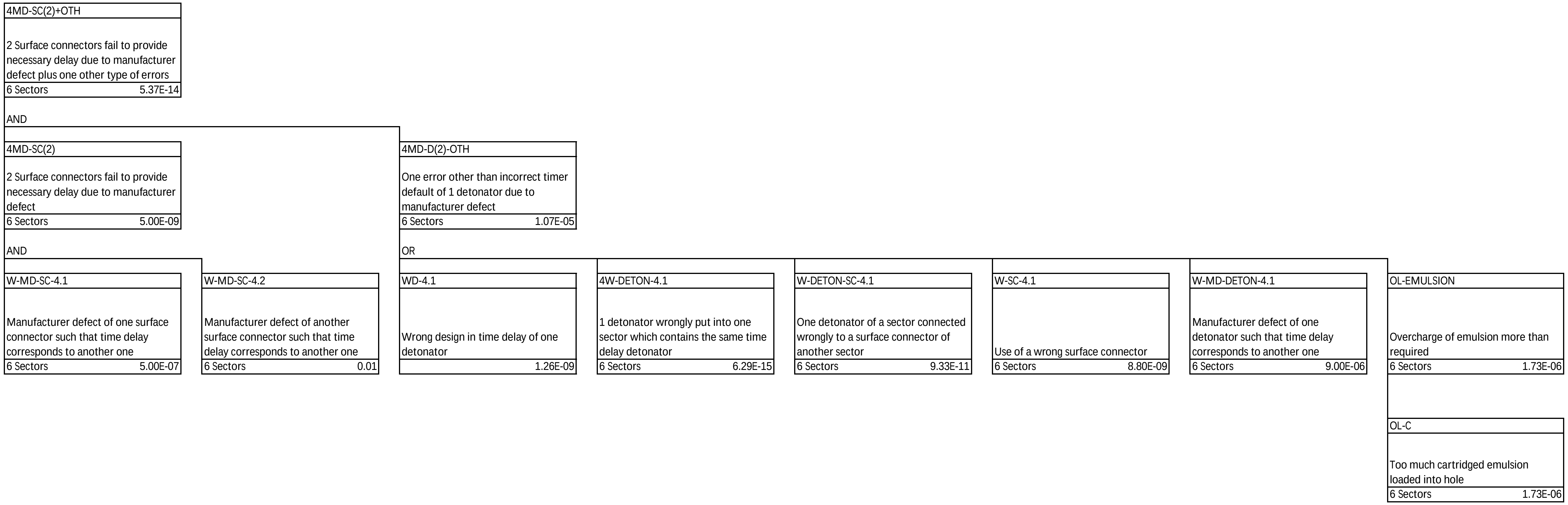
W-SC+OTH-OL
Use of one wrong surface connector plus one other type of errors except overcharge
6 Sectors 8.36E-14

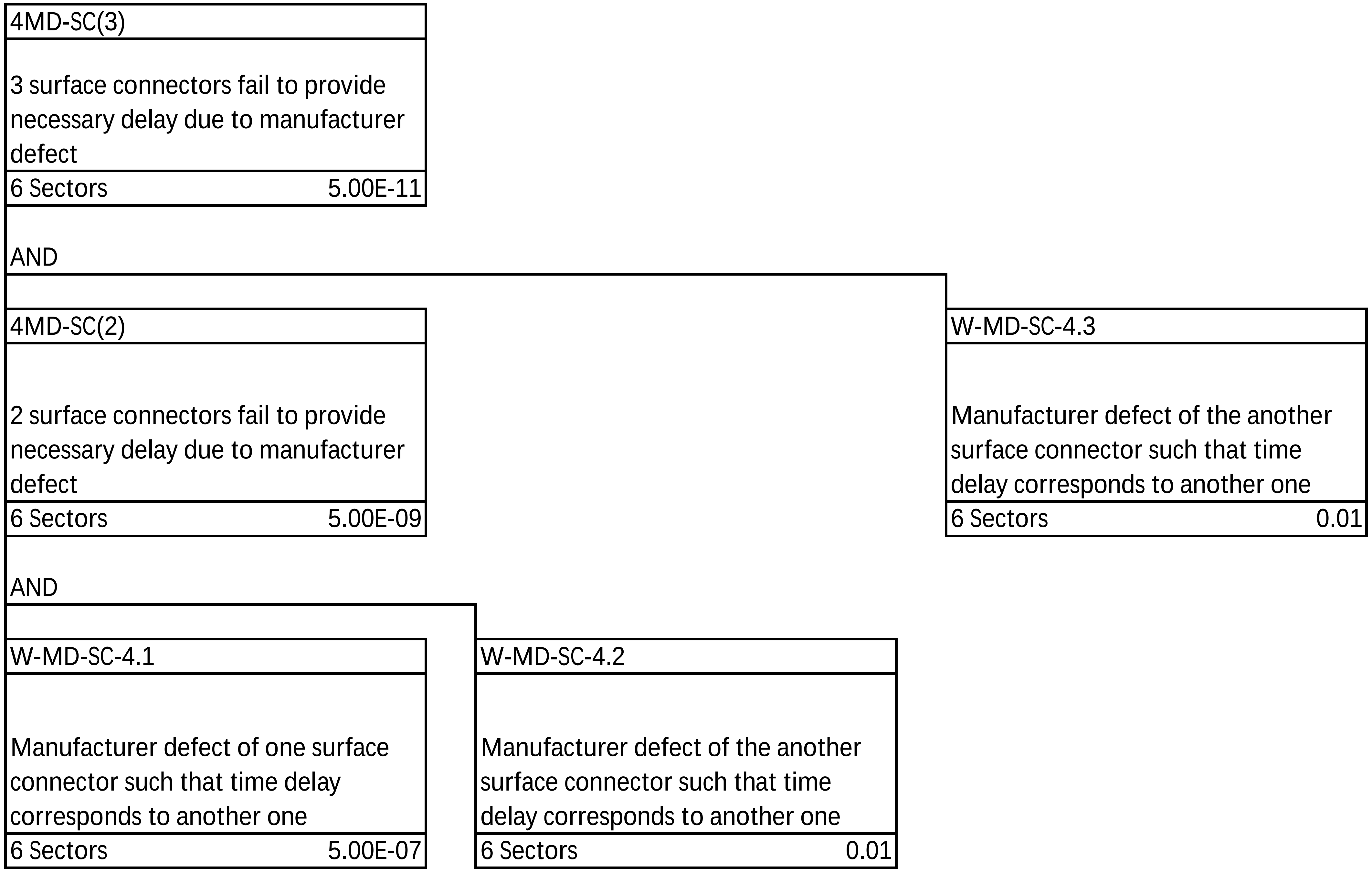
W-MD-DETON+OTH-OL
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except overcharge
6 Sectors 4.59E-12

W-MD-SC+OTH-OL
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except overcharge
6 Sectors 4.51E-12


4MD-D(2)+OTH
Incorrect timer default of 2 detonators due to manufacturer defect plus one other type of errors
6 Sectors
2.02E-13
AND
4MD-D(2)
Incorrect timer default of 2 detonators due to manufacturer defect
6 Sectors
9.00E-08
4MD-D(2)-OTH
One error other than incorrect timer default of 1 detonator due to manufacturer defect
6 Sectors
2.24E-06
AND
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-DETON-4.2
Manufacturer defect of the another detonator such that time delay corresponds to another one
6 Sectors
0.01
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


4MD-D(3)
Incorrect time default of 3 detonators due to manufacturer defect
6 Sectors
9.00E-10
AND
4MD-D(2)
Incorrect timer default of 2 detonaotrs due to manufacturer defect
6 Sectors
9.00E-08
W-MD-DETON-4.3
Manufacturer defect of the another detonator such that time delay corresponds to another one
6 Sectors
0.01
AND
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-DETON-4.2
Manufacturer defect of the another detonator such that time delay corresponds to another one
6 Sectors
0.01


4MD-SC(2)+OTH
2 Surface connectors fail to provide necessary delay due to manufacturer defect plus one other type of errors
6 Sectors
5.37E-14
AND
4MD-SC(2)
2 Surface connectors fail to provide necessary delay due to manufacturer defect
6 Sectors
5.00E-09
4MD-D(2)-OTH
One error other than incorrect timer default of 1 detonator due to manufacturer defect
6 Sectors
1.07E-05
AND
OR
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
W-MD-SC-4.2
Manufacturer defect of another surface connector such that time delay corresponds to another one
6 Sectors
0.01
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06



4MD-SC(3)

3 surface connectors fail to provide necessary delay due to manufacturer defect

6 Sectors 5.00E-11

AND

4MD-SC(2)

2 surface connectors fail to provide necessary delay due to manufacturer defect

6 Sectors 5.00E-09

W-MD-SC-4.3

Manufacturer defect of the another surface connector such that time delay corresponds to another one

6 Sectors 0.01

AND

W-MD-SC-4.1

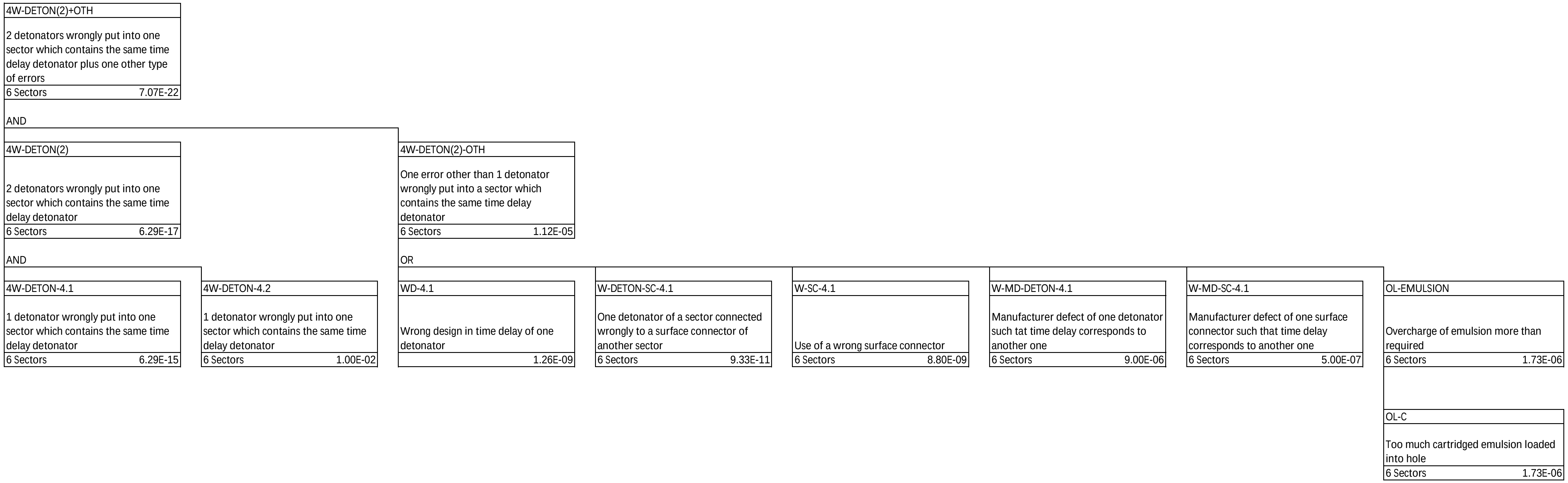
Manufacturer defect of one surface connector such that time delay corresponds to another one

6 Sectors 5.00E-07

W-MD-SC-4.2

Manufacturer defect of the another surface connector such that time delay corresponds to another one

6 Sectors 0.01



4W-DETON(2)+OTH
2 detonators wrongly put into one sector which contains the same time delay detonator plus one other type of errors
6 Sectors 7.07E-22

AND

4W-DETON(2)
2 detonators wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-17

4W-DETON(2)-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 1.12E-05

AND

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

4W-DETON-4.2
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 1.00E-02

OR

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

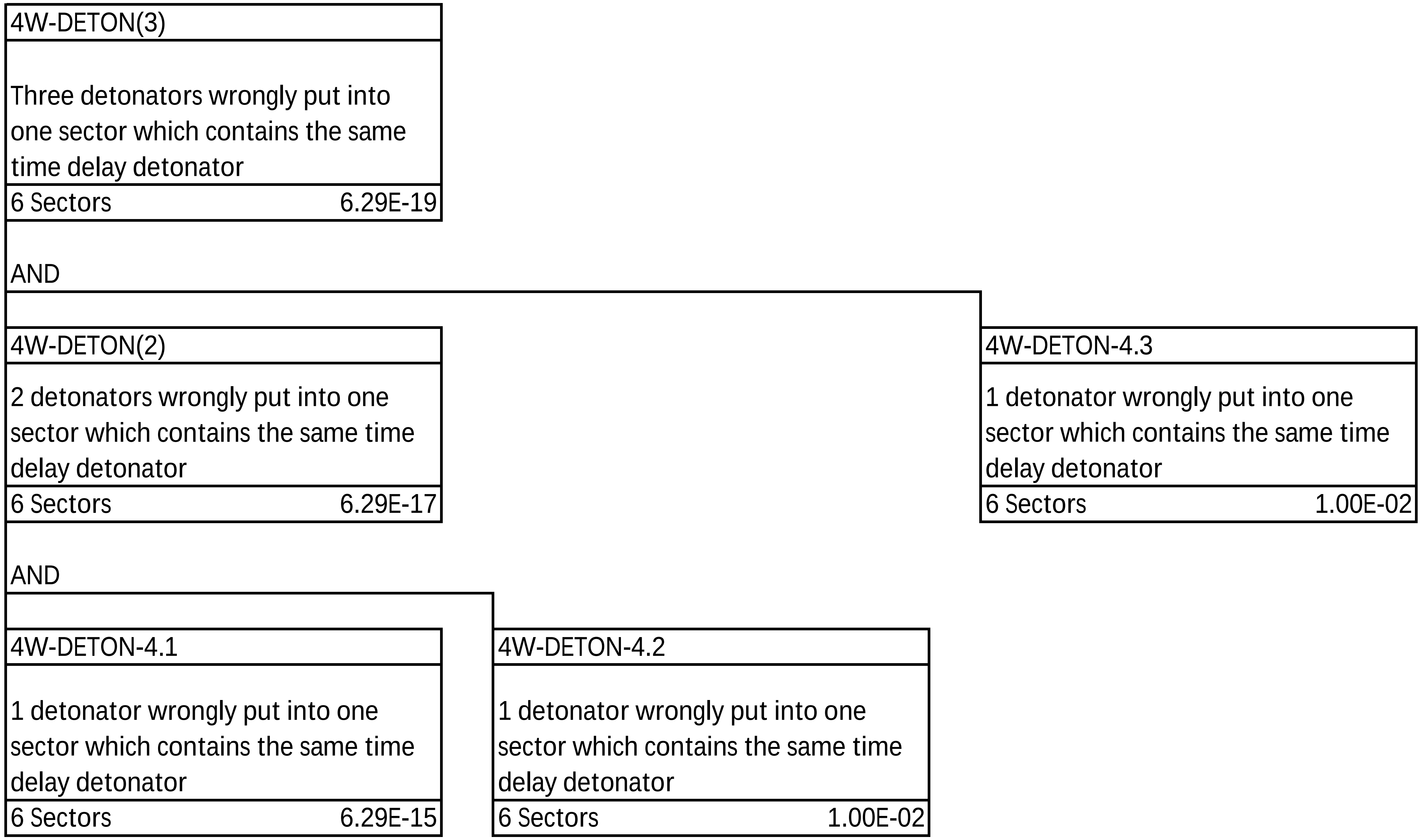
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



4W-DETON(3)

Three detonators wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-19

AND

4W-DETON(2)

2 detonators wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-17

4W-DETON-4.3

1 detonator wrongly put into one sector which contains the same time delay detonator

6 Sectors 1.00E-02

AND

4W-DETON-4.1

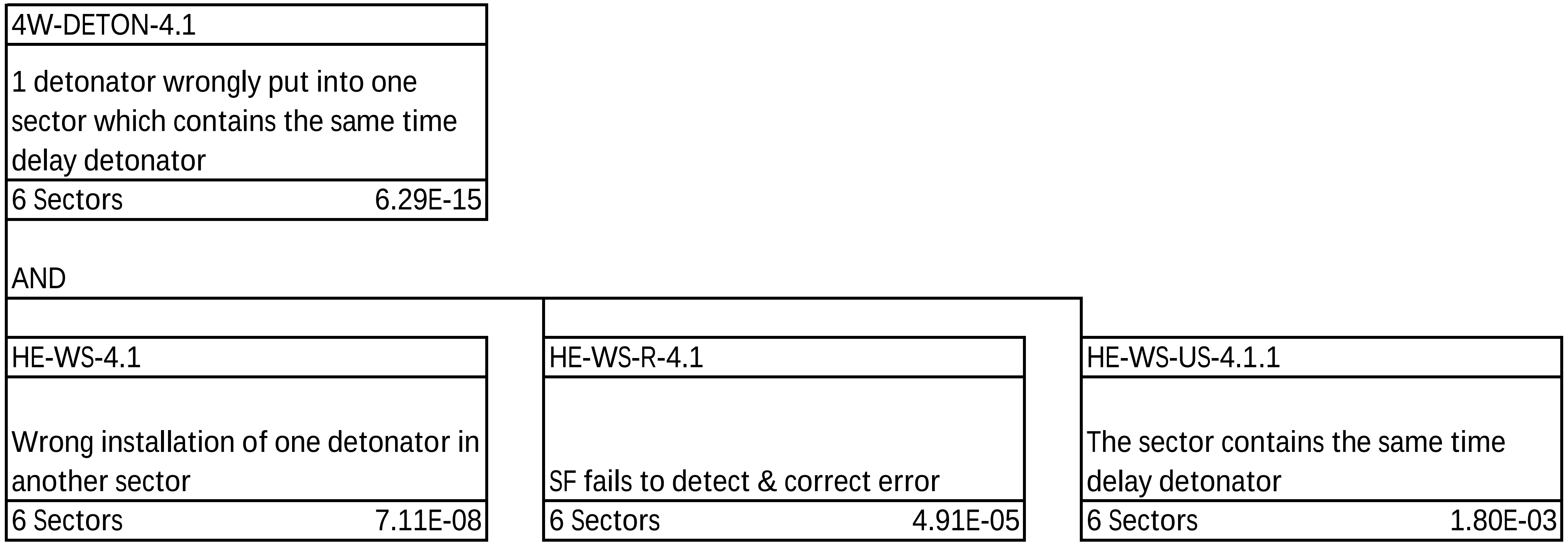
1 detonator wrongly put into one sector which contains the same time delay detonator

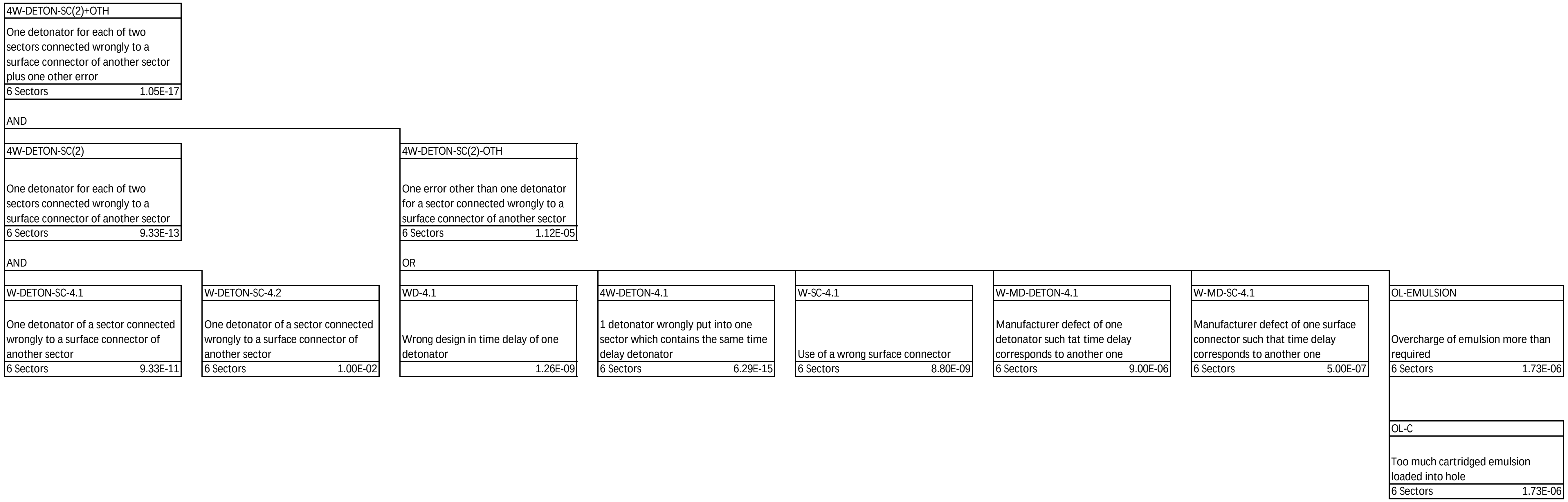
6 Sectors 6.29E-15

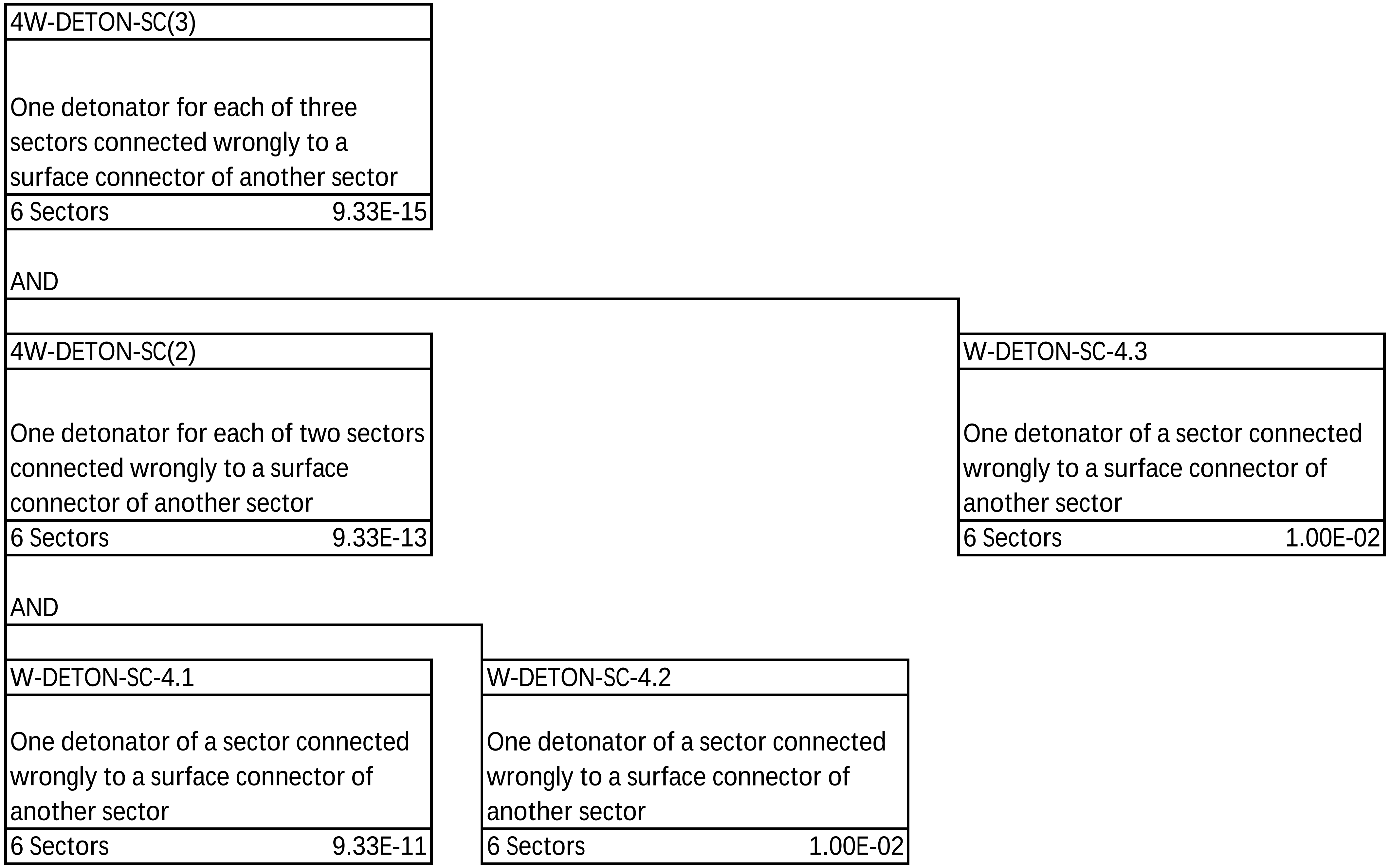
4W-DETON-4.2

1 detonator wrongly put into one sector which contains the same time delay detonator

6 Sectors 1.00E-02


4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
AND
HE-WS-4.1
Wrong installation of one detonator in another sector
6 Sectors
7.11E-08
HE-WS-R-4.1
SF fails to detect & correct error
6 Sectors
4.91E-05
HE-WS-US-4.1.1
The sector contains the same time delay detonator
6 Sectors
1.80E-03


4W-DETON-SC(2)+OTH
One detonator for each of two sectors connected wrongly to a surface connector of another sector plus one other error
6 Sectors 1.05E-17
AND
4W-DETON-SC(2)
One detonator for each of two sectors connected wrongly to a surface connector of another sector
6 Sectors 9.33E-13
4W-DETON-SC(2)-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors 1.12E-05
AND
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-DETON-SC-4.2
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 1.00E-02
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



4W-DETON-SC(3)

One detonator for each of three sectors connected wrongly to a surface connector of another sector

6 Sectors 9.33E-15

AND

4W-DETON-SC(2)

One detonator for each of two sectors connected wrongly to a surface connector of another sector

6 Sectors 9.33E-13

W-DETON-SC-4.3

One detonator of a sector connected wrongly to a surface connector of another sector

6 Sectors 1.00E-02

AND

W-DETON-SC-4.1

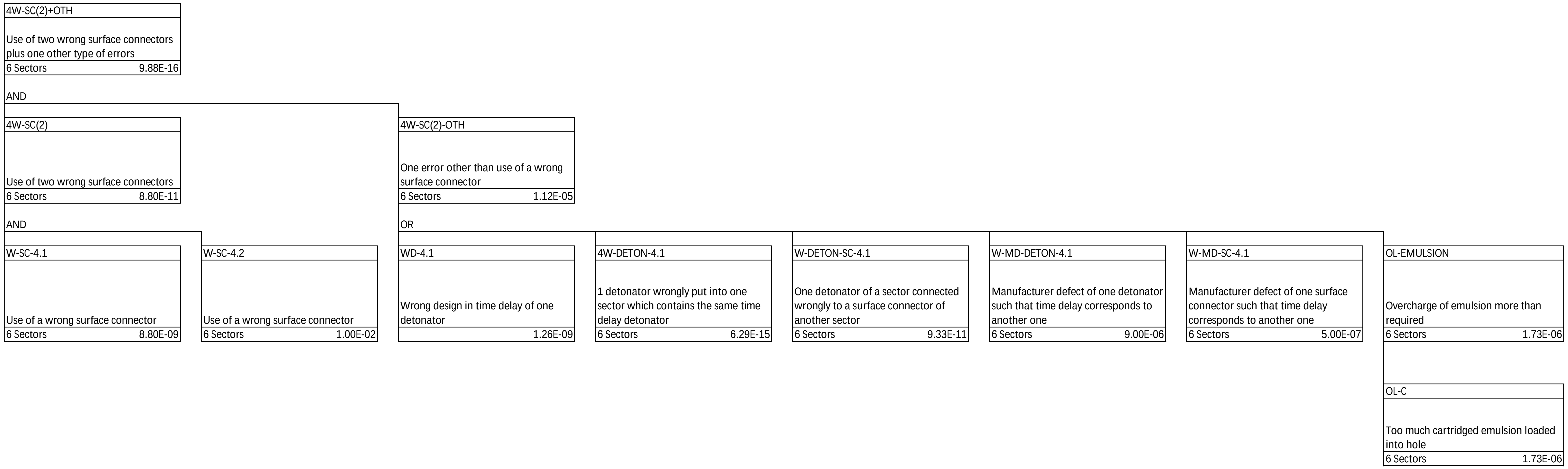
One detonator of a sector connected wrongly to a surface connector of another sector

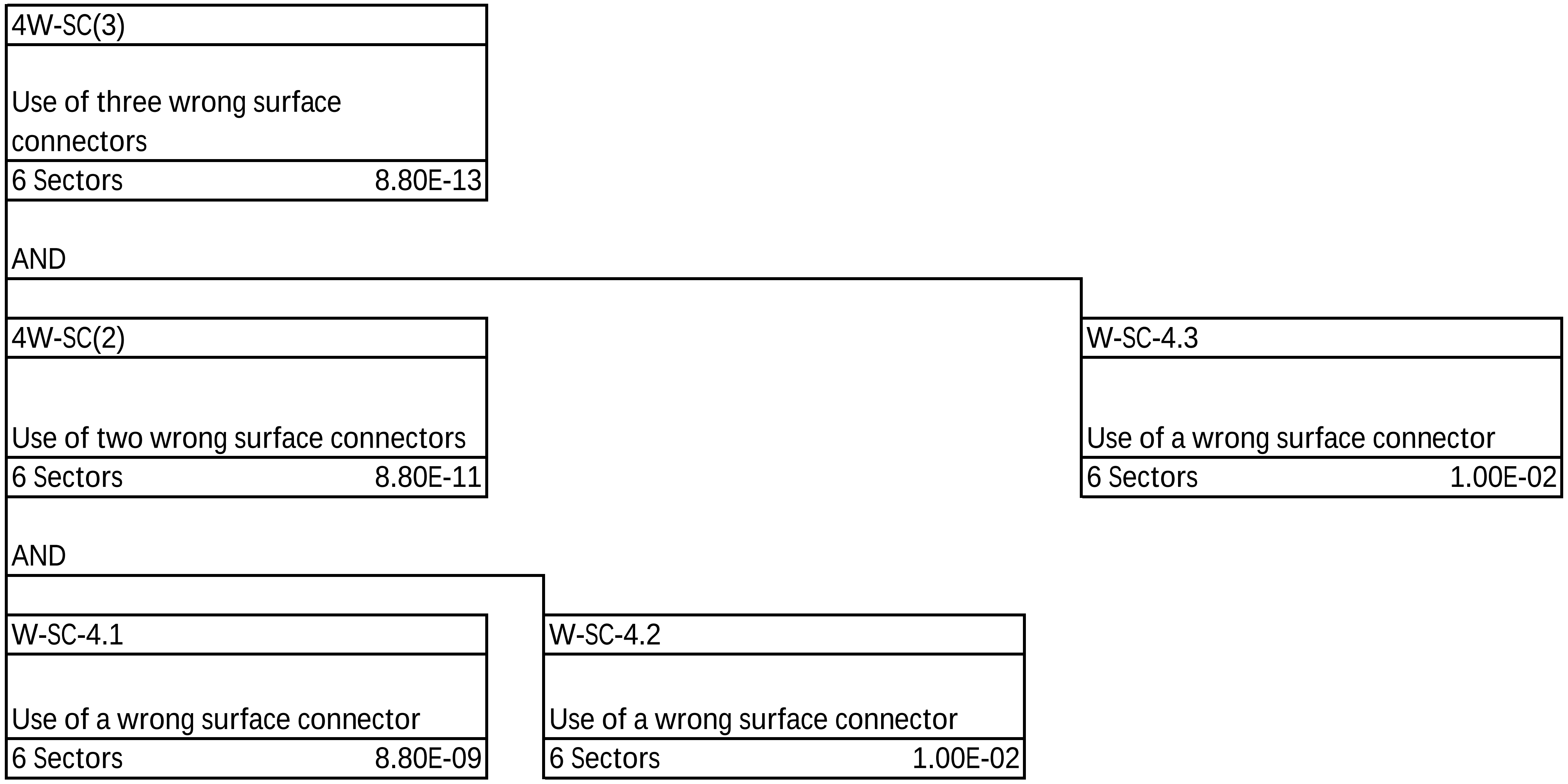
6 Sectors 9.33E-11

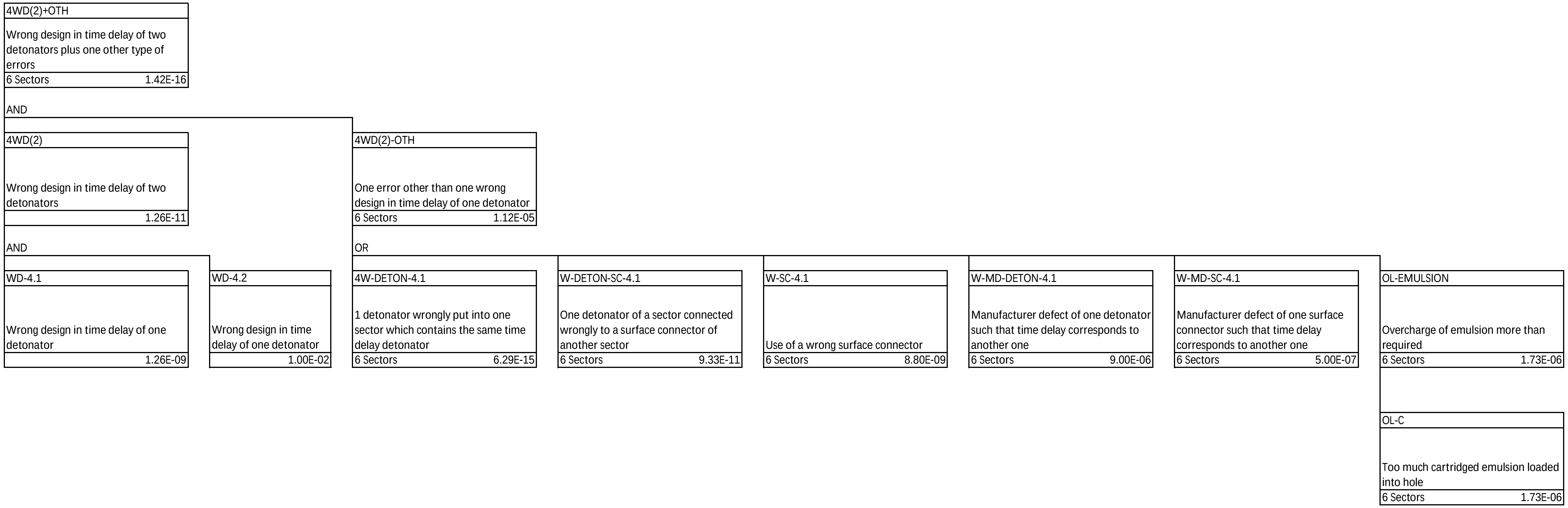
W-DETON-SC-4.2

One detonator of a sector connected wrongly to a surface connector of another sector

6 Sectors 1.00E-02


4W-SC(2)+OTH
Use of two wrong surface connectors plus one other type of errors
6 Sectors
9.88E-16
AND
4W-SC(2)
Use of two wrong surface connectors
6 Sectors
8.80E-11
4W-SC(2)-OTH
One error other than use of a wrong surface connector
6 Sectors
1.12E-05
AND
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-SC-4.2
Use of a wrong surface connector
6 Sectors
1.00E-02
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


4W-SC(3)
Use of three wrong surface connectors
6 Sectors
8.80E-13
AND
4W-SC(2)
Use of two wrong surface connectors
6 Sectors
8.80E-11
W-SC-4.3
Use of a wrong surface connector
6 Sectors
1.00E-02
AND
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-SC-4.2
Use of a wrong surface connector
6 Sectors
1.00E-02



4WD(2)+OTH
Wrong design in time delay of two detonators plus one other type of errors
6 Sectors 1.42E-16

AND

4WD(2)
Wrong design in time delay of two detonators
1.26E-11

AND

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

WD-4.2
Wrong design in time delay of one detonator
1.00E-02

4WD(2)-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors 1.12E-05

OR

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

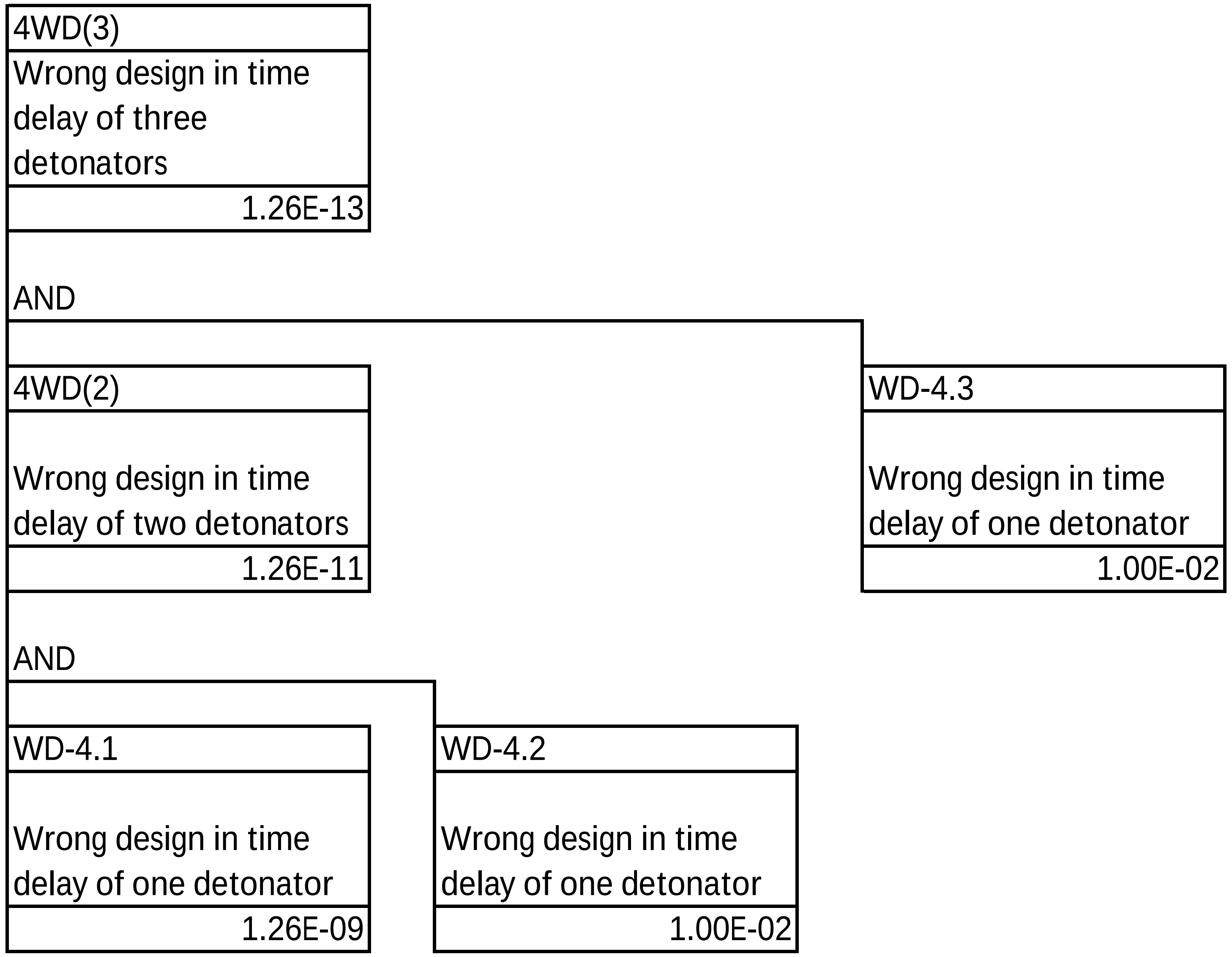
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

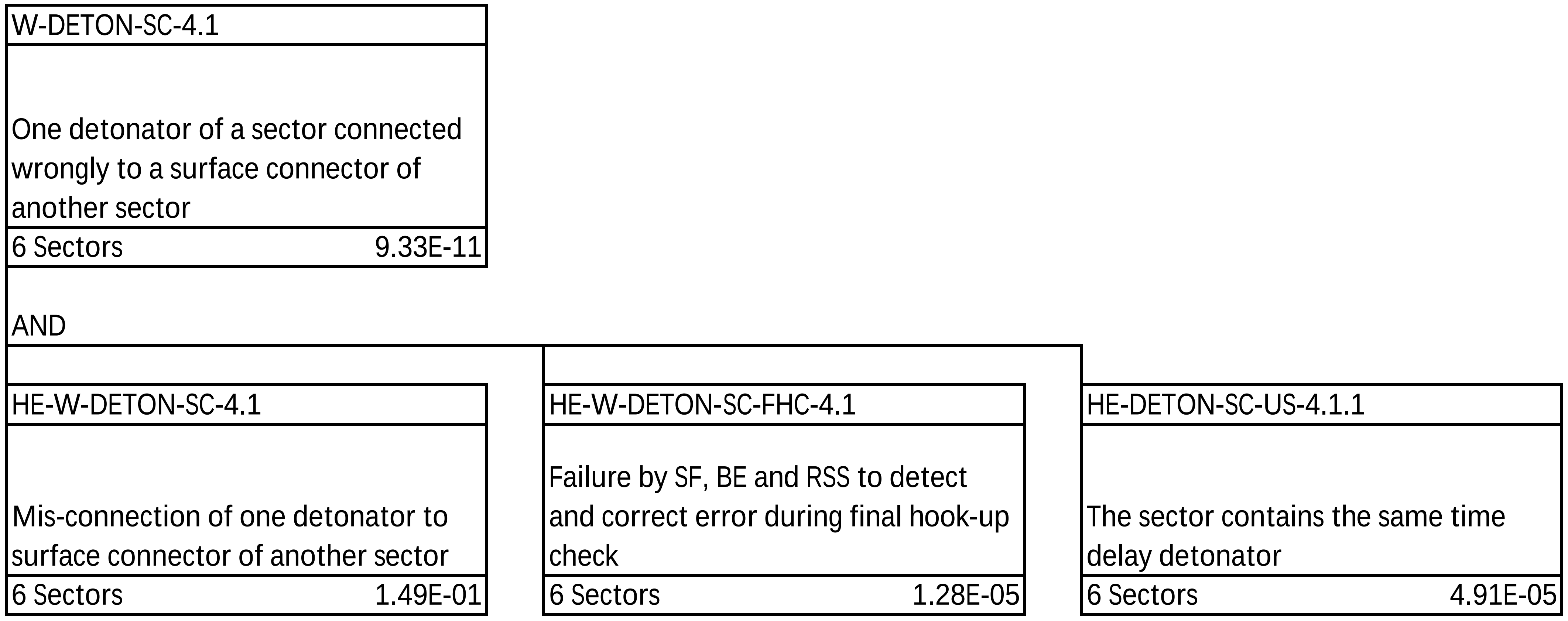
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

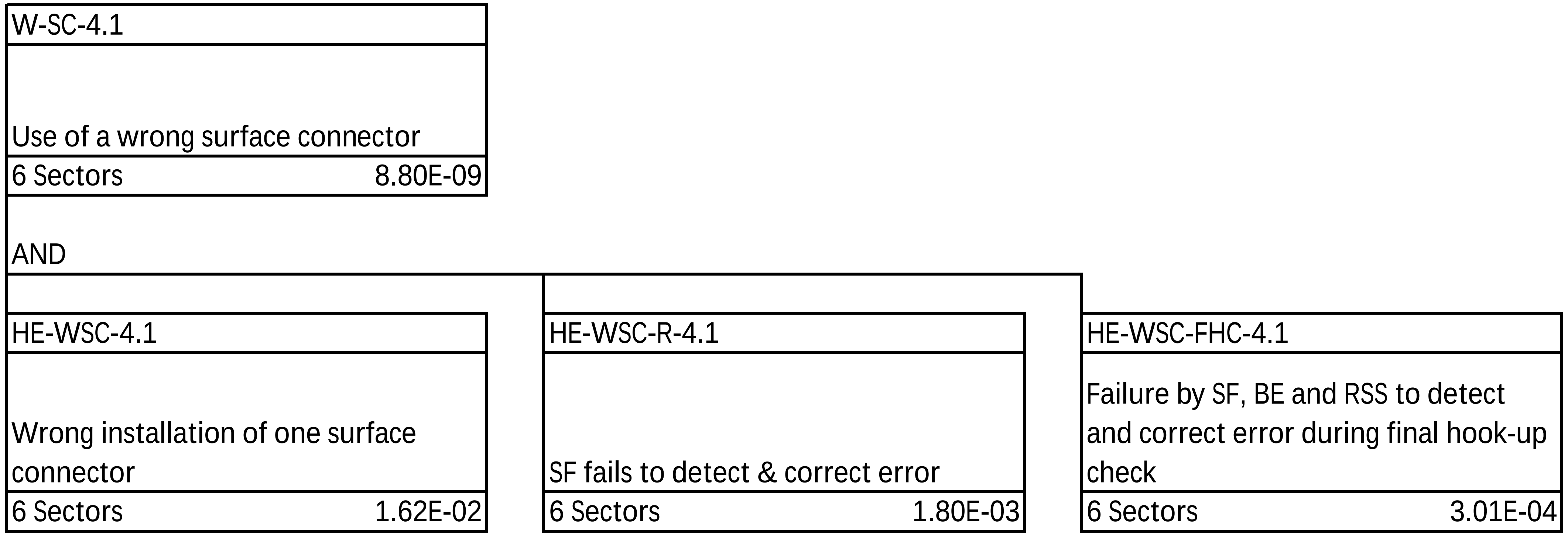
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

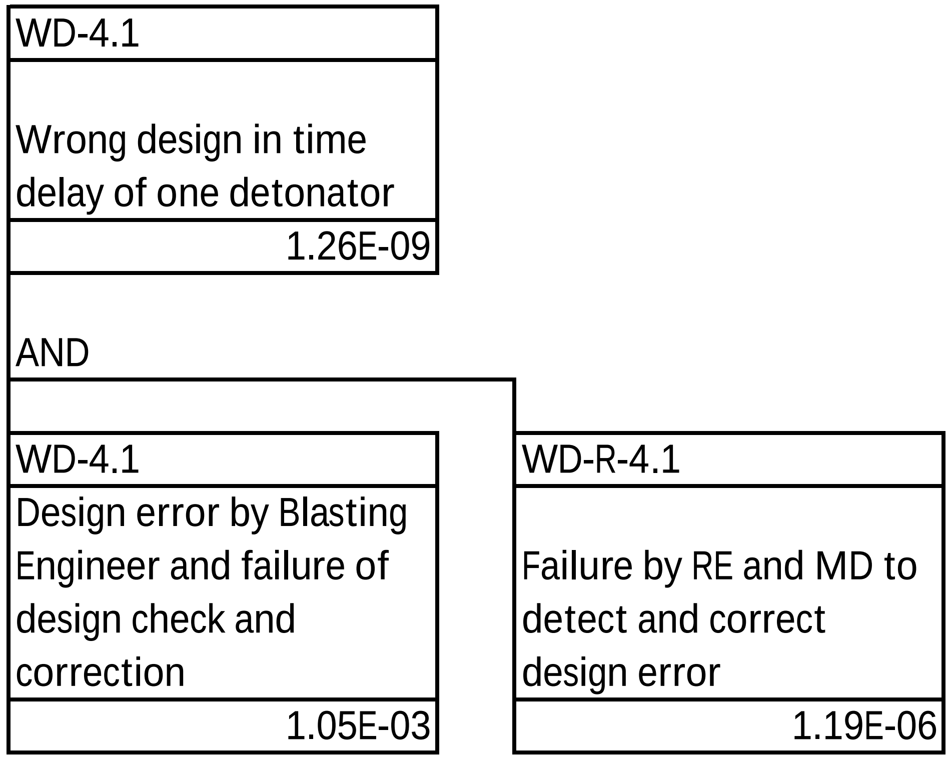
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

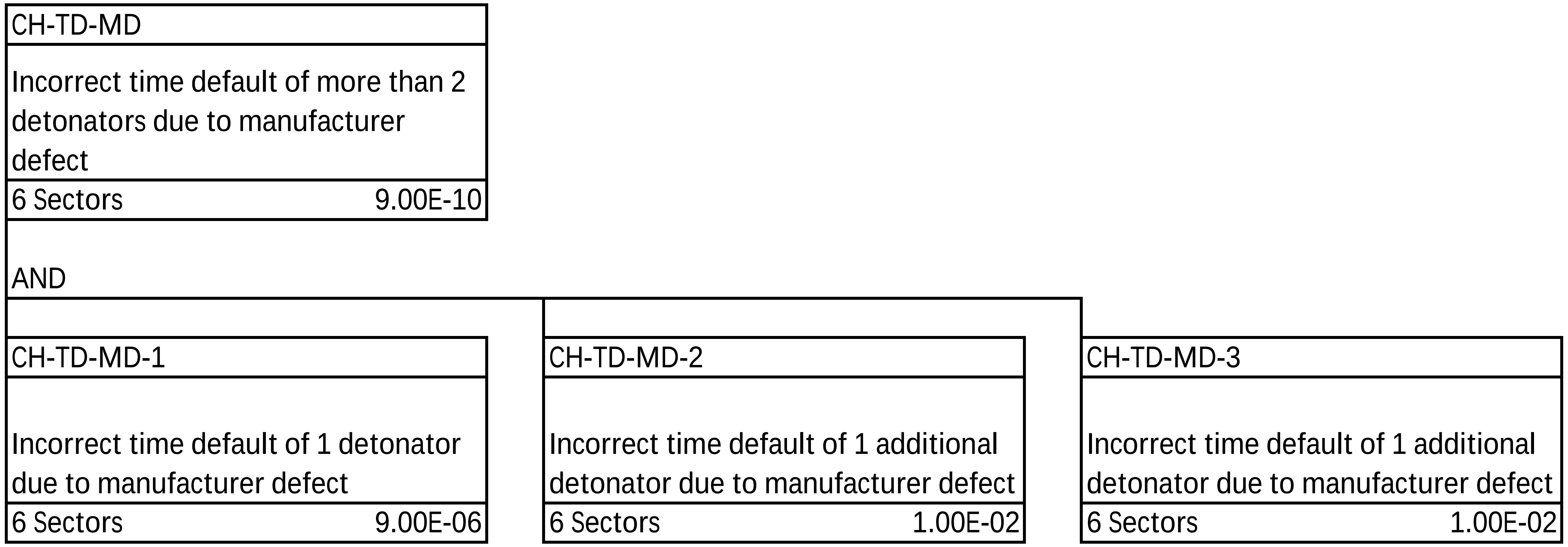
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

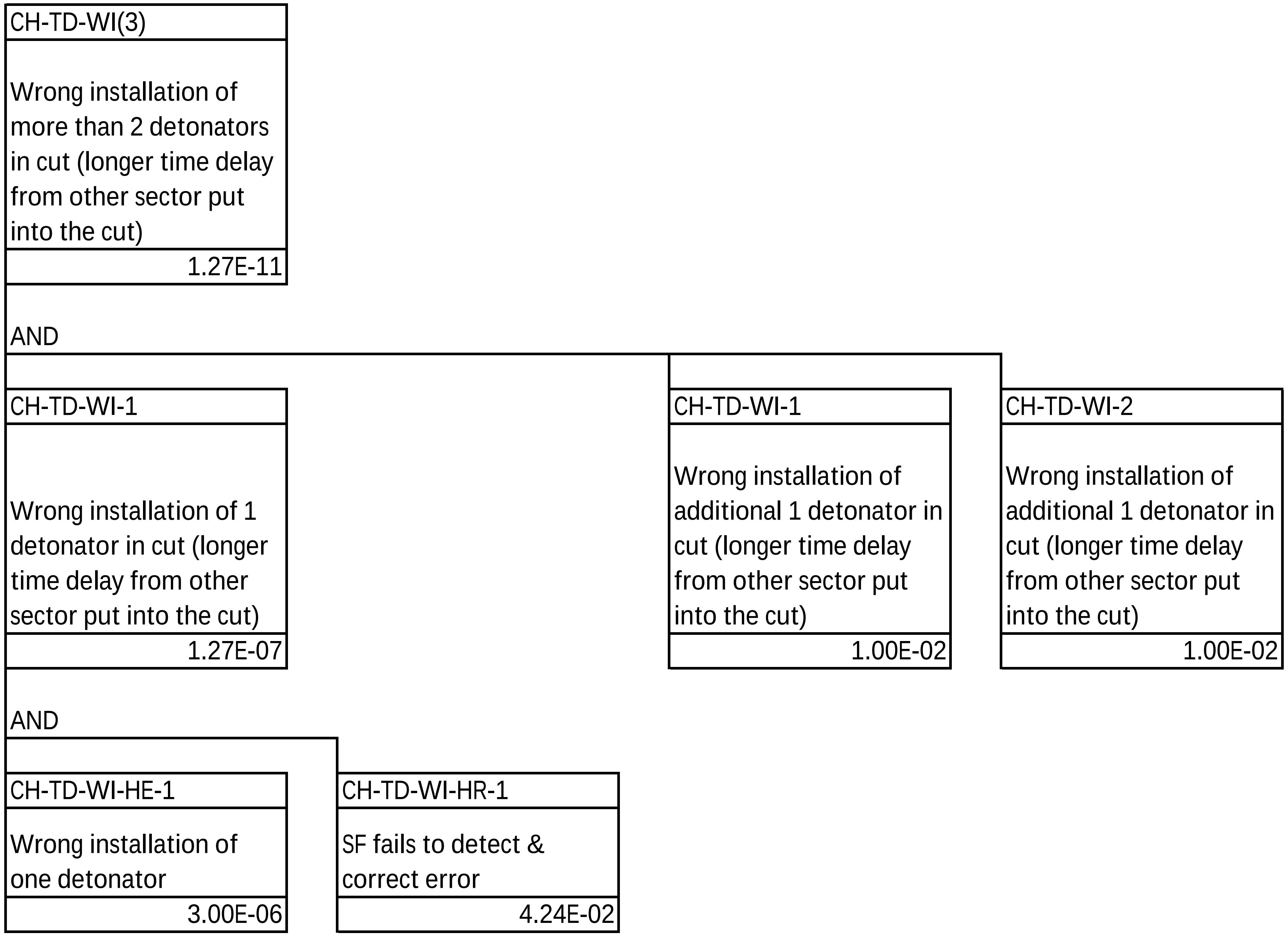

4WD(3)
Wrong design in time delay of three detonators
1.26E-13
AND
4WD(2)
Wrong design in time delay of two detonators
1.26E-11
WD-4.3
Wrong design in time delay of one detonator
1.00E-02
AND
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
WD-4.2
Wrong design in time delay of one detonator
1.00E-02

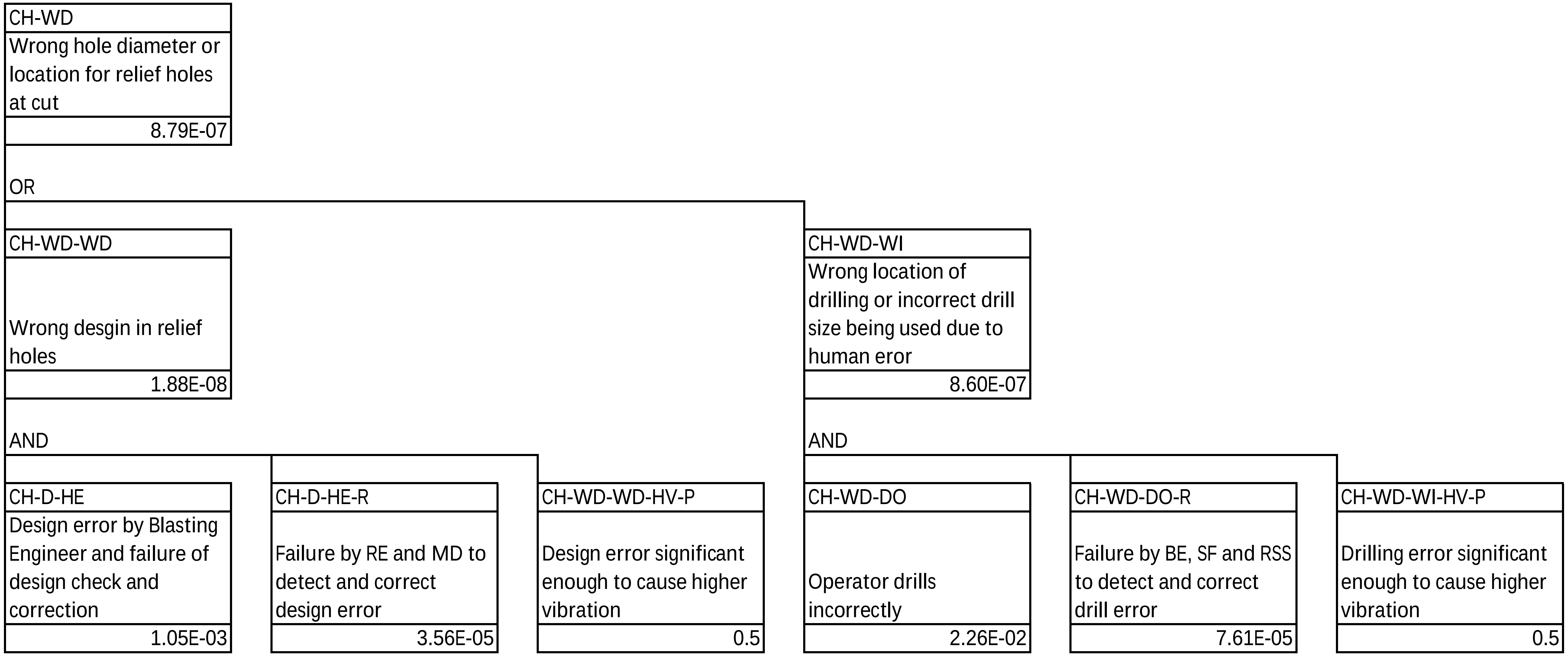

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
AND
HE-W-DETON-SC-4.1
Mis-connection of one detonator to surface connector of another sector
6 Sectors
1.49E-01
HE-W-DETON-SC-FHC-4.1
Failure by SF, BE and RSS to detect and correct error during final hook-up check
6 Sectors
1.28E-05
HE-DETON-SC-US-4.1.1
The sector contains the same time delay detonator
6 Sectors
4.91E-05

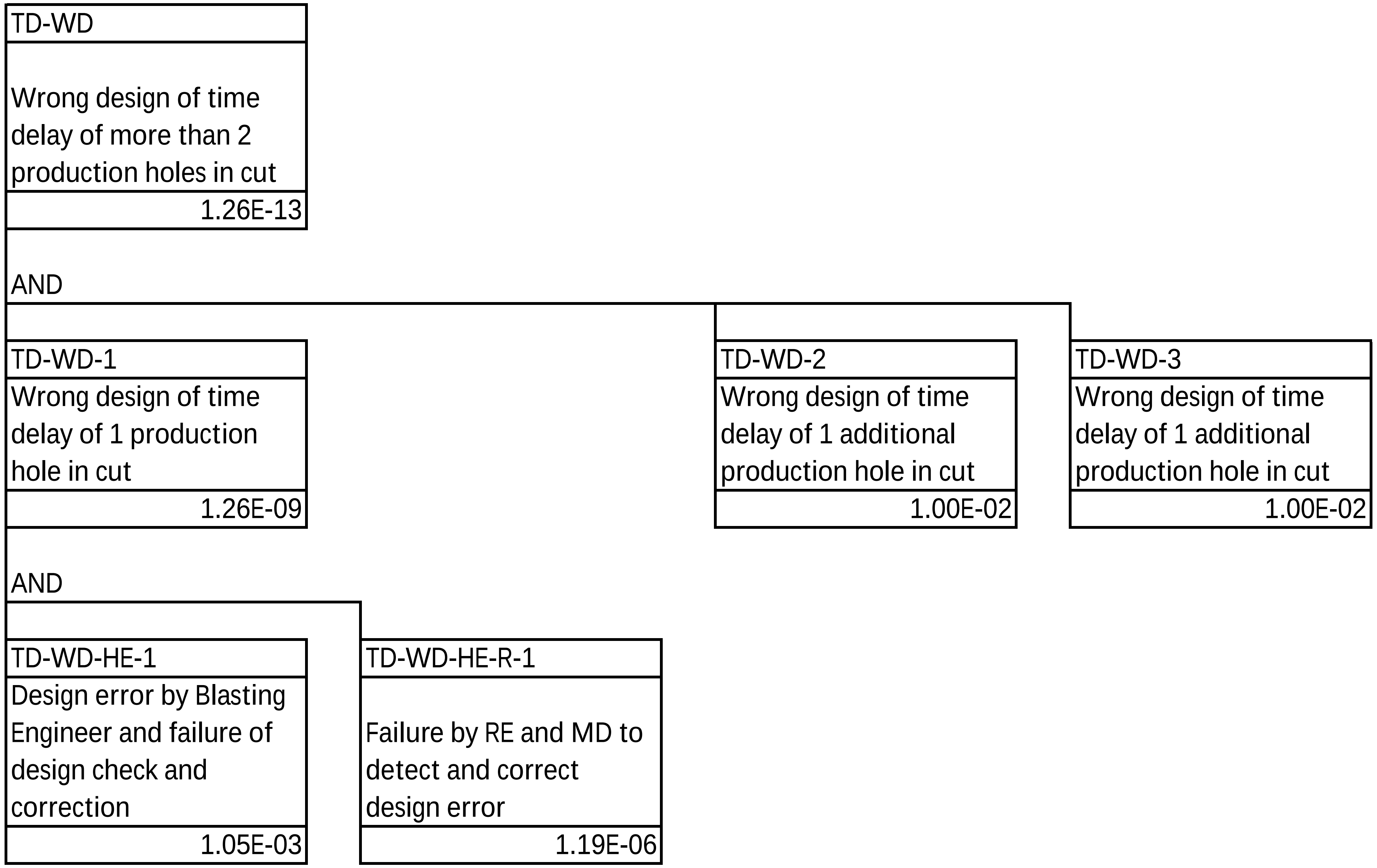

W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
AND
HE-WSC-4.1
Wrong installation of one surface connector
6 Sectors
1.62E-02
HE-WSC-R-4.1
SF fails to detect & correct error
6 Sectors
1.80E-03
HE-WSC-FHC-4.1
Failure by SF, BE and RSS to detect and correct error during final hook-up check
6 Sectors
3.01E-04

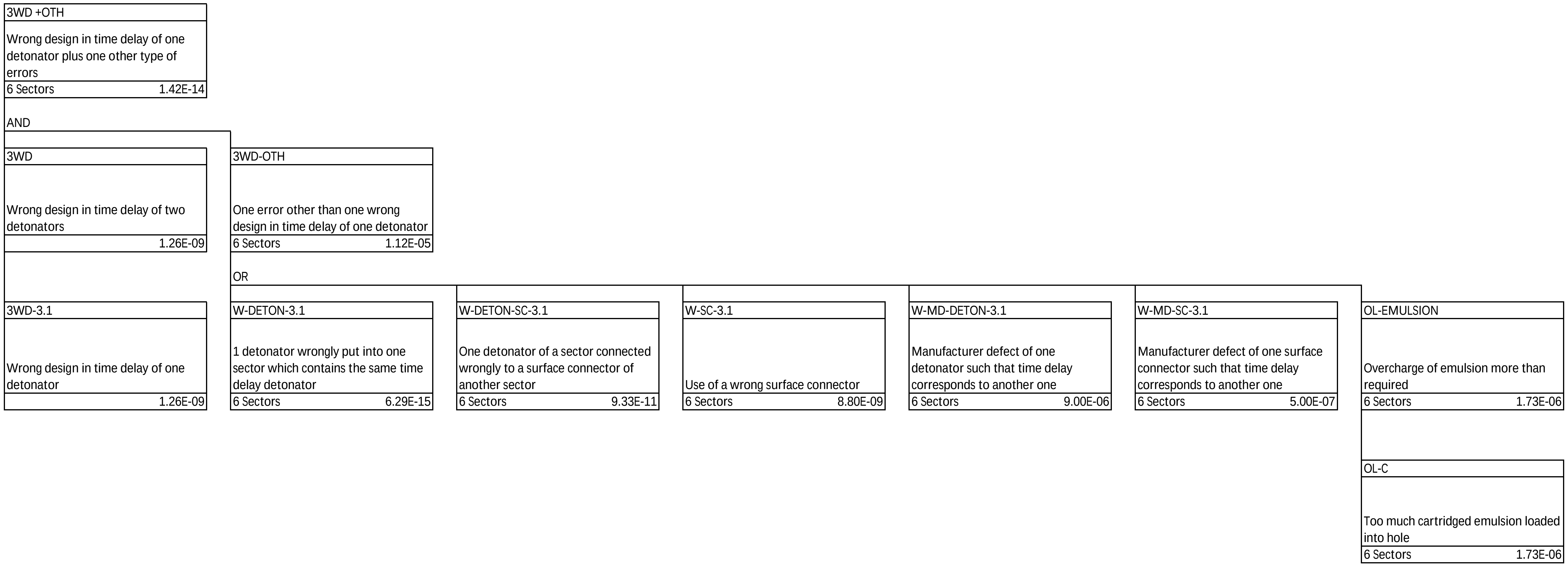

WD-4.1
Wrong design in time delay of one detonator
1.26E-09
AND
WD-4.1
Design error by Blasting Engineer and failure of design check and correction
1.05E-03
WD-R-4.1
Failure by RE and MD to detect and correct design error
1.19E-06

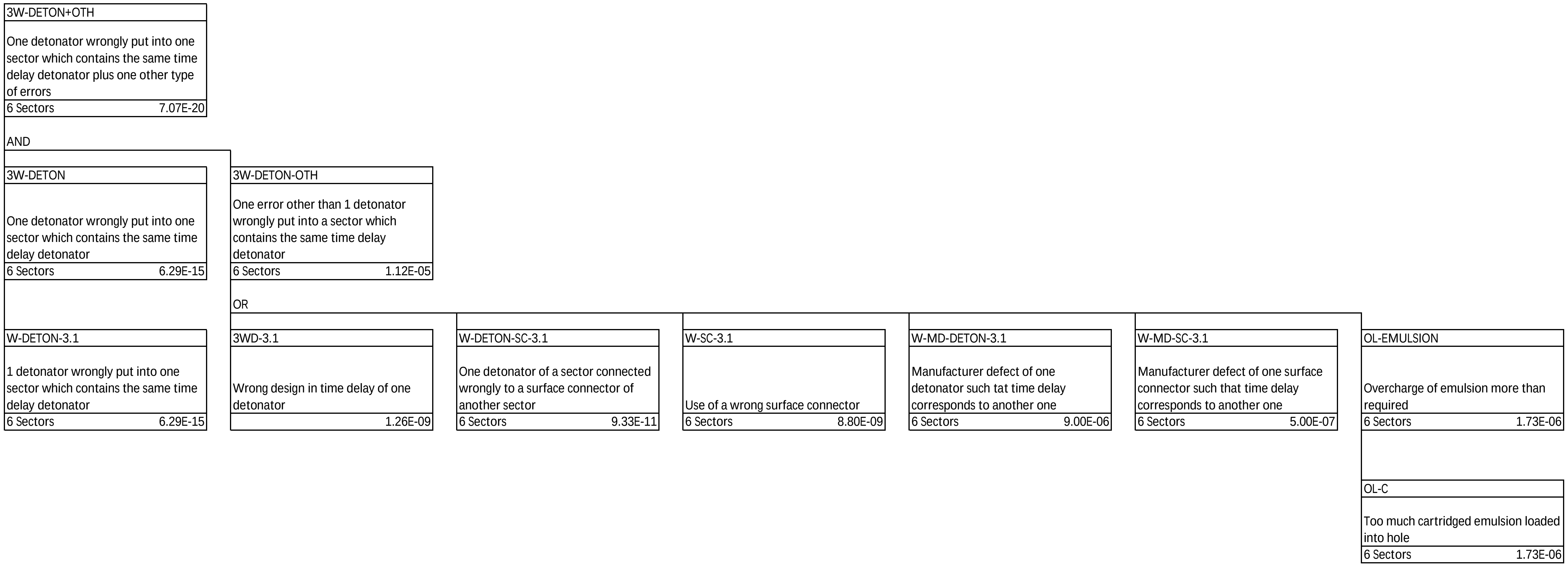

CH-TD-MD
Incorrect time default of more than 2 detonators due to manufacturer defect
6 Sectors
9.00E-10
AND
CH-TD-MD-1
Incorrect time default of 1 detonator due to manufacturer defect
6 Sectors
9.00E-06
CH-TD-MD-2
Incorrect time default of 1 additional detonator due to manufacturer defect
6 Sectors
1.00E-02
CH-TD-MD-3
Incorrect time default of 1 additional detonator due to manufacturer defect
6 Sectors
1.00E-02


CH-TD-WI(3)
Wrong installation of more than 2 detonators in cut (longer time delay from other sector put into the cut)
1.27E-11
AND
CH-TD-WI-1
Wrong installation of 1 detonator in cut (longer time delay from other sector put into the cut)
1.27E-07
CH-TD-WI-1
Wrong installation of additional 1 detonator in cut (longer time delay from other sector put into the cut)
1.00E-02
CH-TD-WI-2
Wrong installation of additional 1 detonator in cut (longer time delay from other sector put into the cut)
1.00E-02
AND
CH-TD-WI-HE-1
Wrong installation of one detonator
3.00E-06
CH-TD-WI-HR-1
SF fails to detect & correct error
4.24E-02


CH-WD
Wrong hole diameter or location for relief holes at cut
8.79E-07
OR
CH-WD-WD
Wrong desgin in relief holes
1.88E-08
AND
CH-D-HE
Design error by Blasting Engineer and failure of design check and correction
1.05E-03
CH-D-HE-R
Failure by RE and MD to detect and correct design error
3.56E-05
CH-WD-WD-HV-P
Design error significant enough to cause higher vibration
0.5
CH-WD-WI
Wrong location of drilling or incorrect drill size being used due to human eror
8.60E-07
AND
CH-WD-DO
Operator drills incorrectly
2.26E-02
CH-WD-DO-R
Failure by BE, SF and RSS to detect and correct drill error
7.61E-05
CH-WD-WI-HV-P
Drilling error significant enough to cause higher vibration
0.5


TD-WD
Wrong design of time delay of more than 2 production holes in cut
1.26E-13
AND
TD-WD-1
Wrong design of time delay of 1 production hole in cut
1.26E-09
TD-WD-2
Wrong design of time delay of 1 additional production hole in cut
1.00E-02
TD-WD-3
Wrong design of time delay of 1 additional production hole in cut
1.00E-02
AND
TD-WD-HE-1
Design error by Blasting Engineer and failure of design check and correction
1.05E-03
TD-WD-HE-R-1
Failure by RE and MD to detect and correct design error
1.19E-06


3WD +OTH
Wrong design in time delay of one detonator plus one other type of errors
6 Sectors
1.42E-14
AND
3WD
Wrong design in time delay of two detonators
1.26E-09
3WD-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors
1.12E-05
OR
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-3.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-3.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06



3W-DETON+OTH
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors
6 Sectors 7.07E-20

AND

3W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

3W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 1.12E-05

W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

OR

3WD-3.1
Wrong design in time delay of one detonator
1.26E-09

W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

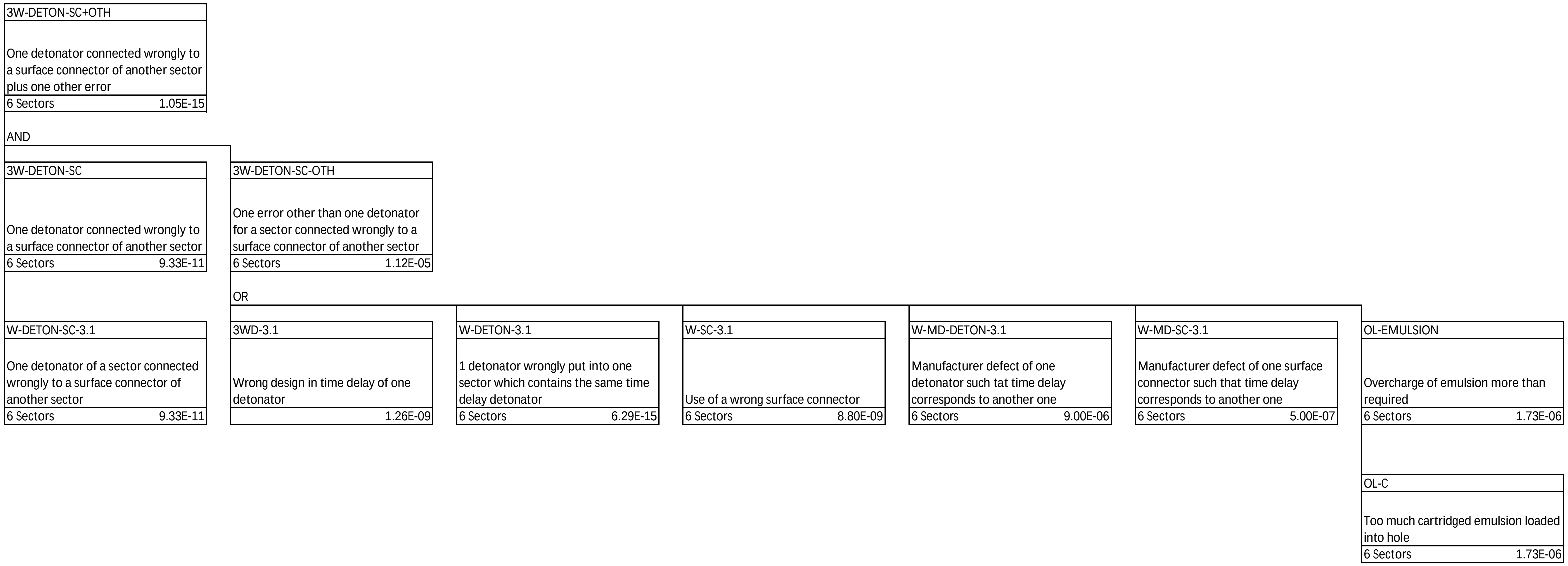
W-SC-3.1
Use of a wrong surface connector
6 Sectors 8.80E-09

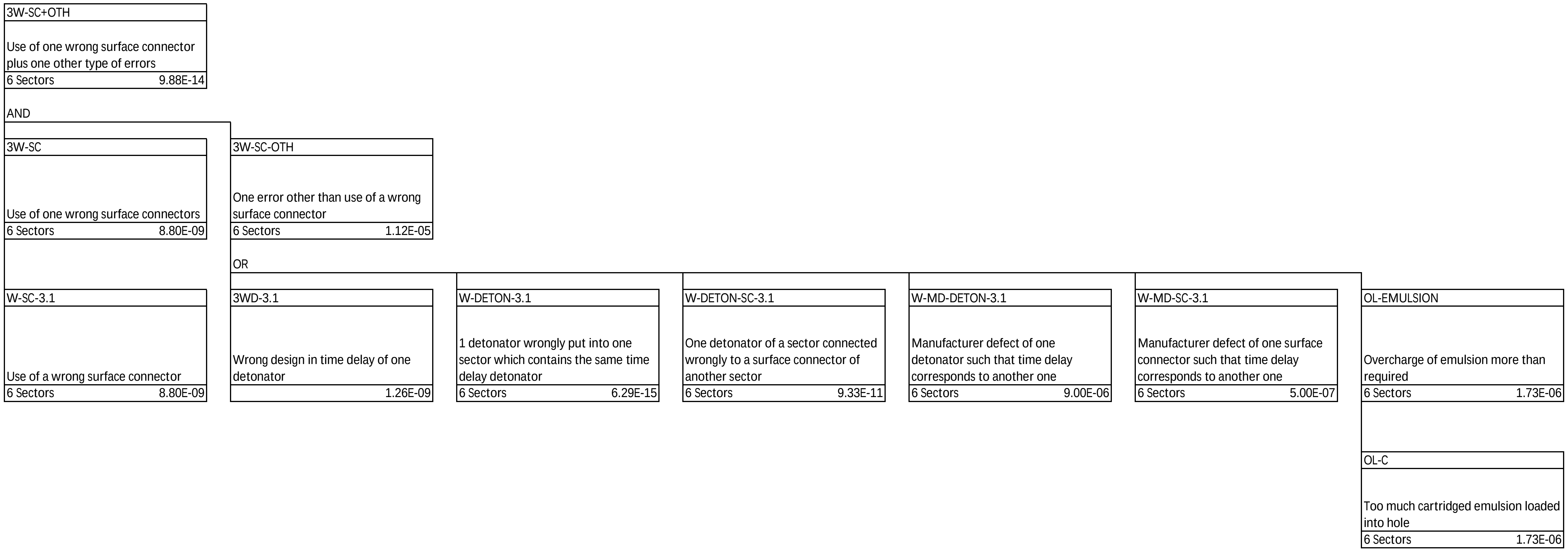
W-MD-DETON-3.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

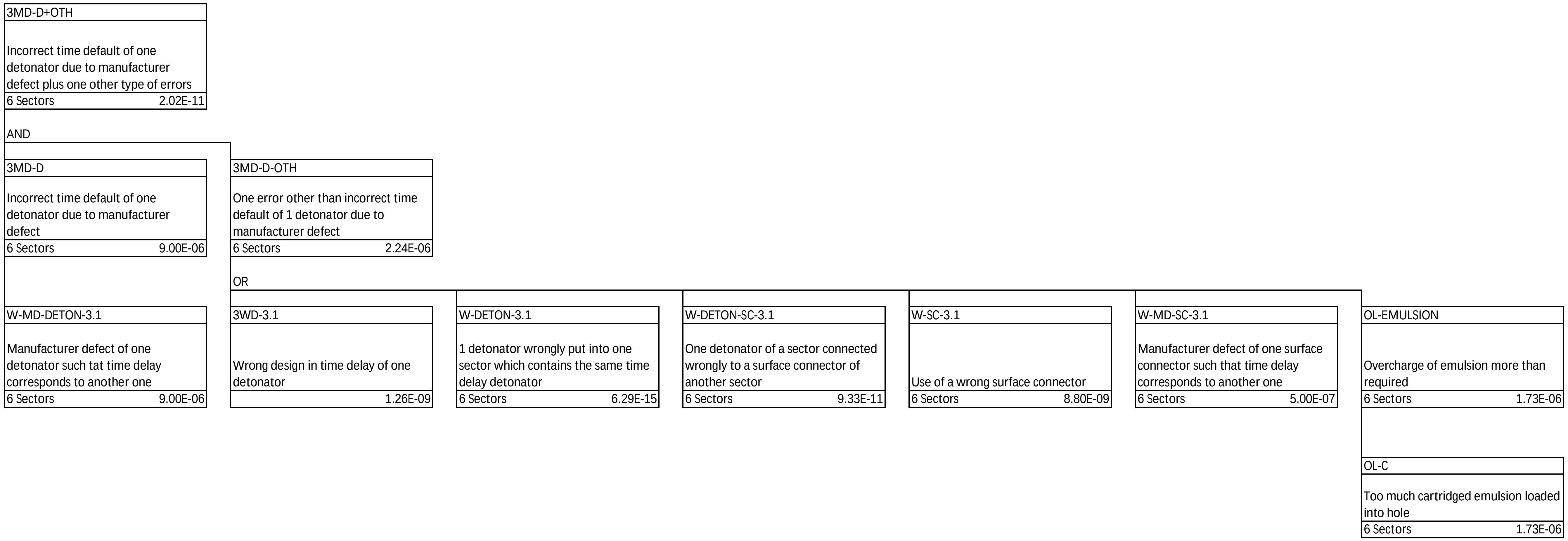
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

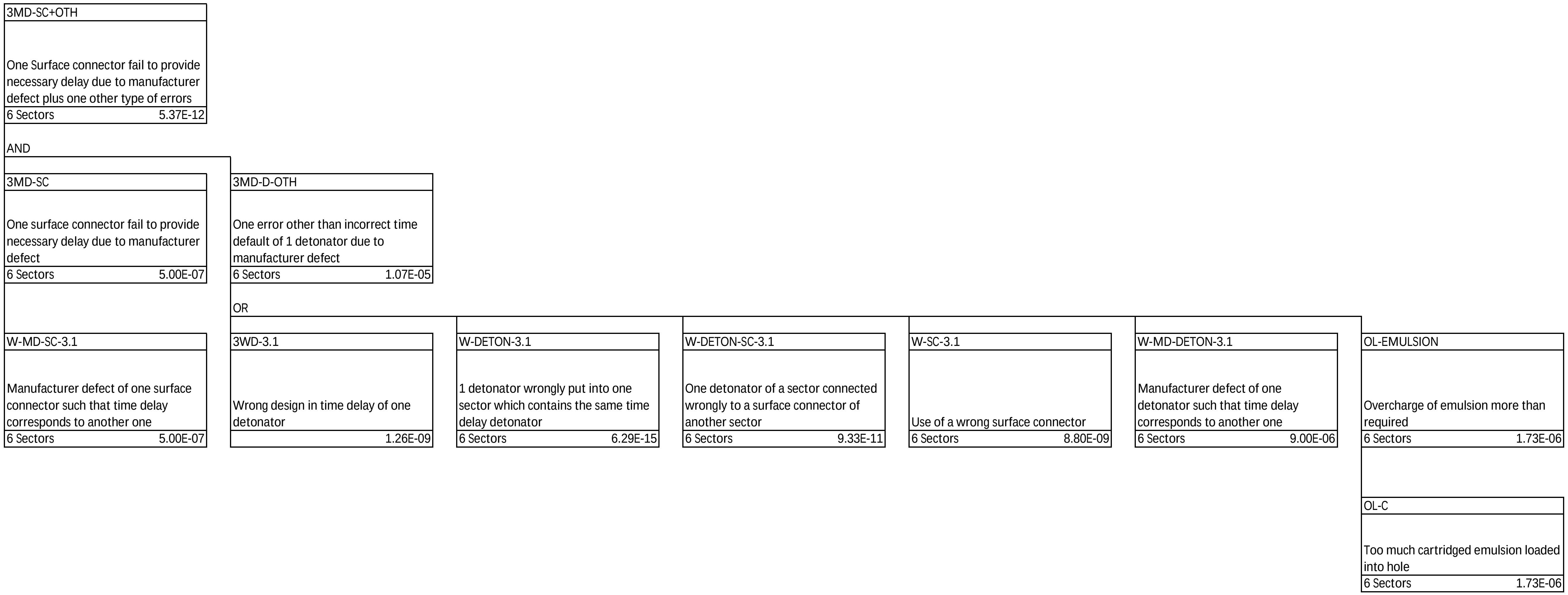
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

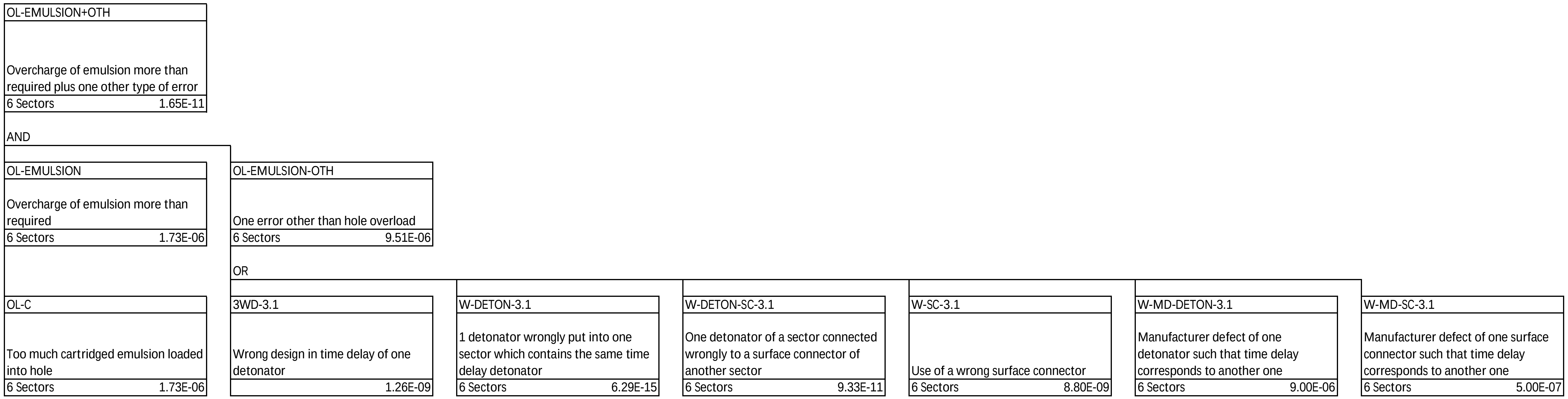
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

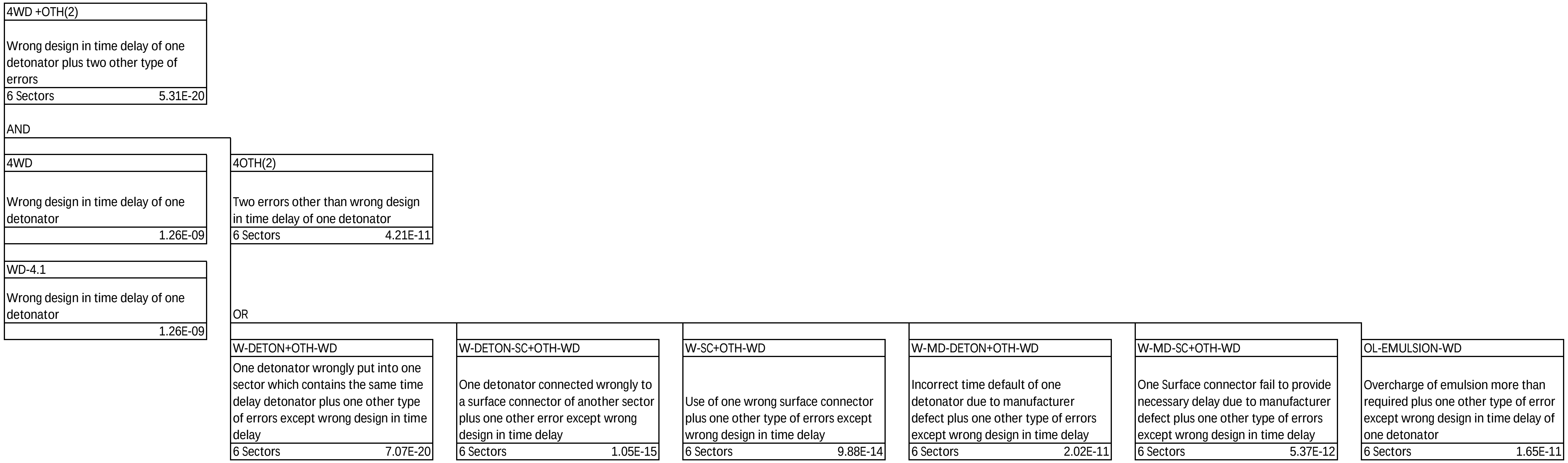

3W-DETON-SC+OTH
One detonator connected wrongly to a surface connector of another sector plus one other error
6 Sectors
1.05E-15
AND
3W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
3W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors
1.12E-05
OR
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-SC-3.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-3.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06

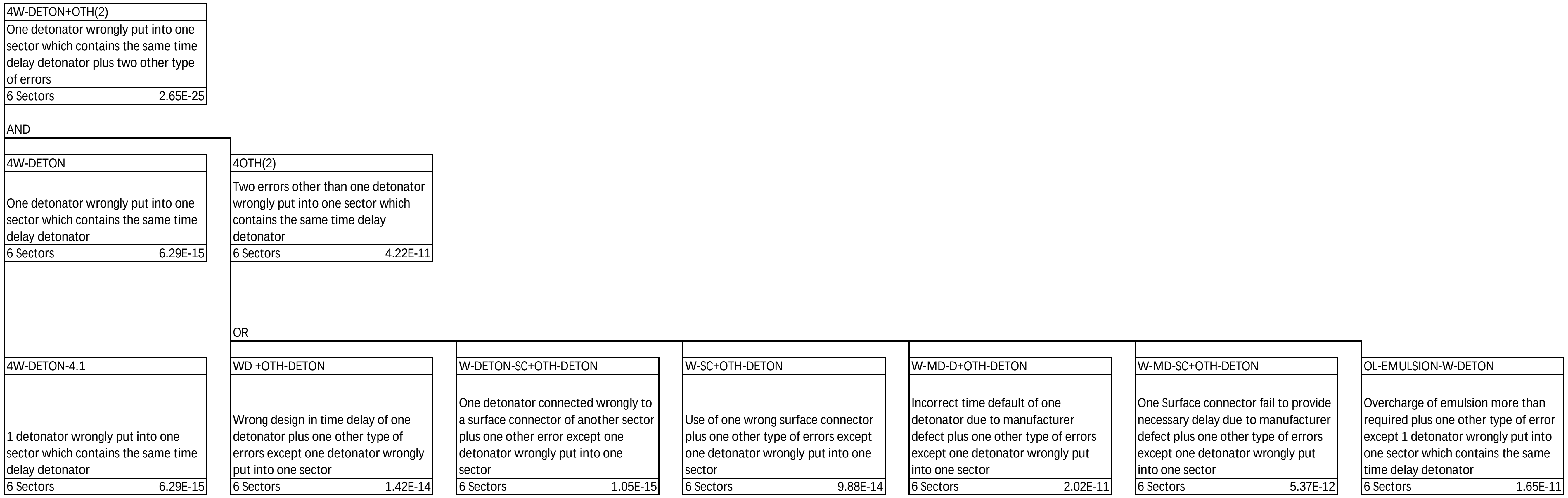

3W-SC+OTH
Use of one wrong surface connector plus one other type of errors
6 Sectors 9.88E-14
AND
3W-SC
Use of one wrong surface connectors
6 Sectors 8.80E-09
3W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors 1.12E-05
W-SC-3.1
Use of a wrong surface connector
6 Sectors 8.80E-09
OR
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-MD-DETON-3.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

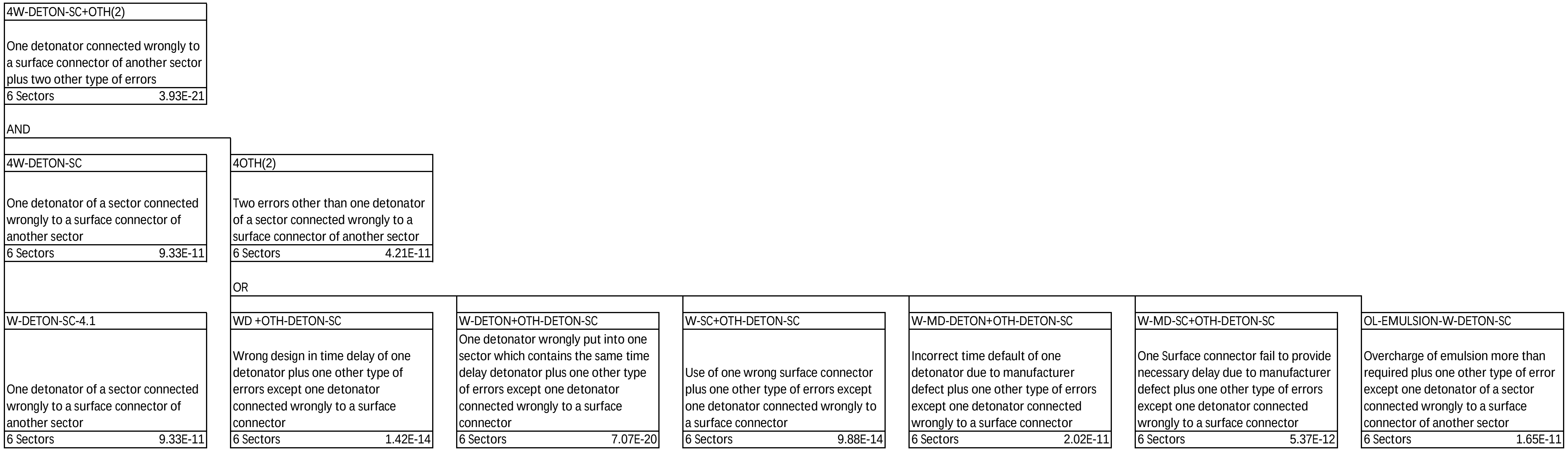

3MD-D+OTH
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors
6 Sectors
2.02E-11
AND
3MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors
9.00E-06
3MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors
2.24E-06
OR
W-MD-DETON-3.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-3.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


3MD-SC+OTH
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors
6 Sectors
5.37E-12
AND
3MD-SC
One surface connector fail to provide necessary delay due to manufacturer defect
6 Sectors
5.00E-07
3MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors
1.07E-05
OR
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-3.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-3.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


OL-EMULSION+OTH
Overcharge of emulsion more than required plus one other type of error
6 Sectors 1.65E-11
AND
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-EMULSION-OTH
One error other than hole overload
6 Sectors 9.51E-06
OR
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06
3WD-3.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-3.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-DETON-SC-3.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-SC-3.1
Use of a wrong surface connector
6 Sectors 8.80E-09
W-MD-DETON-3.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06
W-MD-SC-3.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07


4WD +OTH(2)
Wrong design in time delay of one detonator plus two other type of errors
6 Sectors
5.31E-20
AND
4WD
Wrong design in time delay of one detonator
1.26E-09
4OTH(2)
Two errors other than wrong design in time delay of one detonator
6 Sectors
4.21E-11
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
OR
W-DETON+OTH-WD
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except wrong design in time delay
6 Sectors
7.07E-20
W-DETON-SC+OTH-WD
One detonator connected wrongly to a surface connector of another sector plus one other error except wrong design in time delay
6 Sectors
1.05E-15
W-SC+OTH-WD
Use of one wrong surface connector plus one other type of errors except wrong design in time delay
6 Sectors
9.88E-14
W-MD-DETON+OTH-WD
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except wrong design in time delay
6 Sectors
2.02E-11
W-MD-SC+OTH-WD
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except wrong design in time delay
6 Sectors
5.37E-12
OL-EMULSION-WD
Overcharge of emulsion more than required plus one other type of error except wrong design in time delay of one detonator
6 Sectors
1.65E-11


4W-DETON+OTH(2)
One detonator wrongly put into one sector which contains the same time delay detonator plus two other type of errors
6 Sectors 2.65E-25
AND
4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
4OTH(2)
Two errors other than one detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 4.22E-11
OR
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
WD +OTH-DETON
Wrong design in time delay of one detonator plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 1.42E-14
W-DETON-SC+OTH-DETON
One detonator connected wrongly to a surface connector of another sector plus one other error except one detonator wrongly put into one sector
6 Sectors 1.05E-15
W-SC+OTH-DETON
Use of one wrong surface connector plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 9.88E-14
W-MD-D+OTH-DETON
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 2.02E-11
W-MD-SC+OTH-DETON
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 5.37E-12
OL-EMULSION-W-DETON
Overcharge of emulsion more than required plus one other type of error except 1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 1.65E-11



4W-DETON-SC+OTH(2)
One detonator connected wrongly to a surface connector of another sector plus two other type of errors
6 Sectors 3.93E-21

AND

4W-DETON-SC
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

4OTH(2)
Two errors other than one detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 4.21E-11

OR

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

WD +OTH-DETON-SC
Wrong design in time delay of one detonator plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 1.42E-14

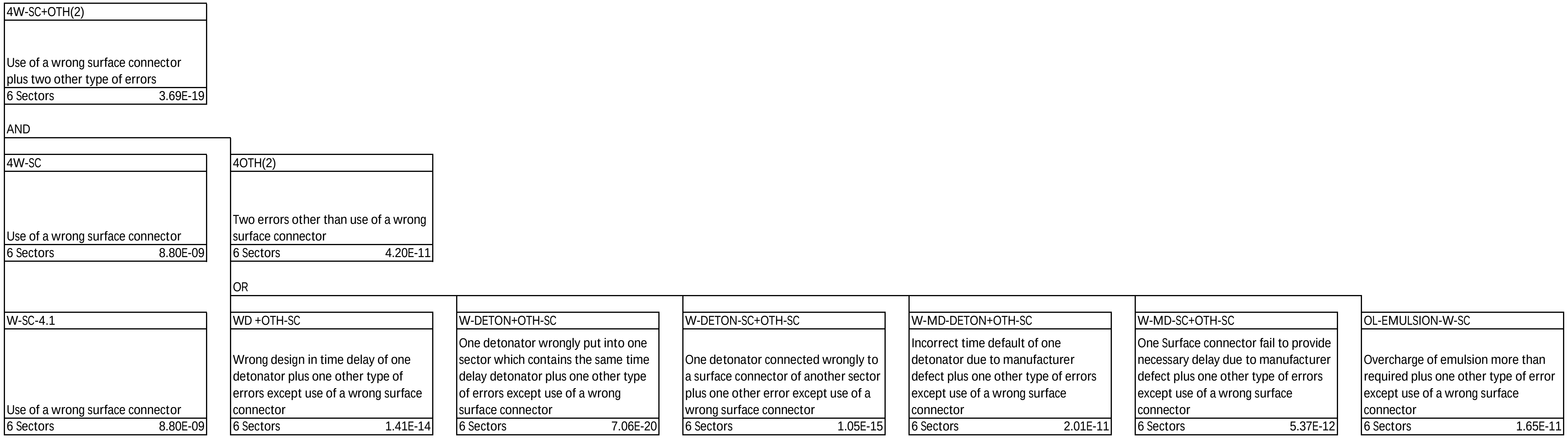
W-DETON+OTH-DETON-SC
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 7.07E-20

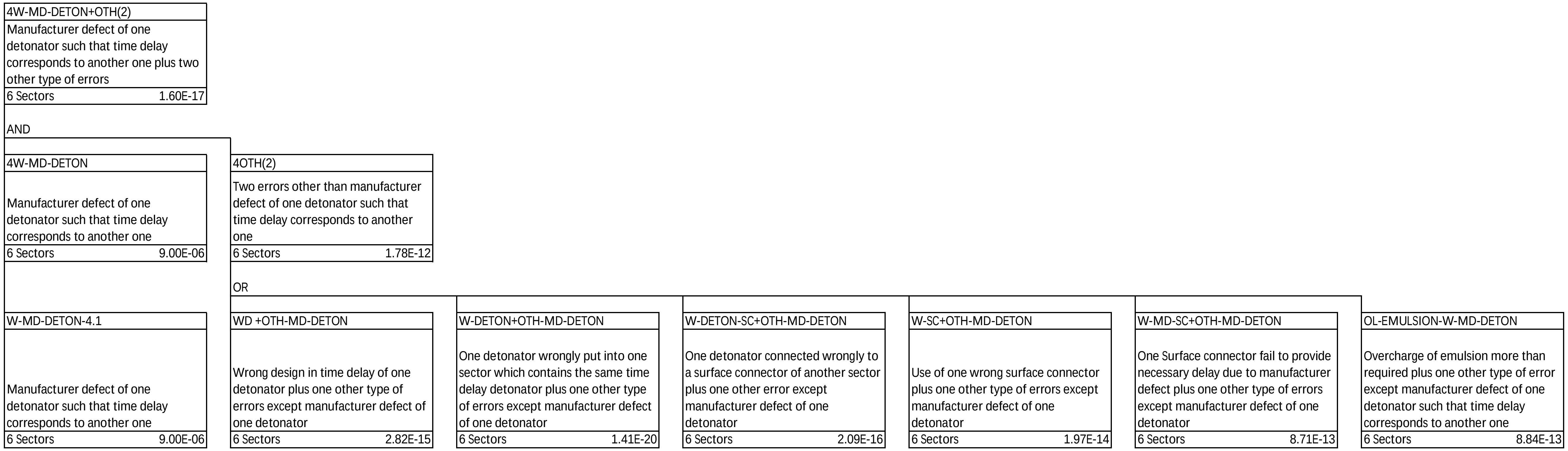
W-SC+OTH-DETON-SC
Use of one wrong surface connector plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 9.88E-14

W-MD-DETON+OTH-DETON-SC
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 2.02E-11

W-MD-SC+OTH-DETON-SC
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 5.37E-12

OL-EMULSION-W-DETON-SC
Overcharge of emulsion more than required plus one other type of error except one detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 1.65E-11


4W-SC+OTH(2)
Use of a wrong surface connector plus two other type of errors
6 Sectors
3.69E-19
AND
4W-SC
Use of a wrong surface connector
6 Sectors
8.80E-09
4OTH(2)
Two errors other than use of a wrong surface connector
6 Sectors
4.20E-11
OR
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
WD +OTH-SC
Wrong design in time delay of one detonator plus one other type of errors except use of a wrong surface connector
6 Sectors
1.41E-14
W-DETON+OTH-SC
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except use of a wrong surface connector
6 Sectors
7.06E-20
W-DETON-SC+OTH-SC
One detonator connected wrongly to a surface connector of another sector plus one other error except use of a wrong surface connector
6 Sectors
1.05E-15
W-MD-DETON+OTH-SC
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except use of a wrong surface connector
6 Sectors
2.01E-11
W-MD-SC+OTH-SC
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except use of a wrong surface connector
6 Sectors
5.37E-12
OL-EMULSION-W-SC
Overcharge of emulsion more than required plus one other type of error except use of a wrong surface connector
6 Sectors
1.65E-11



4W-MD-DETON+OTH(2)
Manufacturer defect of one detonator such that time delay corresponds to another one plus two other type of errors
6 Sectors 1.60E-17

AND

4W-MD-DETON
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

4OTH(2)
Two errors other than manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 1.78E-12

OR

W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

WD +OTH-MD-DETON
Wrong design in time delay of one detonator plus one other type of errors except manufacturer defect of one detonator
6 Sectors 2.82E-15

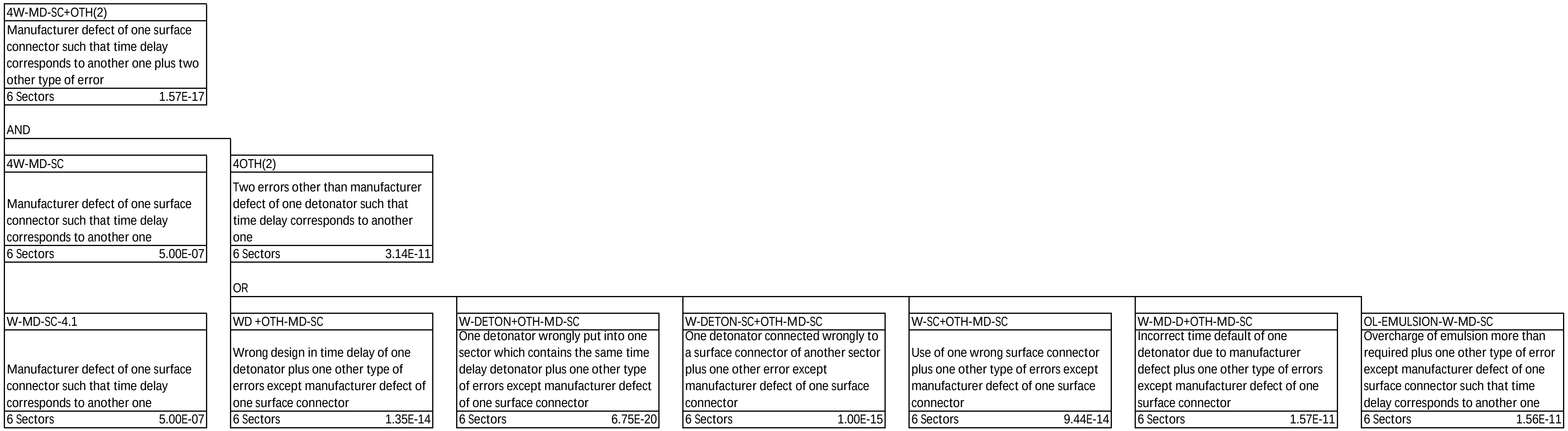
W-DETON+OTH-MD-DETON
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except manufacturer defect of one detonator
6 Sectors 1.41E-20

W-DETON-SC+OTH-MD-DETON
One detonator connected wrongly to a surface connector of another sector plus one other error except manufacturer defect of one detonator
6 Sectors 2.09E-16

W-SC+OTH-MD-DETON
Use of one wrong surface connector plus one other type of errors except manufacturer defect of one detonator
6 Sectors 1.97E-14

W-MD-SC+OTH-MD-DETON
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except manufacturer defect of one detonator
6 Sectors 8.71E-13

OL-EMULSION-W-MD-DETON
Overcharge of emulsion more than required plus one other type of error except manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 8.84E-13



4W-MD-SC+OTH(2)
Manufacturer defect of one surface connector such that time delay corresponds to another one plus two other type of error
6 Sectors 1.57E-17

AND

4W-MD-SC
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

4OTH(2)
Two errors other than manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 3.14E-11

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OR

WD +OTH-MD-SC
Wrong design in time delay of one detonator plus one other type of errors except manufacturer defect of one surface connector
6 Sectors 1.35E-14

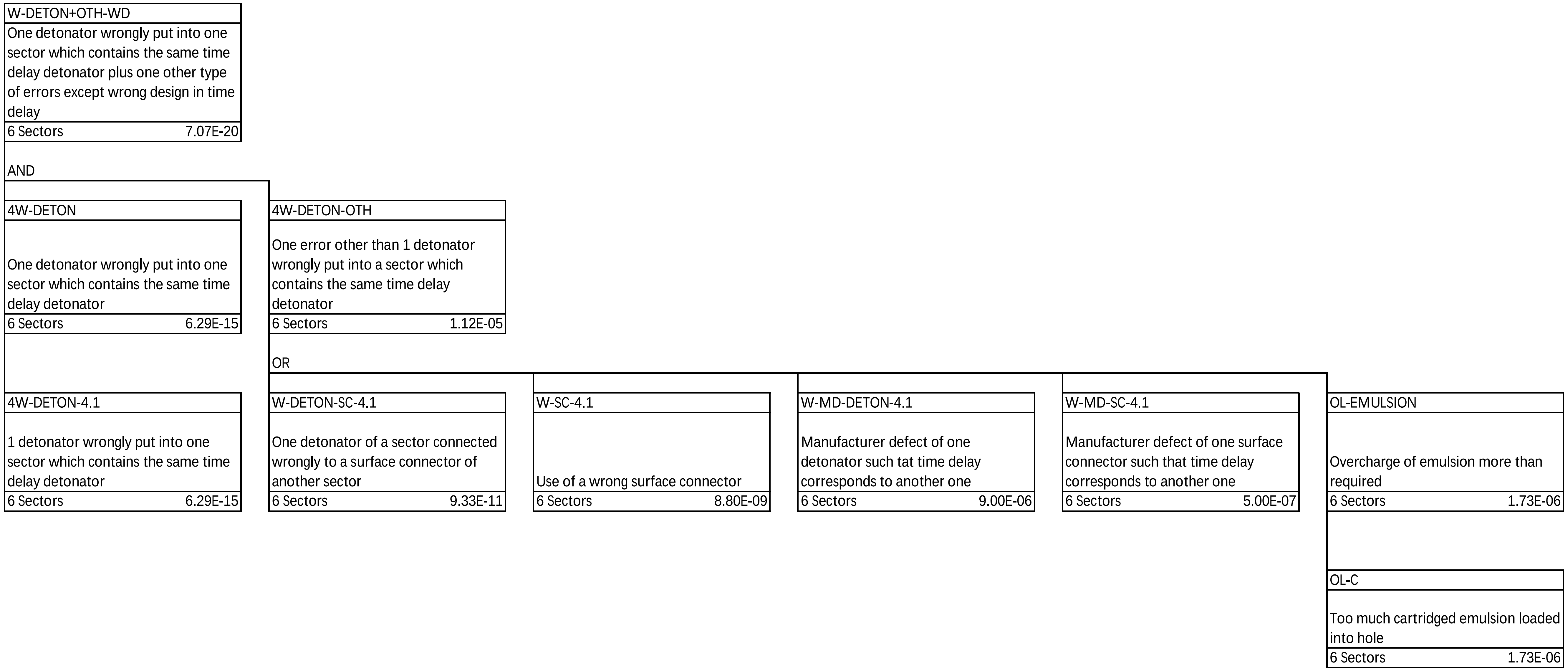
W-DETON+OTH-MD-SC
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except manufacturer defect of one surface connector
6 Sectors 6.75E-20

W-DETON-SC+OTH-MD-SC
One detonator connected wrongly to a surface connector of another sector plus one other error except manufacturer defect of one surface connector
6 Sectors 1.00E-15

W-SC+OTH-MD-SC
Use of one wrong surface connector plus one other type of errors except manufacturer defect of one surface connector
6 Sectors 9.44E-14

W-MD-D+OTH-MD-SC
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except manufacturer defect of one surface connector
6 Sectors 1.57E-11

OL-EMULSION-W-MD-SC
Overcharge of emulsion more than required plus one other type of error except manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 1.56E-11



W-DETON+OTH-WD
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except wrong design in time delay
6 Sectors 7.07E-20

AND

4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

4W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 1.12E-05

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

OR

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

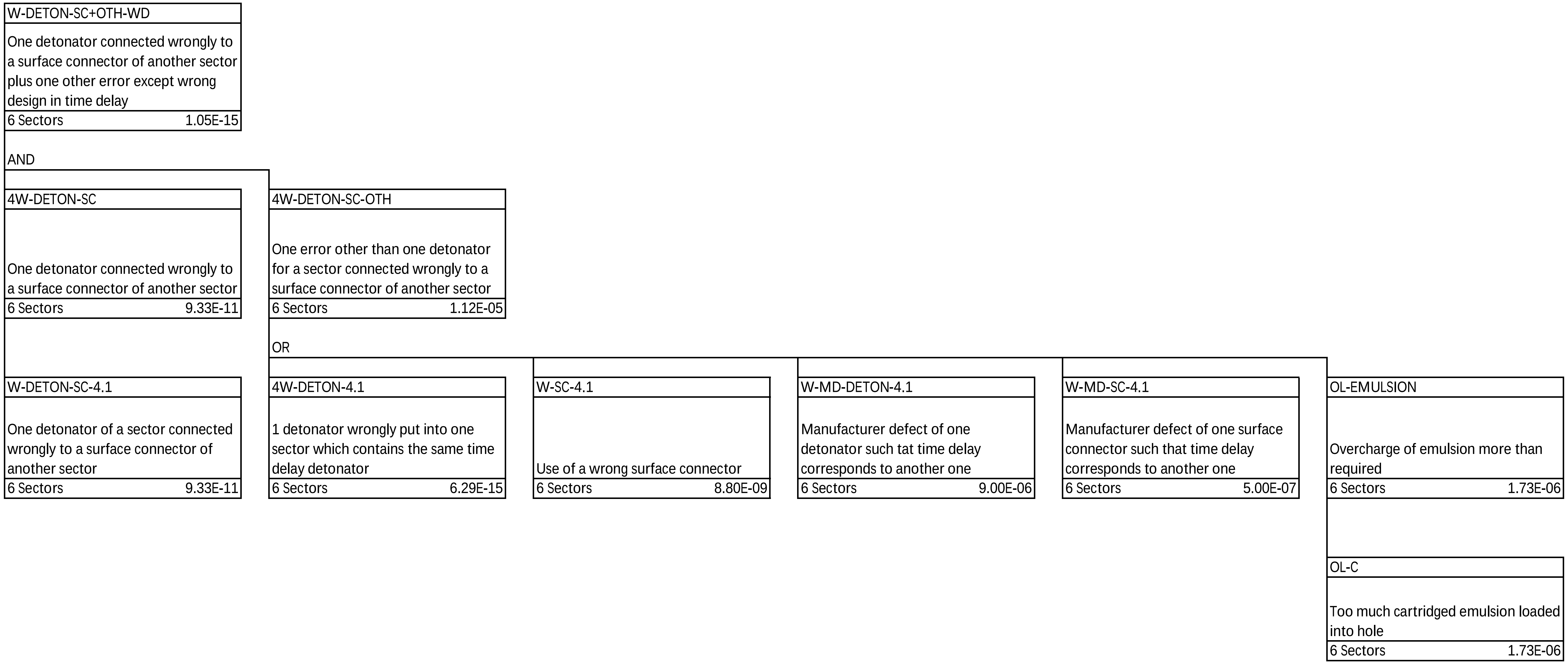
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-DETON-SC+OTH-WD
One detonator connected wrongly to a surface connector of another sector plus one other error except wrong design in time delay
6 Sectors 1.05E-15

AND

4W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

4W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors 1.12E-05

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

OR

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

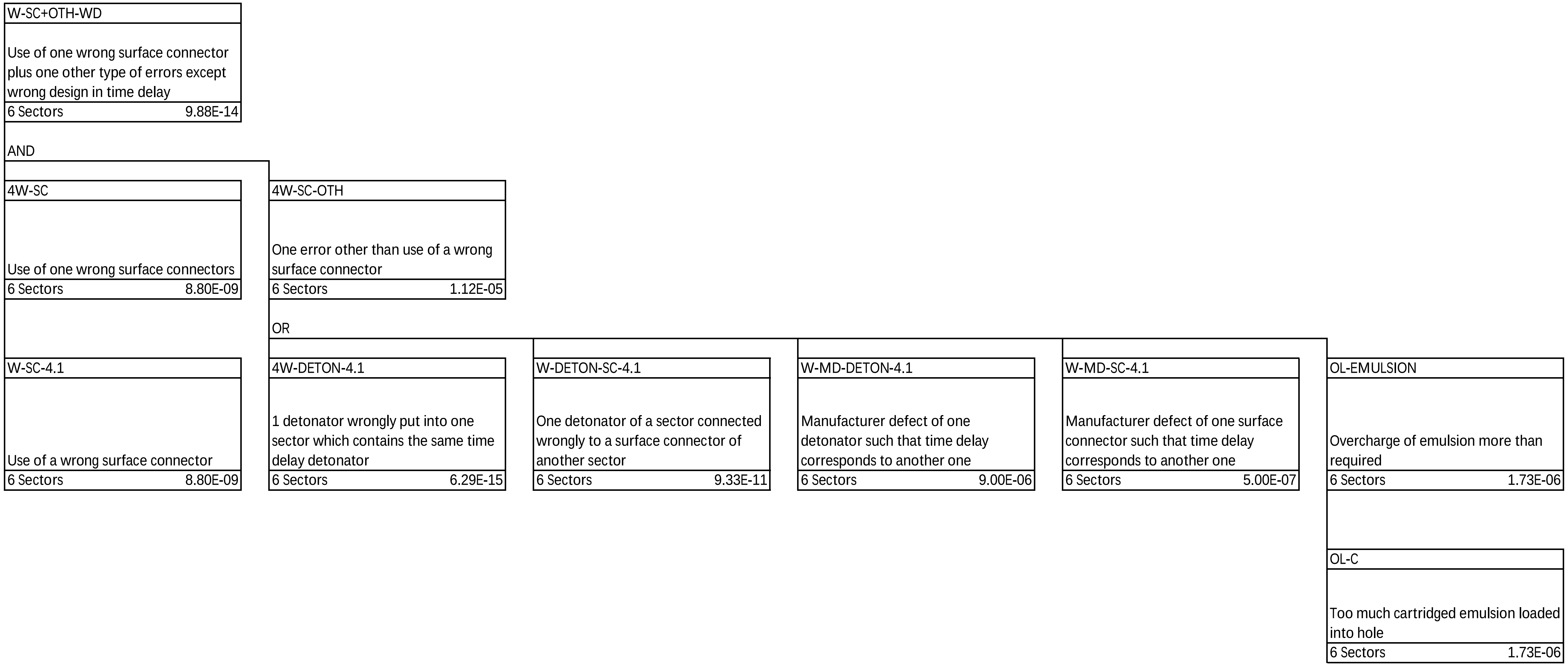
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

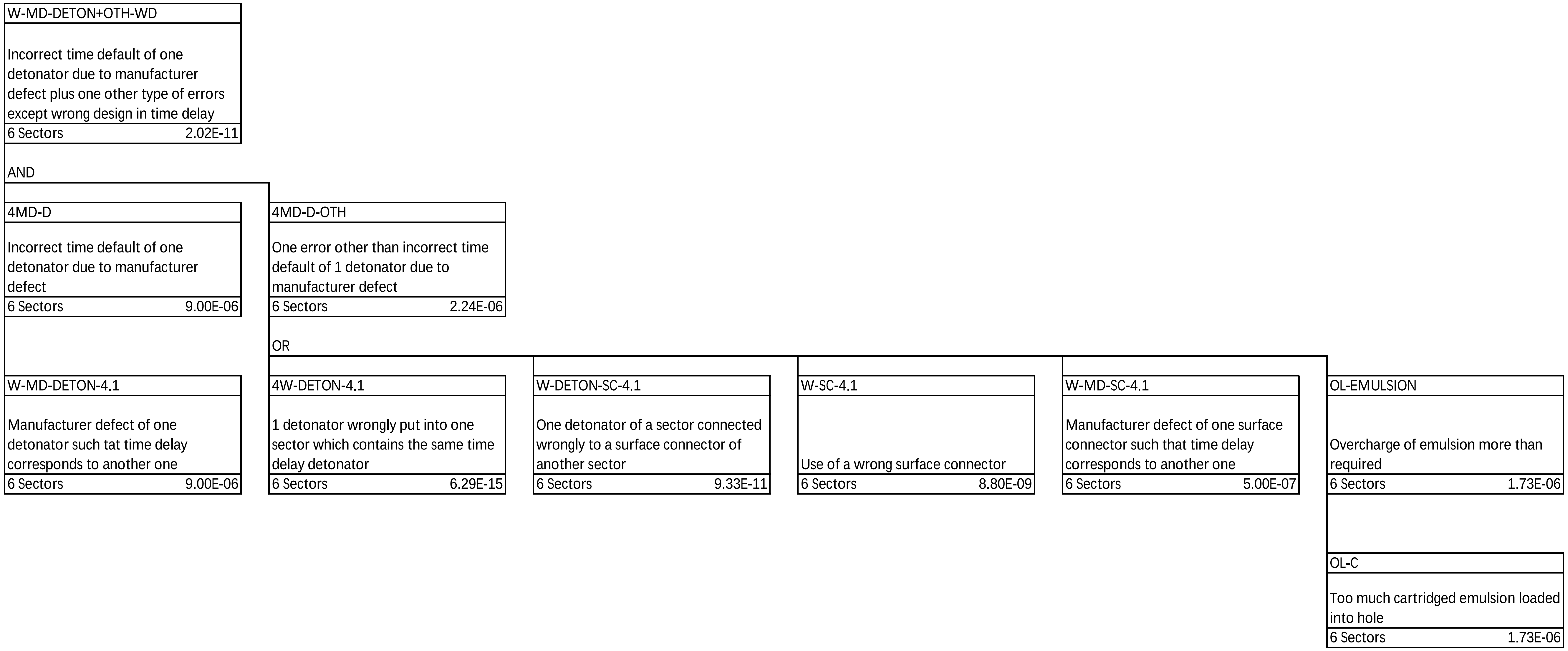
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

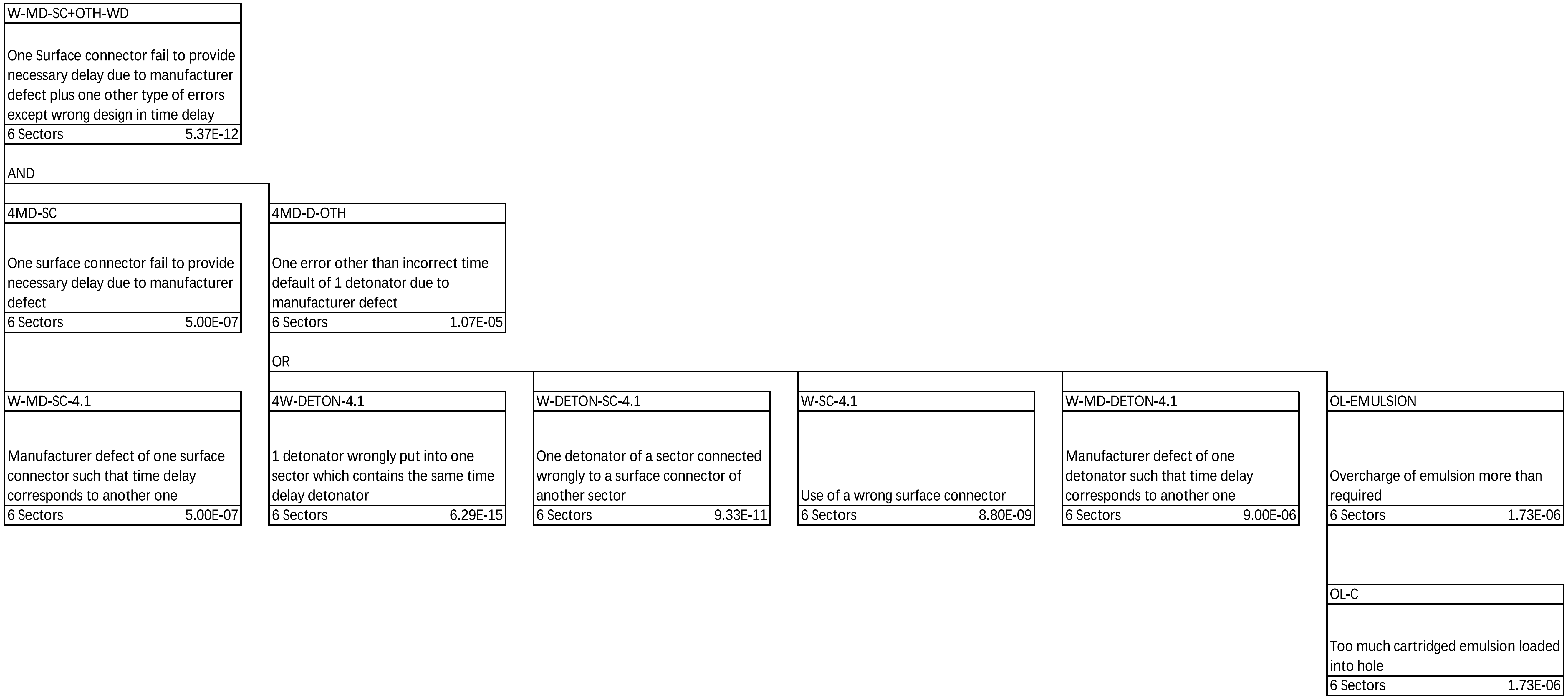
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

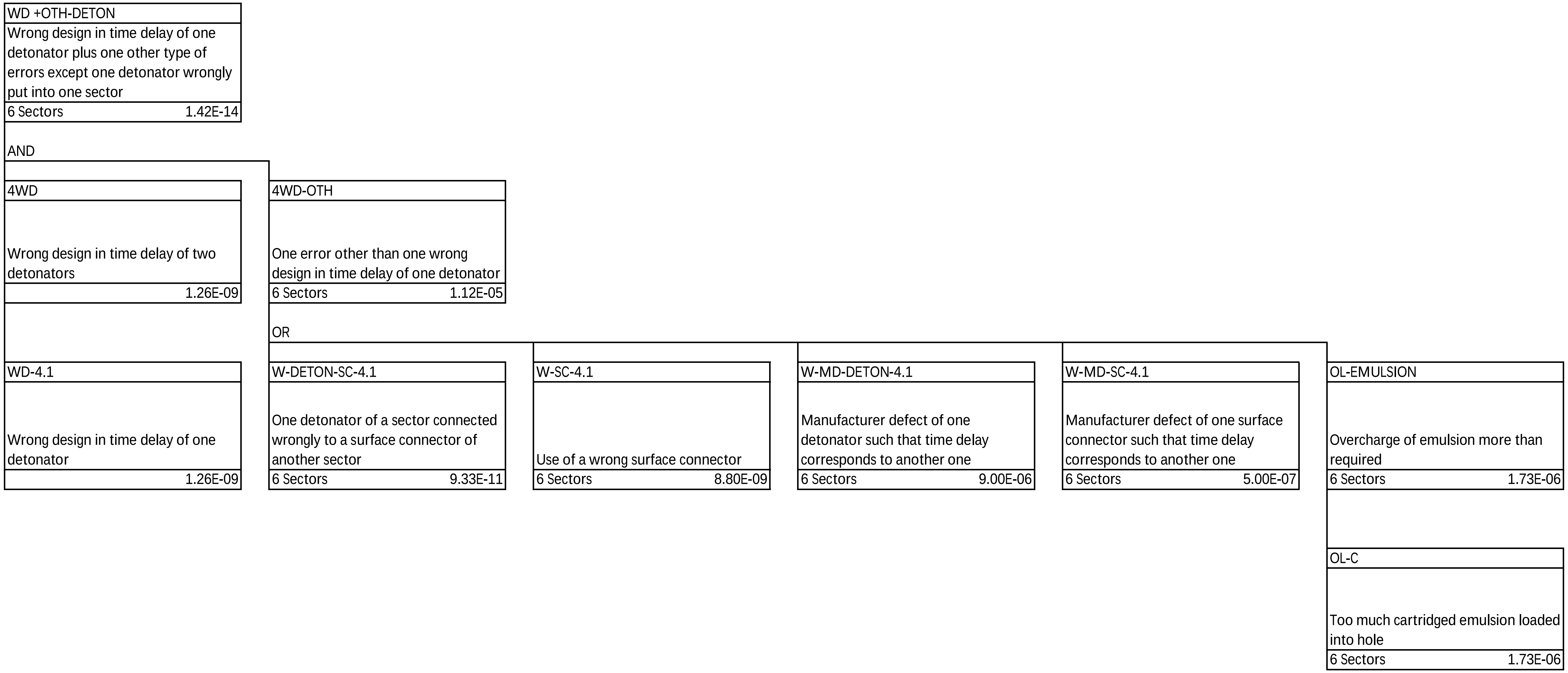
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-SC+OTH-WD
Use of one wrong surface connector plus one other type of errors except wrong design in time delay
6 Sectors
9.88E-14
AND
4W-SC
Use of one wrong surface connectors
6 Sectors
8.80E-09
4W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors
1.12E-05
OR
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


W-MD-DETON+OTH-WD
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except wrong design in time delay
6 Sectors 2.02E-11
AND
4MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors 9.00E-06
4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 2.24E-06
OR
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-MD-SC+OTH-WD
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except wrong design in time delay
6 Sectors 5.37E-12
AND
4MD-SC
One surface connector fail to provide necessary delay due to manufacturer defect
6 Sectors 5.00E-07
4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 1.07E-05
OR
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



WD +OTH-DETON
Wrong design in time delay of one detonator plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 1.42E-14

AND

4WD
Wrong design in time delay of two detonators
1.26E-09

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

4WD-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors 1.12E-05

OR

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

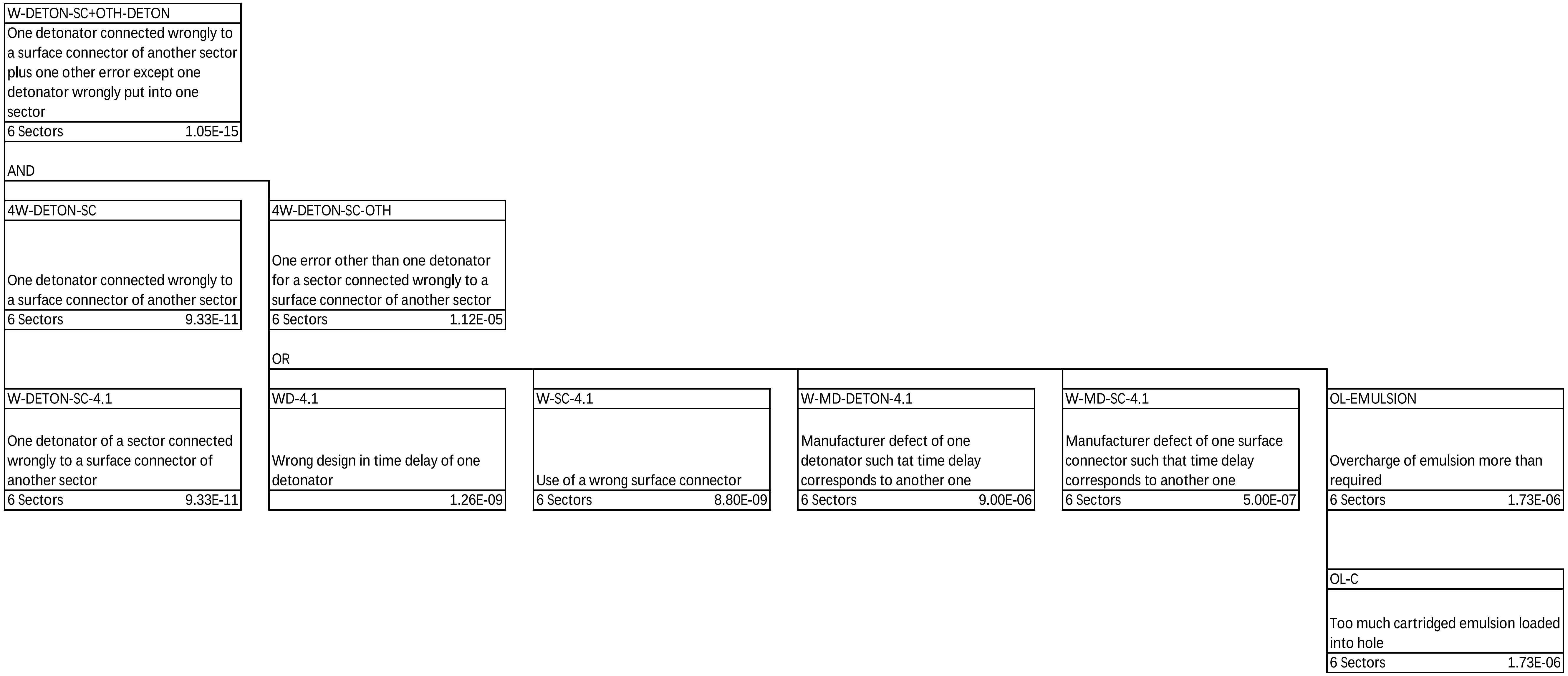
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

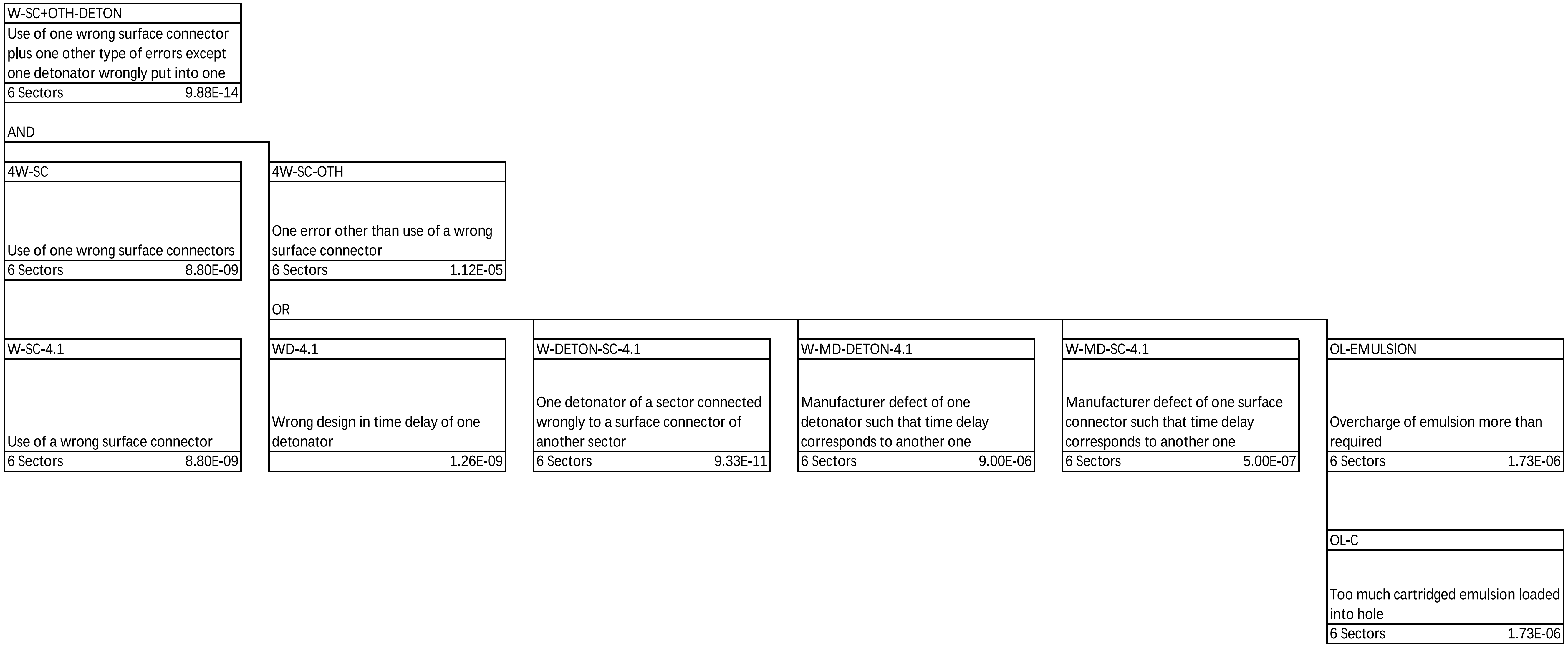
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

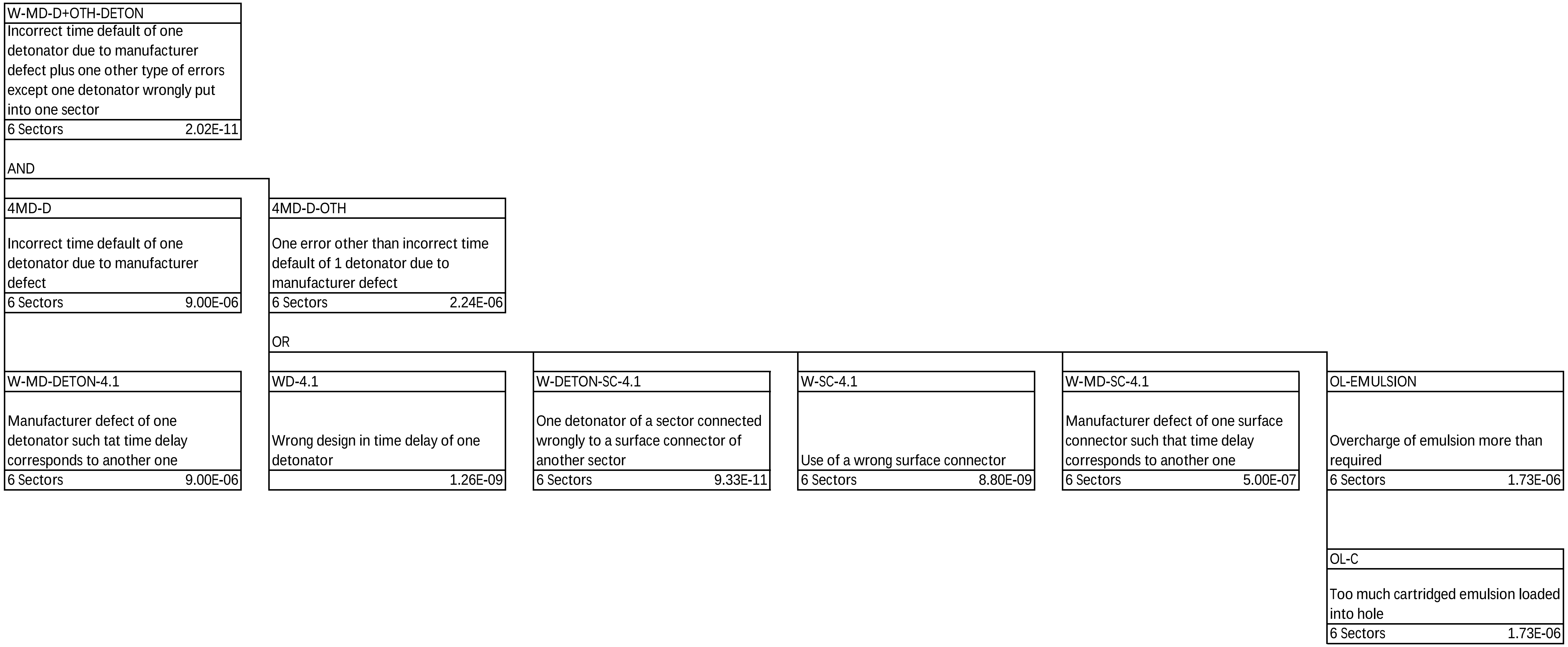
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-DETON-SC+OTH-DETON
One detonator connected wrongly to a surface connector of another sector plus one other error except one detonator wrongly put into one sector
6 Sectors
1.05E-15
AND
4W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
4W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors
1.12E-05
OR
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


W-SC+OTH-DETON
Use of one wrong surface connector plus one other type of errors except one detonator wrongly put into one
6 Sectors 9.88E-14
AND
4W-SC
Use of one wrong surface connectors
6 Sectors 8.80E-09
4W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors 1.12E-05
OR
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-MD-D+OTH-DETON
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 2.02E-11

AND

4MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors 9.00E-06

4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 2.24E-06

OR

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

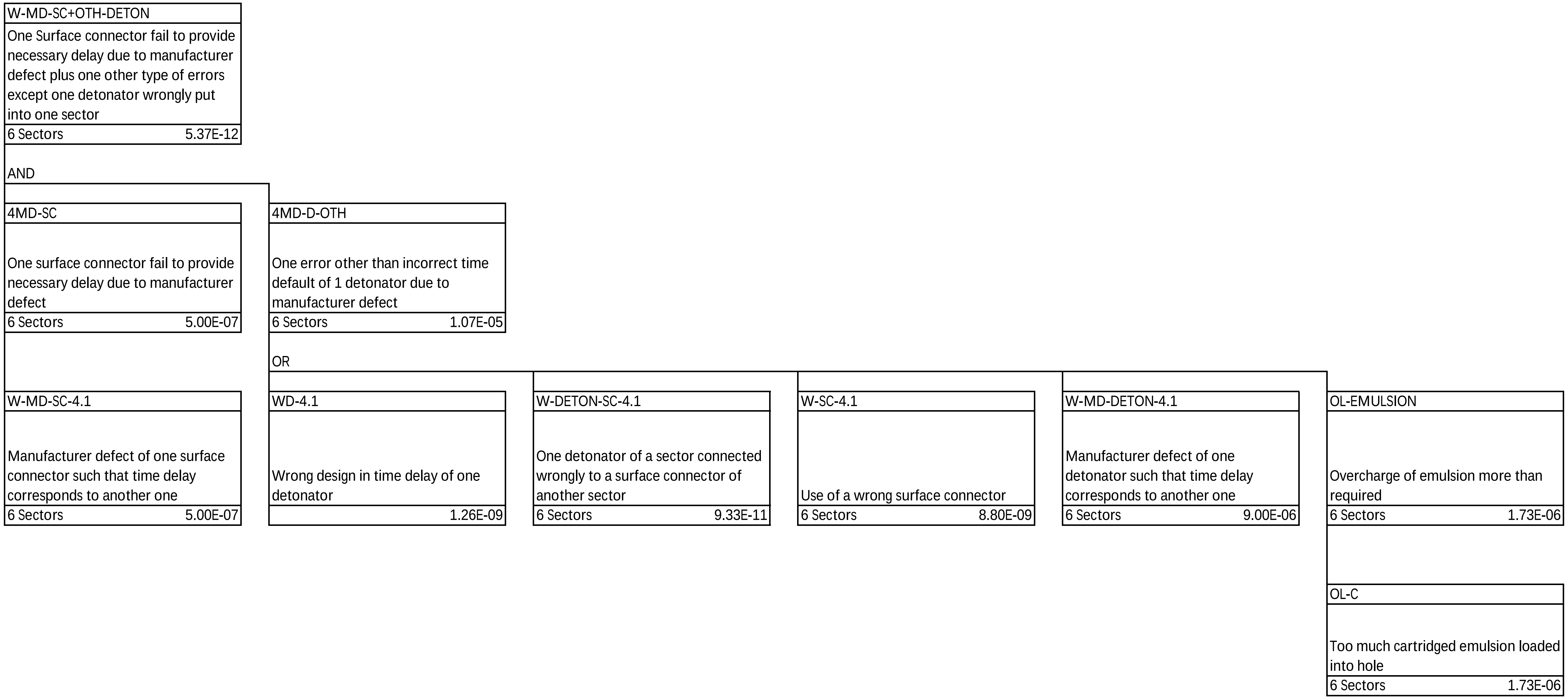
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-MD-SC+OTH-DETON
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except one detonator wrongly put into one sector
6 Sectors 5.37E-12

AND

4MD-SC
One surface connector fail to provide necessary delay due to manufacturer defect
6 Sectors 5.00E-07

4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 1.07E-05

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OR

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

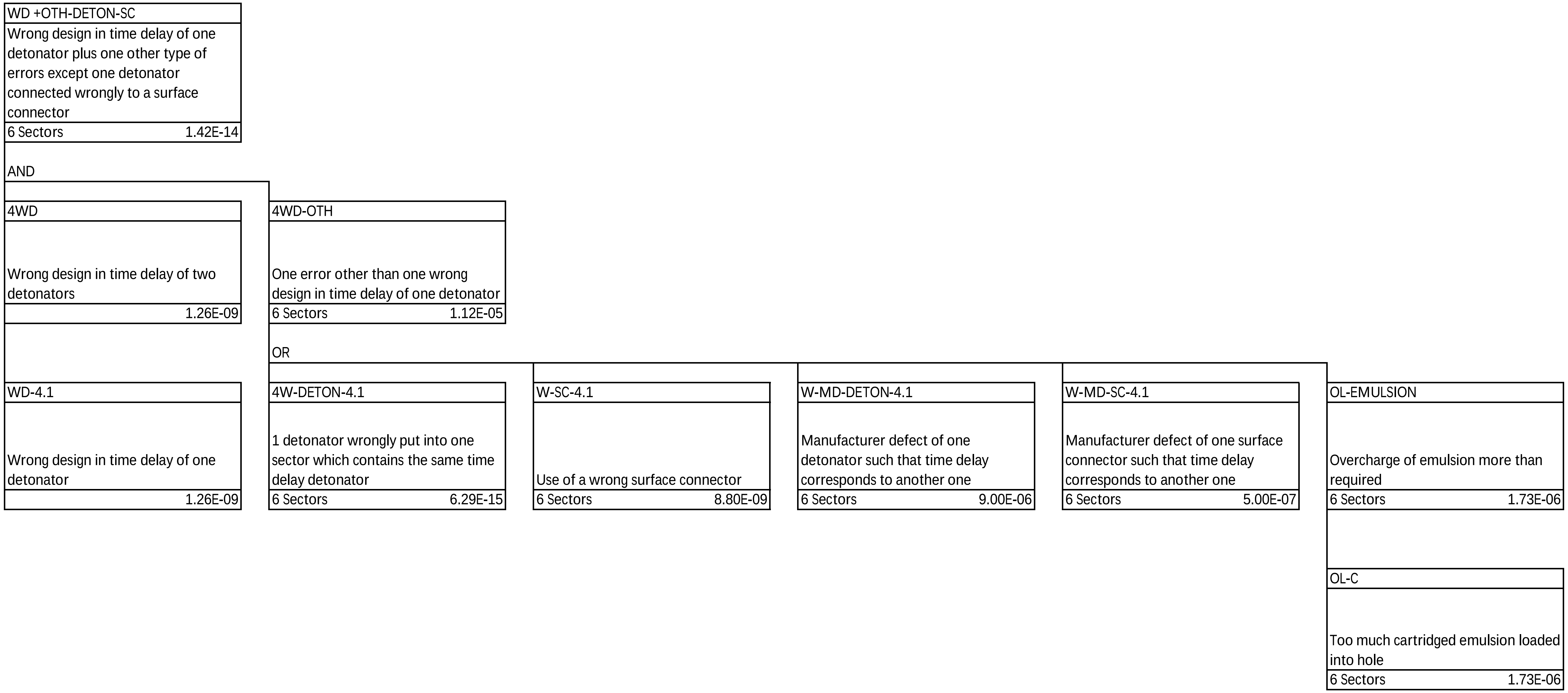
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



WD +OTH-DETON-SC

Wrong design in time delay of one detonator plus one other type of errors except one detonator connected wrongly to a surface connector

6 Sectors 1.42E-14

AND

4WD

Wrong design in time delay of two detonators

1.26E-09

4WD-OTH

One error other than one wrong design in time delay of one detonator

6 Sectors 1.12E-05

WD-4.1

Wrong design in time delay of one detonator

1.26E-09

OR

4W-DETON-4.1

1 detonator wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-15

W-SC-4.1

Use of a wrong surface connector

6 Sectors 8.80E-09

W-MD-DETON-4.1

Manufacturer defect of one detonator such that time delay corresponds to another one

6 Sectors 9.00E-06

W-MD-SC-4.1

Manufacturer defect of one surface connector such that time delay corresponds to another one

6 Sectors 5.00E-07

OL-EMULSION

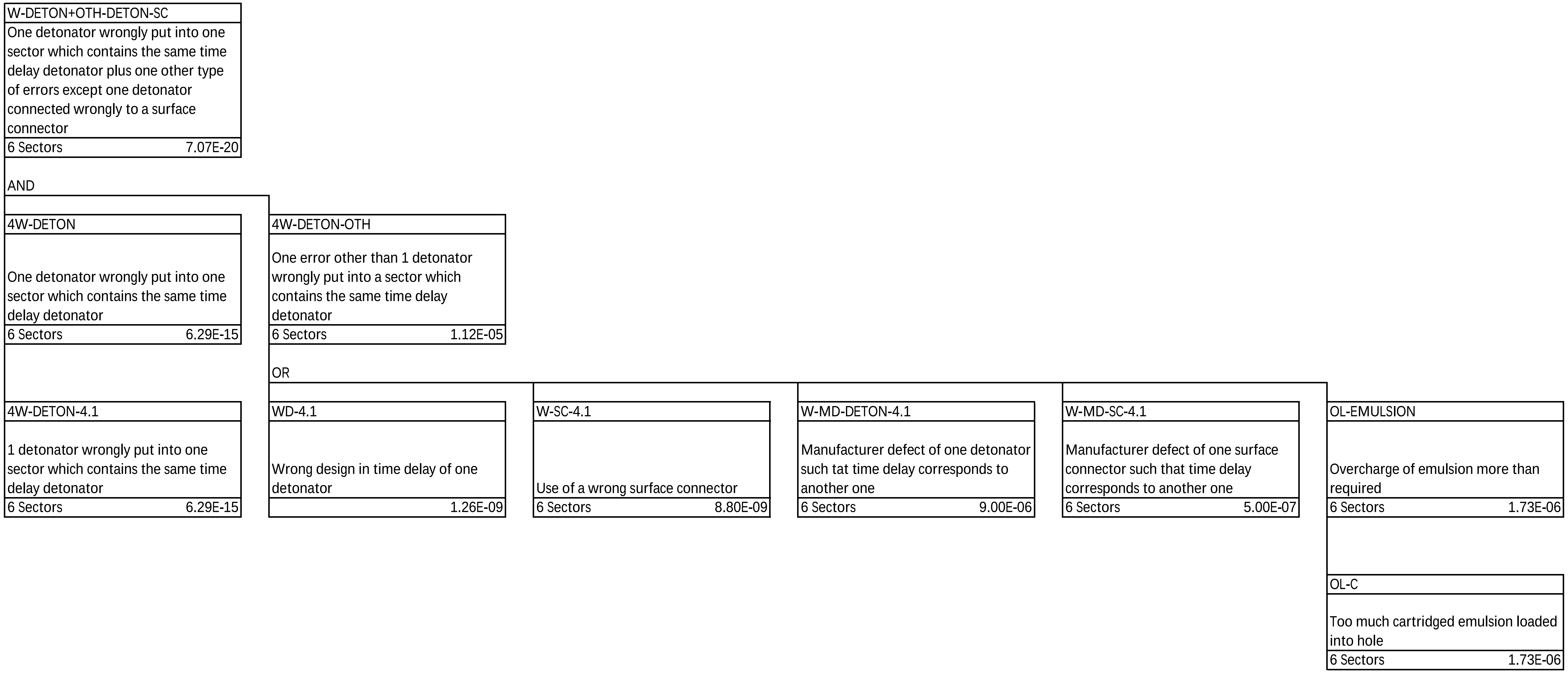
Overcharge of emulsion more than required

6 Sectors 1.73E-06

OL-C

Too much cartridged emulsion loaded into hole

6 Sectors 1.73E-06



W-DETON+OTH-DETON-SC
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 7.07E-20

AND

4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

4W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 1.12E-05

OR

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

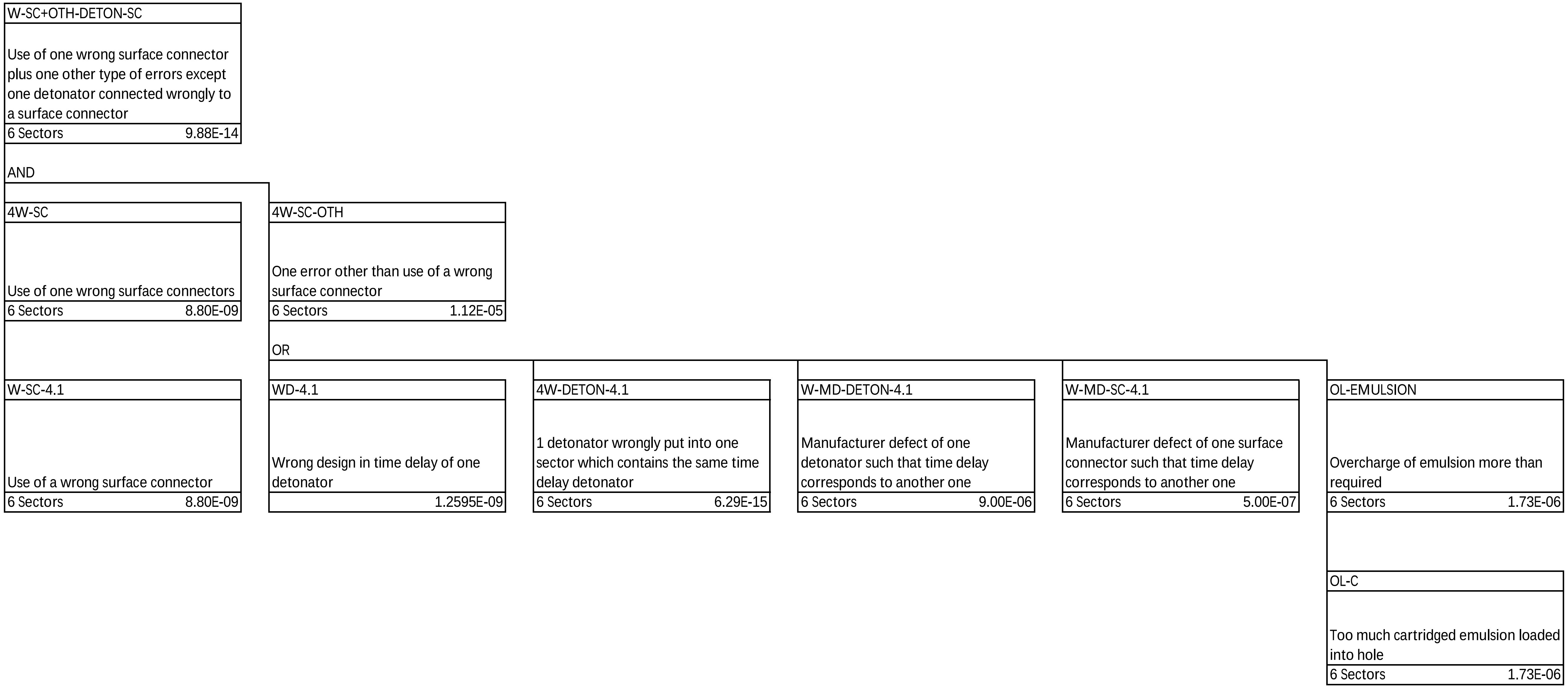
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

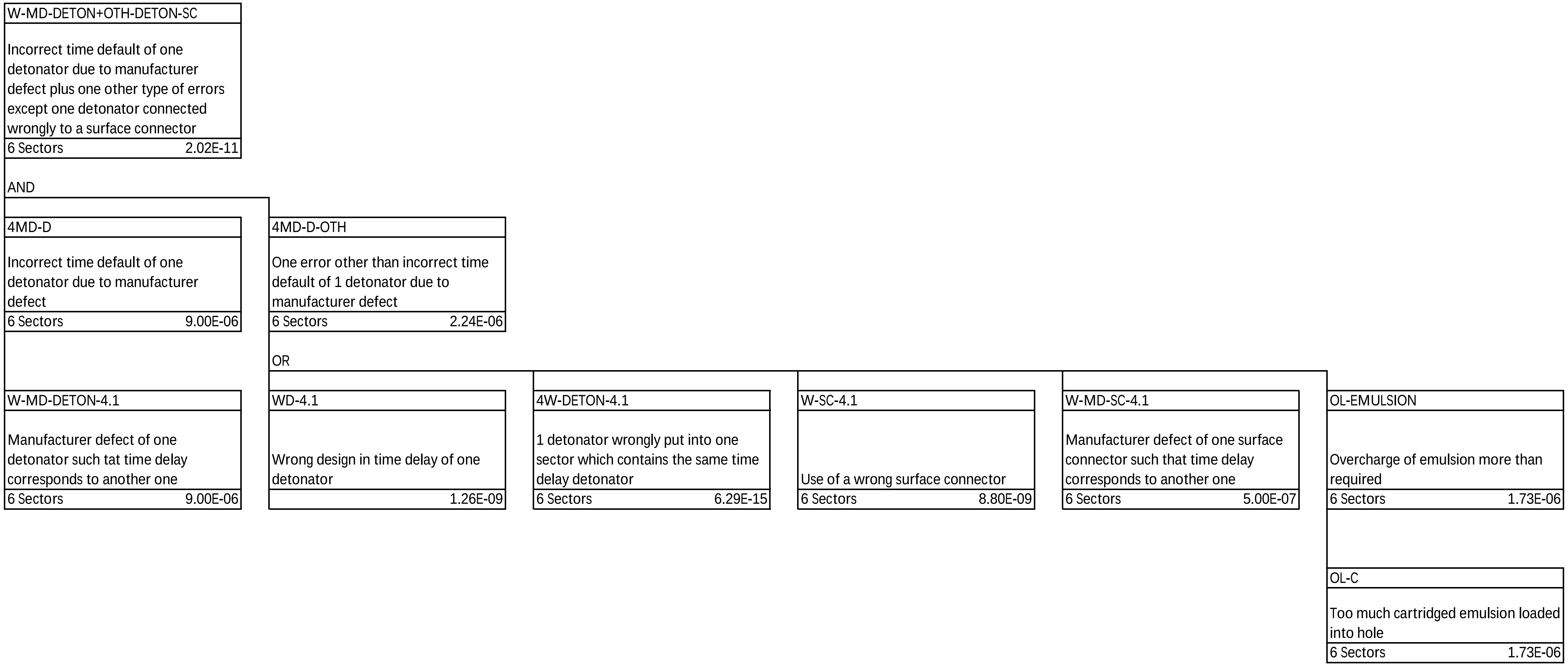
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-SC+OTH-DETON-SC
Use of one wrong surface connector plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 9.88E-14
AND
4W-SC
Use of one wrong surface connectors
6 Sectors 8.80E-09
4W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors 1.12E-05
OR
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09
WD-4.1
Wrong design in time delay of one detonator
1.2595E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-MD-DETON+OTH-DETON-SC
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except one detonator connected wrongly to a surface connector
6 Sectors 2.02E-11

4MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors 9.00E-06

4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 2.24E-06

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

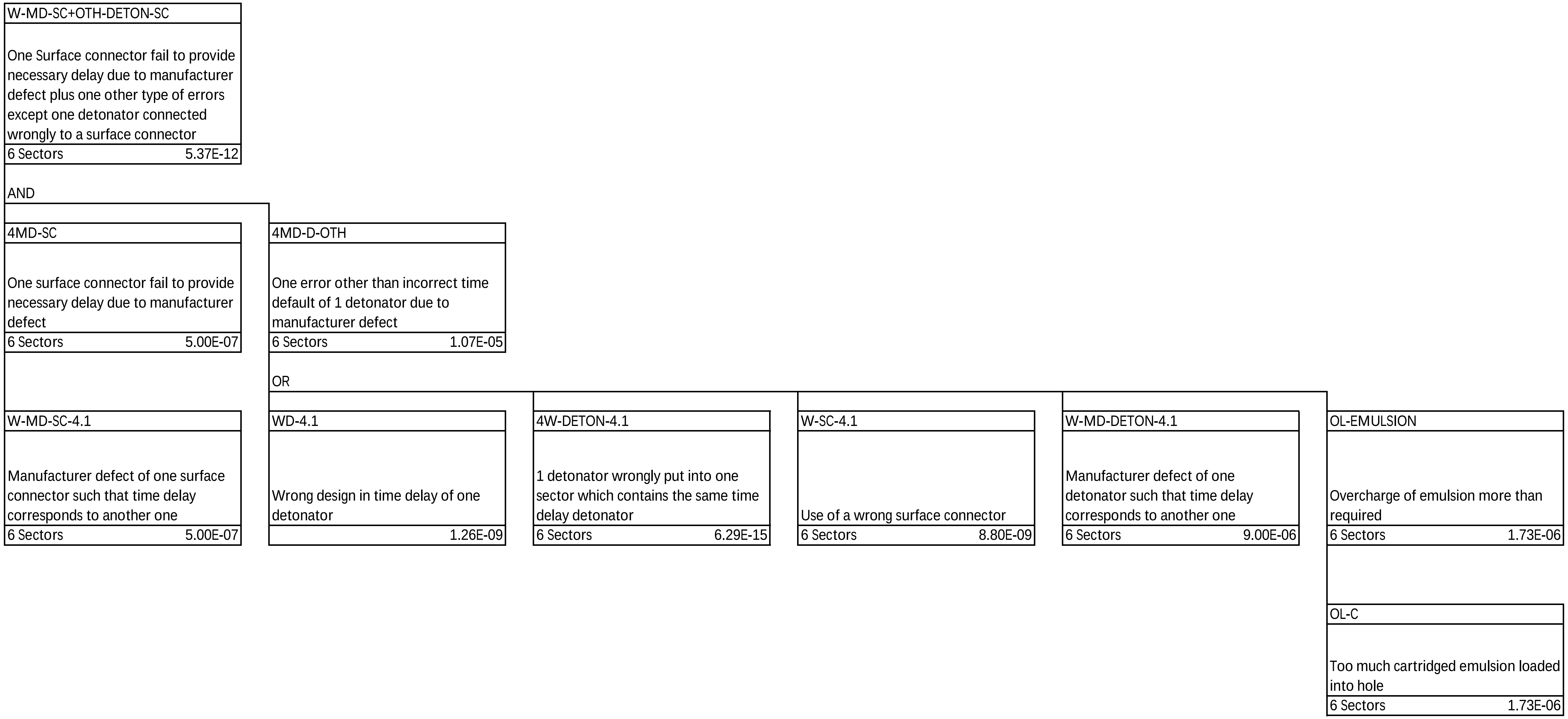
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-MD-SC+OTH-DETON-SC

One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except one detonator connected wrongly to a surface connector

6 Sectors 5.37E-12

AND

4MD-SC

One surface connector fail to provide necessary delay due to manufacturer defect

6 Sectors 5.00E-07

4MD-D-OTH

One error other than incorrect time default of 1 detonator due to manufacturer defect

6 Sectors 1.07E-05

OR

W-MD-SC-4.1

Manufacturer defect of one surface connector such that time delay corresponds to another one

6 Sectors 5.00E-07

WD-4.1

Wrong design in time delay of one detonator

1.26E-09

4W-DETON-4.1

1 detonator wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-15

W-SC-4.1

Use of a wrong surface connector

6 Sectors 8.80E-09

W-MD-DETON-4.1

Manufacturer defect of one detonator such that time delay corresponds to another one

6 Sectors 9.00E-06

OL-EMULSION

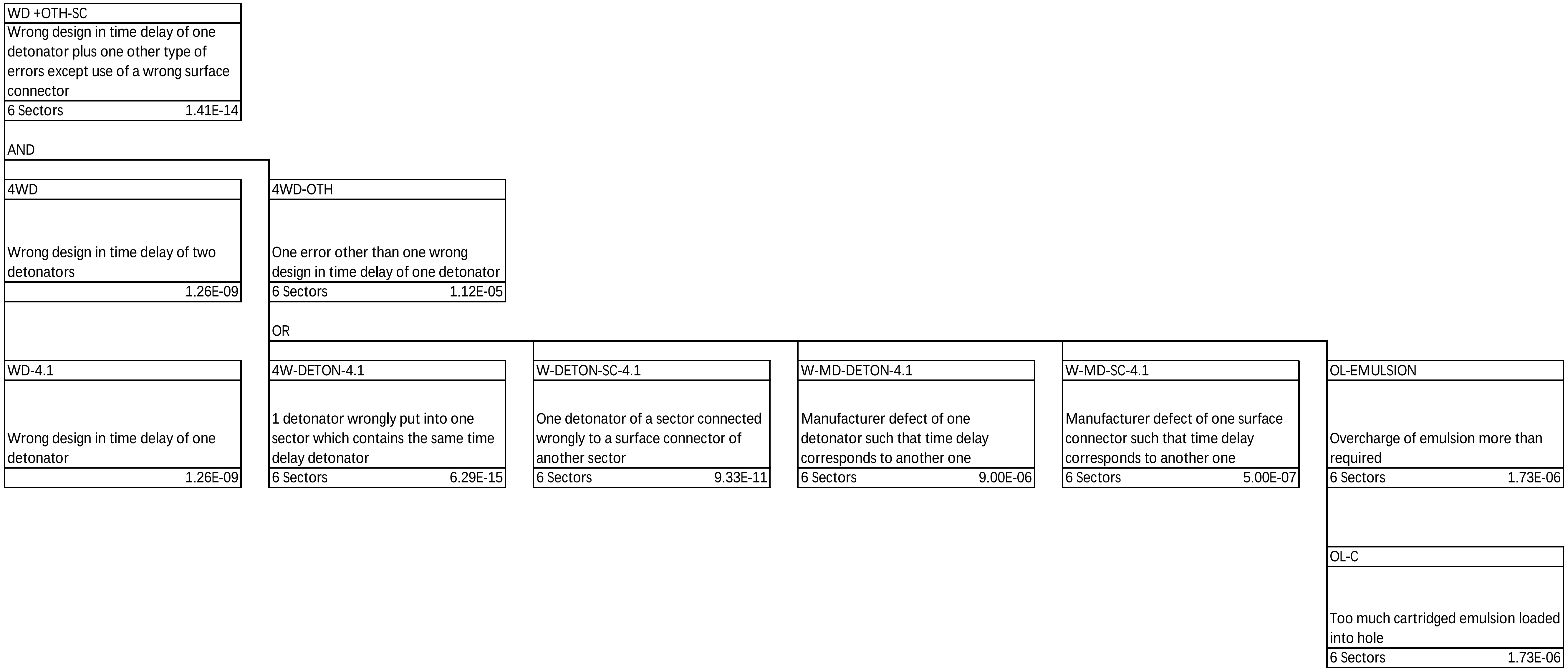
Overcharge of emulsion more than required

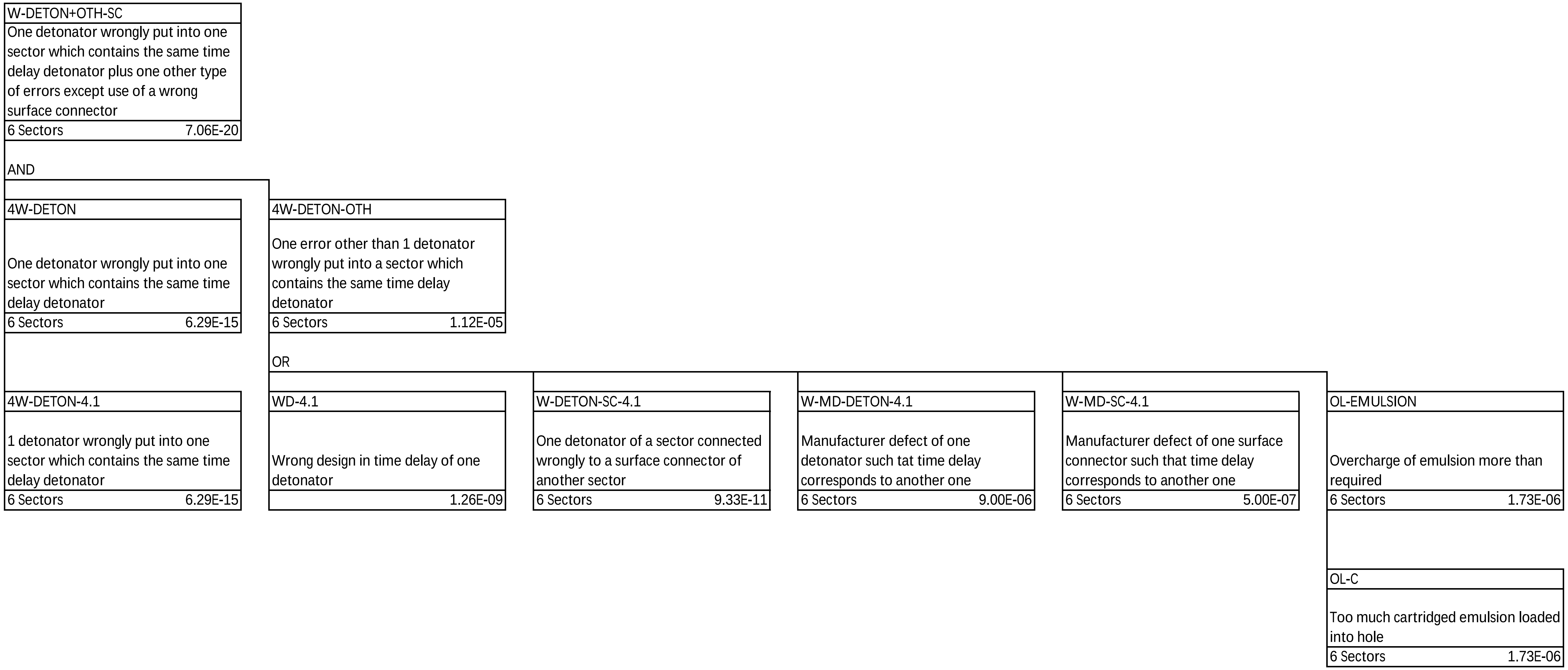
6 Sectors 1.73E-06

OL-C

Too much cartridged emulsion loaded into hole

6 Sectors 1.73E-06


WD +OTH-SC
Wrong design in time delay of one detonator plus one other type of errors except use of a wrong surface connector
6 Sectors
1.41E-14
AND
4WD
Wrong design in time delay of two detonators
1.26E-09
4WD-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors
1.12E-05
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06



W-DETON+OTH-SC
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except use of a wrong surface connector
6 Sectors 7.06E-20

AND

4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

4W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 1.12E-05

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

OR

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

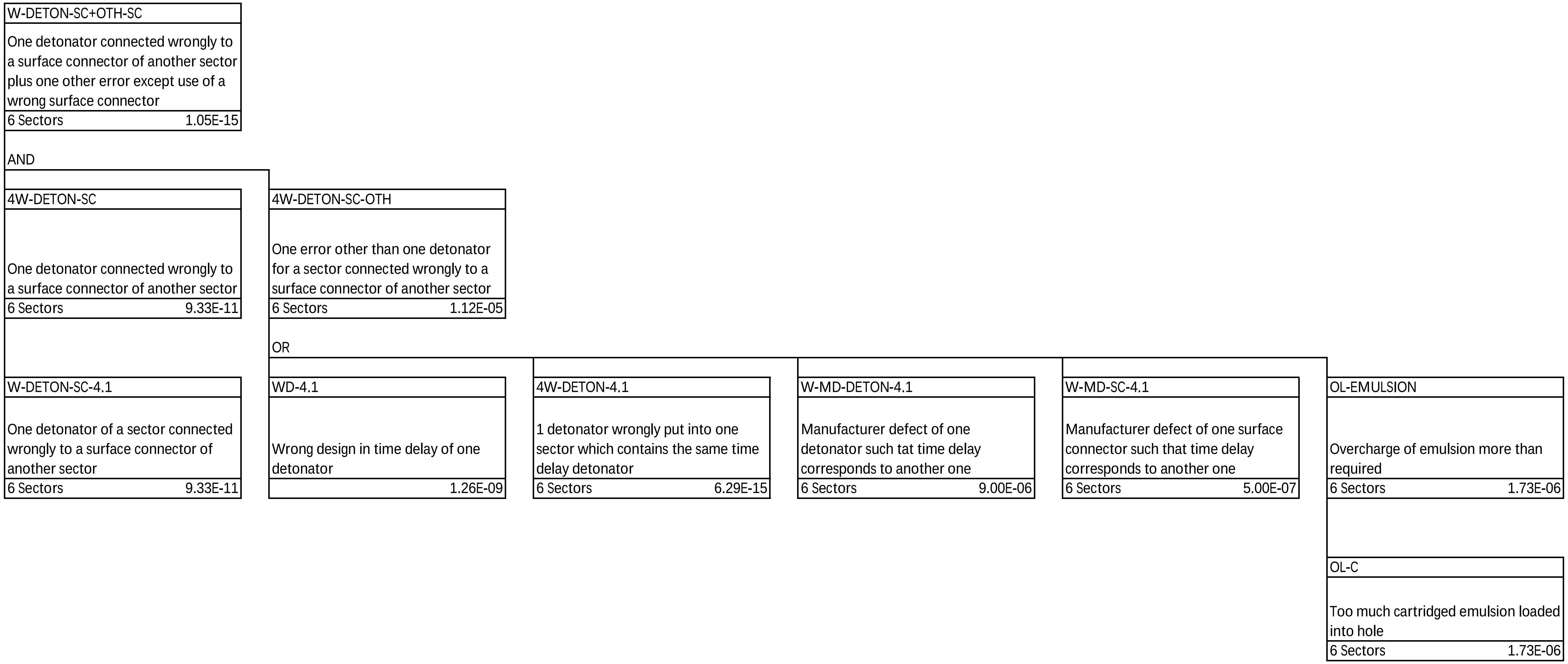
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-DETON-SC+OTH-SC
One detonator connected wrongly to a surface connector of another sector plus one other error except use of a wrong surface connector
6 Sectors 1.05E-15

4W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

4W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors 1.12E-05

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

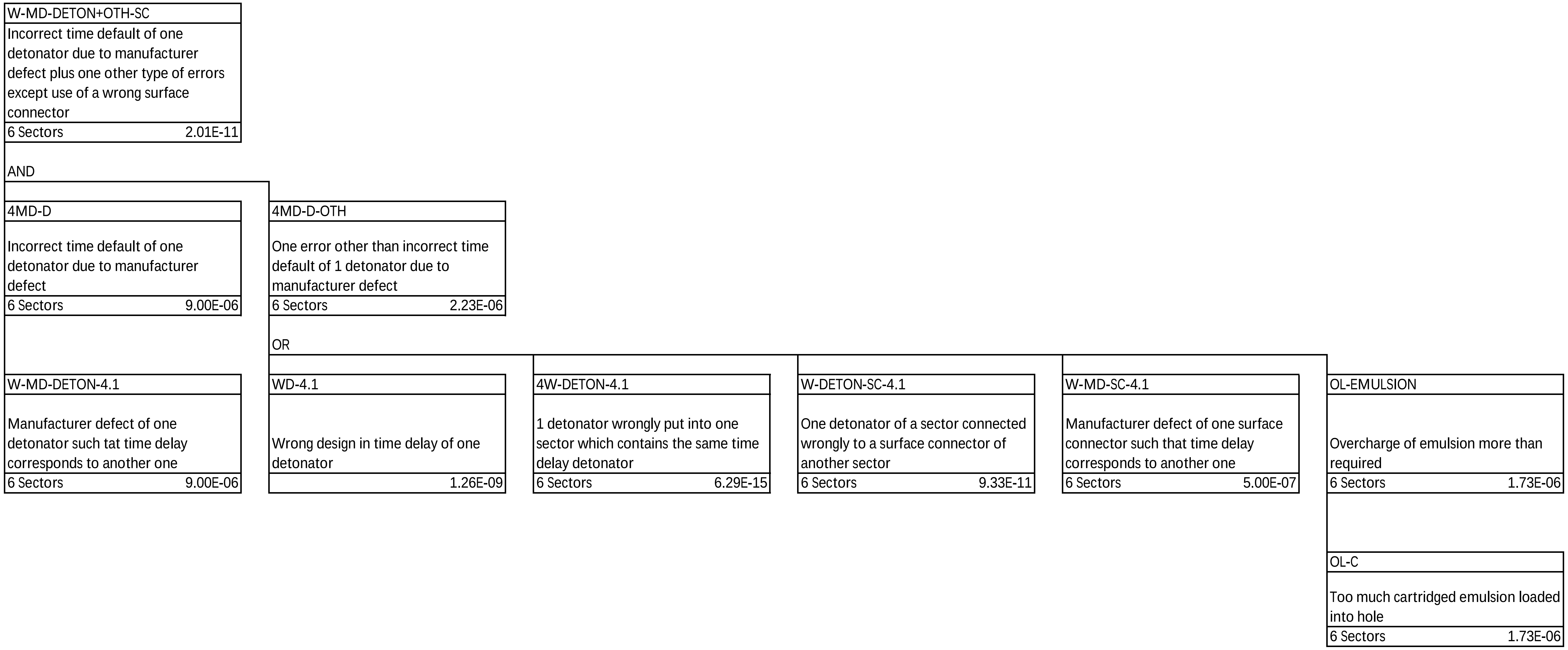
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

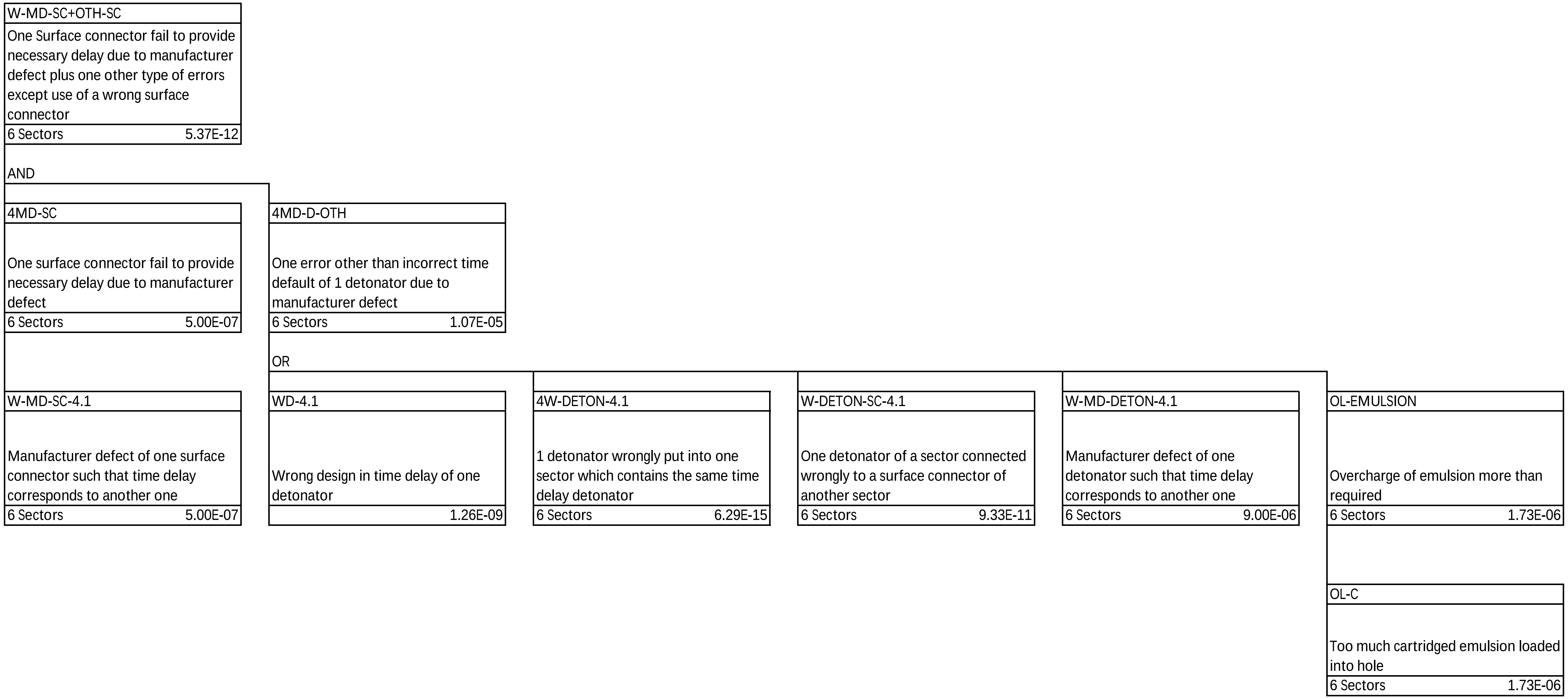
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-MD-DETON+OTH-SC
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except use of a wrong surface connector
6 Sectors 2.01E-11
AND
4MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors 9.00E-06
4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 2.23E-06
OR
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06



W-MD-SC+OTH-SC
One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except use of a wrong surface connector
6 Sectors 5.37E-12

AND

4MD-SC
One surface connector fail to provide necessary delay due to manufacturer defect
6 Sectors 5.00E-07

4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors 1.07E-05

OR

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

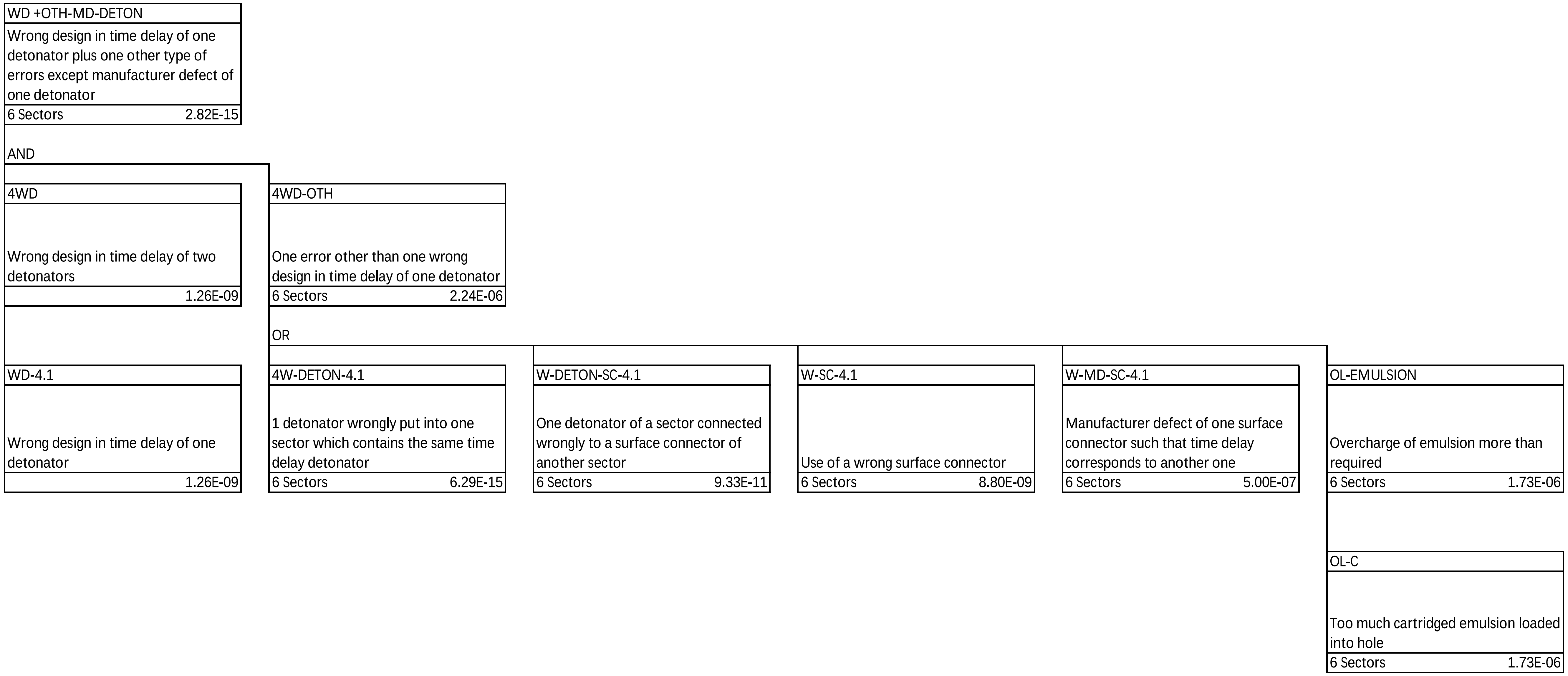
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

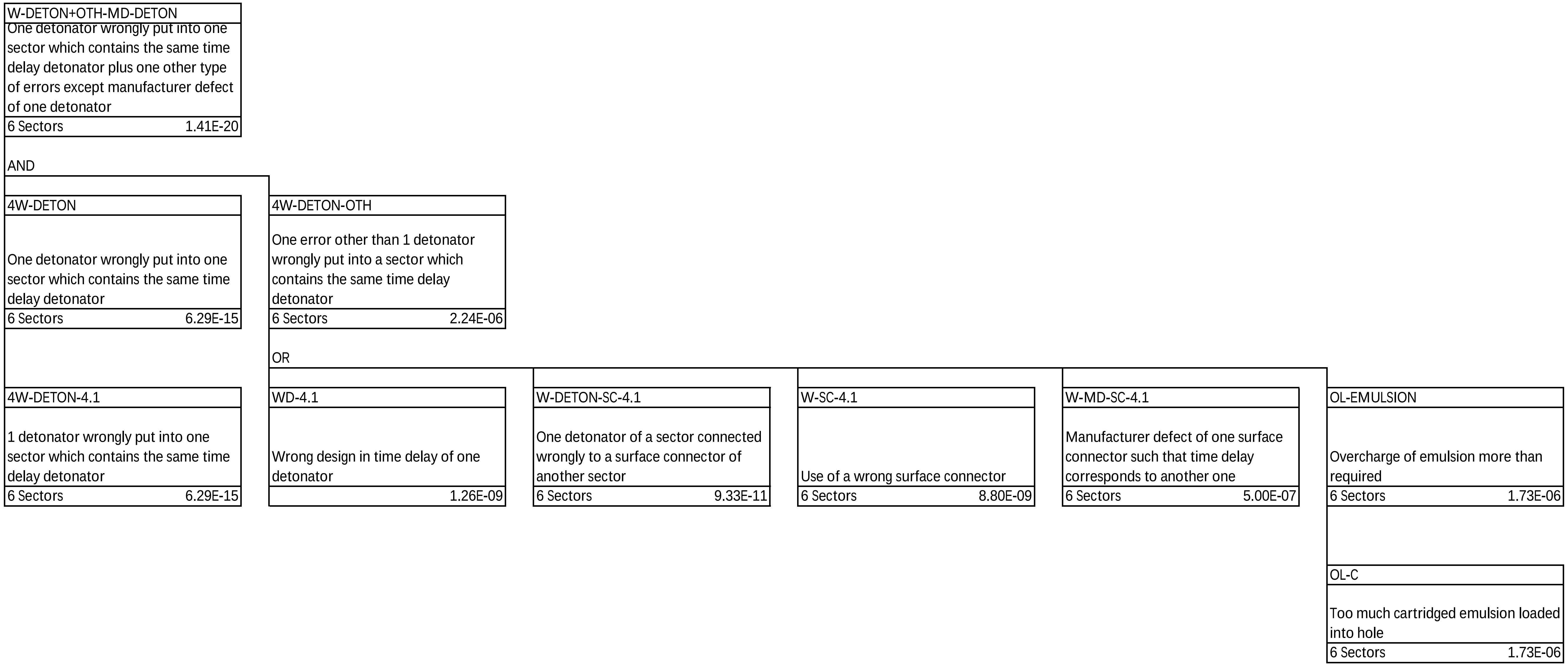
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

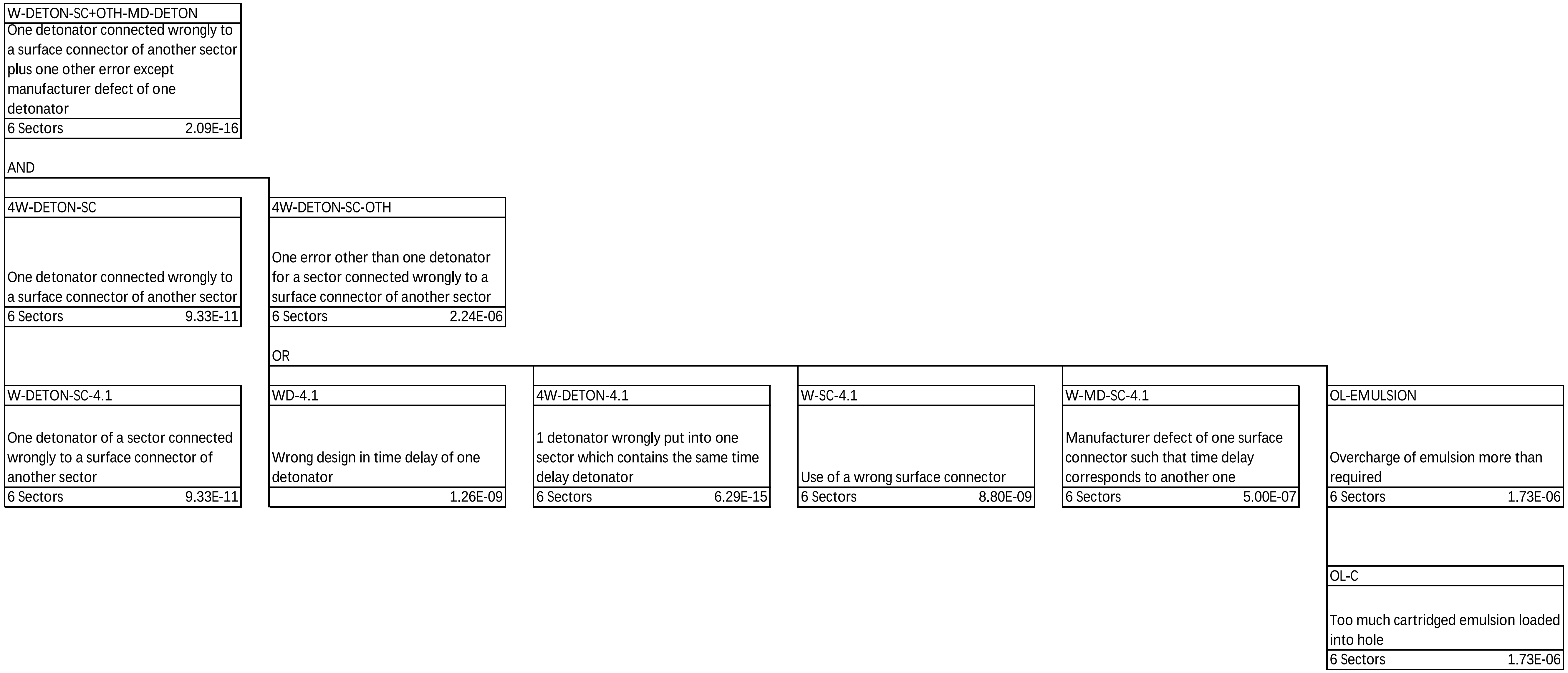
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

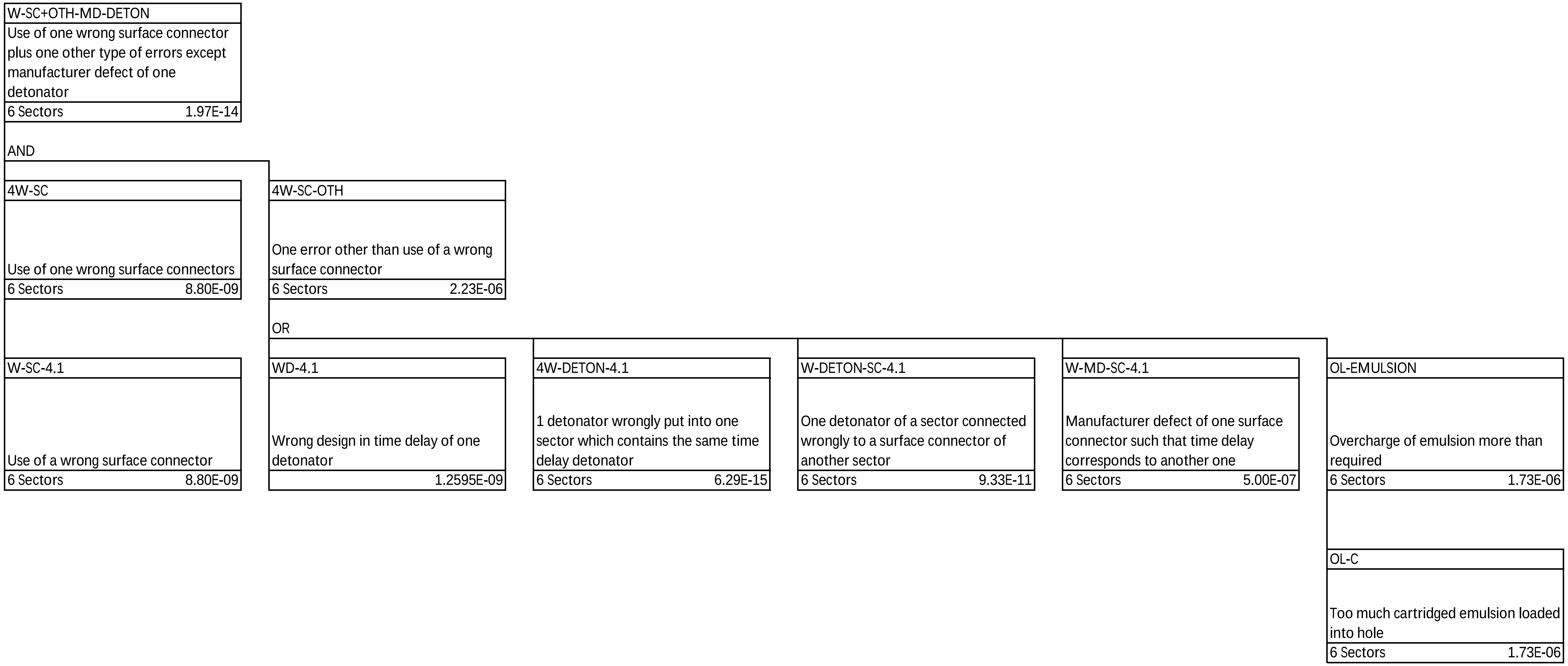
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

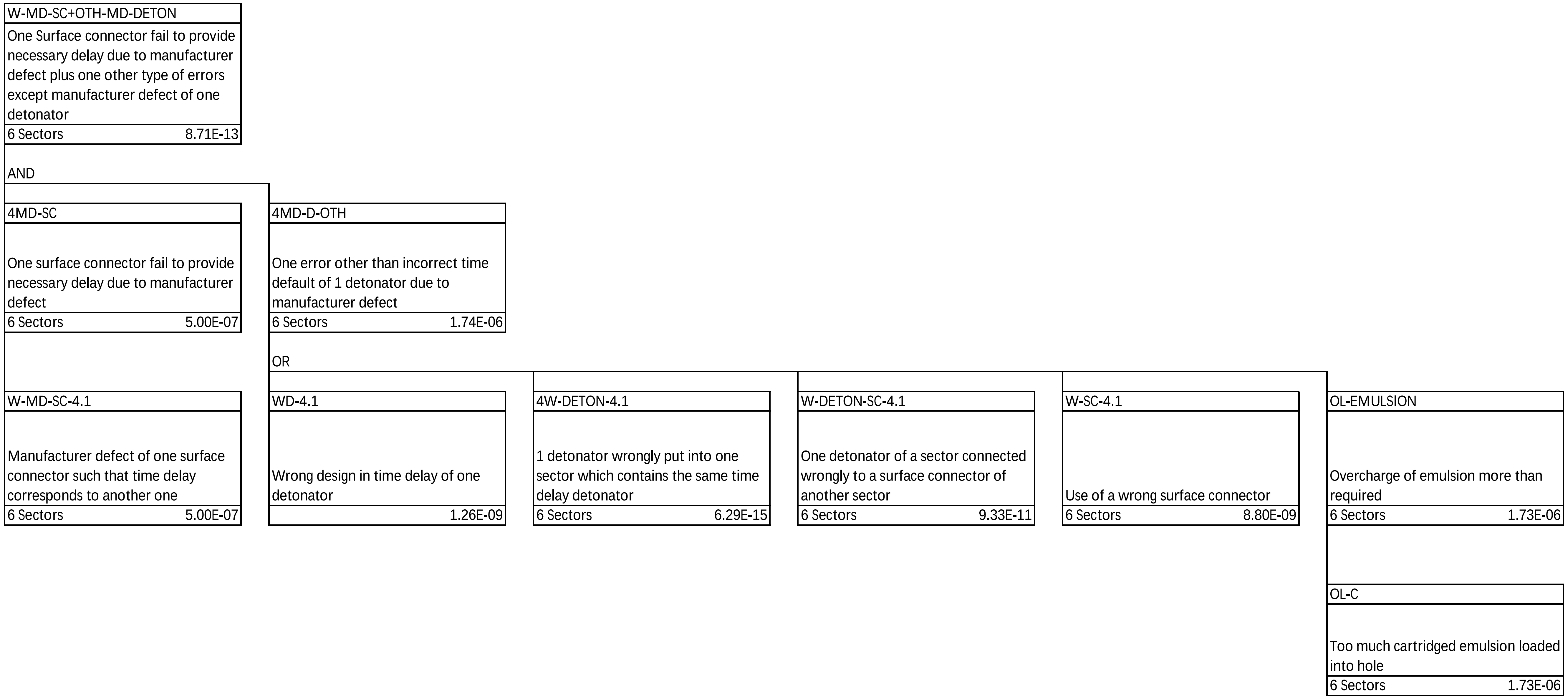
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


WD +OTH-MD-DETON
Wrong design in time delay of one detonator plus one other type of errors except manufacturer defect of one detonator
6 Sectors
2.82E-15
AND
4WD
Wrong design in time delay of two detonators
1.26E-09
4WD-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors
2.24E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
OR
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


W-DETON+OTH-MD-DETON
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except manufacturer defect of one detonator
6 Sectors 1.41E-20
AND
4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
4W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 2.24E-06
OR
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-DETON-SC+OTH-MD-DETON
One detonator connected wrongly to a surface connector of another sector plus one other error except manufacturer defect of one detonator
6 Sectors
2.09E-16
AND
4W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
4W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors
2.24E-06
OR
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


W-SC+OTH-MD-DETON
Use of one wrong surface connector plus one other type of errors except manufacturer defect of one detonator
6 Sectors
1.97E-14
AND
4W-SC
Use of one wrong surface connectors
6 Sectors
8.80E-09
4W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors
2.23E-06
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
OR
WD-4.1
Wrong design in time delay of one detonator
1.2595E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06



W-MD-SC+OTH-MD-DETON

One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except manufacturer defect of one detonator

6 Sectors 8.71E-13

AND

4MD-SC

One surface connector fail to provide necessary delay due to manufacturer defect

6 Sectors 5.00E-07

4MD-D-OTH

One error other than incorrect time default of 1 detonator due to manufacturer defect

6 Sectors 1.74E-06

OR

W-MD-SC-4.1

Manufacturer defect of one surface connector such that time delay corresponds to another one

6 Sectors 5.00E-07

WD-4.1

Wrong design in time delay of one detonator

1.26E-09

4W-DETON-4.1

1 detonator wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-15

W-DETON-SC-4.1

One detonator of a sector connected wrongly to a surface connector of another sector

6 Sectors 9.33E-11

W-SC-4.1

Use of a wrong surface connector

6 Sectors 8.80E-09

OL-EMULSION

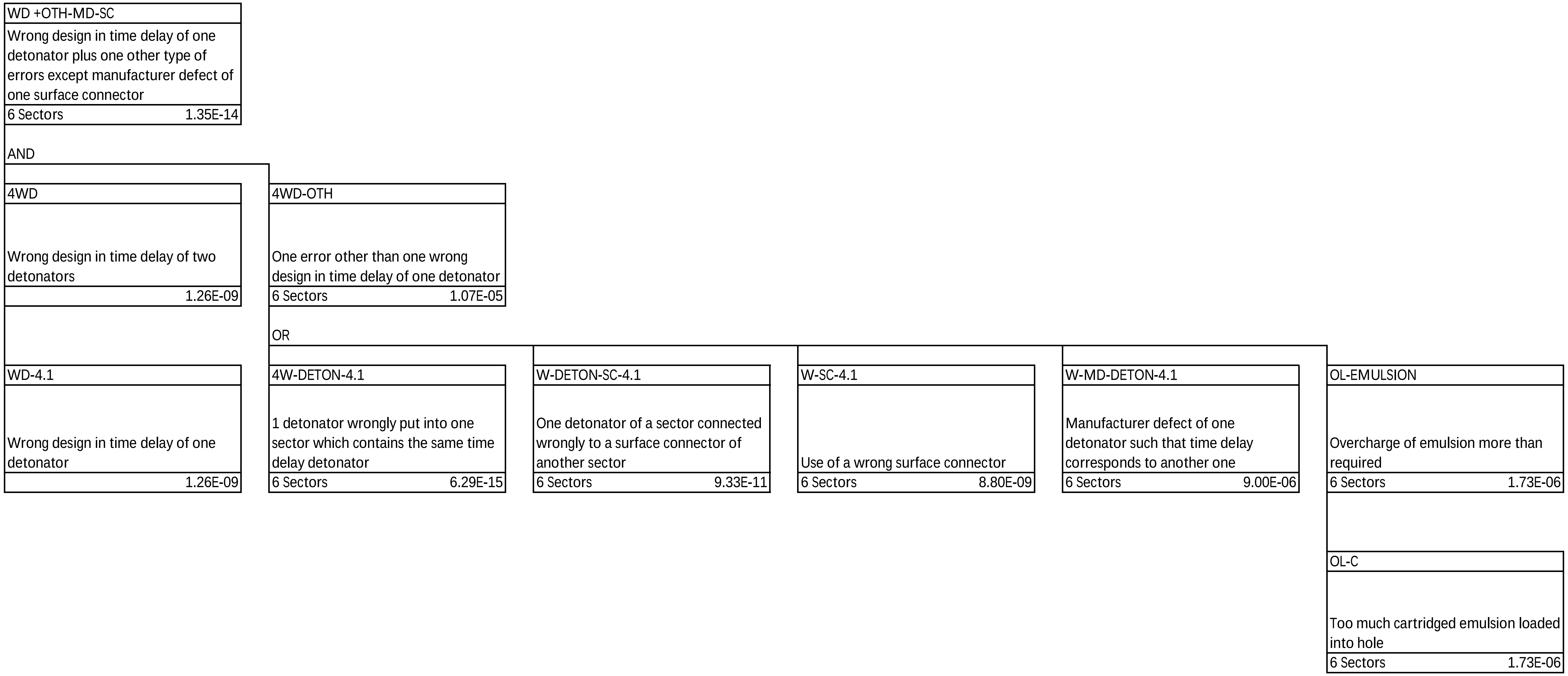
Overcharge of emulsion more than required

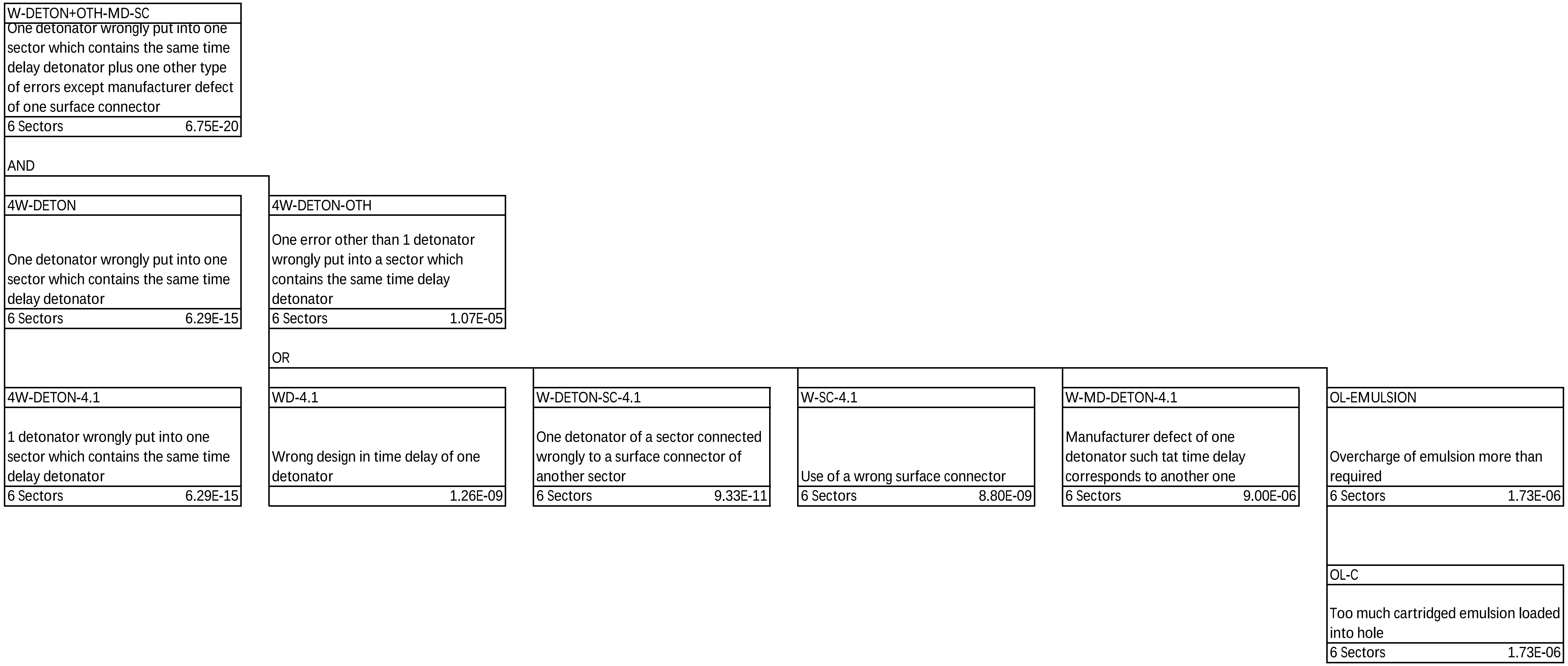
6 Sectors 1.73E-06

OL-C

Too much cartridged emulsion loaded into hole

6 Sectors 1.73E-06


WD +OTH-MD-SC
Wrong design in time delay of one detonator plus one other type of errors except manufacturer defect of one surface connector
6 Sectors
1.35E-14
AND
4WD
Wrong design in time delay of two detonators
1.26E-09
4WD-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors
1.07E-05
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06



W-DETON+OTH-MD-SC
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except manufacturer defect of one surface connector
6 Sectors 6.75E-20

AND

4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

4W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 1.07E-05

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

OR

WD-4.1
Wrong design in time delay of one detonator
1.26E-09

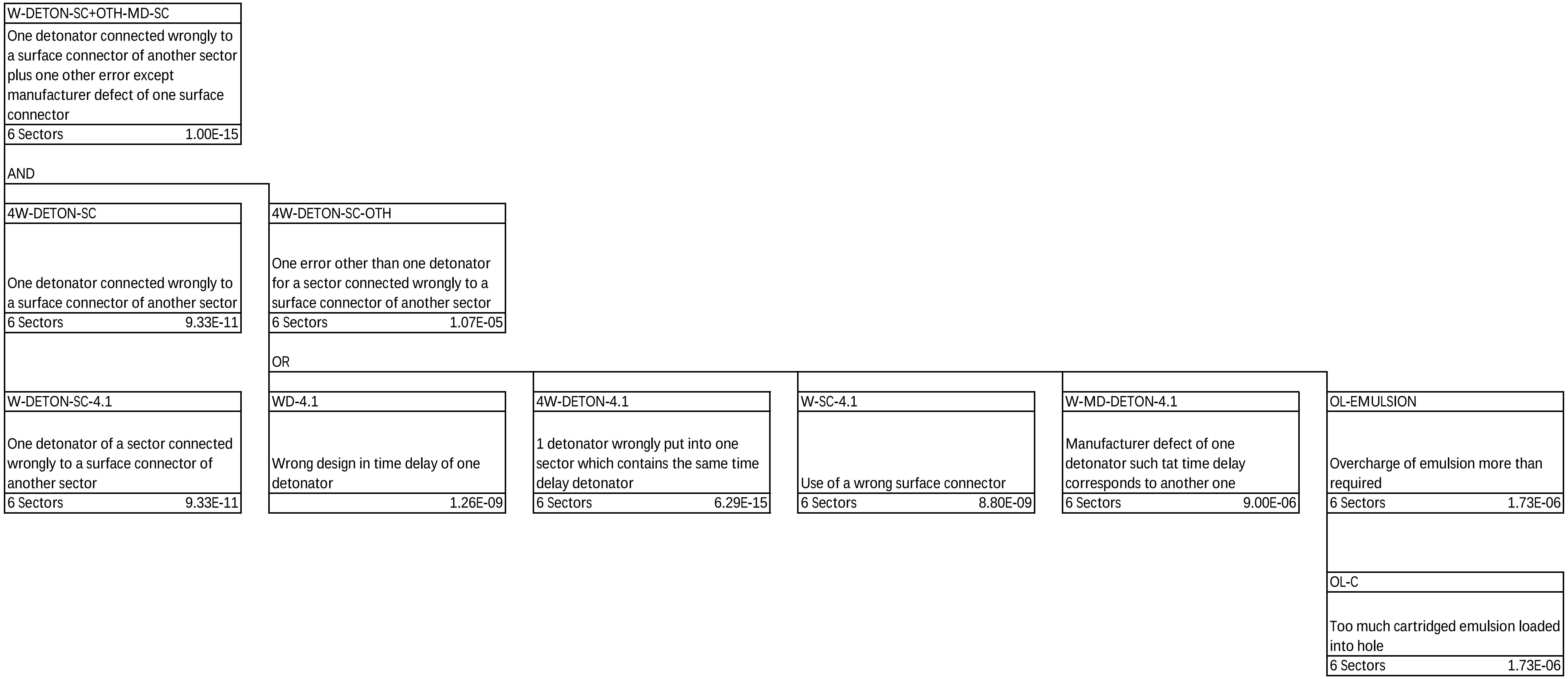
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

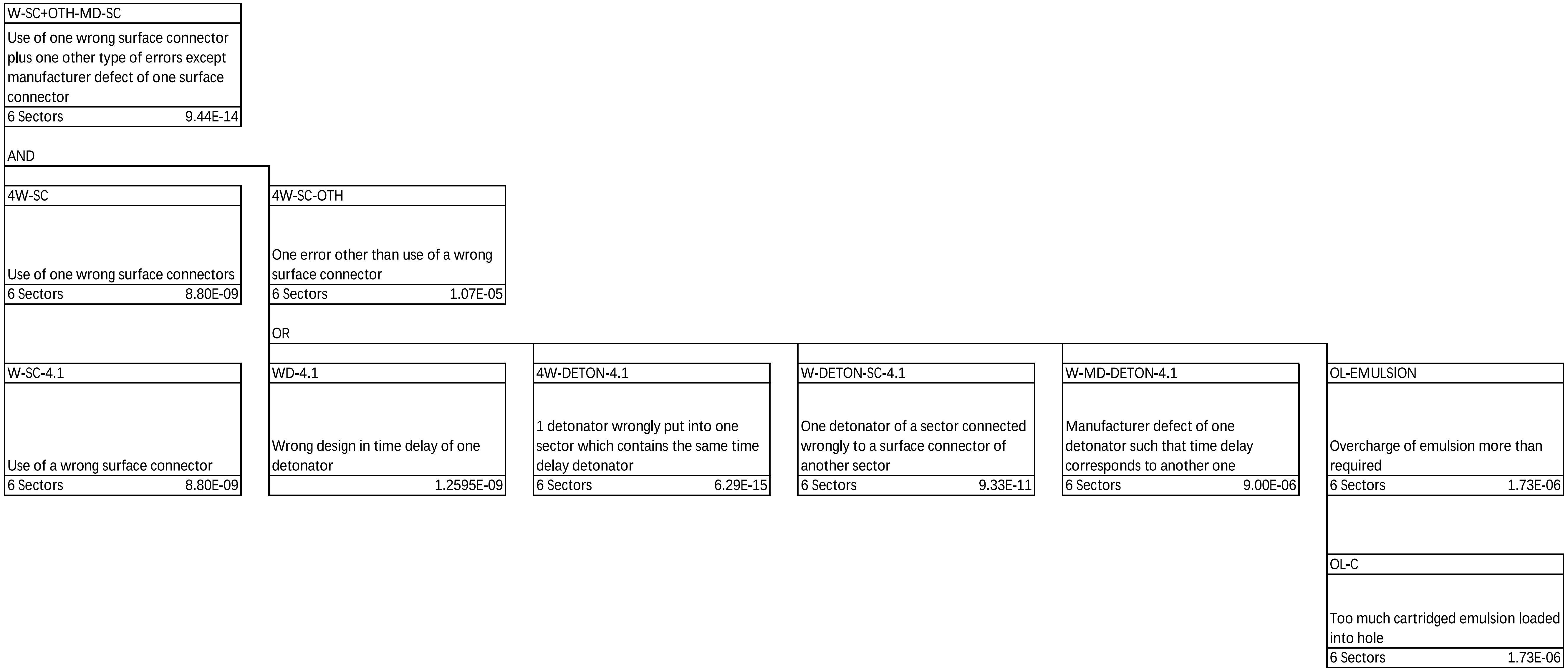
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-DETON-SC+OTH-MD-SC
One detonator connected wrongly to a surface connector of another sector plus one other error except manufacturer defect of one surface connector
6 Sectors
1.00E-15
AND
4W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
4W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors
1.07E-05
OR
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06



W-SC+OTH-MD-SC
Use of one wrong surface connector plus one other type of errors except manufacturer defect of one surface connector
6 Sectors 9.44E-14

AND

4W-SC
Use of one wrong surface connectors
6 Sectors 8.80E-09

4W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors 1.07E-05

OR

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

WD-4.1
Wrong design in time delay of one detonator
1.2595E-09

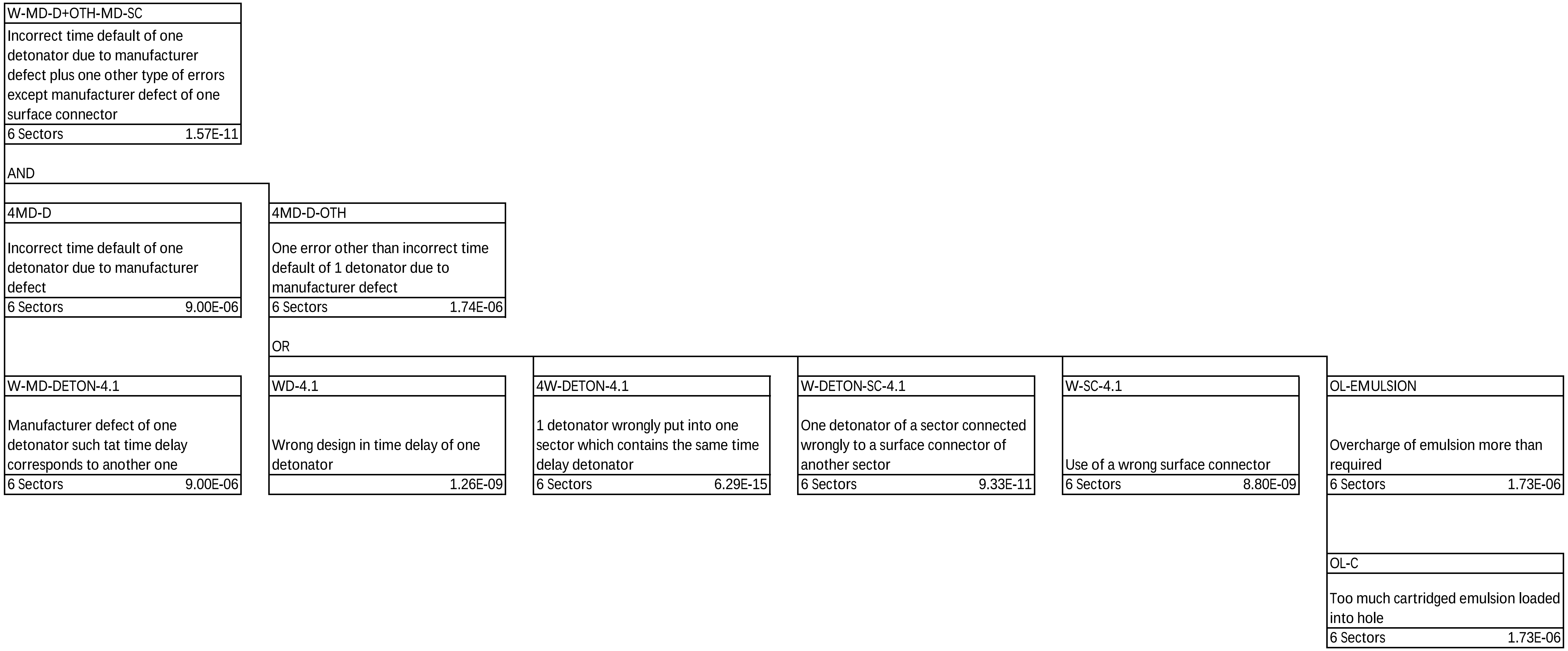
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

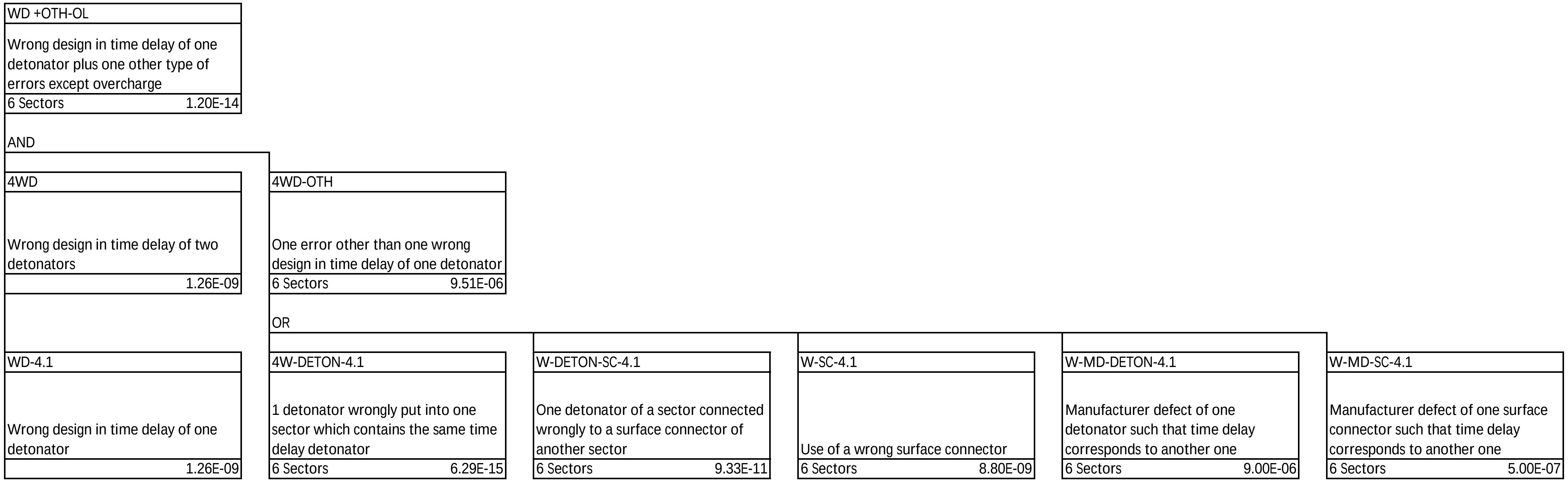
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

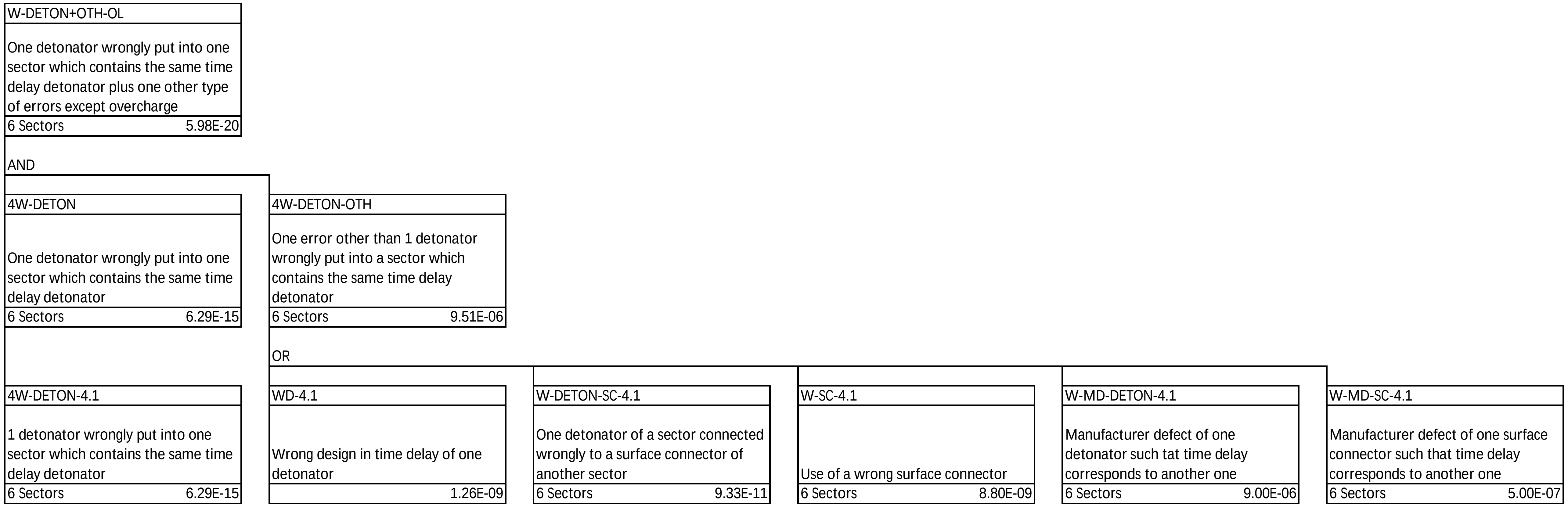
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06


W-MD-D+OTH-MD-SC
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except manufacturer defect of one surface connector
6 Sectors
1.57E-11
AND
4MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors
9.00E-06
4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors
1.74E-06
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06


WD +OTH-OL
Wrong design in time delay of one detonator plus one other type of errors except overcharge
6 Sectors
1.20E-14
AND
4WD
Wrong design in time delay of two detonators
1.26E-09
4WD-OTH
One error other than one wrong design in time delay of one detonator
6 Sectors
9.51E-06
OR
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07


W-DETON+OTH-OL
One detonator wrongly put into one sector which contains the same time delay detonator plus one other type of errors except overcharge
6 Sectors 5.98E-20

AND

4W-DETON
One detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

4W-DETON-OTH
One error other than 1 detonator wrongly put into a sector which contains the same time delay detonator
6 Sectors 9.51E-06

OR

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

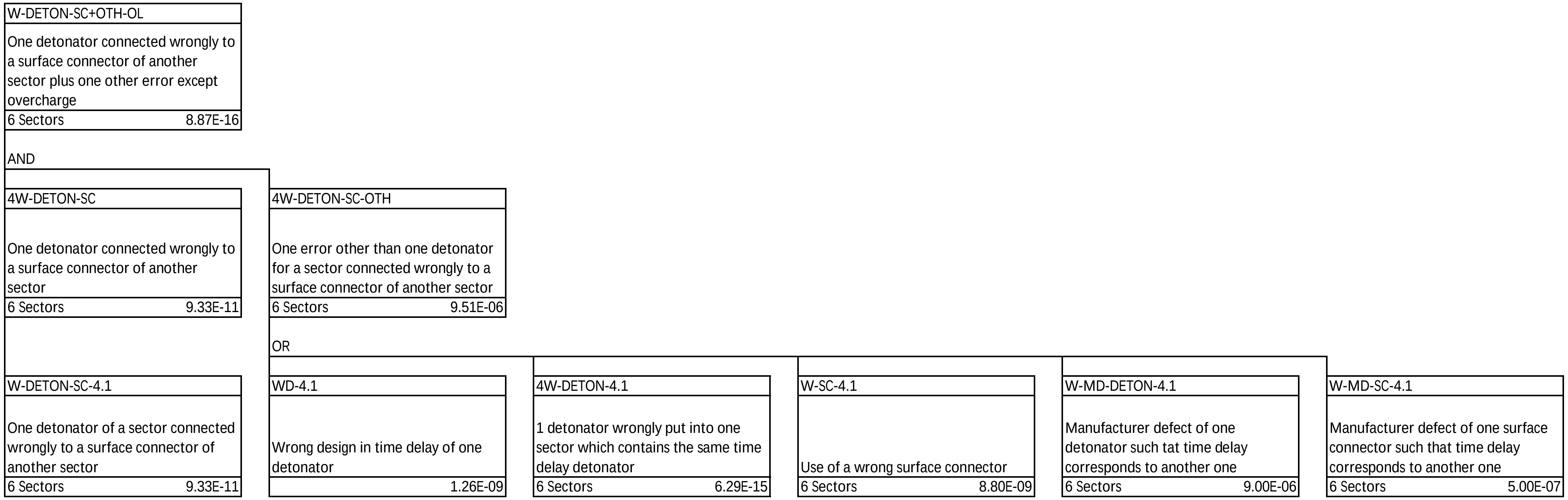
WD-4.1
Wrong design in time delay of one detonator
1.26E-09

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07



W-DETON-SC+OTH-OL
One detonator connected wrongly to a surface connector of another sector plus one other error except overcharge
6 Sectors 8.87E-16

AND

4W-DETON-SC
One detonator connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

4W-DETON-SC-OTH
One error other than one detonator for a sector connected wrongly to a surface connector of another sector
6 Sectors 9.51E-06

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

OR

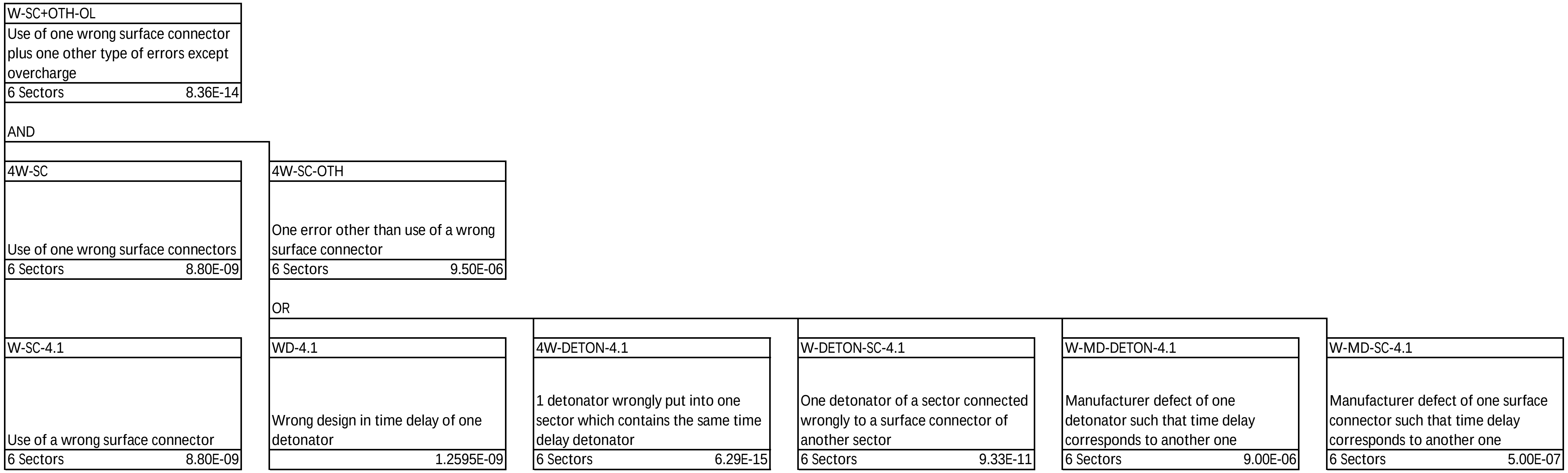
WD-4.1
Wrong design in time delay of one detonator
1.26E-09

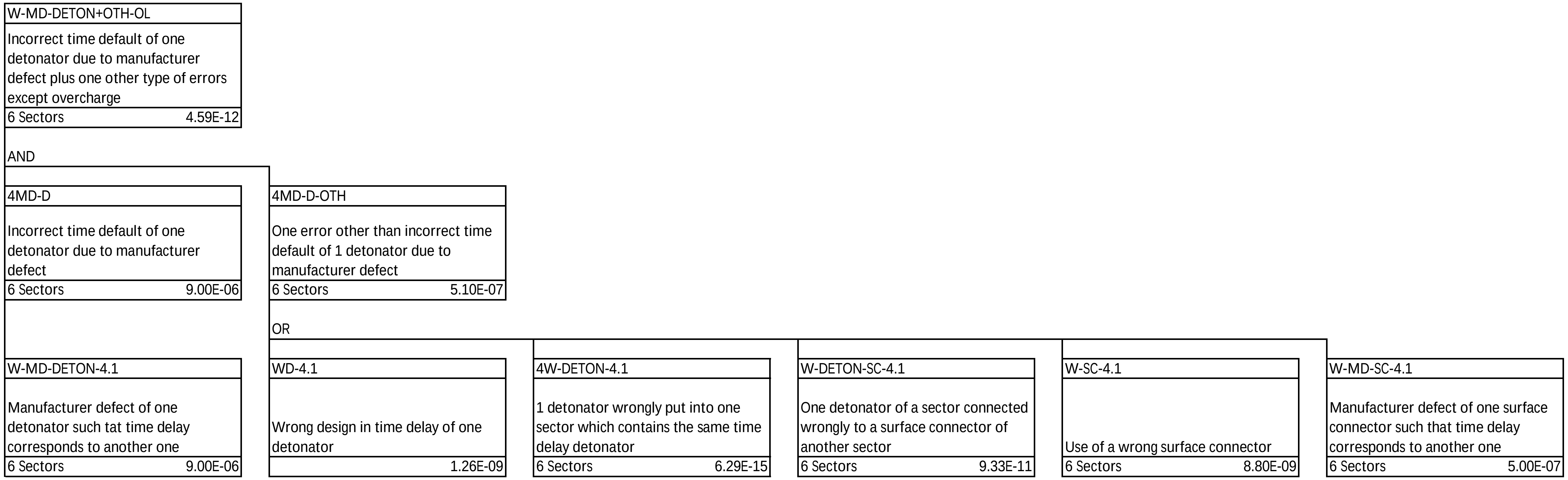
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

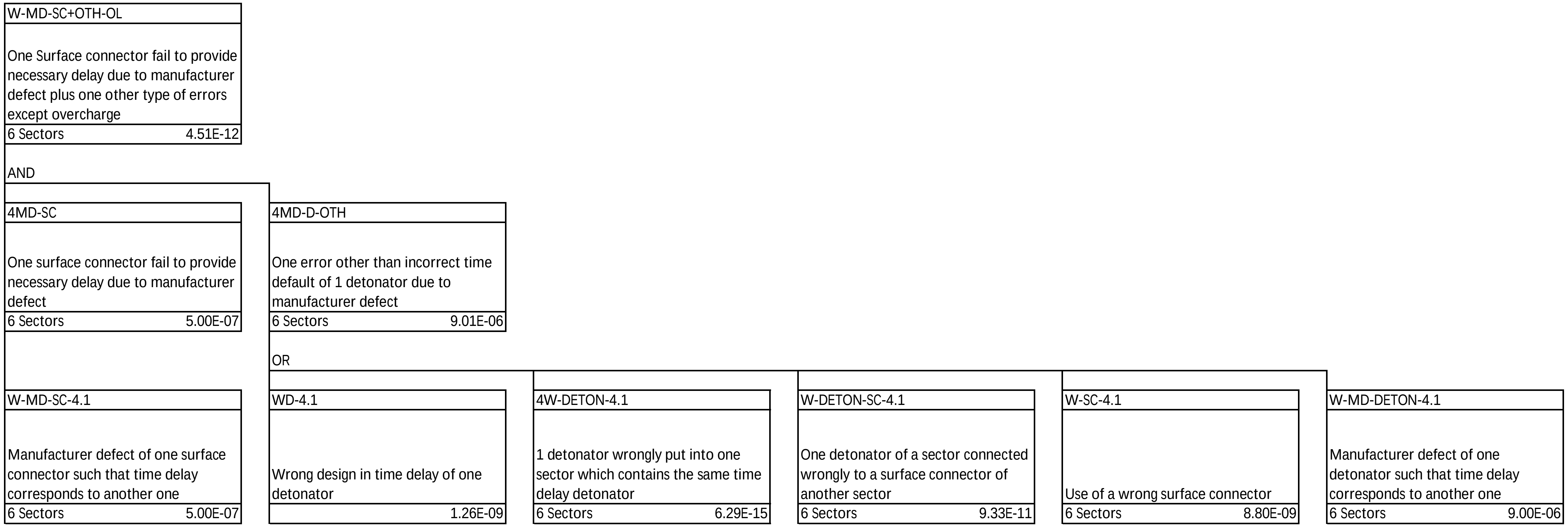
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07


W-SC+OTH-OL
Use of one wrong surface connector plus one other type of errors except overcharge
6 Sectors
8.36E-14
AND
4W-SC
Use of one wrong surface connectors
6 Sectors
8.80E-09
4W-SC-OTH
One error other than use of a wrong surface connector
6 Sectors
9.50E-06
OR
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
WD-4.1
Wrong design in time delay of one detonator
1.2595E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07


W-MD-DETON+OTH-OL
Incorrect time default of one detonator due to manufacturer defect plus one other type of errors except overcharge
6 Sectors
4.59E-12
AND
4MD-D
Incorrect time default of one detonator due to manufacturer defect
6 Sectors
9.00E-06
4MD-D-OTH
One error other than incorrect time default of 1 detonator due to manufacturer defect
6 Sectors
5.10E-07
OR
W-MD-DETON-4.1
Manufacturer defect of one detonator such tat time delay corresponds to another one
6 Sectors
9.00E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07



W-MD-SC+OTH-OL

One Surface connector fail to provide necessary delay due to manufacturer defect plus one other type of errors except overcharge

6 Sectors 4.51E-12

AND

4MD-SC

One surface connector fail to provide necessary delay due to manufacturer defect

6 Sectors 5.00E-07

4MD-D-OTH

One error other than incorrect time default of 1 detonator due to manufacturer defect

6 Sectors 9.01E-06

W-MD-SC-4.1

Manufacturer defect of one surface connector such that time delay corresponds to another one

6 Sectors 5.00E-07

OR

WD-4.1

Wrong design in time delay of one detonator

1.26E-09

4W-DETON-4.1

1 detonator wrongly put into one sector which contains the same time delay detonator

6 Sectors 6.29E-15

W-DETON-SC-4.1

One detonator of a sector connected wrongly to a surface connector of another sector

6 Sectors 9.33E-11

W-SC-4.1

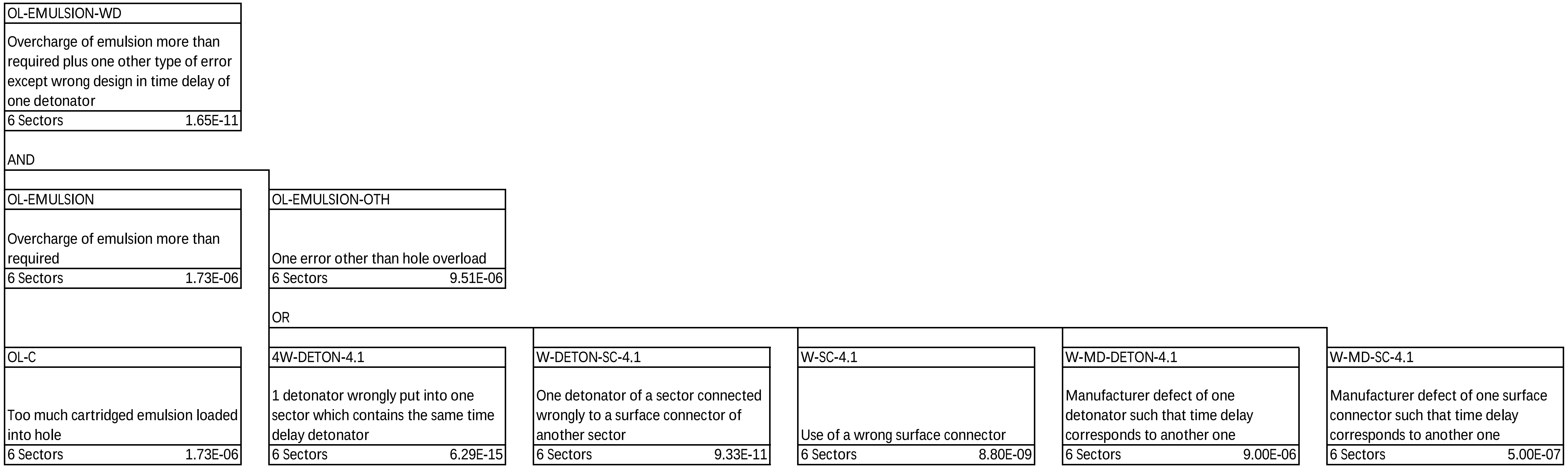
Use of a wrong surface connector

6 Sectors 8.80E-09

W-MD-DETON-4.1

Manufacturer defect of one detonator such that time delay corresponds to another one

6 Sectors 9.00E-06



OL-EMULSION-WD
Overcharge of emulsion more than required plus one other type of error except wrong design in time delay of one detonator
6 Sectors 1.65E-11

AND

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-EMULSION-OTH
One error other than hole overload
6 Sectors 9.51E-06

OR

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

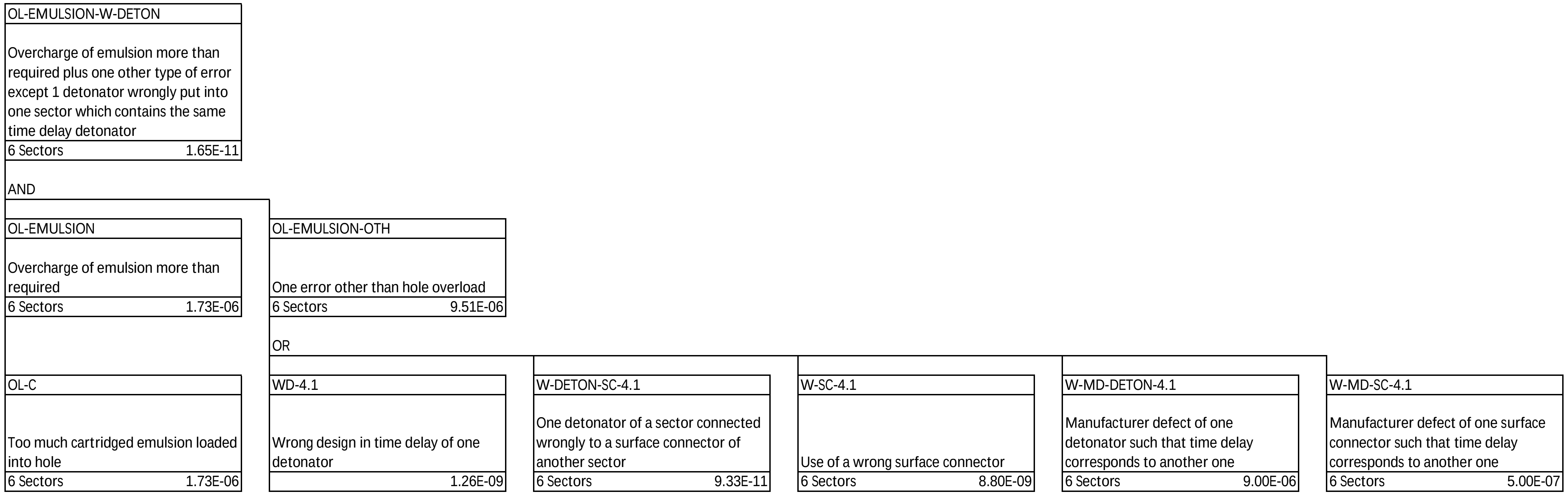
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

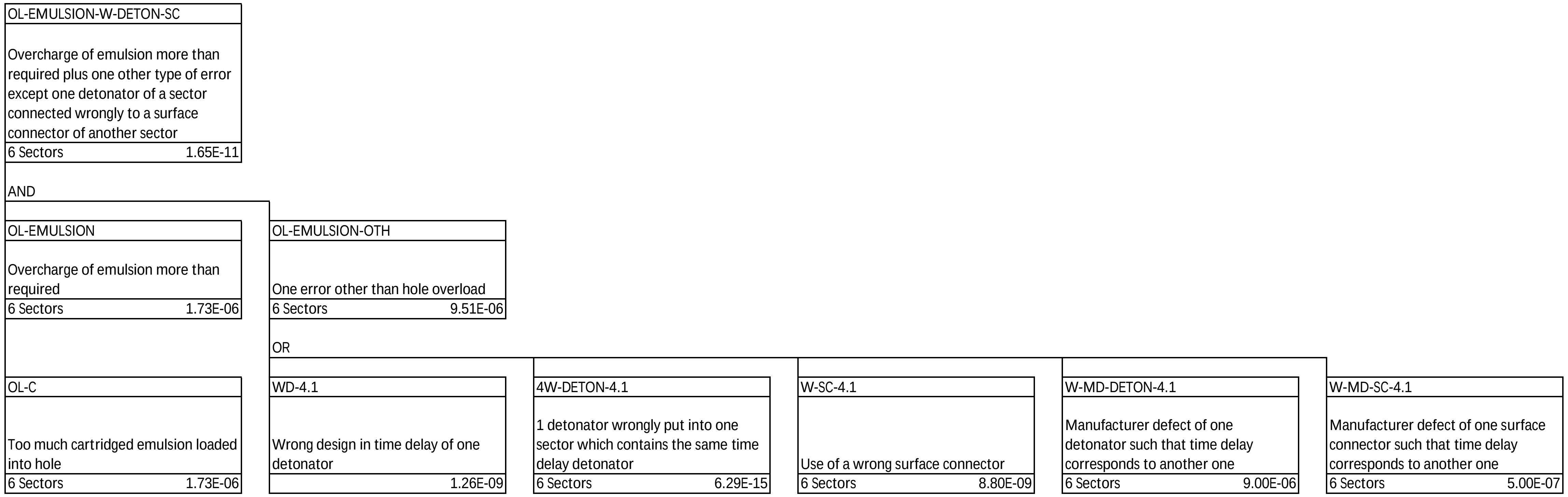
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

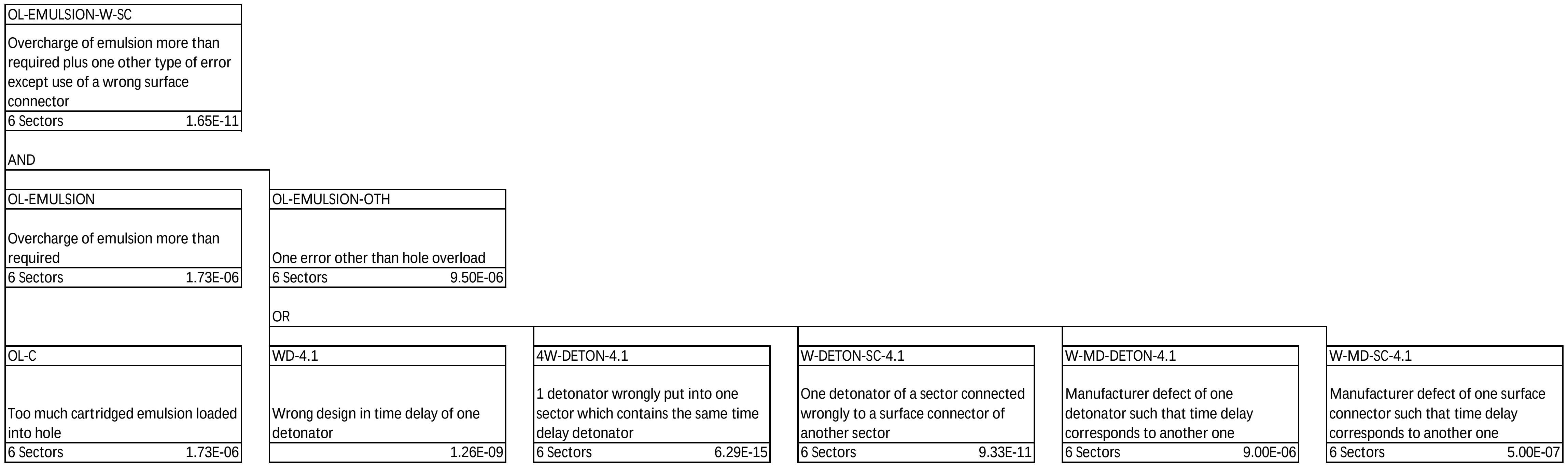
W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

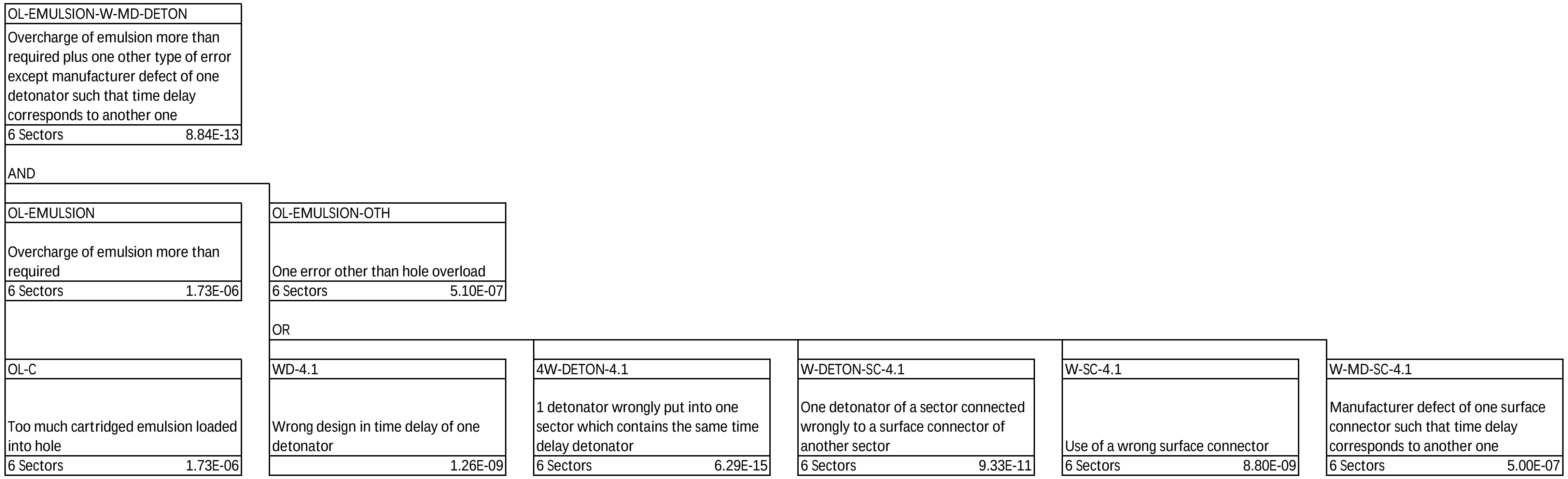
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 9.00E-06

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07


OL-EMULSION-W-DETON
Overcharge of emulsion more than required plus one other type of error except 1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
1.65E-11
AND
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-EMULSION-OTH
One error other than hole overload
6 Sectors
9.51E-06
OR
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07


OL-EMULSION-W-DETON-SC
Overcharge of emulsion more than required plus one other type of error except one detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
1.65E-11
AND
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-EMULSION-OTH
One error other than hole overload
6 Sectors
9.51E-06
OR
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07


OL-EMULSION-W-SC
Overcharge of emulsion more than required plus one other type of error except use of a wrong surface connector
6 Sectors
1.65E-11
AND
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-EMULSION-OTH
One error other than hole overload
6 Sectors
9.50E-06
OR
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06
W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
5.00E-07



OL-EMULSION-W-MD-DETON
Overcharge of emulsion more than required plus one other type of error except manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors 8.84E-13

AND

OL-EMULSION
Overcharge of emulsion more than required
6 Sectors 1.73E-06

OL-EMULSION-OTH
One error other than hole overload
6 Sectors 5.10E-07

OL-C
Too much cartridged emulsion loaded into hole
6 Sectors 1.73E-06

OR

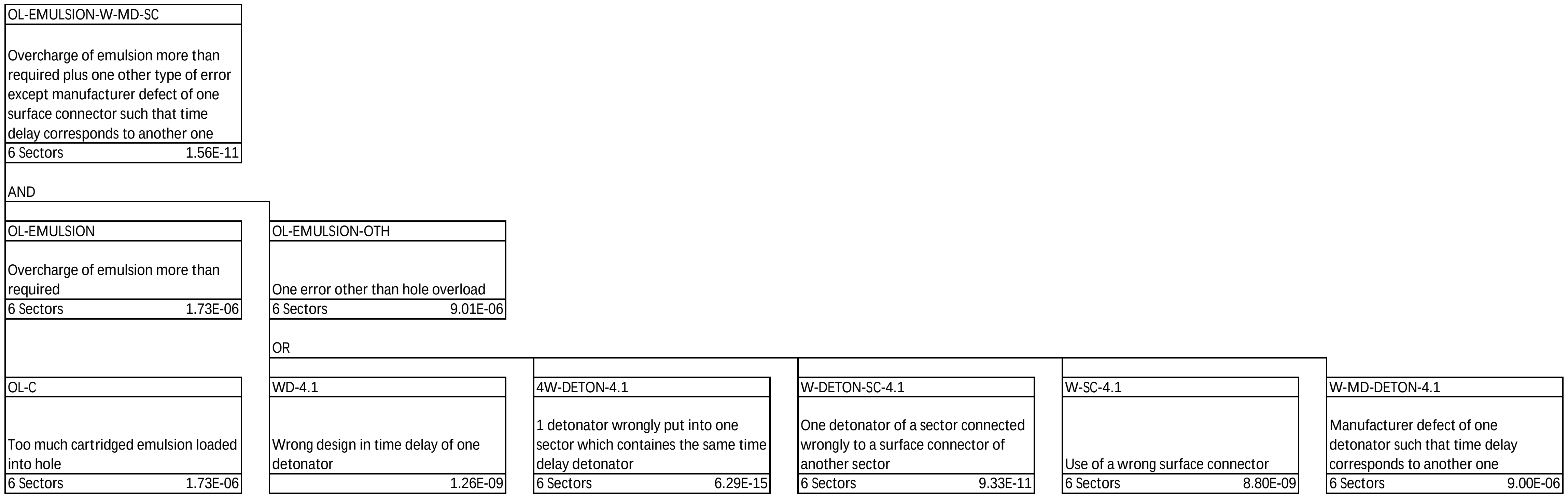
WD-4.1
Wrong design in time delay of one detonator
1.26E-09

4W-DETON-4.1
1 detonator wrongly put into one sector which contains the same time delay detonator
6 Sectors 6.29E-15

W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors 9.33E-11

W-SC-4.1
Use of a wrong surface connector
6 Sectors 8.80E-09

W-MD-SC-4.1
Manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors 5.00E-07


OL-EMULSION-W-MD-SC
Overcharge of emulsion more than required plus one other type of error except manufacturer defect of one surface connector such that time delay corresponds to another one
6 Sectors
1.56E-11
AND
OL-EMULSION
Overcharge of emulsion more than required
6 Sectors
1.73E-06
OL-EMULSION-OTH
One error other than hole overload
6 Sectors
9.01E-06
OR
OL-C
Too much cartridged emulsion loaded into hole
6 Sectors
1.73E-06
WD-4.1
Wrong design in time delay of one detonator
1.26E-09
4W-DETON-4.1
1 detonator wrongly put into one sector which containes the same time delay detonator
6 Sectors
6.29E-15
W-DETON-SC-4.1
One detonator of a sector connected wrongly to a surface connector of another sector
6 Sectors
9.33E-11
W-SC-4.1
Use of a wrong surface connector
6 Sectors
8.80E-09
W-MD-DETON-4.1
Manufacturer defect of one detonator such that time delay corresponds to another one
6 Sectors
9.00E-06

Annex 2 Human Error Assessment & Reduction Technique (HEART)

1 Overview

1.1 General

1.1.1 A human reliability assessment (HRA) has been carried out to assess the likelihood that a process will fail based on the potential of human error. HRA addresses the following questions:

- Which types of human error may occur (e.g. action error, information retrieval error, communication error, violation, etc.)?
- What is estimated probability of such errors being made?
- What factors may influence this probability (e.g. time pressure, stress, poor working environment, etc.)?
- How can the identified human errors be prevented in the design or how can their impacts be reduced by additional mitigating measures?

1.1.2 Human Error Assessment & Reduction Technique (HEART) is one of the HRA methods that has been used in this assessment to quantify human error probabilities related to use of explosives. HEART assesses the interactions between humans, their specific tasks and performance shaping / human factors or error producing conditions (EPCs).

1.2 This Project

1.2.1 The blasting process is composed of numerous subtasks which are carried out by different individuals. In this assessment, fault trees were constructed to identify possible sources of human error during the following four critical blasting subtasks:

- Cut failure;
- 2 MICs detonated in the same face;
- Excessive loading of bulk emulsion; and
- Excessive loading of cartridge emulsion

1.2.2 Fault tree analysis was undertaken to examine the logical relationship between the circumstances, failure events, and human / management errors which must occur in order for these specified undesired events to occur.

1.2.3 Assumptions made in the WIL Study were reviewed and most of them are applicable to this study and thus have been adopted in this assessment. All potential human errors for the entire blasting life cycle, from the design of the blast plant to installation of the explosives, have been quantified. Manufacturer has not been taken into account since interviews with the operators and observation of the manufacturing tasks are required to quantify the human error probability.

2 Methodology

2.1 HEART Methodology

2.1.1 The HEART technique is based on human performance literature, and 5 steps would be undertaken to estimate the contributing human factors of the probability of failure for a specific task:

- Step 1: Classify the task in terms of its generic human unreliability into one of the 9 generic HEART task types (**Table 2.1**);
- Step 2: Identify relevant error producing conditions (EPCs) to the scenario / task under analysis (**Table 2.2**);
- Step 3: Estimate the impact of each EPC on the task based on judgment;
- Step 4: Calculate the ‘assessed impact’ for each EPC according to the formula:

  ((Multiplier – 1) × Assessed Proportion of Effect) + 1

- Step 5: Calculate overall probability of failure of task based on the formula:

  Nominal human unreliability × Assessed impact 1 × Assessed impact 2…etc.

Table 2.1 Generic Task Unreliability

Generic Task		Proposed Nominal Human Unreliability (5th-95th percentile boundaries)
A	Totally unfamiliar, performed at speed with no real idea of likely consequences	0.55 (0.35 – 0.97)
B	Shift or restore system to a new or original state on a single attempt without supervision or procedures	0.26 (0.14 – 0.42)
C	Complex task requiring high level of comprehension and skill	0.16 (0.12 – 0.28)
D	Fairly simple task performed rapidly or given scant attention	0.09 (0.06 – 0.13)
E	Routine, highly practiced, rapid task involving relatively low level of skill	0.02 (0.007 – 0.045)
F	Restore or shift a system to original or new state following procedures, with some checking	0.003 (0.0008 – 0.007)
G	Completely familiar, well-designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated, highly trained and experienced person, totally aware of implications of failure, with time to correct potential error, but without the benefit of significant job aids	0.0004 (0.00008 – 0.009)
H	Respond correctly to system command even when there is an augmented or automated supervisory system providing accurate interpretation of system stage	0.00002 (0.000006 – 0.00009)
M	Miscellaneous task for which no description can be found. (Nominal 5th to 95th percentile data spreads were chosen on the basis of experience suggesting log-normality)	0.03 (0.008 – 0.11)

Table 2.2 Error-Producing Conditions (EPCs)

	Error-producing condition	Maximum predicted nominal amount by which unreliability might change going from 'good' conditions to 'bad'
1	Unfamiliarity with a situation which is potentially important but which only occurs infrequently or which is novel	×17
2	A shortage of time available for error detection and correction	×11
3	A low signal-to-noise ratio	×10
4	A means of suppressing or overriding information or features which is too easily accessible	×9
5	No means of conveying spatial and functional information to operators in a form which they can readily assimilate	×8
6	A mismatch between an operator's model of the world and that imagined by the designer	×8
7	No obvious means of reversing an unintended action	×8
8	A channel capacity overload, particularly one caused by simultaneous presentation of non-redundant information	×6
9	A need to unlearn a technique and apply one which requires the application of an opposing philosophy	×6
10	The need to transfer specific knowledge from task to task without loss	×5.5
11	Ambiguity in the required performance standards	×5
12	A mismatch between perceived and real risk	×4
13	Poor, ambiguous or ill-matched system feedback	×4
14	No clear direct and timely confirmation of an intended action from the portion of the system over which control is to be exerted	×3
15	Operator inexperienced (e.g. a newly qualified tradesman, but not an 'expert')	×3
16	An impoverished quality of information conveyed by procedures and person-person interaction	×3
17	Little or no independent checking or testing of output	×3
18	A conflict between immediate and long-term objectives	×2.5
19	No diversity of information input for veracity checks	×2.5
20	A mismatch between the educational achievement level of an individual and the requirements of the task	×2
21	An incentive to use other more dangerous procedures	×2
22	Little opportunity to exercise mind and body outside the immediate confines of the job	×1.8
23	Unreliable instrumentation (enough that it is noticed)	×1.6
24	A need for absolute judgements which are beyond the capabilities or experience of an operator	×1.6
25	Unclear allocation of function and responsibility	×1.6
26	No obvious way to keep track of progress during an activity	×1.4
27	A danger that finite physical capabilities will be exceeded	×1.4
28	Little or no intrinsic meaning in a task	×1.4
29	High-level emotional stress	×1.3
30	Evidence of ill-health amongst operatives, especially fever	×1.2
31	Low workforce morale	×1.2
32	Inconsistency of meaning of displays and procedures	×1.2
33	A poor or hostile environment (below 75% of health or life-threatening severity)	×1.15
34	Prolonged inactivity or highly repetitious cycling of low mental workload tasks	×1.1 for first half-hour ×1.05 for each hour thereafter
35	Disruption of normal work-sleep cycles	×1.1
36	Task pacing caused by the intervention of others	×1.06
37	Additional team members over and above those necessary to perform task normally and satisfactorily	×1.03 per additional man
38	Age of personnel performing perceptual tasks	×1.02

2.1.2 Each scenario has been analysed separately in the Section 3 to Section 6 to determine the overall probability of human failure. The generic HEART task type and the EPCs and their impacts are discussed. **Attachment 1** presents the fault tree of human error leading to these failure scenarios.

2.2 General Assumptions

2.2.1 The following assumptions are made for performing the HEART analysis.

- The Shotfirer and Blasting Engineer are experienced and competent to perform their tasks;

- The Resident Site Staff will perform the supervisory roles on the blast site, while the Mines Division will carry out on-site audit checking for some blasts where no credit will be taken for the human error assessment;
- The working environment in the tunnel is not optimal for human performance. It is wet, dusty, hot, poorly lit for the tasks to be carried out and noisy. Therefore for all tasks taking place within the tunnel, the maximum weighting for the EPC ‘hostile environment’ has been used;
- A disruption to sleep has been assumed for all tasks apart from design checking and error correction;
- Only 1 Shotfirer will be involved in his responsible tasks, although there may be a few Shotfirer trainees who are qualified to assist the Shotfirer for some tasks in reality; and
- The works performed by the Shotfirer will be check by a Blasting Competent Supervisor (BCS).

3 Scenario 1: Cut Failure

3.1 Event 1.1: Wrong Design of Hole Diameter / Location for Cut

1.1.1 Design Error by Blasting Engineer and Failure of Design Check

3.1.1 The overall probability that the wrong blast plan is submitted to the Resident Engineer and Mines Division for review is **1.05E-3**, based on the failure of all the tasks analysed below.

1.1.1-1 Design error by Blasting Engineer leads to wrong relief hole diameter

3.1.2 If the Blasting Engineer made an error during the design process and the incorrect drawings are distributed to the blasting team, the drilling operator may utilize what he/she believes to be the correct diameter to drill the relief holes, when in fact they are incorrect. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.1**.

Table 3.1 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Design error by Blasting Engineer leads to wrong relief hole diameter	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.03E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

3.1.3 Based on the above estimates, the likelihood of producing an error is **3.03E-2**.

1.1.1-2 Failure to detect error by Blasting Engineer during modeling

3.1.4 The Blasting Engineer utilizes a modelling programme which will highlight any inconsistencies or mistakes. However, it is possible that the Blasting Engineer does not detect the errors highlighted by the modelling programme, or simply does not utilize the software to check the design. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.2**.

Table 3.2 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Blasting Engineer during modelling	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.03E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

3.1.5 Based on the above estimates, the likelihood of producing an error is **3.03E-2**.

1.1.1-3 Failure to correct error by Blasting Engineer during modeling

3.1.6 If the Blasting Engineer identifies a problem with the design, there is potential that he may not act upon this information and fail to rectify the mistake. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.3**.

Table 3.3 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Blasting Engineer during modelling	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.54E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

3.1.7 Based on the above estimates, the likelihood of producing an error is **4.54E-3**.

1.1.2 Failure to Detect and Correct Error by Resident Engineer and Mines Division

3.1.8 The overall probability of failure to detect and correct the design error by the Resident Engineer and the Mines Division is **3.56E-5**, based on the failure of all the tasks analysed below.

1.1.2-1 Failure to detect error by Resident Engineer

3.1.9 The finalized blast design will pass to the Resident Engineer for checking, and then to Mines Division for endorsement. It is assumed that the Resident Engineer is not as competent or experienced as the Blasting Engineer as this is not his sole task within the project. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.4**.

Table 3.4 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Resident Engineer	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.92E-02
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

3.1.10 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

1.1.2-2 Failure to detect error by Mines Division

3.1.11 As stated previously, the Mines Division will also check the design for errors although it is still possible that errors may be made during the check and allows an incorrect design to go unnoticed. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.5**.

Table 3.5 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Mines Division	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.76E-02
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

3.1.12 Based on the above estimates, the likelihood of producing an error is **2.76E-2**.

1.1.2-3 Failure to correct error by Resident Engineer

3.1.13 The Resident Engineer may detect the error but then fail to act on this to correct the design error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.6**.

Table 3.6 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Resident Engineer	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.37E-03
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

3.1.14 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

1.1.2-4 Failure to correct error by Mines Division

3.1.15 The Mines Division may detect the error but then fail to act on this to correct the design error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.7**.

Table 3.7 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Mines Division	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.14E-03
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

3.1.16 Based on the above estimates, the likelihood of producing an error is **4.14E-3**.

1.1.2-5 Failure to detect error by Shotfirer

3.1.17 The Shotfirer will review the blast plan before blasting commences. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.8**.

Table 3.8 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Shotfirer	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	2.92E-02
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	

3.1.18 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

1.1.2-6 Failure to correct error by Shotfirer

3.1.19 If the Shotfirer identifies an error in the blast plan, they must act to correct the error before the blast commences. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.9**.

Table 3.9 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Shotfirer	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	4.37E-03
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	

3.1.20 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

3.2 Event 1.2: Wrong Location of Drilling Or Incorrect Drill Size Used

1.2.1 Operator Fails to Drill Correctly

3.2.1 The overall probability of the operator failing to drill correctly is **2.26E-2**, based on the failure of all the tasks analysed below.

1.2.1-1 Surveyors calculate incorrect co-ordinates, leading to operator having disc with incorrect information

3.2.2 Surveyors will pass the calculated co-ordinates to the Blasting Engineer to programme a computer disc to be used in the drill. There is a potential that the holes be drilled incorrectly if the co-ordinates are miscalculated. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.10**.

Table 3.10 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Surveyors calculate incorrect co-ordinates, leading to operator having disc with incorrect	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.20E-02

3.2.3 Based on the above estimates, the likelihood of producing an error is **2.20E-2**.

1.2.1-2 Blasting Engineer inputs wrong information on to disc

3.2.4 The Blasting Engineer may input or retrieve information incorrectly when programming the computer disc. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 3.11**.

Table 3.11 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer inputs wrong information on to disc	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	6.05E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

3.2.5 Based on the above estimates, the likelihood of producing an error is **6.05E-4**.

1.2.2 Failure by Blasting Engineer / Shotfirer to Check and Correct Drilling Error

3.2.6 The overall probability of operator fails to drill correctly is **7.61E-5**, based on the failure of all the tasks analysed below.

1.2.2-1 Blasting Engineer fails to check holes are drilled correctly

3.2.7 The Blasting Engineer is responsible to check the location and size of the cut holes against plans. However, it is possible that the Blasting Engineer fails to check or check incompletely. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.12**.

Table 3.12 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to check holes are drilled correctly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.79E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.2.8 Based on the above estimates, the likelihood of producing an error is **3.79E-2**.

1.2.2-2 Shotfirer fails to check holes are drilled correctly

3.2.9 In addition to the Blasting Engineer, the Shotfirer will also check the holes have been drilled correctly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.13**.

Table 3.13 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check holes are drilled correctly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.2.10 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

1.2.2-3 Blasting Engineer fails to correct drilling error

3.2.11 It is possible that the Blasting Engineer may do nothing to correct any error detected. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.14**.

Table 3.14 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to correct drilling error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.22E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

3.2.12 Based on the above estimates, the likelihood of producing an error is **5.22E-3**.

1.2.2-4 Shotfirer fails to correct drilling error

3.2.13 The Shotfirer must act to correct the drilling error if it is identified. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.15**.

Table 3.15 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct drilling error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.08E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

3.2.14 Based on the above estimates, the likelihood of producing an error is **5.08E-3**.

1.2.2-5 Blasting Competent Supervisor fails to check holes are drilled correctly

3.2.15 There will also be a Blasting Competent Supervisor on site checking the holes have been drilled correctly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.16**.

Table 3.16 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to check holes are drilled correctly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.2.16 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

1.2.2-6 Blasting Competent Supervisor fails to correct drilling error

3.2.17 The Blasting Competent Supervisor must act to correct the drilling error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.17**.

Table 3.17 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct drilling error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.08E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

3.2.18 Based on the above estimates, the likelihood of producing an error is **5.08E-3**.

3.3 Event 1.3: Detonator is Installed Incorrectly

1.3.1 Wrong Installation of One Detonator by the Shotfirer

3.3.1 The overall probability of wrong location / incorrect drill size being used is **5.00E-7**, based on the failure of all the tasks analysed below.

1.3.1-1 Shotfirer marks holes incorrectly

3.3.2 The Shotfirer is responsible for marking the holes correctly. There is potential for information retrieval errors to occur when looking at the plans and transferring this to the face as well as lapses in concentration when actually marking the holes. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.18**.

Table 3.18 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer marks holes incorrectly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.3.3 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

1.3.1-2 Shotfirer fails to detect marking error

3.3.4 The Shotfirer will check his own work after marking the holes. There is potential that the Shotfirer fails to check and therefore fail to detect the marking error. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.19**.

Table 3.19 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

3.3.5 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

1.3.1-3 Shotfirer fails to correct marking error

3.3.6 The Shotfirer should correct the marking error once detected to ensure it is recovered. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.20**.

Table 3.20 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

3.3.7 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

1.3.1-4 Shotfirer picks up detonator of wrong time delay

3.3.8 The Shotfirer must ensure that detonator with correct time delay is picked up. However, due to an action execution error, the Shotfirer may pick up the wrong one to the intended one. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 3.21**.

Table 3.21 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer picks up detonator of wrong time delay	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.3.9 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

1.3.1-5 Shotfirer fails to check shell & detonator delay tag before placing into the hole

3.3.10 The Shotfirer should check the shell and detonator delay tag before placing it into the hole. However, it is possible that the Shotfirer omit to check before placing the detonator into the hole due to time pressure, poor lighting etc. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 3.22**.

Table 3.22 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check shell & detonator delay tag before placing into the hole	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.3.11 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

1.3.1-6 Shotfirer puts detonator in a hole not within the cut

3.3.12 The Shotfirer may pick up a correct detonator but insert it into a hole not within the cut. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 3.23**.

Table 3.23 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer puts detonator in a hole not within the cut	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	6.77E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

3.3.13 Based on the above estimates, the likelihood of producing an error is **6.77E-4**.

1.3.1-7 Shotfirer fails to check detonator delay tag after placing into the hole

3.3.14 The Shotfirer will make a final check of the delay tag once it has been installed, this is the final check to prevent the wrong detonator being placed in the hole. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 3.24**.

Table 3.24 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check detonator delay tag after placing into the hole	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

3.3.15 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

1.3.1-8 Blasting Competent Supervisor fails to detect marking error

3.3.16 The Blasting Competent Supervisor will check the work done by the Shotfirer after marking the holes. There is potential that the Blasting Competent Supervisor fails to check and therefore fail to detect the marking error. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.25**.

Table 3.25 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

3.3.17 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

1.3.1-9 Blasting Competent Supervisor fails to correct marking error

3.3.18 The Blasting Competent Supervisor should correct the marking error once detected to ensure it is recovered. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.26**.

Table 3.26 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

3.3.19 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

1.3.2 Shotfirer Fails to Detect and Correct that there are Holes Without Detonators Left in the Face

3.3.20 The overall probability of a Shotfirer failing to detect and correct empty holes is **4.24E-2**, based on the failure of all the tasks analysed below.

1.3.2-1 Shotfirer leaves empty holes in the blast face due to not realizing that are detonators left over

3.3.21 Since only the exact number of detonators should be delivered to site, there must be some holes without detonators if there are any remaining detonators. However, if the Shotfirer does not realise that there are detonators left over, empty holes to fill will not be detected. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 3.27**.

Table 3.27 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer leaves empty holes in the blast face due to not realizing that are detonators left over	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

3.3.22 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

1.3.2-2 Shotfirer fails to fill empty holes before detonation

3.3.23 If the Shotfirer identifies any errors during final check of the delay tags, these errors must be rectified. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 3.28**.

Table 3.28 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to fill empty holes before detonation	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

3.3.24 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

4 Scenario 2: Two MIC Detonated in the Same Face

4.1 Event 2.1: Wrong Design of Time Delay

2.1.1 Design Error by Blasting Engineer and Failure of Design Check and Correction

4.1.1 The overall probability that the wrong blast plan is submitted to the Resident Engineer and Mines Division for review is **1.05E-3**, based on the failure of all the tasks analysed below.

2.1.1-1 Design error by Blasting Engineer

4.1.2 If the Blasting Engineer made an error during the design process and the incorrect drawings are distributed to the blasting team, the blast team may utilize the incorrect plan. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.1**.

Table 4.1 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Design error by Blasting Engineer	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.03E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

4.1.3 Based on the above estimates, the likelihood of producing an error is **3.03E-2**.

2.1.1-2 Failure to detect error by Blasting Engineer during modeling

4.1.4 The Blasting Engineer utilizes a modelling programme which will highlight any inconsistencies or mistakes. However, it is possible that the Blasting Engineer does not detect the errors highlighted by the modelling programme, or simply does not utilize the software to check the design. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.2**.

Table 4.2 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Blasting Engineer during modelling	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.03E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

4.1.5 Based on the above estimates, the likelihood of producing an error is **3.03E-2**.

2.1.1-3 Failure to correct error by Blasting Engineer during modeling

4.1.6 If the Blasting Engineer identifies a problem with the design, there is potential that he may not act upon this information and fail to rectify the mistake. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.3**.

Table 4.3 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Blasting Engineer during modeling	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.54E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

4.1.7 Based on the above estimates, the likelihood of producing an error is **4.54E-3**.

2.1.2 Failure to Detect and Correct Error by Resident Engineer, Mines Division, Shotfirer and Blasting Competent Supervisor

4.1.8 The overall probability of failure to detect and correct error by Resident Engineer and Mines Division is **1.19E-6**, based on the failure of all the tasks analysed below.

2.1.2-1 Failure to detect error by Resident Engineer

4.1.9 The finalized blast design will pass to the Resident Engineer for checking, and then to Mines Division for endorsement. It is assumed that the Resident Engineer is not as competent or experienced as the Blasting Engineer as this is not his sole task within the project. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.4**.

Table 4.4 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Resident Engineer	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.92E-02
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.1.10 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

2.1.2-2 Failure to detect error by Mines Division

4.1.11 As stated previously, the Mines Division will also check the design for errors although it is still possible that errors may be made during the check and allows an incorrect design to go unnoticed. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.5**.

Table 4.5 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Mines Division	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.76E-02
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

4.1.12 Based on the above estimates, the likelihood of producing an error is **2.76E-2**.

2.1.2-3 Failure to correct error by Resident Engineer

4.1.13 The Resident Engineer may detect the error but then fail to act on this to correct the design error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.6**.

Table 4.6 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Resident Engineer	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.37E-03
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.1.14 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

2.1.2-4 Failure to correct error by Mines Division

4.1.15 The Mines Division may detect the error but then fail to act on this to correct the design error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.7**.

Table 4.7 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Mines Division	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.14E-03
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

4.1.16 Based on the above estimates, the likelihood of producing an error is **4.14E-3**.

2.1.2-5 Shotfirer fails to detect error

4.1.17 The Shotfirer will review the blast plan before blasting commences. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid tasks involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.8**.

Table 4.8 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	2.92E-02
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	

4.1.18 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

2.1.2-6 Shotfirer fails to correct error

4.1.19 If the Shotfirer identifies an error in the blast plan, he must act to correct the error before the blast commences. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.9**.

Table 4.9 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	4.37E-03
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	

4.1.20 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

2.1.2-7 Blasting Competent Supervisor fails to detect error

4.1.21 The Blasting Competent Supervisor will review the blast plan before blasting commences. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.10**.

Table 4.10 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	2.92E-02
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	

4.1.22 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

2.1.2-8 Blasting Competent Supervisor fails to correct error

4.1.23 If the Blasting Competent Supervisor identifies an error in the blast plan, he must act to correct the error before the blast commences. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.11**.

Table 4.11 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	4.37E-03
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	

4.1.24 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

4.2 Event 2.2: Detonator Put Into Wrong Hole

2.2.1 Delivery of Incorrect Detonators from the Magazine to the Blast Site

4.2.1 The overall probability of a delivery of incorrect detonators from the magazine to the blast site is **7.11E-8**, based on the failure of all the tasks analysed below. If the Shotfirer fails to check the detonator delay label before and after the installation, the delivery error will not be discovered on site. The overall probability of wrong delivery is insignificant when compared to the probability that the Shotfirer fails to check the detonator delay label before installing, hence wrong delivery is not considered in deriving the overall probability for Event 2.2.

2.2.1-1 Detonators are picked incorrectly by the Shotfirer from the magazine

4.2.2 The Shotfirer must pick the correct detonators from the magazine according to the blast plan. There is potential for the Shotfirer to have a lapse in concentration and select the wrong detonators from the magazine. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.12**.

Table 4.12 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Detonators are picked incorrectly by the Shotfirer from the magazine	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	3.53E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	

4.2.3 Based on the above estimates, the likelihood of producing an error is **3.53E-3**.

2.2.1-2 Shotfirer fails to detect error

4.2.4 The Shotfirer should check that the detonators he has picked are the correct ones. However, he may misread the information or forget to check at all. The generic HEART task type taken to represent this task is "Routine, highly practiced, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.13**.

Table 4.13 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.94E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.2.5 Based on the above estimates, the likelihood of producing an error is **2.94E-2**.

2.2.1-3 Resident Engineer's Inspector fails to check correct detonators have been picked

4.2.6 The Resident Engineer's Inspector must check that the correct detonators have been selected. The generic HEART task type taken to represent this task is "Fairly simple task performed rapidly or given scant attention" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 4.14**.

Table 4.14 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer's Inspector fails to check correct detonators have been picked	0.09	Shortage of time available for error detection & correction	11	0.01	1.1	1.32E-01
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.2.7 Based on the above estimates, the likelihood of producing an error is **1.32E-1**.

2.2.1-4 Contractor's Representative fails to check correct detonators have been picked

4.2.8 Contractor's Representative must also check that the correct detonators have been selected. The generic HEART task type taken to represent this task is "Fairly simple task performed rapidly or given scant attention" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 4.15**.

Table 4.15 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Contractor's Representative fail to check correct detonators have been picked	0.09	Shortage of time available for error detection & correction	11	0.01	1.1	1.25E-01
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

4.2.9 Based on the above estimates, the likelihood of producing an error is **1.25E-1**.

2.2.1-5 Shotfirer fails to correct error

4.2.10 If the Shotfirer detects a selection error, he can recover this by acting to change the detonators to the correct ones. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.16**.

Table 4.16 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.42E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.2.11 Based on the above estimates, the likelihood of producing an error is **4.42E-3**.

2.2.1-6 Resident Engineer’s Inspector fails to correct error

4.2.12 If the Resident Engineer’s Inspector identifies the error, he must act on this to prevent the wrong detonators being sent to the blast face. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.17**.

Table 4.17 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer's Inspector fail to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.39E-03
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.2.13 Based on the above estimates, the likelihood of producing an error is **4.39E-3**.

2.2.1-7 Contractor’s Representative fails to correct error

4.2.14 If the Contractor’s Representative identifies the error, he must act on this to prevent the wrong detonators being sent to the blast face. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.18**.

Table 4.18 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Contractor's Representative fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.16E-03
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

4.2.15 Based on the above estimates, the likelihood of producing an error is **4.16E-3**.

2.2.1-8 Blasting Competent Supervisor fails to detect error

4.2.16 The Blasting Competent Supervisor should check that the detonators the Shotfirer has picked are the correct ones. However, he may misread the information or forget to check at all. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in Table **4.19**.

Table 4.19 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.94E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.2.17 Based on the above estimates, the likelihood of producing an error is **2.94E-2**.

2.2.1-9 Blasting Competent Supervisor fails to correct error

4.2.18 If the Blasting Competent Supervisor detects a selection error, he can recover this by asking the Shotfirer to change the detonators to the correct ones. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.20**.

Table 4.20 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.42E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

4.2.19 Based on the above estimates, the likelihood of producing an error is **4.42E-3**.

2.2.2 Installation of One Detonator by Shotfirer into a Section Already Containing a Detonator of that Delay Period

4.2.20 The overall probability of a detonator being wrongly installed is **5.45E-7**, based on the failure of all the tasks analysed below.

2.2.2-1 Shotfirer marks holes incorrectly

4.2.21 The Shotfirer is responsible for marking the holes correctly. There is potential for information retrieval errors to occur when looking at the plans and transferring this to the face as well as lapses in concentration when actually marking the holes. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.21**.

Table 4.21 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer marks holes incorrectly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.2.22 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.2.2-2 Shotfirer fails to detect marking error

4.2.23 The Shotfirer will check his own work after marking the hole. There is potential that the Shotfirer fail to check and therefore fail to detect the marking error. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.22**.

Table 4.22 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.24 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.2.2-3 Shotfirer fails to correct marking error

4.2.25 The Shotfirer should correct the marking error once detected to ensure it is recovered. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.23**.

Table 4.23 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.26 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.2.2-4 Shotfirer picks up detonator of wrong time delay

4.2.27 The Shotfirer must ensure that they choose the detonator with correct time delay when picking up at the magazine. Due to an action execution error, the Shotfirer may pick up the wrong one to the intended one. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.24**.

Table 4.24 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer picks up detonator of wrong time delay	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.2.28 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

2.2.2-5 Shotfirer fails to check shell & detonator delay tag before placing into the hole

4.2.29 The Shotfirer should check the shell and detonator delay tag before placing it into the hole. However, it is possible that the Shotfirer omit to check before placing the detonator into the hole due to time pressure, poor lighting etc. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.25**.

Table 4.25 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check shell & detonator delay tag before placing into the hole	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.2.30 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

2.2.2-6 Shotfirer puts detonator in a wrong hole

4.2.31 The Shotfirer may pick up a correct detonator but insert it into a wrong hole. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.26**.

Table 4.26 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer puts detonator in a worng hole	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.2.32 Based on the above estimates, the likelihood of producing an error is **7.38-E4**.

2.2.2-7 Shotfirer fails to check detonator delay tag after placing into the hole

4.2.33 Shotfirer should make a final check of the delay tag once it has been installed onto a hole. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.27**.

Table 4.27 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check detonator delay tag after placing into the hole	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.2.34 Based on the above estimates, the likelihood of producing an error is **7.38-E4**.

2.2.2-8 Blasting Competent Supervisor fails to detect marking error

4.2.35 The Blasting Competent Supervisor will check the work done by Shotfirer after marking the hole. There is potential that the Blasting Competent Supervisor fails to check and therefore fail to detect the marking error. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.28**.

Table 4.28 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.36 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.2.2-9 Blasting Competent Supervisor fails to correct marking error

4.2.37 The Blasting Competent Supervisor should correct the marking error once detected to ensure it is recovered. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.29**.

Table 4.29 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.38 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.2.3 Shotfirer / Blasting Competent Supervisor Fails to Check and Correct Installation Error

4.2.39 The overall probability of the Shotfirer failing to check and correct and installation error is **1.80E-3**, based on the failure of all the tasks analysed below.

2.2.3-1 Shotfirer leaves empty holes in the blast face due to not realizing there are detonators left over

4.2.40 Since only the exact number of detonators should be delivered to site, there must be some holes without detonators if there are any remaining detonators. However, if the Shotfirer does not realise that there are detonators left over, empty holes to fill will not be detected. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.30**.

Table 4.30 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer leaves empty holes in the blast face due to not realizing there are detonators left over	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.41 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.2.3-2 Shotfirer fails to fill empty holes before detonation

4.2.42 The Shotfirer must rectify errors during final check of the delay tags. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.31**.

Table 4.31 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to fill empty holes before detonation	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.43 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.2.3-3 Blasting Competent Supervisor fails to detect installation error

4.2.44 The Blasting Competent Supervisor should check the work done by the Shotfirer after he installed the detonators. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.32**.

Table 4.32 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect installation error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.45 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.2.3-4 Blasting Competent Supervisor fails to correct installation error

4.2.46 The Blasting Competent Supervisor should correct the installation error once detected to ensure it is recovered. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.33**.

Table 4.33 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct installation error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.2.47 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

4.3 Event 2.3: Detonator Connected to a Surface Connector From Another Sector

2.3.1 Shotfirer Misconnects One Detonator to the Wrong Surface Connector

4.3.1 The overall probability of the Shotfirer making a misconnection is **1.65E-3**, based on the failure of all the tasks analysed below.

2.3.1-1 Shotfirer marks sectors incorrectly

4.3.2 The Shotfirer is responsible for marking the sectors correctly. There is potential for information retrieval errors to occur when looking at the plans and transferring this to the face as well as lapses in concentration when actually marking the sectors. The generic HEART task type taken to represent this task is "Routine, highly practiced, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.34**.

Table 4.26 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer marks sectors incorrectly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.39E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

4.3.3 Based on the above estimates, the likelihood of producing an error is **3.39E-2**.

2.3.1-2 Shotfirer fails to detect marking error

4.3.4 The Shotfirer should check his own work after marking the holes. However, there is potential that the Shotfirer fails to check and detect the marking error. The generic HEART task type taken to represent this task is "Routine, highly practiced, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.35**.

Table 4.35 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.5 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.3.1-3 Shotfirer fails to correct marking error

4.3.6 The Shotfirer must correct marking error once the error is detected. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.36**.

Table 4.36 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	4.43E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.7 Based on the above estimates, the likelihood of producing an error is **4.43E-3**.

2.3.1-4 Shotfirer bundles a detonator from another sector into wrong section

4.3.8 In order to connect the surface connector, the Shotfirer will bundle the detonators together. Where one sector meets another, due to the proximity of the bundles and a poorly lit environment, there is potential that a detonator from another sector may be introduced into the bundle. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.37**.

Table 4.37 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer bundles detonator from another sector into bundle	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.3.9 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

2.3.1-5 Helper bundles a detonator from another sector into wrong section

4.3.10 The Shotfirer may enlist helpers from the blast team to bundle the detonators. These individuals will not be as competent as the Shotfirer, therefore greater potential to make misconnections between sectors. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.38**.

Table 4.38 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Helper bundles a detonator from another sector into wrong section	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	6.70E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.01	1.003	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	
		Operator inexperienced	3	0.7	2.4	

4.3.11 Based on the above estimates, the likelihood of producing an error is **6.70E-2**.

2.3.1-6 Shotfirer fails to detect bundling error by helper

4.3.12 The Shotfirer should check that the detonators have been bundled correctly by the helper. However, there is potential that he may not carry out the check. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.39**.

Table 4.39 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect bundling error by helper	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Low signal-noise ratio	10	0.010	1.09	
		Poor / hostile environment	1.15	1.000	1.15	

4.3.13 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.3.1-7 Shotfirer fails to correct bundling error by helper

4.3.14 The Shotfirer can recover the bundling error by helpers if he detect it. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.40**.

Table 4.40 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct bundling error by helper	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.15 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.3.1-8 Shotfirer connects wrong detonator

4.3.16 The final action error is that the Shotfirer connects the wrong detonator, due to a lapse in concentration. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.41**.

Table 4.41 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer connects wrong detonator	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.3.17 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

2.3.1-9 Blasting Competent Supervisor fails to detect marking error

4.3.18 The Blasting Competent Supervisor should check the work done by the Shotfirer after marking the holes. However, there is potential that the Blasting Competent Supervisor fails to check and detect the marking error. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.42**.

Table 4.42 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.19 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.3.1-10 Blasting Competent Supervisor fails to correct marking error

4.3.20 The Blasting Competent Supervisor must correct marking error once the error is detected. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.43**.

Table 4.43 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	4.43E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.21 Based on the above estimates, the likelihood of producing an error is **4.43E-3**.

2.3.1-11 Blasting Competent Supervisor fails to detect bundling error by helper

4.3.22 The Shotfirer should also check that the detonators have been bundled correctly by the helper. However, there is potential that he may not carry out the check. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.44**.

Table 4.44 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect bundling error by helper	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Low signal-noise ratio	10	0.010	1.09	
		Poor / hostile environment	1.15	1.000	1.15	

4.3.23 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.3.1-12 Blasting Competent Supervisor fails to correct bundling error by helper

4.3.24 The Blasting Competent Supervisor can recover the bundling error by helpers if he detect it. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.45**.

Table 4.45 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct bundling error by helper	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.25 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.3.2 Failure to Detect and Correct Connection Error

4.3.26 The overall probability of failure to detect and correct a connection error is **1.28E-5**, based on the failure of all the tasks analysed below.

2.3.2-1 Shotfirer fails to detect connection error

4.3.27 The Shotfirer should check and ensure that all surface connectors have been connected correctly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.46**.

Table 4.46 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect connection error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.28 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.3.2-2 Shotfirer fails to correct connection error

4.3.29 The Shotfirer can recover the bundling error if he detects it. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.47**.

Table 4.47 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct connection error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.30 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.3.2-3 Blasting Engineer fails to detect connection error

4.3.31 The Blasting Engineer should check that the surface connectors have been connected correctly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.48**.

Table 4.48 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to detect connection error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.79E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.3.32 Based on the above estimates, the likelihood of producing an error is **3.79E-2**.

2.3.2-4 Blasting Engineer fails to correct connection error

4.3.33 The Blasting Engineer should take step to correct any identified error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.49**.

Table 4.49 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to correct connection error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.69E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.3.34 Based on the above estimates, the likelihood of producing an error is **5.69E-3**.

2.3.2-5 Resident Site Staff fails to detect connection error

4.3.35 Representatives from Resident Site Staff should also check that the surface connectors have been connected correctly. The generic HEART task type taken to represent this task is “Fairly simple task performed rapidly or given scant attention” for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 4.50**.

Table 4.50 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Site Staff fails to detect connection error	0.09	Shortage of time available for error detection & correction	11	0.01	1.100	1.57E-01
		Disruption of normal work-sleep cycles	1.1	0.1	1.010	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.250	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.3.36 Based on the above estimates, the likelihood of producing an error is **1.57E-1**.

2.3.2-6 Resident Site Staff fails to correct connection error

4.3.37 The Resident Site Staff must act to correct any identified error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.51**.

Table 4.51 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Site Staff fails to correct connection error	0.003	Shortage of time available for error detection & correction	11	0.01	1.100	5.24E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.010	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.250	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.3.38 Based on the above estimates, the likelihood of producing an error is **5.24E-3**.

2.3.2-7 Blasting Competent Supervisor fails to detect connection error

4.3.39 The Blasting Competent Supervisor should check and ensure that all surface connectors have been connected correctly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.52**.

Table 4.52 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect connection error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.40 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.3.2-8 Blasting Competent Supervisor fails to correct connection error

4.3.41 The Blasting Competent Supervisor can recover the bundling error if he detects it. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.53**.

Table 4.53 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct connection error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.3.42 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

4.4 Event 2.4: Shotfirer Uses Wrong Surface Connector

2.4.1 Incorrect Installation of Surface Connector

4.4.1 The overall probability of the Shotfirer making a misconnection is **1.48E-3**, based on the failure of all the tasks analysed below.

2.4.1-1 Shotfirer fails to check the colour of the surface connector before installing

4.4.2 The Shotfirer should check the colour of the surface connector before connecting to the detonator bundle. The generic HEART task type taken to represent this task is "Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids" for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.54**.

Table 4.54 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check the colour of the surface connector before installing	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.3 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

2.4.1-2 Shotfirer connects wrong surface connector

4.4.4 The Shotfirer may connect the wrong surface connector due to a lapse in concentration. The generic HEART task type taken to represent this task is "Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids" for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 4.55**.

Table 4.55 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer connects wrong surface connector	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.5 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

2.4.2 Shotfirer / Blasting Competent Supervisor Fails to Detect and Respond to Error

4.4.6 The overall probability of the Shotfirer / Blasting Competent Supervisor fails to detect and correct a connection error is **1.80E-3**, based on the failure of all the tasks analysed below.

2.4.2-1 Shotfirer fails to detect error

4.4.7 The Shotfirer should check that correct surface connector has been used after connection. The generic HEART task type taken to represent this task is "Routine, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.56**.

Table 4.56 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.8 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.4.2-2 Shotfirer fails to correct error

4.4.9 The Shotfirer must take action to correct any identified error. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.57**.

Table 4.57 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.10 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.4.2-3 Blasting Competent Supervisor fails to detect error

4.4.11 The Blasting Competent Supervisor should also check that correct surface connector has been used after connection. The generic HEART task type taken to represent this task is “Routine, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.58**.

Table 4.58 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.12 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.4.2-4 Blasting Competent Supervisor fails to correct error

4.4.13 The Blasting Competent Supervisor must take action to correct any identified error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.59**.

Table 4.59 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.14 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

2.4.3 Failure to Detect and Respond During Final Hook-Up Check

4.4.15 The overall probability of failure to detect and correct an connection error is **3.01E-4**, based on the failure of all the tasks analysed below.

2.4.3-1 Blasting Engineer fails to detect error

4.4.16 The Blasting Engineer should check that correct surface connectors have been used. The generic HEART task type taken to represent this task is “Routine, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.60**.

Table 4.60 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.79E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.17 Based on the above estimates, the likelihood of producing an error is **3.79E-2**.

2.4.3-2 Blasting Engineer fails to correct error

4.4.18 The Blasting Engineer should take steps to correct any identified connection error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.61**.

Table 4.61 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.69E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

4.4.19 Based on the above estimates, the likelihood of producing an error is **5.69E-3**.

2.4.3-3 Resident Site Staff fails to detect error

4.4.20 Representatives from the Resident Site Staff should also check that correct surface connectors have been used. The generic HEART task type taken to represent this task is “Fairly simple task performed rapidly or given scant attention” for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 4.62**.

Table 4.62 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Site Staff fails to detect error	0.09	Shortage of time available for error detection & correction	11	0.01	1.100	1.57E-01
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.250	
		Poor / hostile environment	1.15	1	1.150	
		Low signal-noise ratio	10	0.01	1.09	

4.4.21 Based on the above estimates, the likelihood of producing an error is **1.57E-1**.

2.4.3-4 Resident Site Staff fails to correct error

4.4.22 Upon detecting a surface connector error, representatives must act to correct the error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.63**.

Table 4.63 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Site Staff fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.100	5.24E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.250	
		Poor / hostile environment	1.15	1	1.150	
		Low signal-noise ratio	10	0.01	1.090	

4.4.23 Based on the above estimates, the likelihood of producing an error is **5.24E-3**.

2.4.3-5 Shotfirer fails to detect error

4.4.24 The Shotfirer should check that correct surface connectors have been used before the final check. The generic HEART task type taken to represent this task is “Routine, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 4.64**.

Table 4.64 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.69E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.4.25 Based on the above estimates, the likelihood of producing an error is **3.69E-2**.

2.4.3-6 Shotfirer fails to correct error

4.4.26 Upon detecting a surface connector error, the Shotfirer must take action to correct the error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 4.65**.

Table 4.65 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.54E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	
		Low signal-noise ratio	10	0.010	1.09	

4.4.27 Based on the above estimates, the likelihood of producing an error is **5.54E-3**.

5 Scenario 3: MIC Exceeded (Bulk Emulsion)

5.1 Event 3.1: Excess Emulsion Is Loaded Into A Hole

3.1.1 Excess Emulsion is Loaded due to Wrong Density

5.1.1 The overall probability of excess emulsion being loaded due to wrong density is **1.11E-12**, based on the failure of all the tasks analysed below.

3.1.1-1 Truck Operator sets gassing flow meter incorrectly

5.1.2 The truck operator should set the gassing flow meter to the correct setting in order to provide the correct density of bulk emulsion. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.1**.

Table 5.1 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Truck operator sets gassing flow meter incorrectly	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	3.95E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.1	1.03	
		Poor / hostile environment	1.15	1	1.15	

5.1.3 Based on the above estimates, the likelihood of producing an error is **3.95E-3**.

3.1.1-2 Truck Operator reads density chart incorrectly

5.1.4 The truck operator should use the density chart to check once the flow meter has been set. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.2**.

Table 5.2 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Truck operator reads density chart incorrectly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.63E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.1	1.03	
		Poor / hostile environment	1.15	1	1.15	

5.1.5 Based on the above estimates, the likelihood of producing an error is **2.63E-2**.

3.1.1-3 Truck Operator reads scales incorrectly

5.1.6 The truck operator should weigh the product using the scales on the truck. An information retrieval error may occur, leading to the operator reading the scale incorrectly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.3**.

Table 5.3 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Truck operator reads scales incorrectly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.63E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.1	1.03	
		Poor / hostile environment	1.15	1	1.15	

5.1.7 Based on the above estimates, the likelihood of producing an error is **2.63E-2**.

3.1.1-4 Truck Operator reads density chart incorrectly

5.1.8 Once the product has been weighted, the operator should make a further check utilizing a density chart. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.4**.

Table 5.4 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Truck operator reads density chart incorrectly	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.63E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.1	1.03	
		Poor / hostile environment	1.15	1	1.15	

5.1.9 Based on the above estimates, the likelihood of producing an error is **2.63E-2**.

3.1.1-5 Failure to detect error by Blasting Engineer

5.1.10 The Blasting Engineer should check that the density of the emulsion is correct. The generic HEART task type taken to represent this task is “Fairly simple task performed rapidly or given scant attention” for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 5.5**.

Table 5.5 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Blasting Engineer	0.09	Shortage of time available for error detection & correction	11	0.01	1.1	1.57E-01
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

5.1.11 Based on the above estimates, the likelihood of producing an error is **1.57E-1**.

3.1.1-6 Failure to correct error by Blasting Engineer

5.1.12 The Blasting Engineer must take action to correct identified error. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.6**.

Table 5.6 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Blasting Engineer	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.22E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

5.1.13 Based on the above estimates, the likelihood of producing an error is **5.22E-3**.

3.1.1-7 Failure to detect error by Shotfirer

5.1.14 The Shotfirer should also check that the density of the emulsion is correct before loading commences. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.7**.

Table 5.7 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to detect error by Shotfirer	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.39E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

5.1.15 Based on the above estimates, the likelihood of producing an error is **3.39E-2**.

3.1.1-8 Failure to correct error by Shotfirer

5.1.16 Once the Shotfirer has detected an error, he must communicate with the Truck Operator to correct the density. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.8**.

Table 5.8 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Failure to correct error by Shotfirer	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	5.08E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

5.1.17 Based on the above estimates, the likelihood of producing an error is **5.08E-3**.

3.1.2 Shotfirer does not Realise Hole is Overloaded

5.1.18 The overall probability that the Shotfirer not realise a hole is overloaded is **1.35E-6**, based on the failure of all the tasks analysed below.

3.1.2-1 Truck Operator inputs incorrect revolutions / weight into PLC

5.1.19 The truck operator must input the appropriate number of revolutions to deliver the correct amount of bulk emulsion. However, the Truck Operator may make an action error due to a lapse of concentration. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.9**.

Table 5.9 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Truck Operator inputs incorrect revolutions / weight into PLC	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	3.95E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.1	1.03	
		Poor / hostile environment	1.15	1	1.15	

5.1.20 Based on the above estimates, the likelihood of producing an error is **3.95E-3**.

3.1.2-2 Shotfirer puts mark on hose in the wrong place

5.1.21 The Shotfirer should mark the emulsion hose to designate the correct loading depth. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.10**.

Table 5.10 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer puts mark on hose in the wrong place	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.39E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

5.1.22 Based on the above estimates, the likelihood of producing an error is **3.39E-2**.

3.1.2-3 Shotfirer fails to detect hose marking error

5.1.23 The Shotfirer may realise before or once the emulsion begins to arrive that the hose is marked incorrectly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.11**.

Table 5.11 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect hose marking error	0.02	Shortage of time available for error detection & correction	11	0.010	1.100	3.39E-02
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	

5.1.24 Based on the above estimates, the likelihood of producing an error is **3.39E-2**.

3.1.2-4 Shotfirer fails to correct hose marking error

5.1.25 The Shotfirer must correct the error once it has been identified. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.12**.

Table 5.12 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct hose marking error	0.003	Shortage of time available for error detection & correction	11	0.010	1.100	5.08E-03
		Disruption of normal work-sleep cycles	1.1	0.100	1.010	
		High level of emotional stress	1.3	0.200	1.06	
		Channel capacity overload	6	0.050	1.250	
		Poor / hostile environment	1.15	1.000	1.15	

5.1.26 Based on the above estimates, the likelihood of producing an error is **5.08E-3**.

3.1.2-5 Truck Operator fails to check totaliser

5.1.27 The Truck Operator should obtain a print out detailing the total volume of emulsion delivered. Any differences between the volume expected and actually delivered should be highlighted. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.13**.

Table 5.13 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Truck operator fails to check totaliser	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.63E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.1	1.03	
		Poor / hostile environment	1.15	1	1.15	

5.1.28 Based on the above estimates, the likelihood of producing an error is **2.63E-2**.

3.1.2-6 Blasting Engineer fails to check totaliser

5.1.29 The Blasting Engineer should also check the print out to ensure that the actually delivered amount of emulsion match with the blast plan. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.14**.

Table 5.14 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to check totaliser	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.48E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	

5.1.30 Based on the above estimates, the likelihood of producing an error is **3.48E-2**.

5.2 Event 3.2: Wrong Design of MIC

3.2.1 Design Error by the Blasting Engineer

5.2.1 The overall probability of a design with an unsafe MIC being released to the Resident Engineer and Mines Division is **2.11E-5**, based on the failure of all the tasks analysed below.

3.2.1-1 Design Error by Blasting Engineer

5.2.2 The Blasting Engineer may design an unsafe MIC even the process involves use of a simple equation. The generic HEART task type taken to represent this task is “Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 5.15**.

Table 5.15 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Design error by Blasting Engineer	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	6.05E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

5.2.3 Based on the above estimates, the likelihood of producing an error is **6.05E-4**.

3.2.1-2 Blasting Engineer fails to detect error

5.2.4 The Blasting Engineer should utilize a modelling programme to detect any design error. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.16**.

Table 5.16 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.03E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

5.2.5 Based on the above estimates, the likelihood of producing an error is **3.03E-2**.

3.2.1-3 Blasting Engineer fails to correct error

5.2.6 The Blasting Engineer must take an action to correct the identified error during the checking phase. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.17**.

Table 5.17 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.54E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

5.2.7 Based on the above estimates, the likelihood of producing an error is **4.54E-3**.

3.2.2 Failure to Detect and Correct Design Error

5.2.8 The overall probability of failure to detect and correct the design error is **3.70E-5**, based on the failure of all the tasks analysed below.

3.2.2-1 Resident Engineer fails to detect error

5.2.9 The Resident Engineer is responsible to examine the design for potential errors. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 5.18**.

Table 5.18 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.92E-02
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

5.2.10 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

3.2.2-2 Resident Engineer fails to correct error

5.2.11 The Resident Engineer may detect the design error but fails to correct it. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 5.19**.

Table 5.19 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.37E-03
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

5.2.12 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

3.2.2-3 Mines Division fails to detect error

5.2.13 Mines Division will also check the design to ensure a safe MIC is designed. The generic HEART task type taken to represent this task is “Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 5.20**.

Table 5.20 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Mines Division fails to detect error	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	5.52E-04
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

5.2.14 Based on the above estimates, the likelihood of producing an error is **5.52E-4**.

3.2.2-4 Mines Division fails to correct error

5.2.15 Mines Division may detect the design error but fails to correct it. The generic HEART task type taken to represent this task is “Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 5.21**.

Table 5.21 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Mines Division fails to correct error	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	5.52E-04
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

5.2.16 Based on the above estimates, the likelihood of producing an error is **5.52E-4**.

6 Scenario 4: MIC Exceeded (Cartridge Emulsion)

6.1 Event 4.1: Excess Cartridges Are Loaded Into Holes

4.1.1 Excess Cartridges are Loaded into Holes

6.1.1 The overall probability of excess cartriges being loaded is **7.38E-4**, based on the failure of all the tasks analysed below.

4.1.1-1 Shotfirer does not count number of cartridges picked up and loads too many

6.1.2 The Shotfirer must count the number of cartridges being picked up, however, due to a lapse of concentration he may pick up too many cartridges. The generic HEART task type taken to represent this task is “Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 6.1**.

Table 6.1 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer does not count number of cartridges picked up and loads too many	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

6.1.3 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

4.1.2 Cartridges from Blocked Holes are not Disposed of Correctly

6.1.4 The overall probability of holes being overloaded due to incorrect disposal of additional cartridges is **8.13E-3**, based on the failure of all the tasks analysed below.

4.1.2-1 Shotfirer intentionally overloads lifter holes

6.1.5 If there are any cartridges left over due to the presence of blocked holes, the Shotfirer may not dispose them as advised by the Resident Site Staff. Instead, he may load additional cartridges into the lifter holes to ensure a good blast. The generic HEART task type taken to represent this task is “Restore or shift a system to original or new state following procedures, with some checking” for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.2**.

Table 6.2 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer intentionally overloads lifter holes	0.003	An incentive to use more dangerous procedures	2	1	2	8.13E-03
		Shortage of time available for error detection & correction	11	0.01	1.1	
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Poor / hostile environment	1.15	1	1.15	

6.1.6 Based on the above estimates, the likelihood of producing an error is **8.13E-3**.

4.1.3 Shotfirer does not realise holes are overloaded

6.1.7 The overall probability of Shotfirer not realizing that there are holes being overloaded is **2.45E-5**, based on the failure of all the tasks analysed below.

4.1.3-1 Shotfirer collects too many kgs of cartridge from the magazine

6.1.8 The Shotfirer must collect only the exact number of cartridges from the magazine to ensure that holes will not be overloaded. The generic HEART task type taken to represent this task is “Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 6.3**.

Table 6.3 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer collects too many kgs of cartridge from the magazine	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	5.89E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.1.9 Based on the above estimates, the likelihood of producing an error is **5.89E-4**.

4.1.3-2 Shotfirer fails to detect collection error

6.1.10 The Shotfirer should check that he has collect the correct amount of cartridges from the magazine. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 6.4**.

Table 6.4 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to detect collection error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.94E-02
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.1.11 Based on the above estimates, the likelihood of producing an error is **2.94E-2**.

4.1.3-3 Shotfirer fails to correct collection error

6.1.12 The Shotfirer should correct any identified error to ensure only the exact number of cartridges are delivered to the blasting site. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.5**.

Table 6.5 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to correct collection error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.42E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.1.13 Based on the above estimates, the likelihood of producing an error is **4.42E-3**.

4.1.3-4 Resident Engineer's Inspector fails to detect collection error

6.1.14 The Resident Engineer's Inspector should check the number of cartridges selected before they leave the magazine. The generic HEART task type taken to represent this task is "Fairly simple task performed rapidly or given scant attention" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 6.6**.

Table 6.6 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer's Inspector fails to detect collection error	0.09	Shortage of time available for error detection & correction	11	0.01	1.1	1.32E-01
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.1.15 Based on the above estimates, the likelihood of producing an error is **1.32E-1**.

4.1.3-5 Resident Engineer's Inspector fails to correct collection error

6.1.16 The Resident Engineer's Inspector should correct any identified error to ensure only the exact number of cartridges are delivered to the blasting site. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.7**.

Table 6.7 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer's Inspector fails to correct collection error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.39E-03
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.1.17 Based on the above estimates, the likelihood of producing an error is **4.39E-3**.

4.1.3-6 Contractor's Representative fails to detect collection error

6.1.18 The Contractor's Representative should also check the number of cartridges selected before they leave the magazine. The generic HEART task type taken to represent this task is "Fairly simple task performed rapidly or given scant attention" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 6.8**.

Table 6.8 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Contractor's Representative fails to detect collection error	0.09	Shortage of time available for error detection & correction	11	0.01	1.1	1.28E-01
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.1	1.03	
		Channel capacity overload	6	0.05	1.25	

6.1.19 Based on the above estimates, the likelihood of producing an error is **1.28E-1**.

4.1.3-7 Contractor's Representative fails to correct collection error

6.1.20 The Contractor's Representative should correct any identified error to ensure only the exact number of cartridges are delivered to the blasting site. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.9**.

Table 6.9 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Contractor's Representative fails to correct collection error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.16E-03
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

6.1.21 Based on the above estimates, the likelihood of producing an error is **4.16E-3**.

4.1.3-8 Shotfirer fails to check for any remaining detonator bundles

6.1.22 If there are any detonator bundles remaining on the face, the Shotfirer has not yet loaded any emulsion and attached the detonator. The generic HEART task type taken to represent this task is "Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids" for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 6.10**.

Table 6.10 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check for any remaining detonator bundles	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	6.95E-04
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

6.1.23 Based on the above estimates, the likelihood of producing an error is **6.95E-4**.

4.1.3-9 Blasting Engineer fails to check face for remaining detonator bundles / empty holes

6.1.24 The Blasting Engineer should check if there are any detonator bundles remaining on the face. The generic HEART task type taken to represent this task is "Routine, highly practiced, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 6.11**.

Table 6.11 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to check face for remaining bundles / empty holes	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.47E-02
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

6.1.25 Based on the above estimates, the likelihood of producing an error is **3.47E-2**.

4.1.4 Shotfirer / Blasting Engineer / Blasting Competent Supervisor do not realise the cartridges left over due to presence of blocked holes are not disposed of

6.1.26 The overall probability of the Shotfirer / Blasting Engineer / Blasting Competent Supervisor not realizing that the cartridges left over due to presence of blocked holes are not disposed of is **1.78E-8**, based on the failure of all the tasks analysed below.

4.1.4-1 Shotfirer fails to check for remaining cartridges leftover due to blocked holes

6.1.27 A Shotfirer may not dispose of the cartridges left over due to the presence of blocked holes and load additional cartridges into the lifter holes. The generic HEART task type taken to represent this task is "Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 6.12**.

Table 6.12 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Shotfirer fails to check for remaining cartridges leftover due to blocked holes	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	6.95E-04
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

6.1.28 Based on the above estimates, the likelihood of producing an error is **6.95E-4**.

4.1.4-2 Blasting Engineer fails to check for remaining cartridges leftover due to blocked holes

6.1.29 The Blasting Engineer will also be aware of the presence of blocked holes and check if cartridges are disposed of correctly. The generic HEART task type taken to represent this task is “Routine, highly practiced, rapid task involving relatively low level of skill” for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 6.13**.

Table 6.13 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to check for remaining cartridges leftover due to blocked holes	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	3.47E-02
		Disruption of normal work-sleep cycles	1.1	0.05	1.005	
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

6.1.30 Based on the above estimates, the likelihood of producing an error is **3.47E-2**.

4.1.4-3 Blasting Competent Supervisor fails to check for remaining cartridges leftover due to blocked holes

6.1.31 The Blasting Competent Supervisor will also be aware of the presence of blocked holes and check if cartridges are disposed of correctly. The generic HEART task type taken to represent this task is “Completely familiar, well design, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids” for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 6.14**.

Table 6.14 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Competent Supervisor fails to check for remaining cartridges leftover due to blocked holes	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	7.38E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	
		Poor / hostile environment	1.15	1	1.15	
		Low signal-noise ratio	10	0.01	1.09	

6.1.32 Based on the above estimates, the likelihood of producing an error is **7.38E-4**.

6.2 Event 4.2: Wrong Design of MIC

4.2.1 Design Error by the Blasting Engineer

6.2.1 The overall probability of a design with an unsafe MIC being released to the Resident Engineer and Mines Division is **8.52E-5**, based on the failure of all the tasks analysed below.

4.2.1-1 Design Error by Blasting Engineer

6.2.2 The Blasting Engineer may design an unsafe MIC even the process involves use of a simple equation. The generic HEART task type taken to represent this task is "Completely familiar, well designed, highly practiced, routine task occurring several times per hour, performed to highest possible standards by highly motivated and experienced person, totally aware of the implications of failure, with time to correct potential error, but without the benefit of significant job aids" for which the nominal unreliability is 0.0004. The EPCs and their impacts are shown in **Table 6.15**.

Table 6.15 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Design error by Blasting Engineer	0.0004	Shortage of time available for error detection & correction	11	0.01	1.1	6.05E-04
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

6.2.3 Based on the above estimates, the likelihood of producing an error is **6.05E-4**.

4.2.1-2 Blasting Engineer fails to detect error

6.2.4 The Blasting Engineer should utilize a modelling programme to detect any design error. The generic HEART task type taken to represent this task is "Fairly simple task performed rapidly or given scant attention" for which the nominal unreliability is 0.09. The EPCs and their impacts are shown in **Table 6.16**.

Table 6.16 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to detect error	0.09	Shortage of time available for error detection & correction	11	0.01	1.1	1.36E-01
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

6.2.5 Based on the above estimates, the likelihood of producing an error is **1.36E-1**.

4.2.1-3 Blasting Engineer fails to correct error

6.2.6 The Blasting Engineer must take an action to correct the identified error during the checking phase. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.17**.

Table 6.17 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Blasting Engineer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.54E-03
		Disruption of normal work-sleep cycles	1.1	0.1	1.01	
		High level of emotional stress	1.3	0.3	1.09	
		Channel capacity overload	6	0.05	1.25	

6.2.7 Based on the above estimates, the likelihood of producing an error is **4.54E-3**.

4.2.2 Failure to Detect and Correct Design Error

6.2.8 The overall probability of failure to detect and correct the design error is **1.06E-3**, based on the failure of all the tasks analysed below.

4.2.2-1 Resident Engineer fails to detect error

6.2.9 The Resident Engineer is responsible to examine the design for potential errors. The generic HEART task type taken to represent this task is "Routine, highly practiced, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 6.18**.

Table 6.18 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.92E-02
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.2.10 Based on the above estimates, the likelihood of producing an error is **2.92E-2**.

4.2.2-2 Resident Engineer fails to correct error

6.2.11 The Resident Engineer may detect the design error but fails to correct it. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.19**.

Table 6.19 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Resident Engineer fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.37E-03
		High level of emotional stress	1.3	0.2	1.06	
		Channel capacity overload	6	0.05	1.25	

6.2.12 Based on the above estimates, the likelihood of producing an error is **4.37E-3**.

4.2.2-3 Mines Division fails to detect error

6.2.13 Mines Division will also check the design to ensure a safe MIC is designed. The generic HEART task type taken to represent this task is "Routine, highly practiced, rapid task involving relatively low level of skill" for which the nominal unreliability is 0.02. The EPCs and their impacts are shown in **Table 6.20**.

Table 6.20 HEART Calculation

Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Mines Division fails to detect error	0.02	Shortage of time available for error detection & correction	11	0.01	1.1	2.76E-02
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

6.2.14 Based on the above estimates, the likelihood of producing an error is **2.76E-2**.

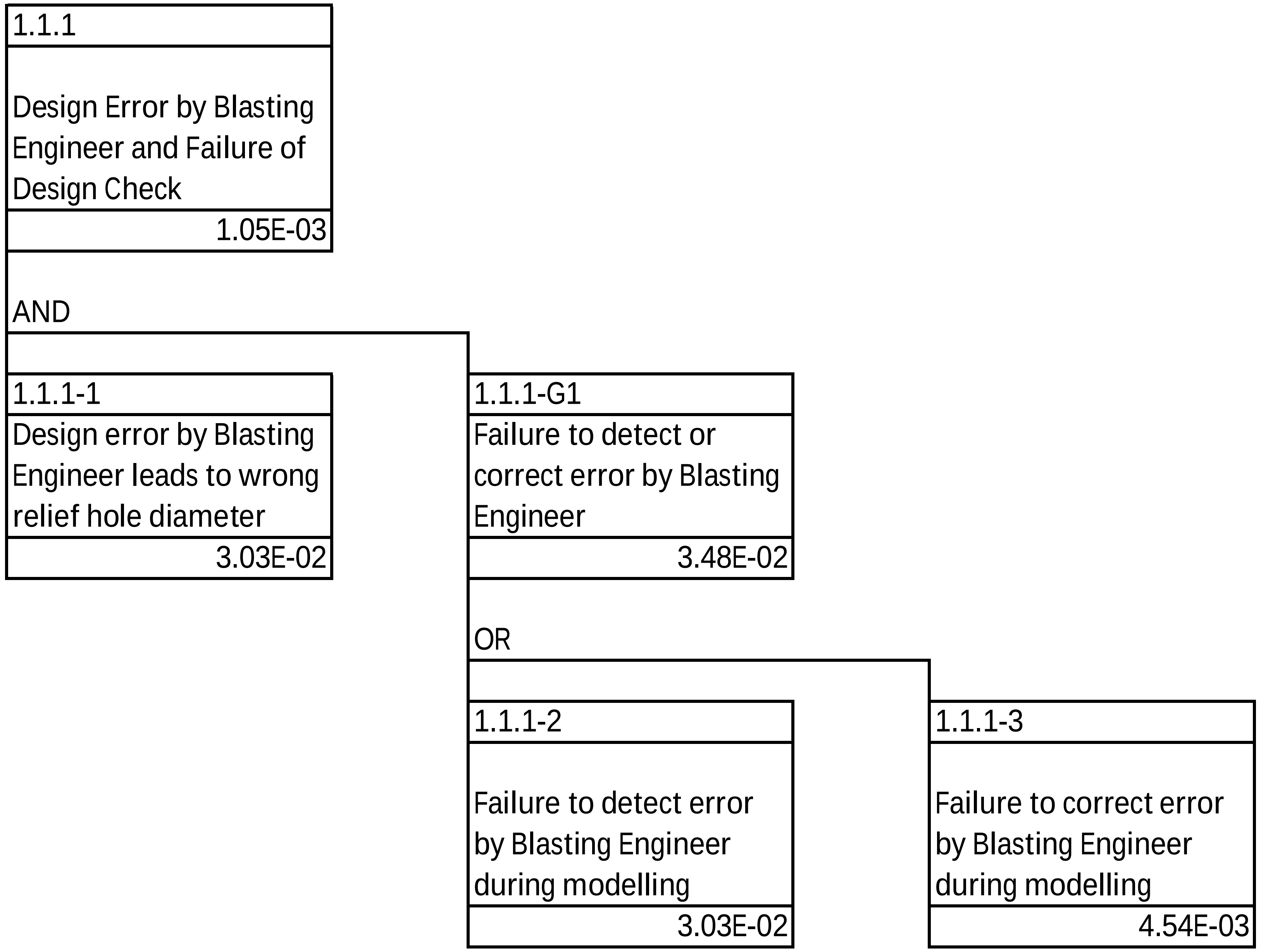
4.2.2-4 Mines Division fails to correct error

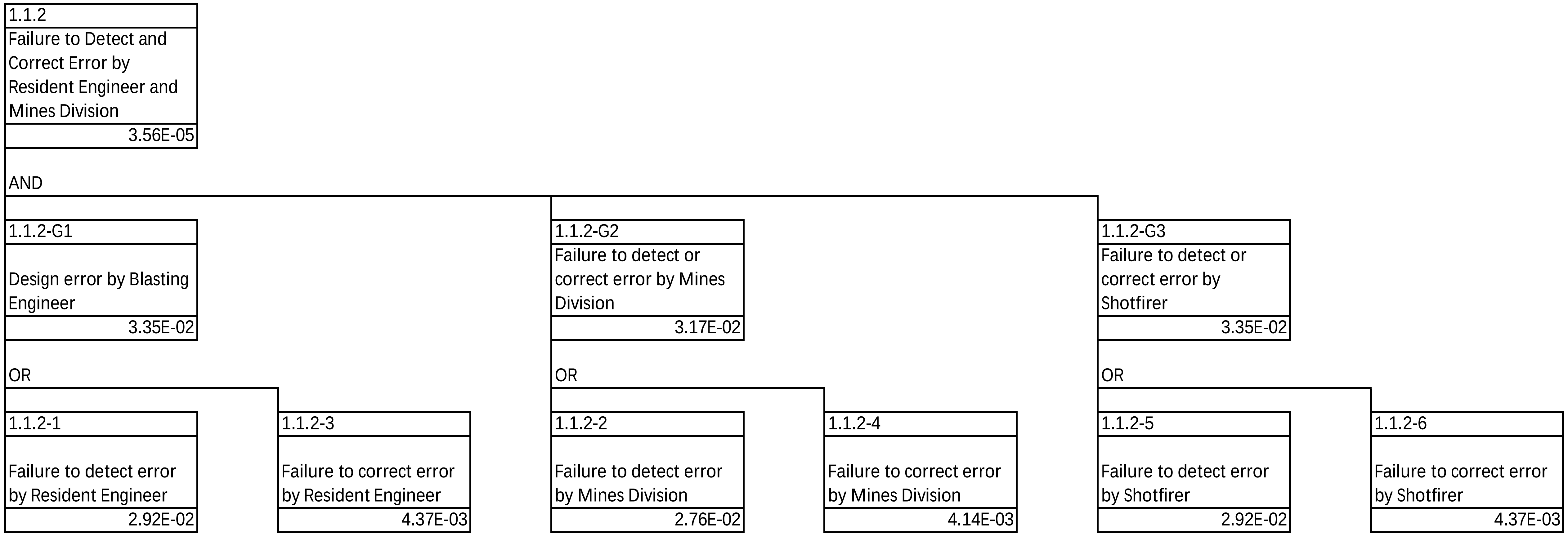
6.2.15 Mines Division may detect the design error but fails to correct it. The generic HEART task type taken to represent this task is "Restore or shift a system to original or new state following procedures, with some checking" for which the nominal unreliability is 0.003. The EPCs and their impacts are shown in **Table 6.21**.

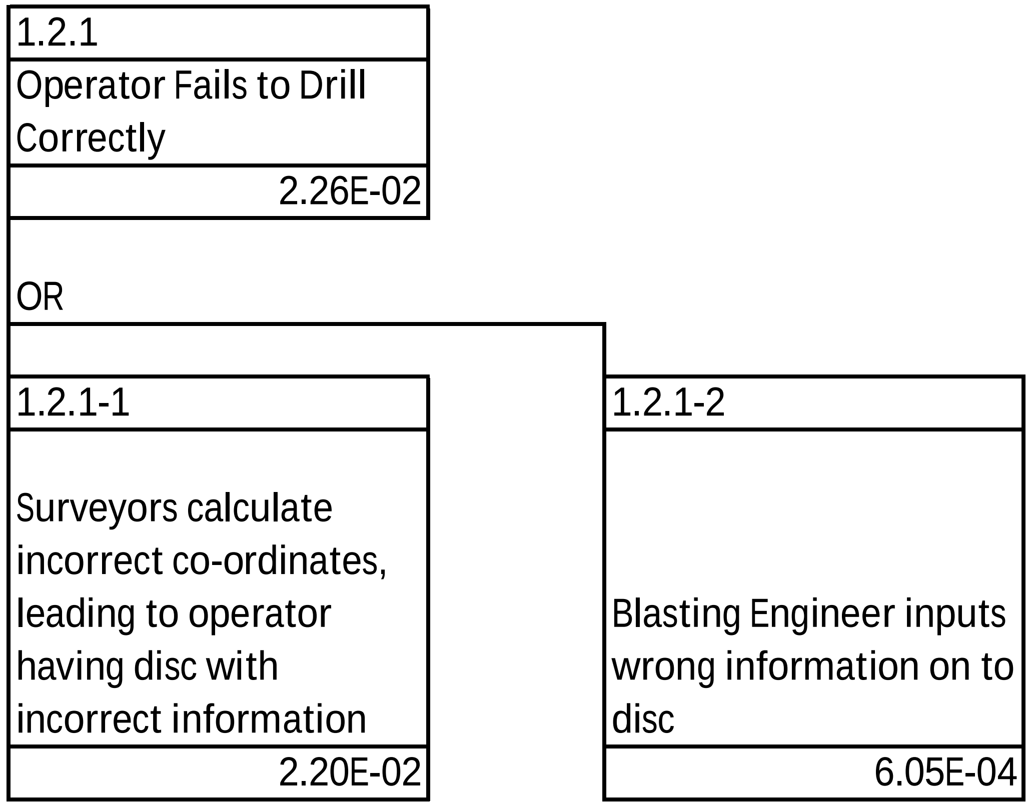
Table 6.21 HEART Calculation

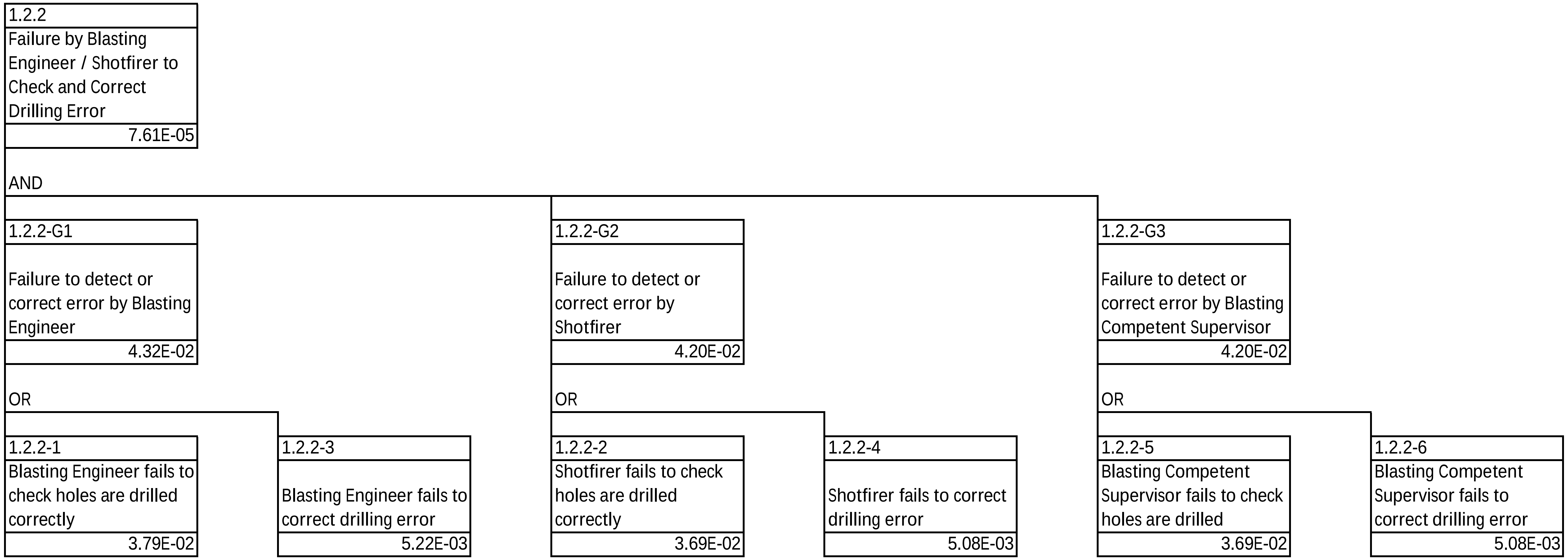
Task	Generic task unreliability	EPCs	Multiplier	Assessed Proportion of Effect	Assessed Effect	Human Error Probability
Mines Division fails to correct error	0.003	Shortage of time available for error detection & correction	11	0.01	1.1	4.14E-03
		High level of emotional stress	1.3	0.01	1.003	
		Channel capacity overload	6	0.05	1.25	

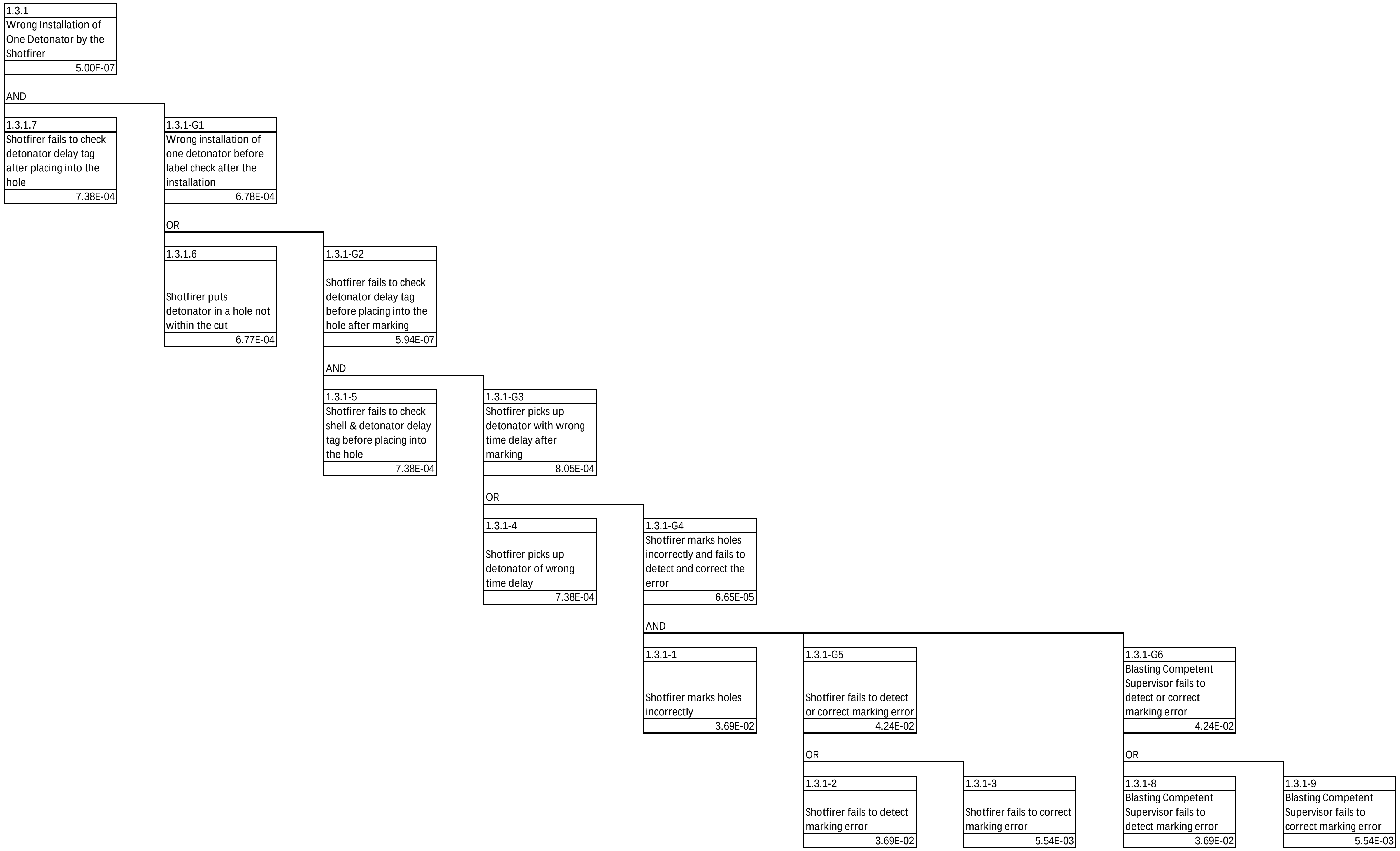
6.2.16 Based on the above estimates, the likelihood of producing an error is **4.14E-3**.

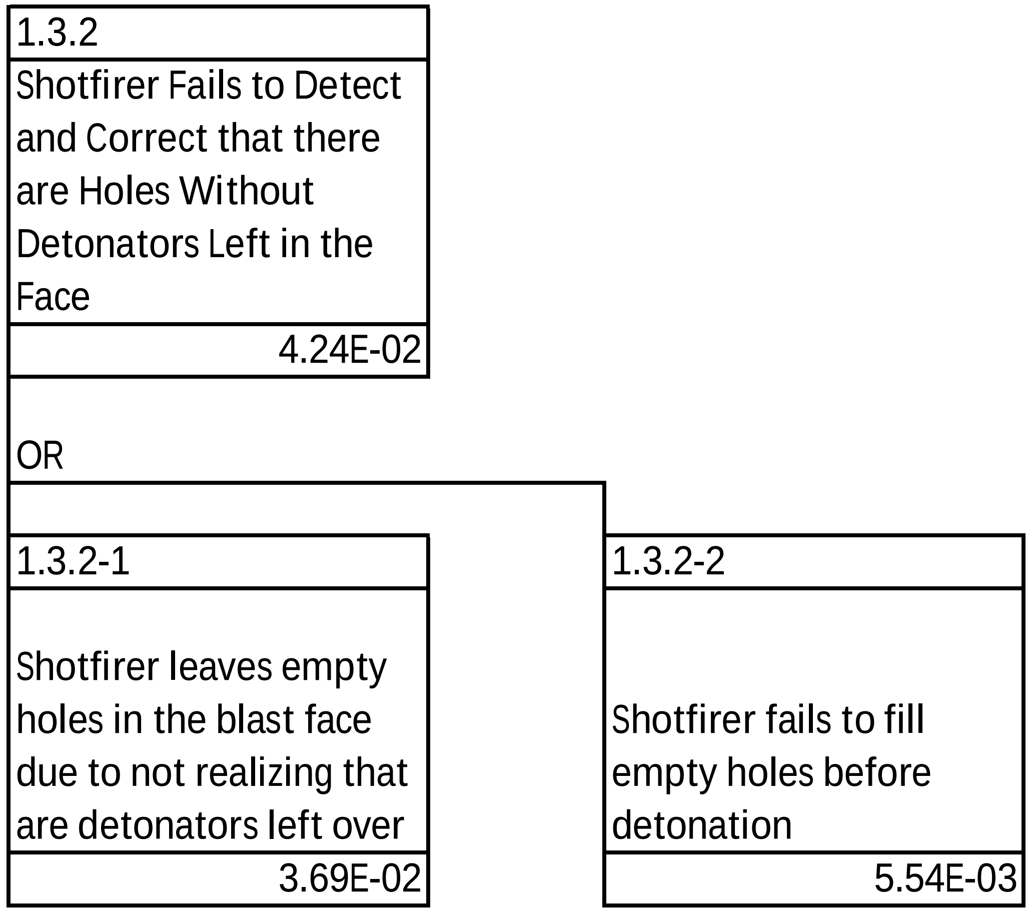

1.1.1
Design Error by Blasting Engineer and Failure of Design Check
1.05E-03
AND
1.1.1-1
Design error by Blasting Engineer leads to wrong relief hole diameter
3.03E-02
1.1.1-G1
Failure to detect or correct error by Blasting Engineer
3.48E-02
OR
1.1.1-2
Failure to detect error by Blasting Engineer during modelling
3.03E-02
1.1.1-3
Failure to correct error by Blasting Engineer during modelling
4.54E-03

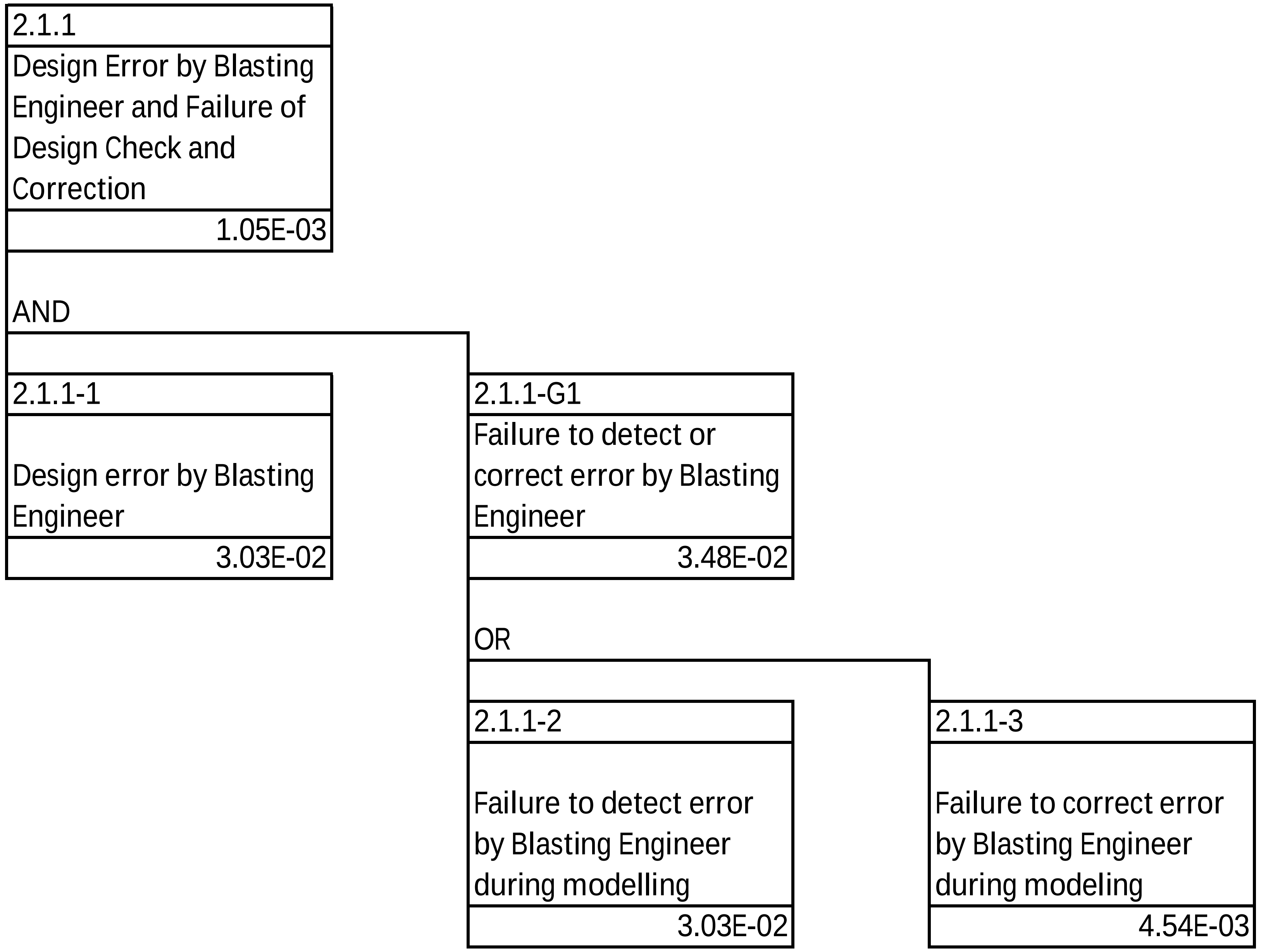

1.1.2
Failure to Detect and Correct Error by Resident Engineer and Mines Division
3.56E-05
AND
1.1.2-G1
Design error by Blasting Engineer
3.35E-02
1.1.2-G2
Failure to detect or correct error by Mines Division
3.17E-02
1.1.2-G3
Failure to detect or correct error by Shotfirer
3.35E-02
OR
OR
OR
1.1.2-1
Failure to detect error by Resident Engineer
2.92E-02
1.1.2-3
Failure to correct error by Resident Engineer
4.37E-03
1.1.2-2
Failure to detect error by Mines Division
2.76E-02
1.1.2-4
Failure to correct error by Mines Division
4.14E-03
1.1.2-5
Failure to detect error by Shotfirer
2.92E-02
1.1.2-6
Failure to correct error by Shotfirer
4.37E-03

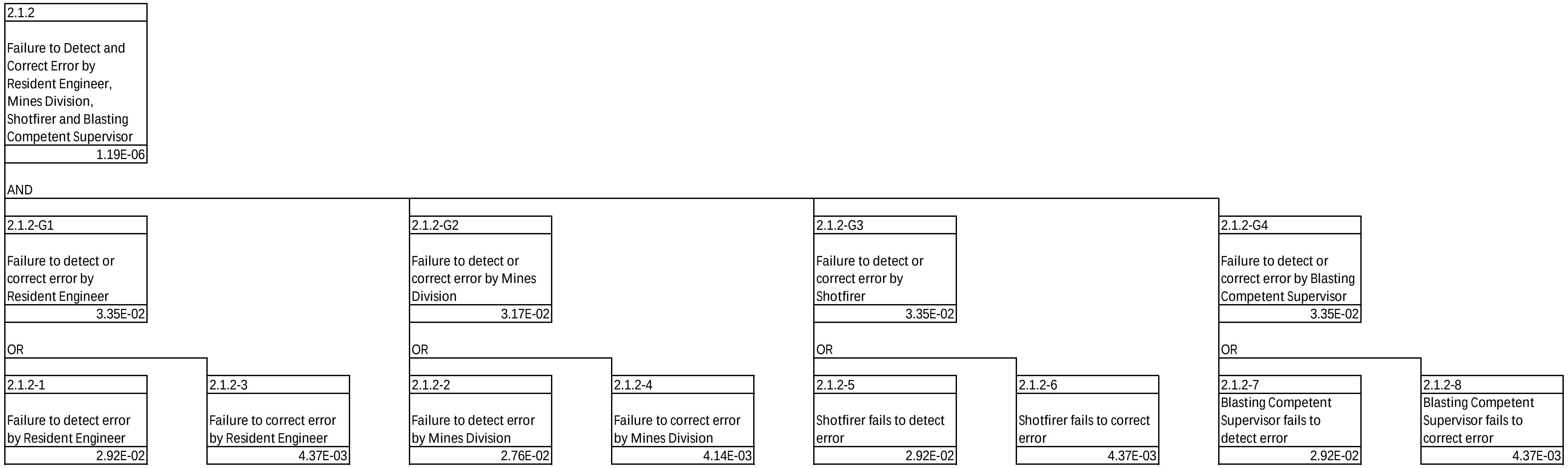

1.2.1
Operator Fails to Drill Correctly
2.26E-02
OR
1.2.1-1
Surveyors calculate incorrect co-ordinates, leading to operator having disc with incorrect information
2.20E-02
1.2.1-2
Blasting Engineer inputs wrong information on to disc
6.05E-04

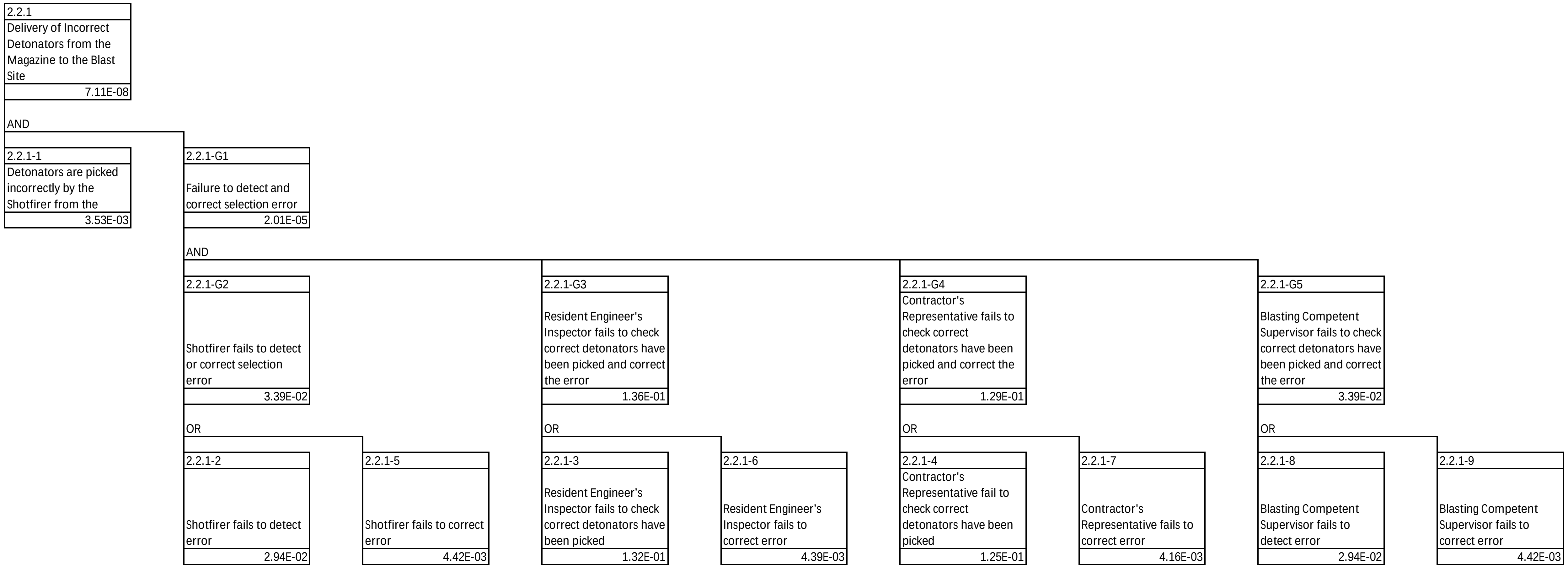

1.2.2
Failure by Blasting Engineer / Shotfirer to Check and Correct Drilling Error
7.61E-05
AND
1.2.2-G1
Failure to detect or correct error by Blasting Engineer
4.32E-02
1.2.2-G2
Failure to detect or correct error by Shotfirer
4.20E-02
1.2.2-G3
Failure to detect or correct error by Blasting Competent Supervisor
4.20E-02
OR
1.2.2-1
Blasting Engineer fails to check holes are drilled correctly
3.79E-02
1.2.2-3
Blasting Engineer fails to correct drilling error
5.22E-03
OR
1.2.2-2
Shotfirer fails to check holes are drilled correctly
3.69E-02
1.2.2-4
Shotfirer fails to correct drilling error
5.08E-03
OR
1.2.2-5
Blasting Competent Supervisor fails to check holes are drilled
3.69E-02
1.2.2-6
Blasting Competent Supervisor fails to correct drilling error
5.08E-03

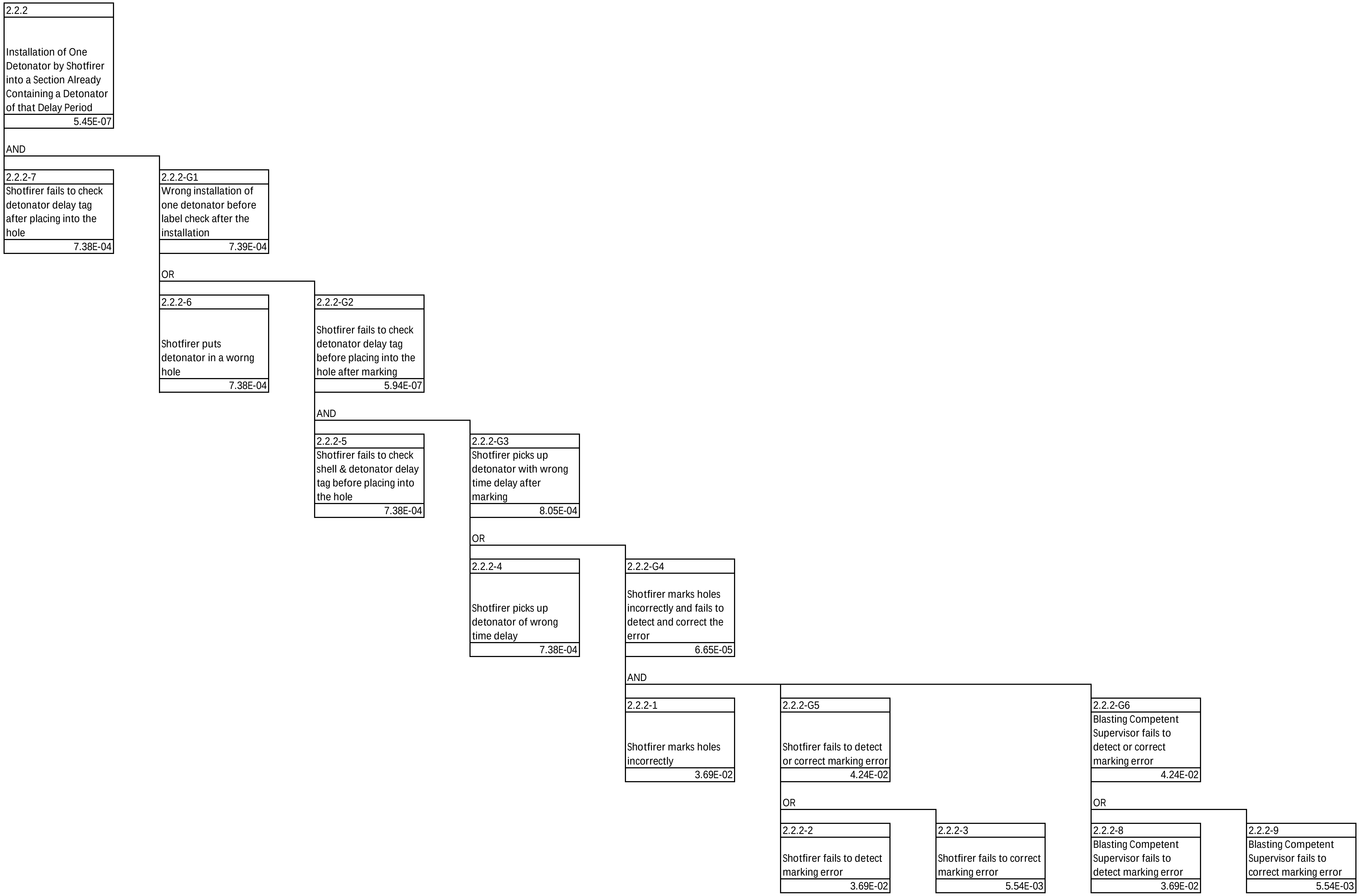

1.3.1
Wrong Installation of One Detonator by the Shotfirer
5.00E-07
AND
1.3.1.7
Shotfirer fails to check detonator delay tag after placing into the hole
7.38E-04
1.3.1-G1
Wrong installation of one detonator before label check after the installation
6.78E-04
OR
1.3.1.6
Shotfirer puts detonator in a hole not within the cut
6.77E-04
1.3.1-G2
Shotfirer fails to check detonator delay tag before placing into the hole after marking
5.94E-07
AND
1.3.1-5
Shotfirer fails to check shell & detonator delay tag before placing into the hole
7.38E-04
1.3.1-G3
Shotfirer picks up detonator with wrong time delay after marking
8.05E-04
OR
1.3.1-4
Shotfirer picks up detonator of wrong time delay
7.38E-04
1.3.1-G4
Shotfirer marks holes incorrectly and fails to detect and correct the error
6.65E-05
AND
1.3.1-1
Shotfirer marks holes incorrectly
3.69E-02
1.3.1-G5
Shotfirer fails to detect or correct marking error
4.24E-02
1.3.1-G6
Blasting Competent Supervisor fails to detect or correct marking error
4.24E-02
OR
1.3.1-2
Shotfirer fails to detect marking error
3.69E-02
1.3.1-3
Shotfirer fails to correct marking error
5.54E-03
OR
1.3.1-8
Blasting Competent Supervisor fails to detect marking error
3.69E-02
1.3.1-9
Blasting Competent Supervisor fails to correct marking error
5.54E-03

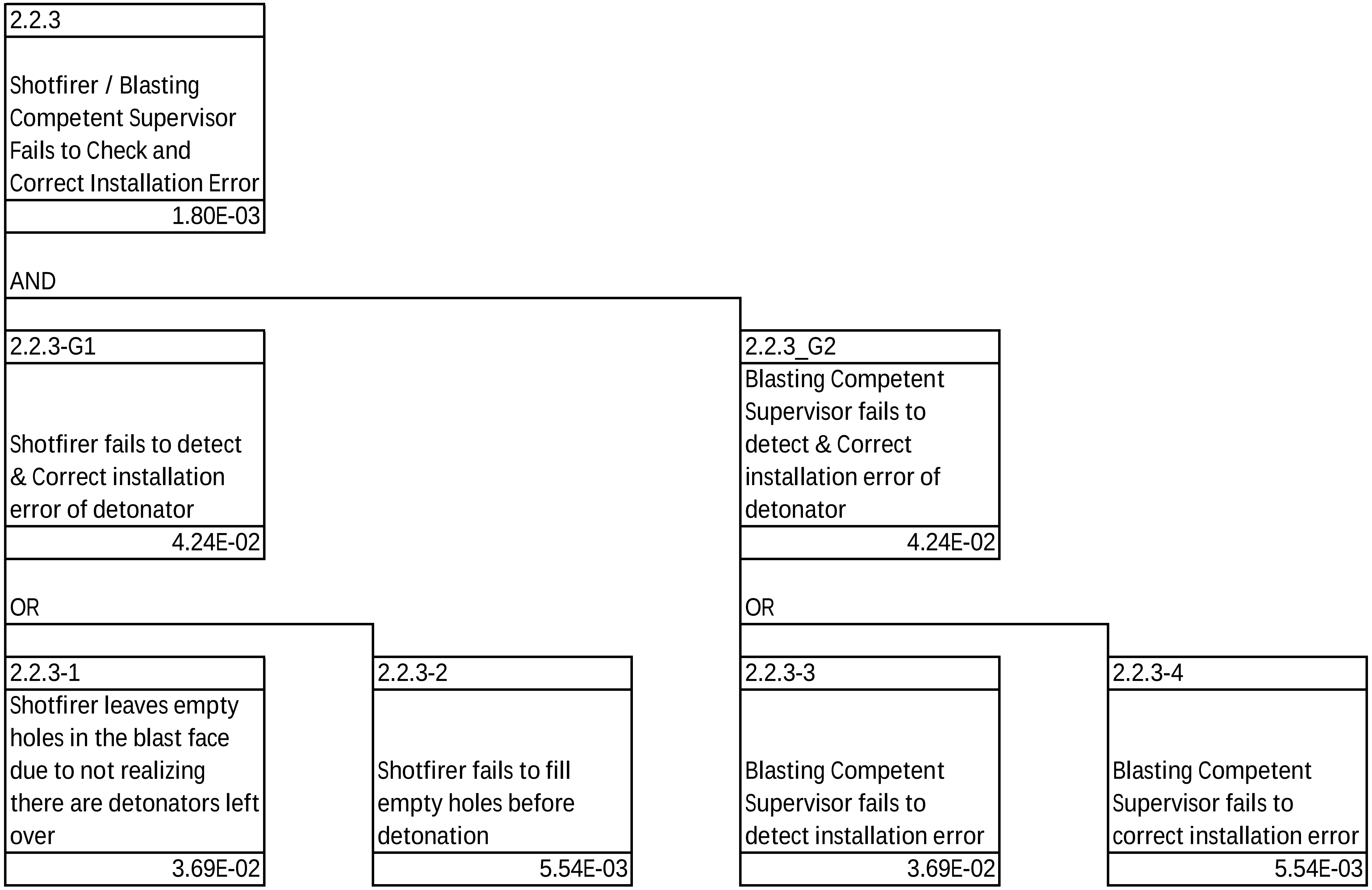

1.3.2
Shotfirer Fails to Detect and Correct that there are Holes Without Detonators Left in the Face
4.24E-02
OR
1.3.2-1
Shotfirer leaves empty holes in the blast face due to not realizing that are detonators left over
3.69E-02
1.3.2-2
Shotfirer fails to fill empty holes before detonation
5.54E-03


2.1.1
Design Error by Blasting Engineer and Failure of Design Check and Correction
1.05E-03
AND
2.1.1-1
Design error by Blasting Engineer
3.03E-02
2.1.1-G1
Failure to detect or correct error by Blasting Engineer
3.48E-02
OR
2.1.1-2
Failure to detect error by Blasting Engineer during modelling
3.03E-02
2.1.1-3
Failure to correct error by Blasting Engineer during modeling
4.54E-03


2.1.2
Failure to Detect and Correct Error by Resident Engineer, Mines Division, Shotfirer and Blasting Competent Supervisor
1.19E-06
AND
2.1.2-G1
Failure to detect or correct error by Resident Engineer
3.35E-02
2.1.2-G2
Failure to detect or correct error by Mines Division
3.17E-02
2.1.2-G3
Failure to detect or correct error by Shotfirer
3.35E-02
2.1.2-G4
Failure to detect or correct error by Blasting Competent Supervisor
3.35E-02
OR
2.1.2-1
Failure to detect error by Resident Engineer
2.92E-02
2.1.2-3
Failure to correct error by Resident Engineer
4.37E-03
OR
2.1.2-2
Failure to detect error by Mines Division
2.76E-02
2.1.2-4
Failure to correct error by Mines Division
4.14E-03
OR
2.1.2-5
Shotfirer fails to detect error
2.92E-02
2.1.2-6
Shotfirer fails to correct error
4.37E-03
OR
2.1.2-7
Blasting Competent Supervisor fails to detect error
2.92E-02
2.1.2-8
Blasting Competent Supervisor fails to correct error
4.37E-03


2.2.1
Delivery of Incorrect Detonators from the Magazine to the Blast Site
7.11E-08
AND
2.2.1-1
Detonators are picked incorrectly by the Shotfirer from the
3.53E-03
2.2.1-G1
Failure to detect and correct selection error
2.01E-05
AND
2.2.1-G2
Shotfirer fails to detect or correct selection error
3.39E-02
2.2.1-G3
Resident Engineer's Inspector fails to check correct detonators have been picked and correct the error
1.36E-01
2.2.1-G4
Contractor's Representative fails to check correct detonators have been picked and correct the error
1.29E-01
2.2.1-G5
Blasting Competent Supervisor fails to check correct detonators have been picked and correct the error
3.39E-02
OR
2.2.1-2
Shotfirer fails to detect error
2.94E-02
2.2.1-5
Shotfirer fails to correct error
4.42E-03
OR
2.2.1-3
Resident Engineer's Inspector fails to check correct detonators have been picked
1.32E-01
2.2.1-6
Resident Engineer's Inspector fails to correct error
4.39E-03
OR
2.2.1-4
Contractor's Representative fail to check correct detonators have been picked
1.25E-01
2.2.1-7
Contractor's Representative fails to correct error
4.16E-03
OR
2.2.1-8
Blasting Competent Supervisor fails to detect error
2.94E-02
2.2.1-9
Blasting Competent Supervisor fails to correct error
4.42E-03


2.2.2
Installation of One Detonator by Shotfirer into a Section Already Containing a Detonator of that Delay Period
5.45E-07
AND
2.2.2-7
Shotfirer fails to check detonator delay tag after placing into the hole
7.38E-04
2.2.2-G1
Wrong installation of one detonator before label check after the installation
7.39E-04
OR
2.2.2-6
Shotfirer puts detonator in a worng hole
7.38E-04
2.2.2-G2
Shotfirer fails to check detonator delay tag before placing into the hole after marking
5.94E-07
AND
2.2.2-5
Shotfirer fails to check shell & detonator delay tag before placing into the hole
7.38E-04
2.2.2-G3
Shotfirer picks up detonator with wrong time delay after marking
8.05E-04
OR
2.2.2-4
Shotfirer picks up detonator of wrong time delay
7.38E-04
2.2.2-G4
Shotfirer marks holes incorrectly and fails to detect and correct the error
6.65E-05
AND
2.2.2-1
Shotfirer marks holes incorrectly
3.69E-02
2.2.2-G5
Shotfirer fails to detect or correct marking error
4.24E-02
2.2.2-G6
Blasting Competent Supervisor fails to detect or correct marking error
4.24E-02
OR
2.2.2-2
Shotfirer fails to detect marking error
3.69E-02
2.2.2-3
Shotfirer fails to correct marking error
5.54E-03
OR
2.2.2-8
Blasting Competent Supervisor fails to detect marking error
3.69E-02
2.2.2-9
Blasting Competent Supervisor fails to correct marking error
5.54E-03



2.2.3
Shotfirer / Blasting Competent Supervisor Fails to Check and Correct Installation Error
1.80E-03

AND

2.2.3-G1
Shotfirer fails to detect & Correct installation error of detonator
4.24E-02

OR

2.2.3-1
Shotfirer leaves empty holes in the blast face due to not realizing there are detonators left over
3.69E-02

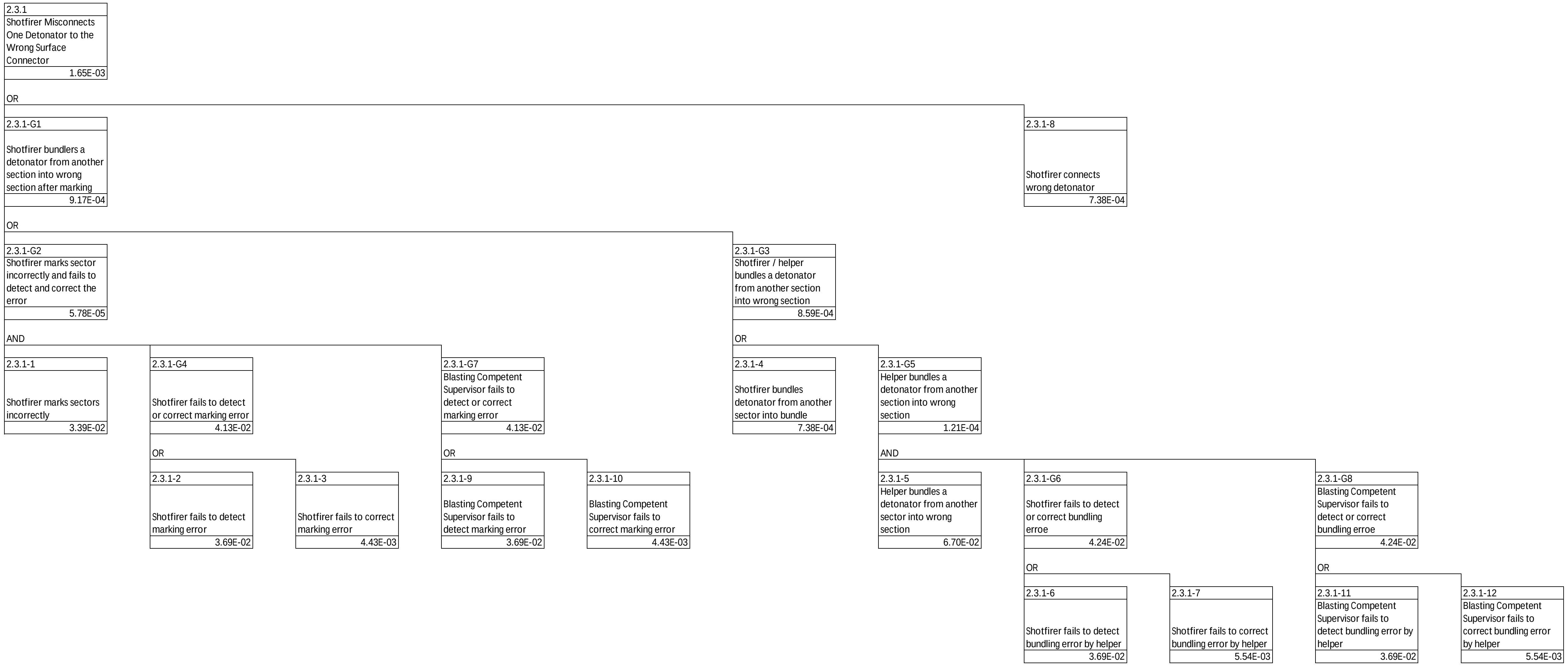
2.2.3-2
Shotfirer fails to fill empty holes before detonation
5.54E-03

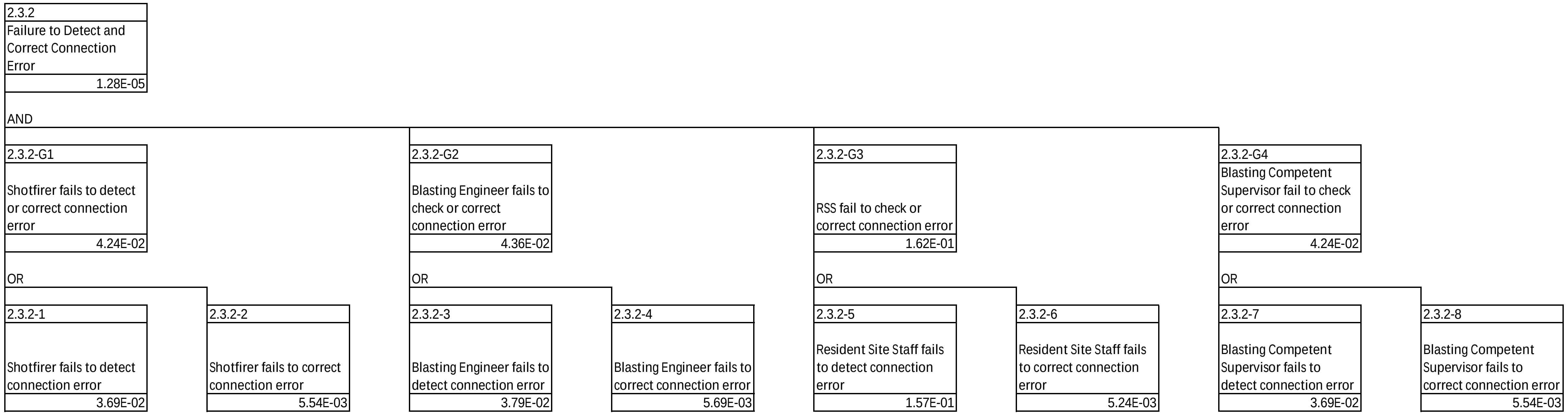
2.2.3_G2
Blasting Competent Supervisor fails to detect & Correct installation error of detonator
4.24E-02

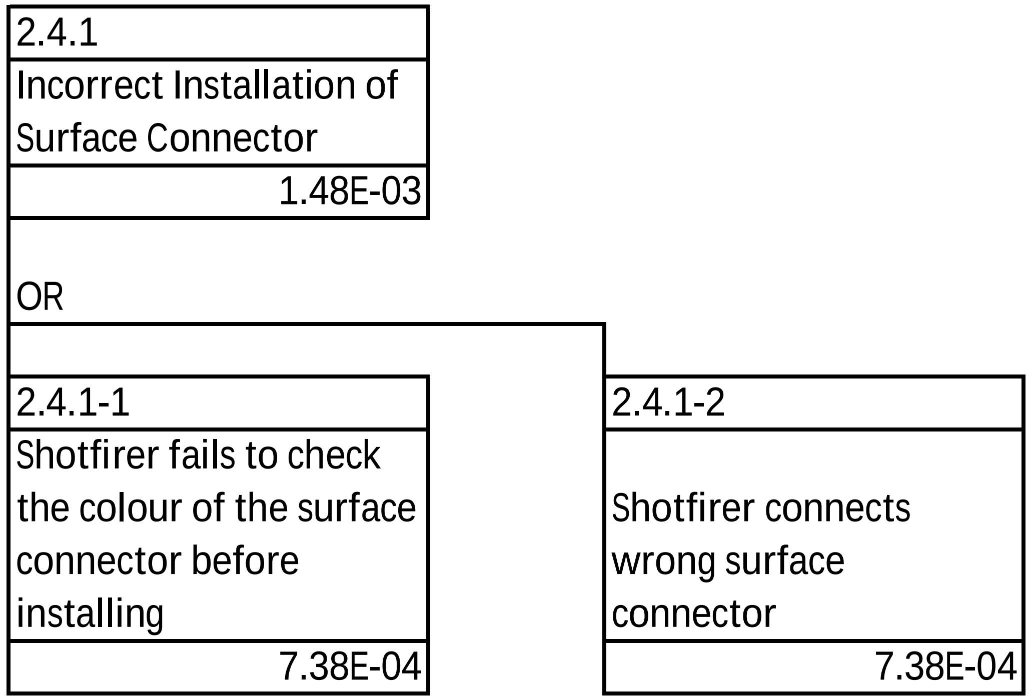
OR

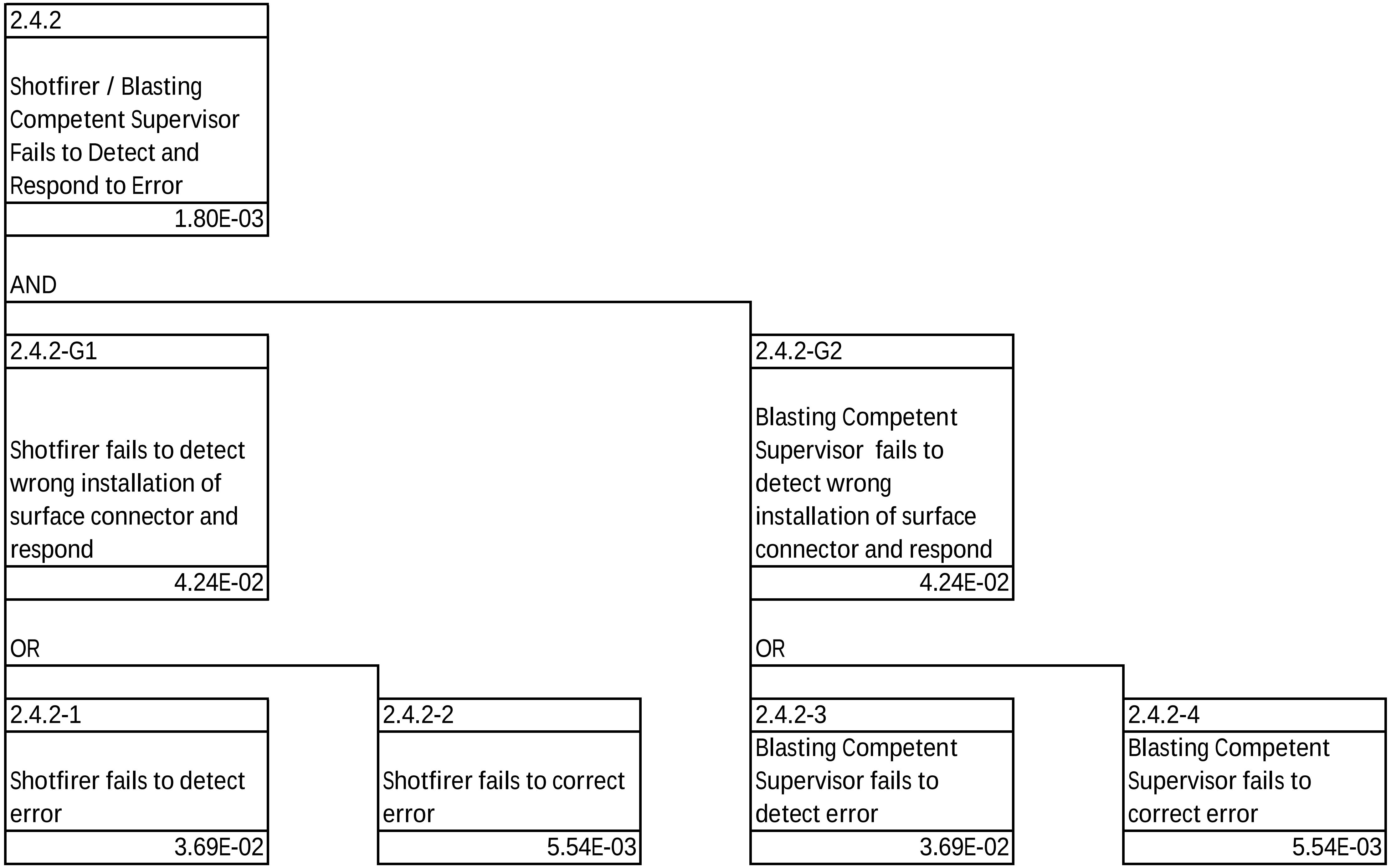
2.2.3-3
Blasting Competent Supervisor fails to detect installation error
3.69E-02

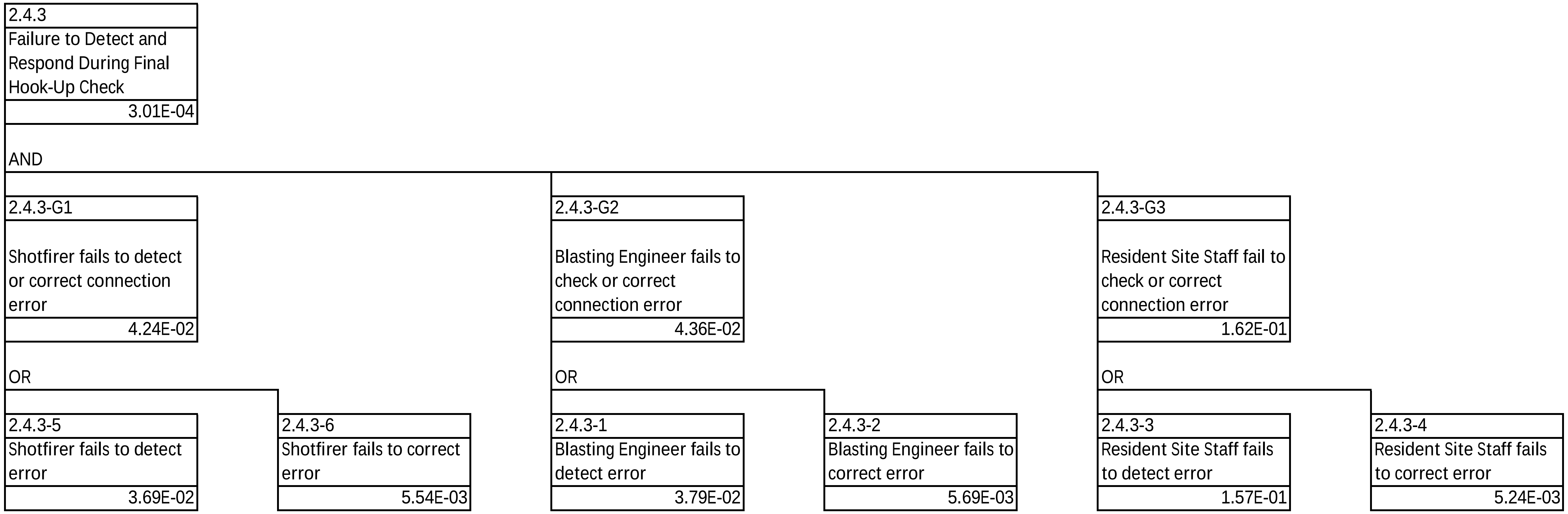
2.2.3-4
Blasting Competent Supervisor fails to correct installation error
5.54E-03

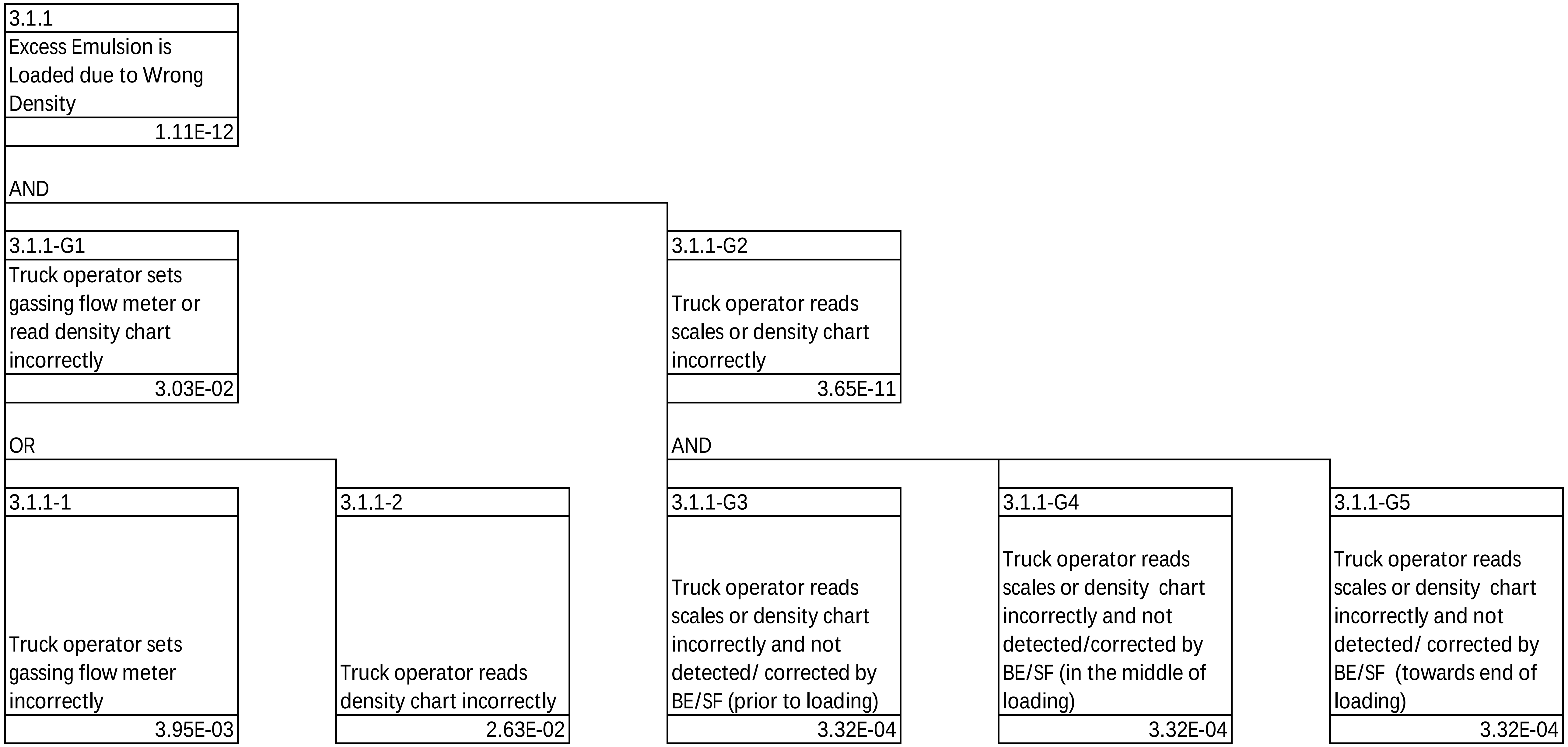

2.3.1
Shotfirer Misconnects One Detonator to the Wrong Surface Connector
1.65E-03
OR
2.3.1-G1
Shotfirer bundlers a detonator from another section into wrong section after marking
9.17E-04
2.3.1-8
Shotfirer connects wrong detonator
7.38E-04
OR
2.3.1-G2
Shotfirer marks sector incorrectly and fails to detect and correct the error
5.78E-05
2.3.1-G3
Shotfirer / helper bundles a detonator from another section into wrong section
8.59E-04
AND
2.3.1-1
Shotfirer marks sectors incorrectly
3.39E-02
2.3.1-G4
Shotfirer fails to detect or correct marking error
4.13E-02
2.3.1-G7
Blasting Competent Supervisor fails to detect or correct marking error
4.13E-02
OR
2.3.1-4
Shotfirer bundles detonator from another sector into bundle
7.38E-04
2.3.1-G5
Helper bundles a detonator from another section into wrong section
1.21E-04
OR
2.3.1-2
Shotfirer fails to detect marking error
3.69E-02
2.3.1-3
Shotfirer fails to correct marking error
4.43E-03
OR
2.3.1-9
Blasting Competent Supervisor fails to detect marking error
3.69E-02
2.3.1-10
Blasting Competent Supervisor fails to correct marking error
4.43E-03
AND
2.3.1-5
Helper bundles a detonator from another sector into wrong section
6.70E-02
2.3.1-G6
Shotfirer fails to detect or correct bundling erroe
4.24E-02
2.3.1-G8
Blasting Competent Supervisor fails to detect or correct bundling erroe
4.24E-02
OR
2.3.1-6
Shotfirer fails to detect bundling error by helper
3.69E-02
2.3.1-7
Shotfirer fails to correct bundling error by helper
5.54E-03
OR
2.3.1-11
Blasting Competent Supervisor fails to detect bundling error by helper
3.69E-02
2.3.1-12
Blasting Competent Supervisor fails to correct bundling error by helper
5.54E-03

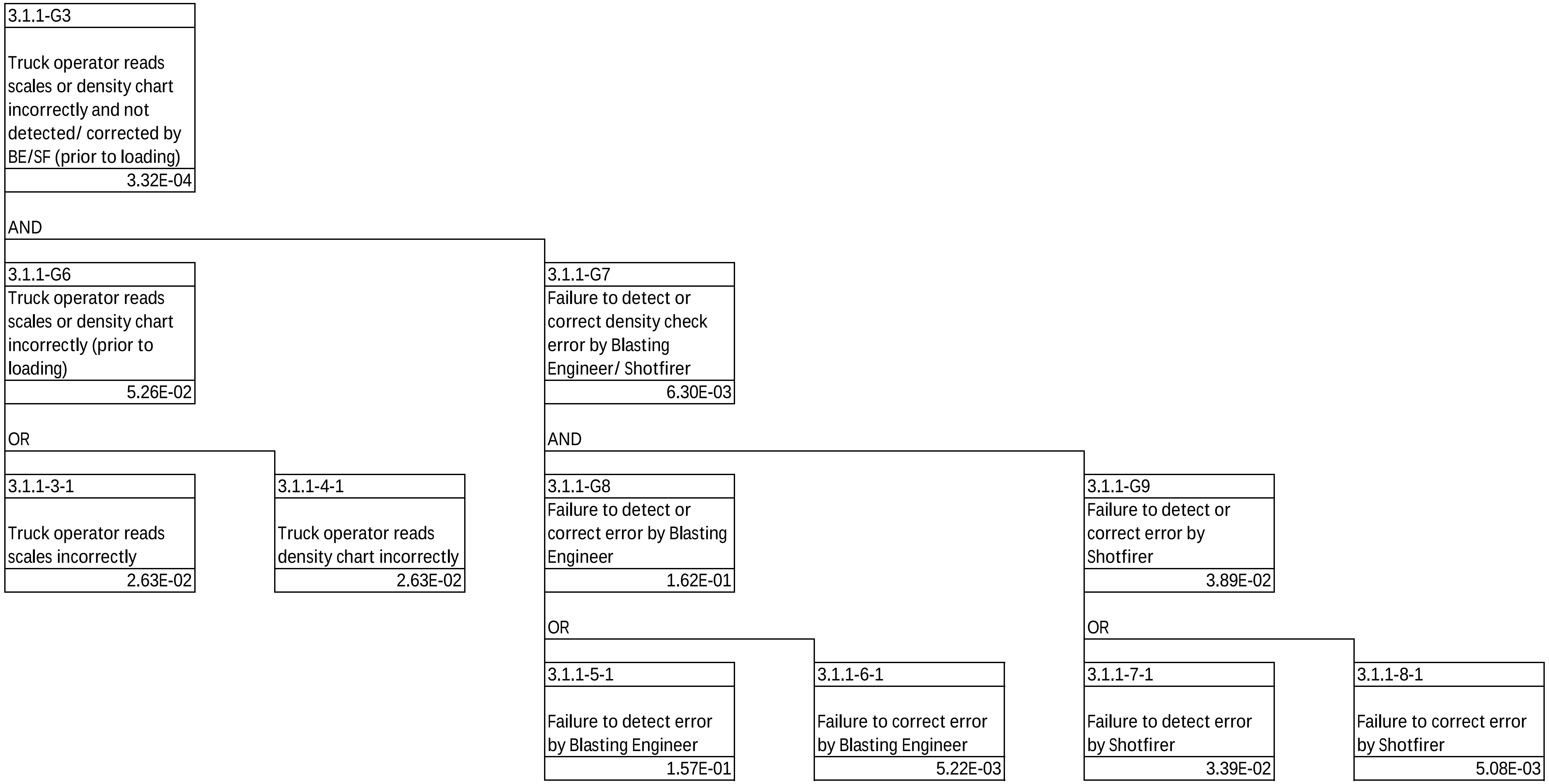

2.3.2
Failure to Detect and Correct Connection Error
1.28E-05
AND
2.3.2-G1
Shotfirer fails to detect or correct connection error
4.24E-02
OR
2.3.2-1
Shotfirer fails to detect connection error
3.69E-02
2.3.2-2
Shotfirer fails to correct connection error
5.54E-03
2.3.2-G2
Blasting Engineer fails to check or correct connection error
4.36E-02
OR
2.3.2-3
Blasting Engineer fails to detect connection error
3.79E-02
2.3.2-4
Blasting Engineer fails to correct connection error
5.69E-03
2.3.2-G3
RSS fail to check or correct connection error
1.62E-01
OR
2.3.2-5
Resident Site Staff fails to detect connection error
1.57E-01
2.3.2-6
Resident Site Staff fails to correct connection error
5.24E-03
2.3.2-G4
Blasting Competent Supervisor fail to check or correct connection error
4.24E-02
OR
2.3.2-7
Blasting Competent Supervisor fails to detect connection error
3.69E-02
2.3.2-8
Blasting Competent Supervisor fails to correct connection error
5.54E-03

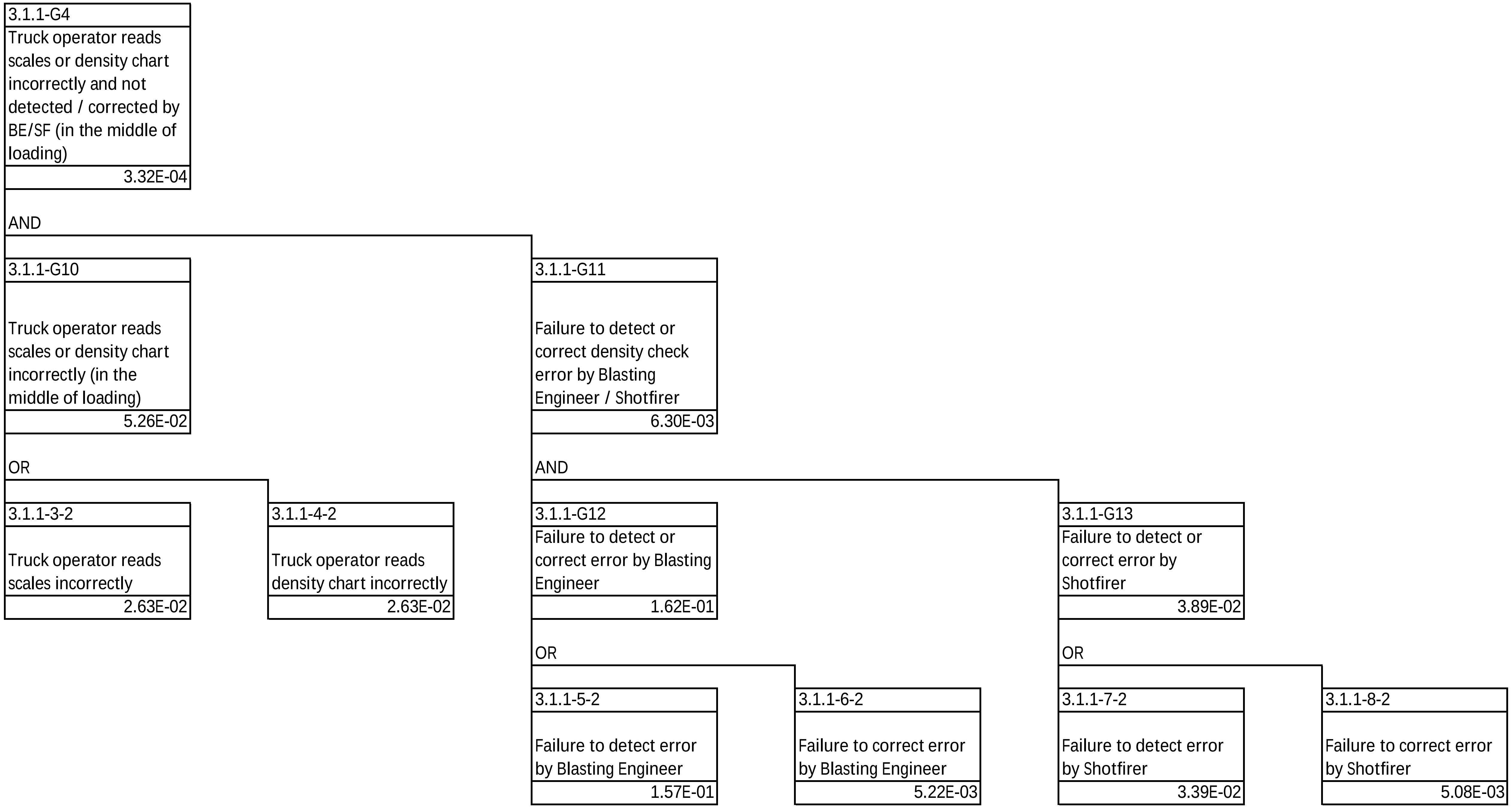

2.4.1
Incorrect Installation of Surface Connector
1.48E-03
OR
2.4.1-1
Shotfirer fails to check the colour of the surface connector before installing
7.38E-04
2.4.1-2
Shotfirer connects wrong surface connector
7.38E-04

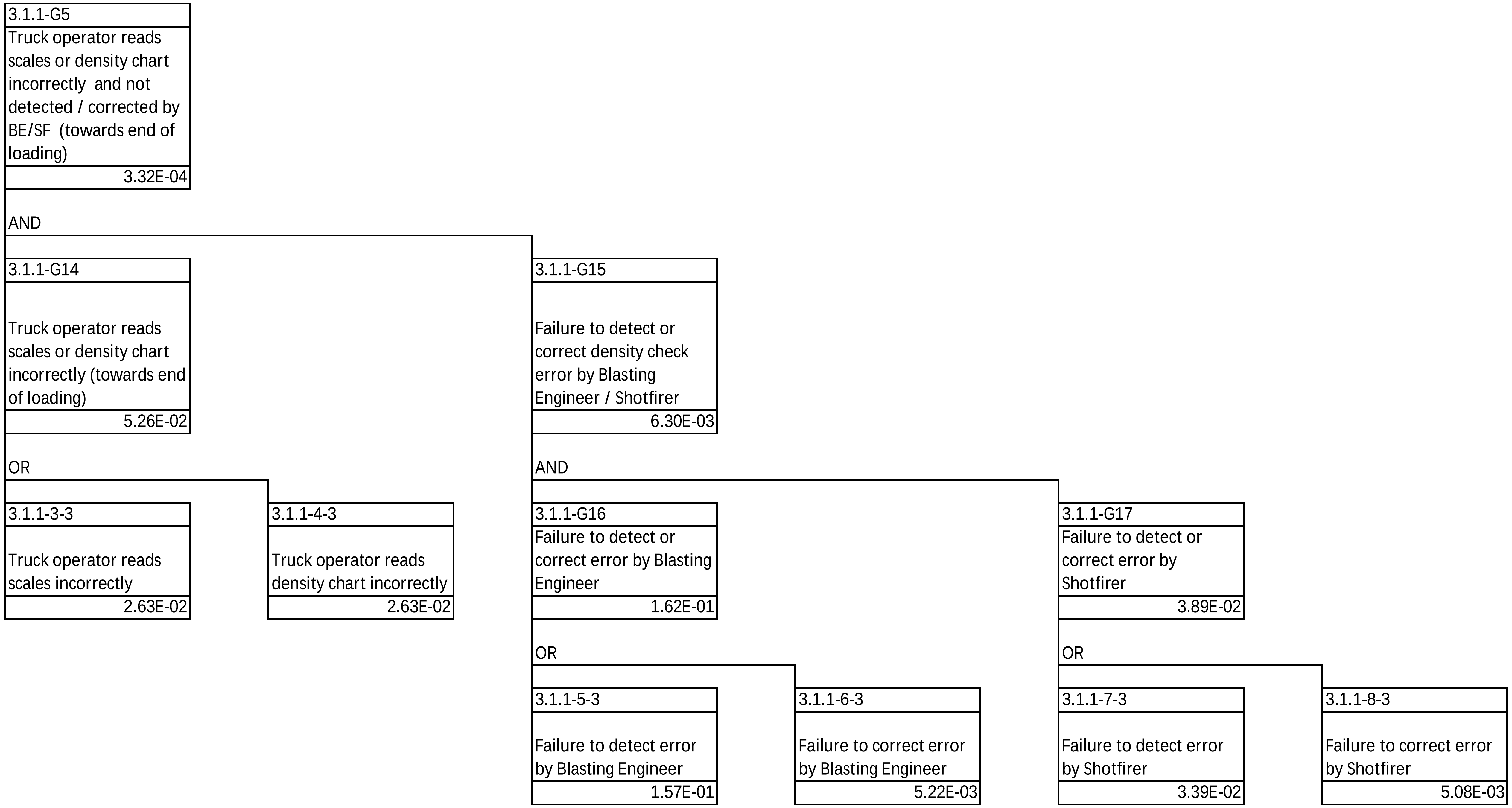

2.4.2
Shotfirer / Blasting Competent Supervisor Fails to Detect and Respond to Error
1.80E-03
AND
2.4.2-G1
Shotfirer fails to detect wrong installation of surface connector and respond
4.24E-02
2.4.2-G2
Blasting Competent Supervisor fails to detect wrong installation of surface connector and respond
4.24E-02
OR
2.4.2-1
Shotfirer fails to detect error
3.69E-02
2.4.2-2
Shotfirer fails to correct error
5.54E-03
OR
2.4.2-3
Blasting Competent Supervisor fails to detect error
3.69E-02
2.4.2-4
Blasting Competent Supervisor fails to correct error
5.54E-03

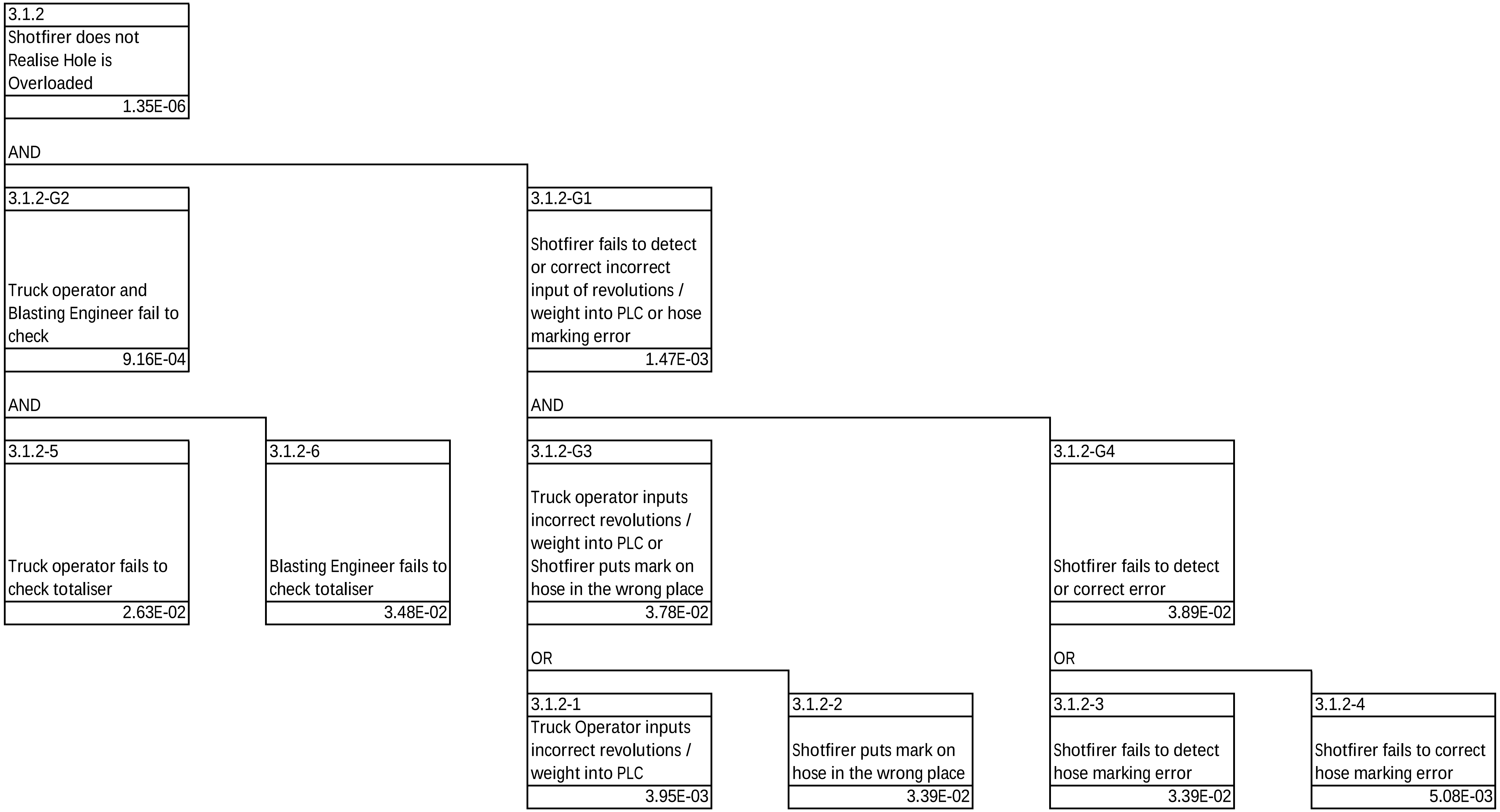

2.4.3
Failure to Detect and Respond During Final Hook-Up Check
3.01E-04
AND
2.4.3-G1
Shotfirer fails to detect or correct connection error
4.24E-02
2.4.3-G2
Blasting Engineer fails to check or correct connection error
4.36E-02
2.4.3-G3
Resident Site Staff fail to check or correct connection error
1.62E-01
OR
OR
OR
2.4.3-5
Shotfirer fails to detect error
3.69E-02
2.4.3-6
Shotfirer fails to correct error
5.54E-03
2.4.3-1
Blasting Engineer fails to detect error
3.79E-02
2.4.3-2
Blasting Engineer fails to correct error
5.69E-03
2.4.3-3
Resident Site Staff fails to detect error
1.57E-01
2.4.3-4
Resident Site Staff fails to correct error
5.24E-03

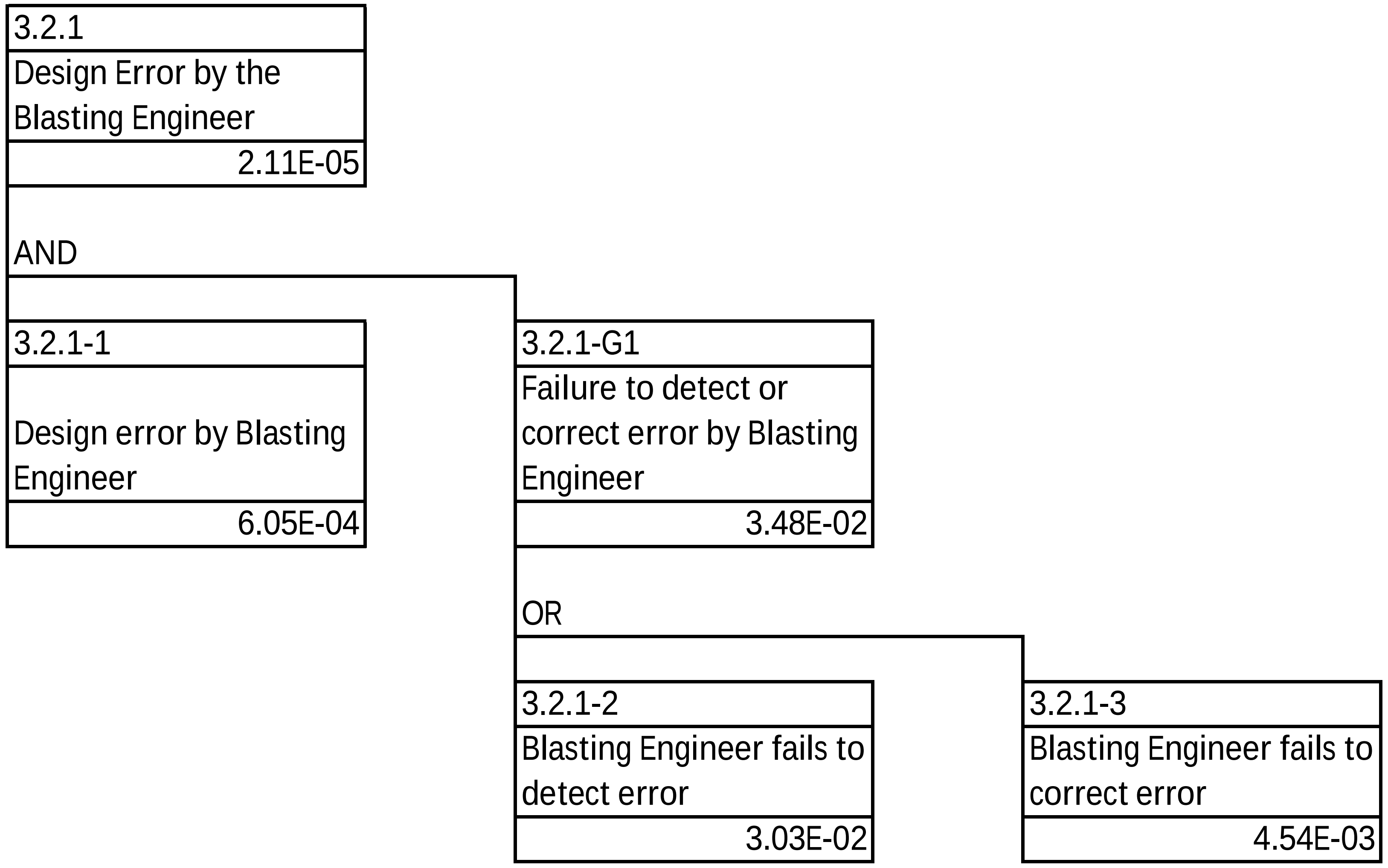

3.1.1
Excess Emulsion is Loaded due to Wrong Density
1.11E-12
AND
3.1.1-G1
Truck operator sets gassing flow meter or read density chart incorrectly
3.03E-02
3.1.1-G2
Truck operator reads scales or density chart incorrectly
3.65E-11
OR
AND
3.1.1-1
Truck operator sets gassing flow meter incorrectly
3.95E-03
3.1.1-2
Truck operator reads density chart incorrectly
2.63E-02
3.1.1-G3
Truck operator reads scales or density chart incorrectly and not detected/ corrected by BE/SF (prior to loading)
3.32E-04
3.1.1-G4
Truck operator reads scales or density chart incorrectly and not detected/corrected by BE/SF (in the middle of loading)
3.32E-04
3.1.1-G5
Truck operator reads scales or density chart incorrectly and not detected/ corrected by BE/SF (towards end of loading)
3.32E-04

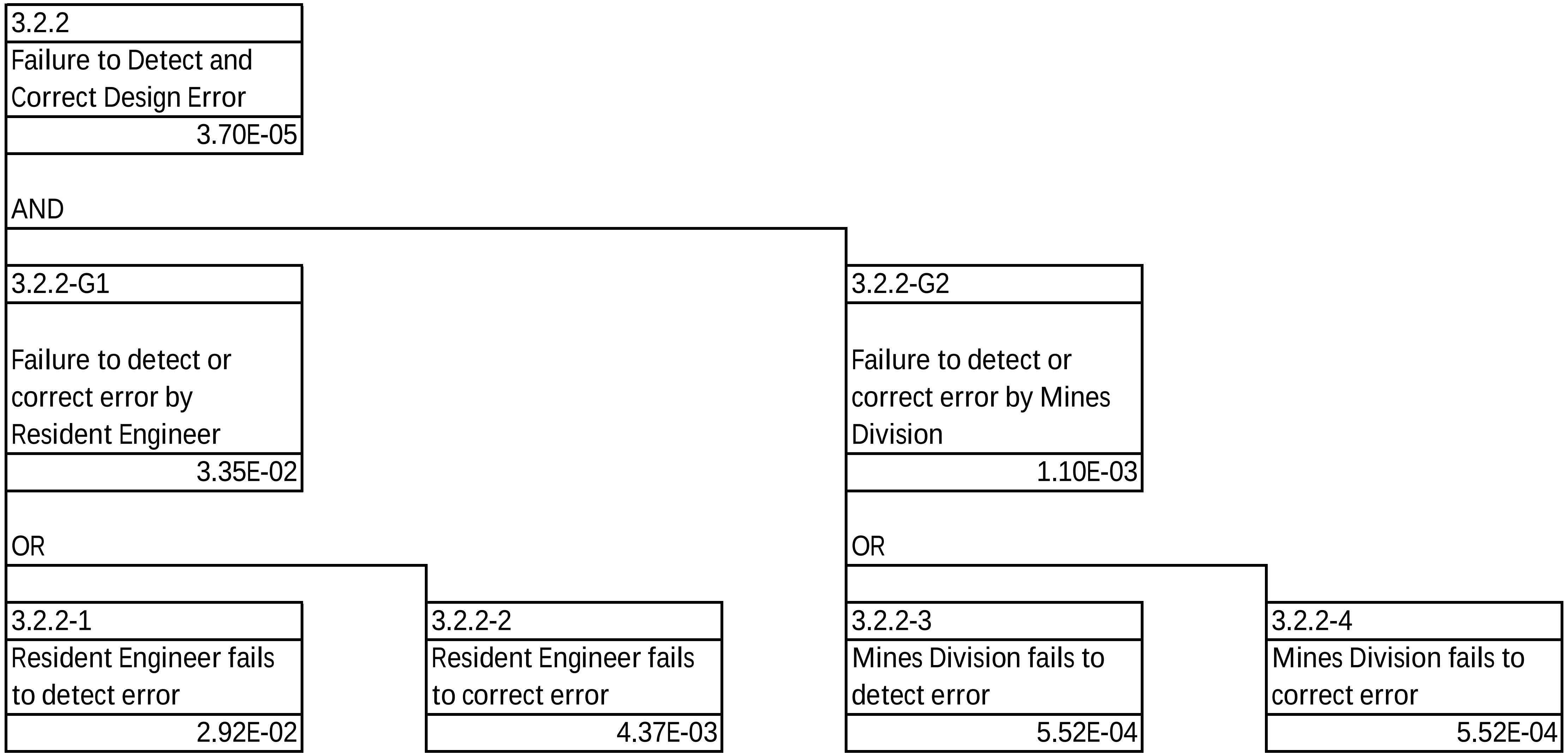

3.1.1-G3
Truck operator reads scales or density chart incorrectly and not detected/ corrected by BE/SF (prior to loading)
3.32E-04
AND
3.1.1-G6
Truck operator reads scales or density chart incorrectly (prior to loading)
5.26E-02
3.1.1-G7
Failure to detect or correct density check error by Blasting Engineer/ Shotfirer
6.30E-03
OR
3.1.1-3-1
Truck operator reads scales incorrectly
2.63E-02
3.1.1-4-1
Truck operator reads density chart incorrectly
2.63E-02
AND
3.1.1-G8
Failure to detect or correct error by Blasting Engineer
1.62E-01
3.1.1-G9
Failure to detect or correct error by Shotfirer
3.89E-02
OR
3.1.1-5-1
Failure to detect error by Blasting Engineer
1.57E-01
3.1.1-6-1
Failure to correct error by Blasting Engineer
5.22E-03
OR
3.1.1-7-1
Failure to detect error by Shotfirer
3.39E-02
3.1.1-8-1
Failure to correct error by Shotfirer
5.08E-03

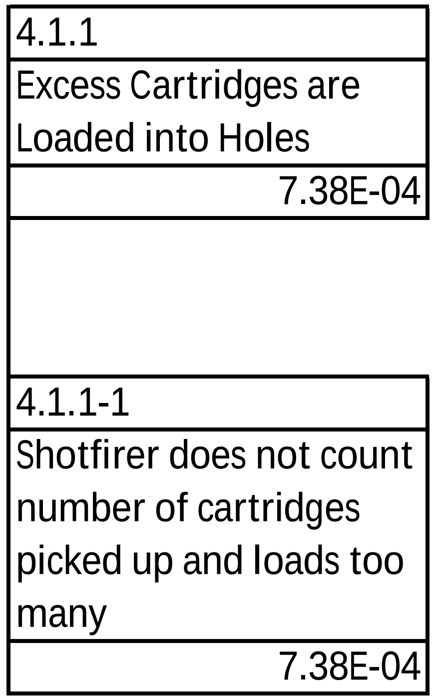

3.1.1-G4
Truck operator reads scales or density chart incorrectly and not detected / corrected by BE/SF (in the middle of loading)
3.32E-04
AND
3.1.1-G10
Truck operator reads scales or density chart incorrectly (in the middle of loading)
5.26E-02
3.1.1-G11
Failure to detect or correct density check error by Blasting Engineer / Shotfirer
6.30E-03
OR
3.1.1-3-2
Truck operator reads scales incorrectly
2.63E-02
3.1.1-4-2
Truck operator reads density chart incorrectly
2.63E-02
AND
3.1.1-G12
Failure to detect or correct error by Blasting Engineer
1.62E-01
3.1.1-G13
Failure to detect or correct error by Shotfirer
3.89E-02
OR
3.1.1-5-2
Failure to detect error by Blasting Engineer
1.57E-01
3.1.1-6-2
Failure to correct error by Blasting Engineer
5.22E-03
OR
3.1.1-7-2
Failure to detect error by Shotfirer
3.39E-02
3.1.1-8-2
Failure to correct error by Shotfirer
5.08E-03

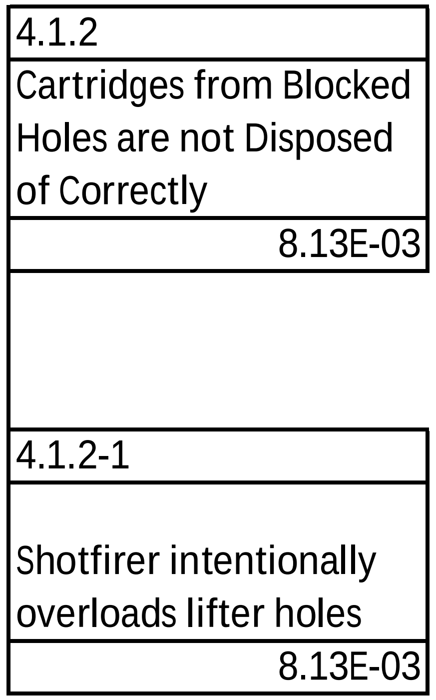

3.1.1-G5
Truck operator reads scales or density chart incorrectly and not detected / corrected by BE/SF (towards end of loading)
3.32E-04
AND
3.1.1-G14
Truck operator reads scales or density chart incorrectly (towards end of loading)
5.26E-02
3.1.1-G15
Failure to detect or correct density check error by Blasting Engineer / Shotfirer
6.30E-03
OR
3.1.1-3-3
Truck operator reads scales incorrectly
2.63E-02
3.1.1-4-3
Truck operator reads density chart incorrectly
2.63E-02
AND
3.1.1-G16
Failure to detect or correct error by Blasting Engineer
1.62E-01
3.1.1-G17
Failure to detect or correct error by Shotfirer
3.89E-02
OR
3.1.1-5-3
Failure to detect error by Blasting Engineer
1.57E-01
3.1.1-6-3
Failure to correct error by Blasting Engineer
5.22E-03
OR
3.1.1-7-3
Failure to detect error by Shotfirer
3.39E-02
3.1.1-8-3
Failure to correct error by Shotfirer
5.08E-03

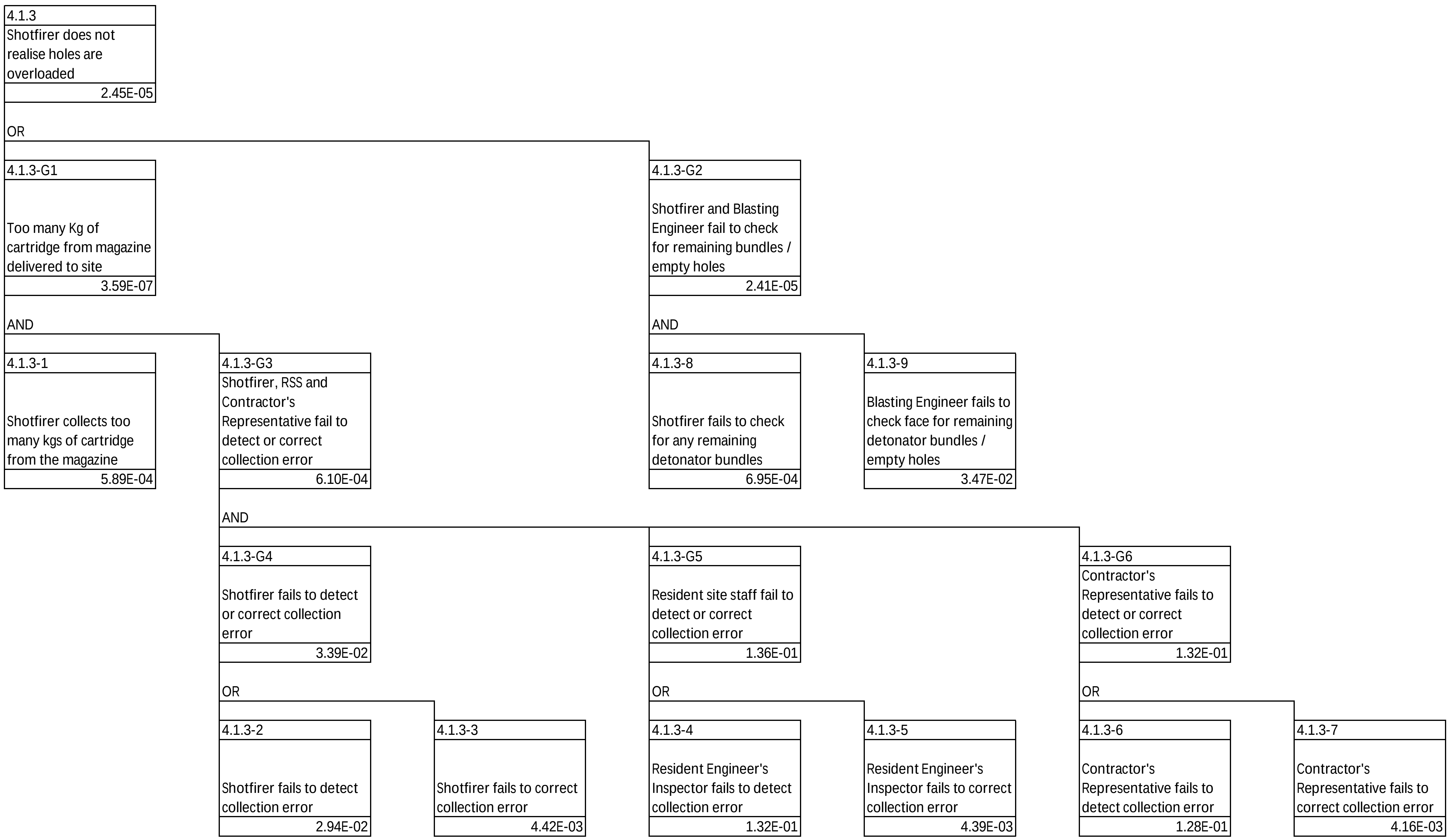

3.1.2
Shotfirer does not Realise Hole is Overloaded
1.35E-06
AND
3.1.2-G2
Truck operator and Blasting Engineer fail to check
9.16E-04
3.1.2-G1
Shotfirer fails to detect or correct incorrect input of revolutions / weight into PLC or hose marking error
1.47E-03
AND
3.1.2-5
Truck operator fails to check totaliser
2.63E-02
3.1.2-6
Blasting Engineer fails to check totaliser
3.48E-02
AND
3.1.2-G3
Truck operator inputs incorrect revolutions / weight into PLC or Shotfirer puts mark on hose in the wrong place
3.78E-02
3.1.2-G4
Shotfirer fails to detect or correct error
3.89E-02
OR
3.1.2-1
Truck Operator inputs incorrect revolutions / weight into PLC
3.95E-03
3.1.2-2
Shotfirer puts mark on hose in the wrong place
3.39E-02
OR
3.1.2-3
Shotfirer fails to detect hose marking error
3.39E-02
3.1.2-4
Shotfirer fails to correct hose marking error
5.08E-03

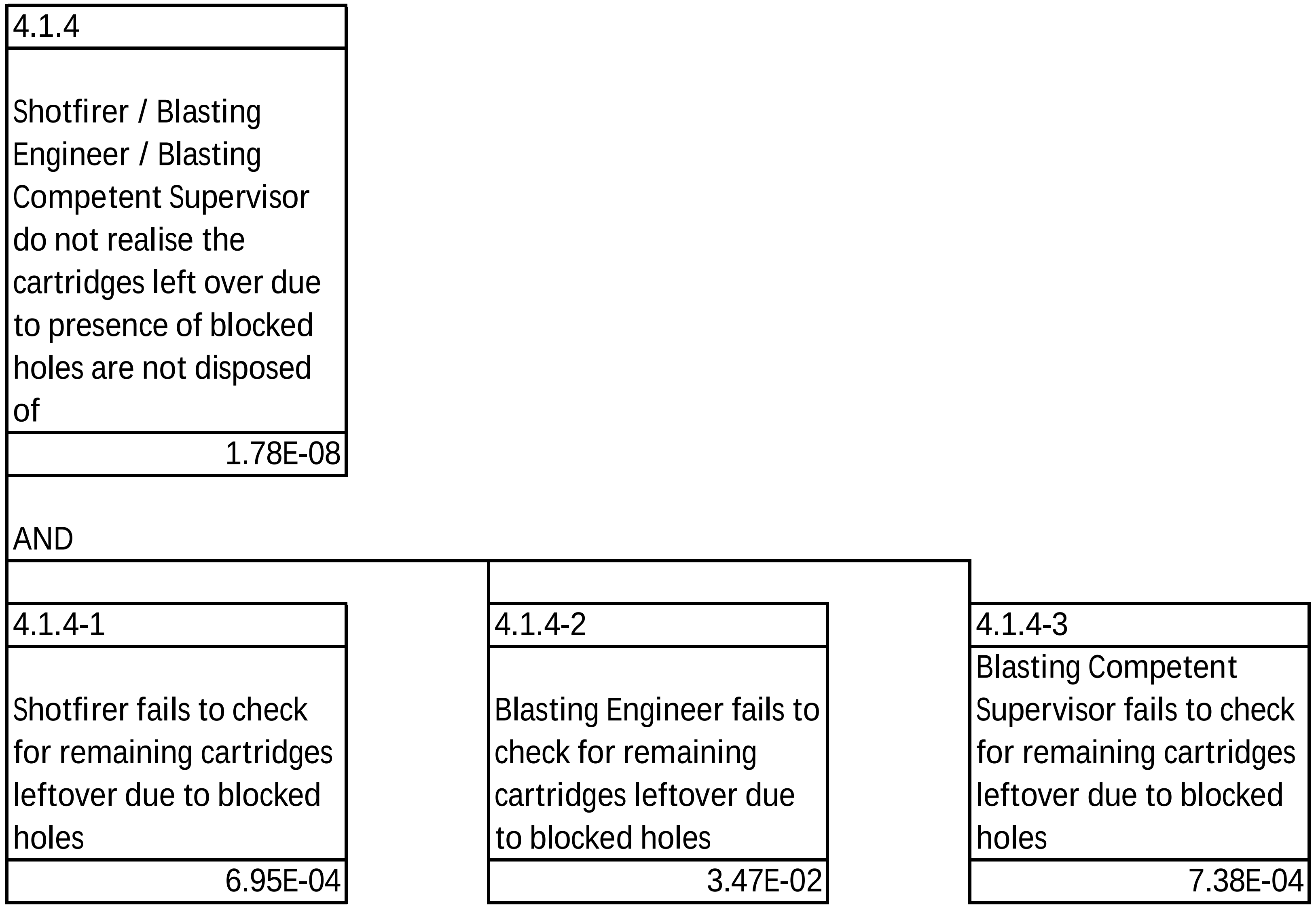

3.2.1
Design Error by the Blasting Engineer
2.11E-05
AND
3.2.1-1
Design error by Blasting Engineer
6.05E-04
3.2.1-G1
Failure to detect or correct error by Blasting Engineer
3.48E-02
OR
3.2.1-2
Blasting Engineer fails to detect error
3.03E-02
3.2.1-3
Blasting Engineer fails to correct error
4.54E-03

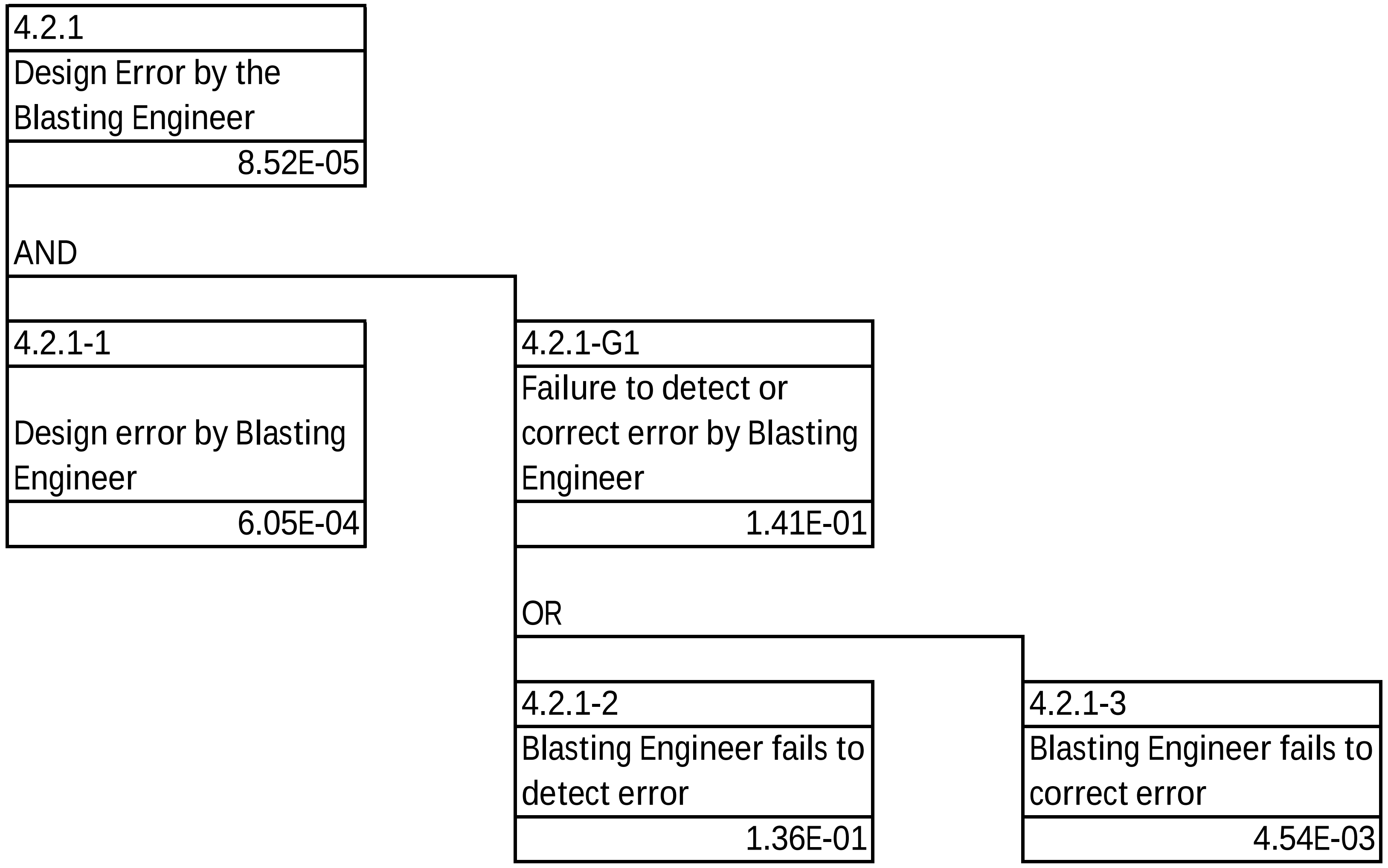

3.2.2
Failure to Detect and Correct Design Error
3.70E-05
AND
3.2.2-G1
Failure to detect or correct error by Resident Engineer
3.35E-02
3.2.2-G2
Failure to detect or correct error by Mines Division
1.10E-03
OR
OR
3.2.2-1
Resident Engineer fails to detect error
2.92E-02
3.2.2-2
Resident Engineer fails to correct error
4.37E-03
3.2.2-3
Mines Division fails to detect error
5.52E-04
3.2.2-4
Mines Division fails to correct error
5.52E-04

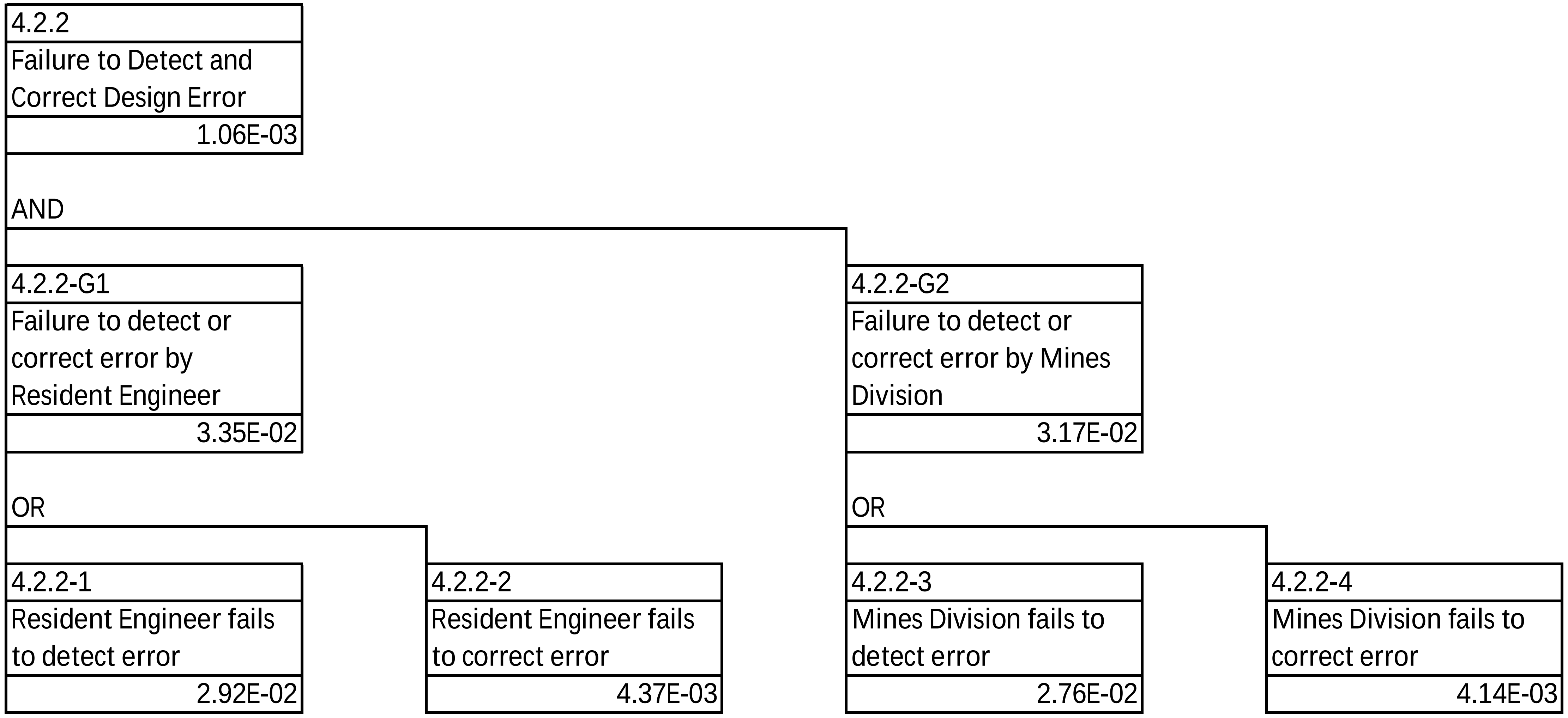

4.1.1
Excess Cartridges are Loaded into Holes
7.38E-04
4.1.1-1
Shotfirer does not count number of cartridges picked up and loads too many
7.38E-04


4.1.2
Cartridges from Blocked Holes are not Disposed of Correctly
8.13E-03
4.1.2-1
Shotfirer intentionally overloads lifter holes
8.13E-03


4.1.3
Shotfirer does not realise holes are overloaded
2.45E-05
OR
4.1.3-G1
Too many Kg of cartridge from magazine delivered to site
3.59E-07
4.1.3-G2
Shotfirer and Blasting Engineer fail to check for remaining bundles / empty holes
2.41E-05
AND
4.1.3-1
Shotfirer collects too many kgs of cartridge from the magazine
5.89E-04
4.1.3-G3
Shotfirer, RSS and Contractor's Representative fail to detect or correct collection error
6.10E-04
AND
4.1.3-8
Shotfirer fails to check for any remaining detonator bundles
6.95E-04
4.1.3-9
Blasting Engineer fails to check face for remaining detonator bundles / empty holes
3.47E-02
AND
4.1.3-G4
Shotfirer fails to detect or correct collection error
3.39E-02
4.1.3-G5
Resident site staff fail to detect or correct collection error
1.36E-01
4.1.3-G6
Contractor's Representative fails to detect or correct collection error
1.32E-01
OR
4.1.3-2
Shotfirer fails to detect collection error
2.94E-02
4.1.3-3
Shotfirer fails to correct collection error
4.42E-03
OR
4.1.3-4
Resident Engineer's Inspector fails to detect collection error
1.32E-01
4.1.3-5
Resident Engineer's Inspector fails to correct collection error
4.39E-03
OR
4.1.3-6
Contractor's Representative fails to detect collection error
1.28E-01
4.1.3-7
Contractor's Representative fails to correct collection error
4.16E-03


4.1.4
Shotfirer / Blasting Engineer / Blasting Competent Supervisor do not realise the cartridges left over due to presence of blocked holes are not disposed of
1.78E-08
AND
4.1.4-1
Shotfirer fails to check for remaining cartridges leftover due to blocked holes
6.95E-04
4.1.4-2
Blasting Engineer fails to check for remaining cartridges leftover due to blocked holes
3.47E-02
4.1.4-3
Blasting Competent Supervisor fails to check for remaining cartridges leftover due to blocked holes
7.38E-04


4.2.1
Design Error by the Blasting Engineer
8.52E-05
AND
4.2.1-1
Design error by Blasting Engineer
6.05E-04
4.2.1-G1
Failure to detect or correct error by Blasting Engineer
1.41E-01
OR
4.2.1-2
Blasting Engineer fails to detect error
1.36E-01
4.2.1-3
Blasting Engineer fails to correct error
4.54E-03


4.2.2
Failure to Detect and Correct Design Error
1.06E-03
AND
4.2.2-G1
Failure to detect or correct error by Resident Engineer
3.35E-02
4.2.2-G2
Failure to detect or correct error by Mines Division
3.17E-02
OR
4.2.2-1
Resident Engineer fails to detect error
2.92E-02
4.2.2-2
Resident Engineer fails to correct error
4.37E-03
OR
4.2.2-3
Mines Division fails to detect error
2.76E-02
4.2.2-4
Mines Division fails to correct error
4.14E-03