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CRC CALCAPTURE QRA

Final Report

California Resources Corporation (CRC)

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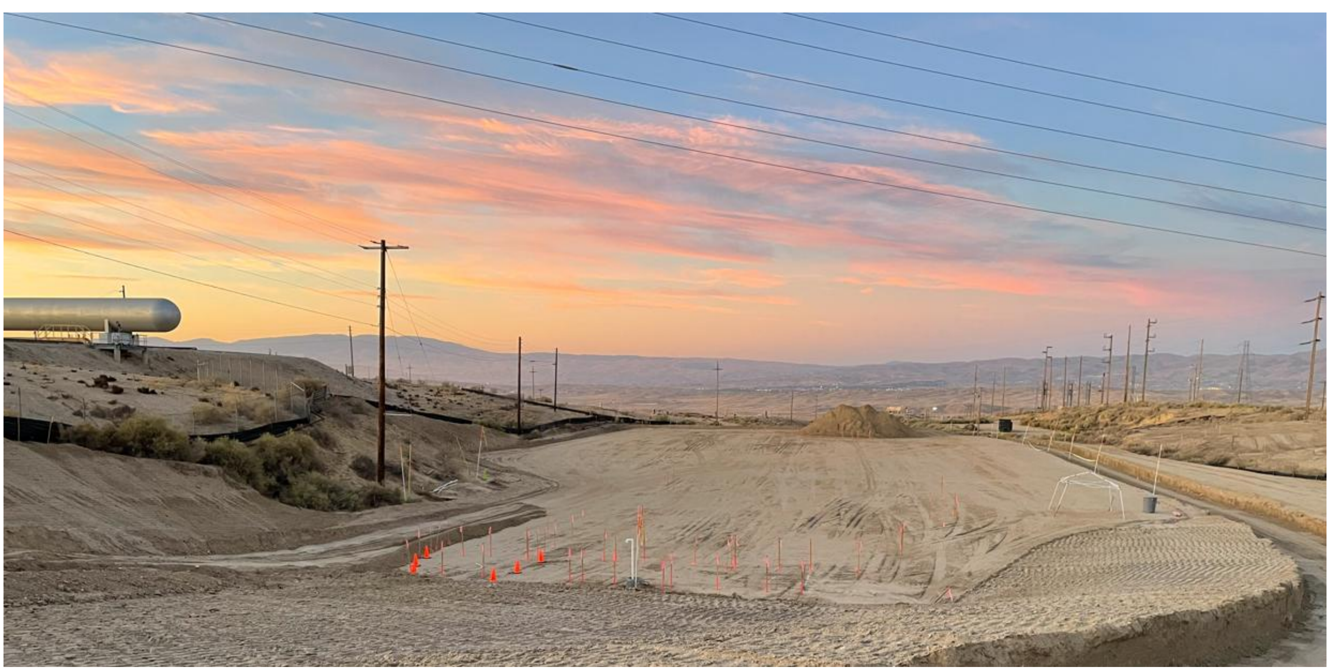

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Objective:

This is to perform a comprehensive Quantitative Risk Assessment (QRA) for the CRC CalCapture Carbon Capture and Storage (CCS) Project.

Prepared by:	Verified by:	Approved by:
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ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AFC	Application For Certification
CARB	California Air Resources Board
CCS	Carbon Capture and Storage
CCR	California Code of Regulations
CCU	Carbon Capture Unit
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CO_2	Carbon Dioxide
CRC	California Resources Corporation
CTV	Carbon TerraVault
CUP	Conditional Use Permit
EFG+	Econamine FG Plus^{SM}
EG	Ethylene Glycol
EGIG	European Gas pipeline Incident data Group
EHOF	Elk Hills Oil and Gas Field
EHPP	Elk Hills Power Plant
EIR	Environmental Impact Report
FMCSA	U.S. Department of Transportation Federal Motor Carrier Safety Administration
FN	Frequency-Number of Fatalities
FRED	Failure Rate and Event Data
GT	Gas Turbine
H_2SO_4	Sulfuric Acid
HCA	High Consequence Area
HCRD	Hydrocarbon Release Database
HDD	Horizontal Directional Drilling
HRSG	Heat Recovery Steam Generator
HSE	Health, Safety and Environment
IDLH	Immediately Dangerous to Life or Health
IOGP	International Association of Oil & Gas Producers
IRPA	Individual Risk Per Annum
ISO	International Organization for Standardization

KFX	Kameleon FireEx™
LCFS	Low Carbon Fuel Standard
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Risk
MDB&M	Mount Diablo Base and Meridian
MEA	Monoethanolamine
MMTPY	Million metric tons per year
MTPD	Metric tons per day
MVMT	Million vehicle miles traveled
NaOH	Sodium Hydroxide
NIOSH	National Institute for Occupational Safety and Health
OSFM	Office of the State Fire Marshal
OSHA	U.S. Occupational Safety and Health Administration
P&ID	Process Instrumentation Diagram
PHMSA	U.S. Pipeline and Hazardous Material Safety Administration
PLL	Potential Loss of Life
PTA	Petition To Amend
QRA	Quantitative Risk Assessment
RO	Reverse Osmosis
SLOD	Significant Likelihood of Death
SLOT	Specified Level of Toxicity
ST	Steam Turbine
STEL	Short-Term Exposure Limit
TEG	Triethylene Glycol
TLV	Threshold Limit Value
UFL	Upper Flammable Limit
UIC	Underground Injection Control
U.S. DOT	United States Department of Transport
U.S. EPA	United States Environmental Protection Agency
WSAC	Wet Surface Air Coolers

EXECUTIVE SUMMARY

California Resources Corporation (CRC) engaged DNV to perform a Quantitative Risk Assessment (QRA) for the CalCapture Carbon Capture and Storage (CCS) Project, located in rural western Kern County, California. The assessment covers the Carbon Capture Unit (CCU), the ~0.5-mile 10-inch buried carbon dioxide (CO_2) pipeline from the CCU to the Carbon TerraVault I (CTV I) 35R manifold that will be tied in to CRC's Class VI Injection wells for CO_2 disposal, as well as the chemical storage and supply chain, which includes transit operations within a 50-mile radius, on-site unloading, and storage. In support of the CalCapture CCS project, CRC submitted a Petition to Amend (PTA) application to the California Energy Commission (CEC) on October 10, 2025; reference TN# 266900, The QRA will be submitted to the CEC under Docket # 99-AFC-01C to evaluate the impacts of the CalCapture CCS Project.

Dispersion and consequence modeling calculations were performed using DNV's proprietary tools: Phast for free-field modeling, KFX for computational fluid dynamics (CFD) modeling to refine the worst-case full-bore rupture pipeline scenario over local terrain and topography, and Safeti for risk calculations.

Although the QRA applies free-field, two-dimensional modeling in Safeti based on flat terrain, specific CFD simulations were performed in KFX to account for terrain and topographic variations for the CO_2 pipeline release cases. These CFD results were then used to refine the dispersion behavior for the worst-case rupture CO_2 pipeline release, in order to provide a more realistic representation of plume movement over the local terrain.

The results from the risk analysis, described in greater detail below, illustrate that safety features already included in the proposed facility's design (e.g., leak detection devices, emergency shutoff valves, etc.) are effective to reduce risk to the public to levels well below established tolerability thresholds for individual and societal risk. It can, therefore, be concluded from the QRA results that the design and operational controls are sufficient to support the conclusion that the proposed project changes would not result in a significant impact to public health or safety – no mitigation is necessary.

Individual Risk – CalCapture Facility and Pipeline

The individual risk around the facility is very low. The highest location-specific individual risk (LSIR) contour remains within the immediate CRC facility, and the 1E-06 per year (1 in 1 million years) contour, which is a threshold used by the California Department of Education specifically for hazardous pipelines [Ref /10/], does not reach the nearest public area which is the Elk Hills Road. The closest sensitive receptors, near the residential area of Valley Acres, are nearly 5 miles away and would not be exposed to any measurable risk from a potential hazardous material release from the CalCapture facility or pipeline.

Overall Outdoor LSIR (per year) Contours

Additionally, individual risk at representative points along the Elk Hills Road is in the order of 10^{-8} per year (1 in 100 million years) or negligible, which is far below broadly acceptable public-risk criteria adopted by multiple jurisdictions.

Individual Risk Results for Key Locations of Interest

Risk Ranking Point Name[1]	Risk Total [/yr]	Comparison against criteria for various jurisdictions (Refer to Appendix A)
1	Negligible	Acceptable - Below broadly acceptable public risk
2	Negligible	Acceptable - Below broadly acceptable public risk
3	2.3E-08 (1 in 40 million years)	Acceptable - Below broadly acceptable public risk
4	3.0E-08 (1 in 30 million years)	Acceptable - Below broadly acceptable public risk
5	1.1E-08 (1 in 90 million years)	Acceptable - Below broadly acceptable public risk
6	Negligible	Acceptable - Below broadly acceptable public risk

Individual Risk – Road Transit

A separate analysis was conducted for chemical delivery from within a 50-mile radius of the facility. Historical incident data from the U.S. Department of Transportation (U.S. DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) database (2000–2025) were reviewed for chemicals of interest: amine solvent (ethanolamine), hydrogen, sulfuric acid, and sodium hydroxide. The estimated overall individual risk from transportation is approximately 1.2E-05 per year (1 in 85,500 years), based on conservative assumptions regarding release probabilities and public exposure. This remains within the upper-bound criteria commonly applied in jurisdictions such as Canada, the United Kingdom, the Netherlands, and Hong Kong. At this stage of

[1] The exact location of these reference points is illustrated in Figure 8-10 of this report.

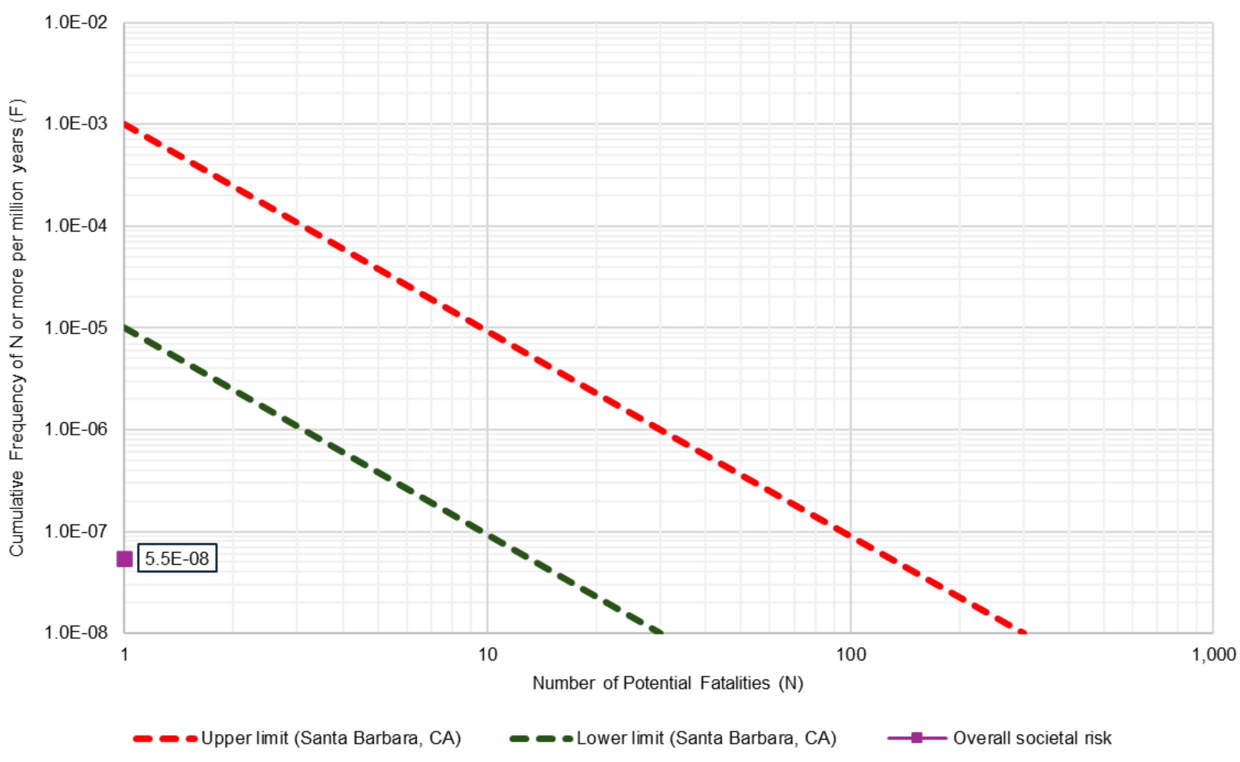
the project, detailed inputs needed for a full transportation risk analysis are not yet defined. Key elements such as final supplier locations, routing, road characteristics, and traffic density are not available. As a result, the current estimate is based on conservative assumptions which tend to overstate risk.

It is important to note that chemical delivery often represents one of the largest contributors to overall societal and individual risk in many QRAs. This is driven by the inherent risks associated with vehicle operation on public roadways rather than the specific properties of the chemicals transported. Most incidents historically involve small leaks, with large releases accounting for only 10% of events. No historical fatalities are reported related to amine or sodium hydroxide transport; historical incident data indicate that hydrogen and sulfuric acid incidents have resulted in injuries [/6/]. These findings indicate that transportation risk, while higher than CalCapture facility and pipeline risk, remains within established maximum tolerable risk thresholds and is consistent with risk levels typically associated with projects that involve road transportation.

Societal Risk

Societal risk exposure to public populations is negligible. The modeled Potential Loss of Life (PLL) is approximately 5.5E-08 per year, which is equivalent to 1 fatality in 18 million years.

The Frequency-Number of Fatalities (FN) curve shown below, used to present the cumulative frequency (F) for N or more fatalities, indicates that the societal risk is well below the maximum tolerable societal risk criteria adopted by multiple jurisdictions (Santa Barbara, CA criteria line indicated in figure), and the analysis predicts at most a roughly 1 in 18 million chance for a single fatality for credible scenarios, with no scenarios producing multiple simultaneous fatalities. It should be noted that FN curves are used to present the cumulative frequency (F) for there being N or more fatalities.



Frequency-Number of Fatalities (FN) Curve

The QRA concludes that the overall risk to the public on Elk Hills Road is very low. All calculated risk metrics are below international referenced benchmarks commonly applied to land-use planning and public safety for similar facilities. To place these values in context, the 2023 National Safety Council (NSC) publishes fatality statistics for everyday activities, showing that common risks such as driving, accidental falls, or pedestrian incidents occur at orders of magnitude higher [Ref /22/]. For example, the NSC estimates the individual causes of death from a motor-vehicle incident at roughly 1 in 95, from accidental falls at roughly 1 in 91, or from cataclysmic storm at roughly 1 in 39,192. By comparison, the CalCapture facility and pipeline risks, in the range of 1 in 100,000 to 1 in 10,000,000 per year, fall far below the risk levels associated with typical daily activities encountered by the public.

1 INTRODUCTION

DNV Energy USA Inc. (DNV) was requested by California Resources Corporation (CRC) to perform a comprehensive Quantitative Risk Assessment (QRA) for the CRC CalCapture Carbon Capture and Storage (CCS) Project. A full description of the Project is discussed in Section 2.

1.1 Objectives

The main objectives of the QRA analysis are to:

- Define foreseeable release scenarios related to CalCapture's CO_2 capture and storage, and supporting utilities
- Quantify consequence using dispersion modeling of release scenarios
- Estimate frequency of release scenarios based on relevant industry datasets
- Calculate the individual and societal risk to offsite / public receptors, specifically Elk Hills Road
- Identify key risk drivers in order to inform mitigation measures to the extent significant impacts are identified

To achieve the objectives of the assessment, DNV utilized the Phast and KFX software for the consequence modeling, for both free-field and using computational fluid dynamics (CFD), and Safeti software for risk modeling.

1.2 QRA Study Boundary

The QRA scope consists of the following:

1. Carbon Capture Unit (CCU), which is subdivided into seven sections:
    a. Flue Gas Cooling
    b. CO_2 Absorption
    c. Solvent Regeneration
    d. Solvent Maintenance
    e. Chemical Storage and Supply (This includes releases during transit to the facility within a 50-mile region from the facility, chemical unloading, and storage).
    f. CO_2 Compression and Cooling
    g. Utility Support Systems
2. CO_2 Emitter Pad Header (at CalCapture Unit Emitter Pad)
3. Transportation of dense phase CO_2 via 10" buried pipeline to the Carbon TerraVault (CTV) I permitted 35R manifold facility (pad).
4. CO_2 Emitter Manifold Header (at CTV I 35R Pad)

The location of the CCU facility, 10" pipeline, and injection manifold are shown in Figure 1-1.

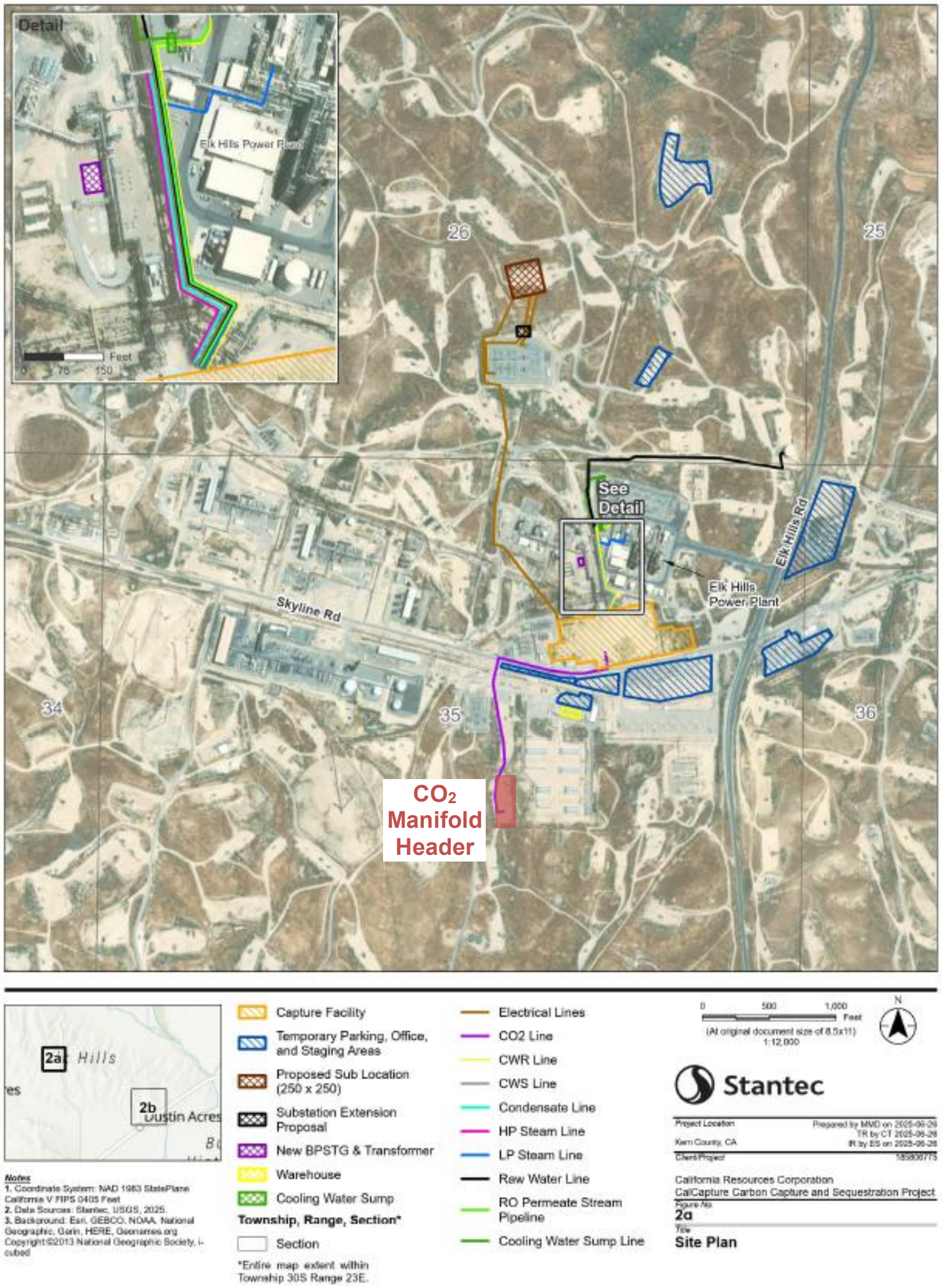


Figure 1-1 Location of CCU Facility and CO_2 Pipeline

1.3 Definitions

Several terms are used throughout this analysis, which are worth defining in the context of this report.

Term	Definition
Computational Fluid Dynamics (CFD)	A numerical modeling technique used to simulate fluid flow, gas dispersion, thermal radiation, and other physical processes. In QRA, CFD is often used to analyze detailed dispersion, fire, toxic gas plume, or explosion behavior where simplified models may not fully capture complex geometry (terrain or topography) or environmental influences.
Consequence	The outcome or impact resulting from the occurrence of a hazardous event. It is typically expressed in terms of harm to people (injuries or fatalities), damage to property, environmental effects, or economic loss. In QRA, consequences are often quantified to assess severity and combined with frequency or probability to evaluate overall risk.
FN Curve	An FN curve shows the cumulative frequency (F) of there being N or more fatalities among a population set. It is a way of assessing societal risk and the level of risk that a society would tolerate.
Free-field (modeling)	A dispersion modeling condition that represents open, unobstructed space without the influence of buildings, structures, or terrain features. Free-field assumptions are commonly used to estimate dispersion behavior in the absence of significant physical obstructions. Results may differ from CFD predictions when complex site geometry significantly affects flow patterns.
Frequency	Frequency is the number of occurrences of an event per unit of time.
Hazard	A hazard is a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation.
Location Specific Individual Risk (LSIR)	LSIR is the risk experienced by a single unprotected individual continuously located in a specific location. It does not include any reduction factor for being present only part of the time.
Probability	Probability is the chance of a particular outcome of an event.
Potential Loss of Life (PLL)	PLL is the average number of fatalities per year. It is calculated from the product of the hazard frequency and severity of the hazard in terms of predicted fatalities.
Risk	Risk is the combination of the likelihood of a hazardous event occurring and the severity of its consequences. ISO 31000 defines risk as "*the effect of uncertainty on objectives*." Risk is typically expressed as a function of frequency (or probability) and consequence, and may be evaluated at individual, societal, or asset levels.

2 PROJECT DESCRIPTION

The proposed CalCapture Project would capture carbon dioxide (CO_2) generated as a by-product by CRC's 550-megawatt-equivalent (MWe) Elk Hills Power Plant (EHPP), located in the Elk Hills Oil and Gas Field (EHOF) near Tupman, Kern County, California. The EHPP was commissioned in 2003 and is powered by two General Electric 7FA gas turbines (GTs), with two heat recovery steam generators (HRSGs) providing steam to a General Electric D11 steam turbine (ST). The Carbon Capture Unit (CCU), not including pipelines or temporary staging and parking areas, would be located immediately south of the EHPP in a 7.64-acre existing disturbed area.

Implementation of the Project will require approval of a Petition to Amend (PTA) from the California Energy Commission (CEC), who has the exclusive authority for licensing thermal power plants of 50 MW or larger, as well as related transmission lines, fuel supply lines, and other facilities. CRC submitted a PTA application to the California Energy Commission (CEC) on October 10, 2025; reference TN# 266900, The QRA will be submitted to the CEC under Docket # 99-AFC-01C as part of the CalCapture CCS Project.

The CCU would utilize Fluor's Econamine FG Plus^{SM} (EFG+) process to capture and concentrate the CO_2. The EFG+ process is designed to capture 95 percent of the CO_2 from the total flue gas feed to the unit. The EFG+ CCU can be divided into seven primary subsystems or sections: Flue Gas Cooling, CO_2 Absorption, Solvent Regeneration, Solvent Maintenance, Chemical Storage and Supply, CO_2 Compression, and Utility Support Systems. The treated flue gas is vented to the atmosphere directly from the EFG+ CCU plant absorber. The concentrated CO_2 would then be compressed, dehydrated, and stripped of oxygen prior to conveyance to the permitted manifold emitter pad, permitted as part of the approved Carbon TerraVault I (CTV I) project (State Clearinghouse No. 2022030180), which will direct the CO_2 to the U.S. Environmental Protection Agency (U.S. EPA) approved Class VI Underground Injection Control (UIC) wells to be injected into a depleted oil and gas reservoir located on the CRC property and approved as part of the CTV I project. The previously approved and constructed CTV I manifold pad, Class VI injection wells, depleted oil and gas reservoir and related facilities further discussed in Section 2.1 below are not part of the CalCapture CCS Project analyzed in this report.

A new, approximately 0.5-mile, 8- to 10-inch pipeline, installed primarily below ground utilizing either trenching or horizontal directional drilling (HDD) techniques, would transport the CO_2 from the CCU to the tie-in with the Carbon TerraVault I (CTV I) permitted 35R manifold facility (pad). It is anticipated that the proposed Project would capture approximately 4,400 metric tons of CO_2 per day (MTPD) (1.6 million metric tons of CO_2 per year [MMTPY]). The proposed Project is estimated to be in operation for up to 26 years.[2]

Water use during operation of the CalCapture CCU would be minimized by the inclusion of a hybrid cooling system (Wet Surface Air Coolers [WSAC], air coolers, secondary glycol cooling, and water cooling). Additionally, the CCU would be equipped with a water treatment system, consisting of a reverse osmosis (RO) unit that is designed to recover and reuse water from the Cooling Tower blowdown. The recovered water is utilized as make-up to the CO_2 absorption system and the Wash Water WSAC Basin. A wastewater stream (less than 10 gallons per minute) would be collected at the CalCapture CCU and transferred by a new surface pipeline to the EHPP for disposal via an existing UIC Class I injection well.

The proposed Project includes a single connection to the CRC Power System and would include a connection of a new 115-kilovolt (kV) transmission line to a new CRC electrical substation. The proposed Project would require a new transmission tie line to connect the Project switching station to the existing CRC substation. Electrical power would be supplied to the CalCapture Substation with a new dedicated electrical transformer. The new 115-

[2] The life of the project is dependent on the sources permitted for injection into the CTV I approved storage reservoir, the ability of the project year by year to obtain CO_2 and inject at the maximum 2,210,000 million tons per year, and the total estimated storage capacity of up to 48 million tons of CO_2.

kV transmission tie line is expected to be built using pre-engineered steel poles with anchor bolt foundation designs.

During construction, temporary offices and existing parking areas would be used by construction personnel. Temporary office and parking areas have been designated on previously disturbed areas to the south and northeast of the Project site. Two additional areas are located approximately 5.5 miles southeast of the Project site. There are no permanent new buildings proposed for the Project, and no grading would occur within the temporary office and parking areas. Total temporary staging and parking area would be approximately 30.74 acres.

2.1 CTV I Background Information

On December 31, 2024, the U.S. EPA issued four UIC Class VI well permits to Carbon TerraVault, LLC (CTV), a carbon management subsidiary of CRC.

The specific U.S. EPA permits issued for the four wells are as follows:

- R9UIC-CA6-FY22 1.1 for well 373-35R
- R9UIC-CA6-FY22 1.2 for well 345C-36R
- R9UIC-CA6-FY22 1.3 for well 353XC-35R
- R9UIC-CA6-FY22 1.4 for well 363C-27R

These four wells would be utilized to inject the CO_2 captured from the proposed Project into the Monterey Formation 26R storage reservoir located approximately 6,000 feet below the ground surface. The CTV I project area is located within the EHOF, which is a suitable area for long-term CO_2 storage and sequestration. The CTV I project was designed to implement sustainable CCS in support of California's initiative to combat climate change by reducing CO_2 levels in the atmosphere.

In addition to the Class VI Permit, CTV obtained a conditional use permit (CUP) from the Kern County Planning and Natural Resources Department (Kern County) in 2024. Specifically, the CTV I project was approved by the Kern County Board of Supervisors on October 21, 2024, based on a final Environmental Impact Report (EIR, State Clearinghouse #2022030180) prepared by Kern County and certified by it on the same date. A Notice of Determination was filed with the Kern County Clerk on October 22, 2024. The CTV I project is subject to the terms, conditions and restrictions set forth in the CUPs issued by Kern County and identified as CUP No. 13, Map 118; CUP No. 14, Map 118; CUP No. 5, Map 119; CUP No. 3, Map 120; CUP No. 2, Map 138; and CUP No. 6, Map 119 (collectively, "the CUP"). Implementation of the CUP authorizes the construction and operation of underground CO_2 facility pipelines to support the CTV I CCS facility and related infrastructure (e.g., injection/monitoring wells, CO_2 manifold piping and metering facilities) within the 9,104-acre project site, located within the EHOF.

Four monitoring wells permitted by the California Geologic Energy Management Division (CalGEM), as part of the CUP issued by Kern County for the CTV I project would be used for monitoring the CO_2 reservoir. In addition, six CTV I permitted wells would be used to monitor for seismic activity. The seismic monitoring wells will be used to detect seismic events at or above magnitude (M) 1.0 in real time as required by the California Air Resources Board (CARB) CCS Protocol under the Low Carbon Fuel Standard (LCFS) (C.4.3.2.3). Additionally, the California Integrated Seismic Network will be monitored continuously for indication of a 2.7 M or greater earthquake or greater occurring within a 1-mile radius of injection operations from commencement of injection activity to its completion.

Monitoring activities would extend beyond the injection phase of the Project pursuant to Code of Federal Regulation (CFR) Title 40 Section 146.93 until site closure is granted. Monitoring requirements during post-injection are similar to those during injection, with activities such as sampling occurring quarterly and monitoring well integrity testing at frequency per U.S. EPA requirement.

As noted above, the facilities approved as part of the CTV I project, including but not limited to the manifold, pad, injection wells, monitoring wells and related transmission lines, pipelines and other related facilities that have already been approved by applicable agencies with jurisdiction over those facilities, including the U.S. EPA, CalGEM and Kern County, are not included as part of the proposed Project. Accordingly, such facilities are not analyzed in this report.

2.2 Project Location

The Project is located within the EHOF in the southwestern edge of the San Joaquin Valley near Tupman in Kern County, California.

The Project comprises portions of six parcels owned by CRC. The Project is contained within the following sections of EHOF: sections 26, 34, and 35 of Township 30 South Range 23 East and for equipment staging and materials storage sections 10 and 11 of Township 31 South Range 24 East, Mount Diablo Base and Meridian (MDB&M), Kern County, State of California (Table 2-1). The proposed Project would be located on approximately 52 acres within the identified parcels.

Table 2-1 Project Parcel Data

Assessor's Parcel Number	Section/ Township/ Range	Acreage*
158-090-19	Section 35/ Township 30S/ Range 23E	590.61
158-090-16	Section 35/ Township 30S/ Range 23E	14.78
158-090-02	Section 26/ Township 30S/ Range 23E	640
158-090-04	Section 34/ Township 30S/ Range 23E	682.86
298-070-05	Section 11/Township 31S/Range 24E	640
298-070-06	Section 10/Township 31S/Range 24E	640
Notes: Assessor's parcel acreages from Kern County Web Map (Kern County GIS, 2025).		

3 REGULATORY FRAMEWORK

This QRA study has been prepared to support the proposed CRC CalCapture Project and focuses on potential risks to the public from accidental releases of CO_2 and other hazardous materials associated with the CalCapture CCU, the CO_2 pipeline, and hazardous material road transport.

This section summarizes the statutory and regulatory basis for performing a QRA and demonstrates how it meets the CEC Application for Certification (AFC) requirements, California Environmental Quality Act (CEQA) disclosures, and applicable federal pipeline and geologic sequestration safety obligations. It also identifies industry standards used to structure the risk assessment and the risk acceptance criteria applied. There is no single regulation which prescribes a specific QRA method; however, this study has been structured so that it can be used to directly support applicable regulatory requirements and to align with the information needs of other project technical evaluations conducted under the Post-Certification PTA, including those addressing hazards and hazardous materials, and public health.

3.1 Federal Regulations and Guidance

Several U.S. federal programs govern aspects of CO_2 management, pipeline safety, and public protection that are relevant to the systems evaluated in this QRA:

- The U.S. EPA UIC Class VI program regulates the long-term subsurface injection and storage of CO_2. The CalCapture Project would deliver CO_2 to Class VI wells that have been approved as part of the CTV I project. The UIC program requires demonstration that injection activities will not endanger underground sources of drinking water and places requirements on characterization, monitoring, and corrective action.
- The U.S. Department of Transportation (U.S. DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) regulates the design, construction, operation, and maintenance of hazardous liquid pipelines. CO_2 transmission pipelines are subject to these regulations, which include integrity management requirements and reporting of incidents. These regulations inform the selection of pipeline design parameters and the historical failure data used in the pipeline frequency analysis.

Although these federal programs do not specify formal individual or societal risk criteria, they provide the regulatory context within which the systems that are part of the Project are designed and operated. The QRA applies industry standard methods to quantify risk in a manner consistent with this framework and suitable for supporting federal and state permitting decisions.

3.2 State of California Regulations and Local Requirements

The CalCapture Project is subject to state and local regulatory requirements that address environmental impacts, hazardous materials, and risks to sensitive receptors. These requirements are implemented through the Post-Certification PTA process and associated technical evaluations conducted in accordance with California Code of Regulations, Title 20, Section 1769.

The proposed CO_2 pipeline will be located entirely within CRC's operating property. As a result, the pipeline is not subject to U.S. DOT PHMSA regulations for hazardous liquids pipelines. However, with the passage of Senate Bill 614, the Office of the State Fire Marshal (OSFM) is required to develop state regulations for CO_2 pipelines. These regulations are expected to be at least as stringent as the federal requirements under 49 CFR Part 195. CRC will coordinate with the OSFM during final pipeline design to ensure compliance with the forthcoming regulatory framework.

In addition, the California Environmental Quality Act (CEQA) requires state and local agencies to evaluate and disclose the potential environmental impacts of discretionary projects, including risks associated with accidental releases of hazardous materials. The QRA supports this requirement by providing a quantitative evaluation of potential accidental release scenarios and associated risks to the public.

The CEC requires that the project comply with all applicable Laws, Ordinances, Regulations, and Standards (LORS). Accordingly, the PTA identifies specific Kern County General Plan goals and policies that are applicable to the project. These local policies address issues such as public safety, hazardous materials management, and protection of sensitive receptors, and provide the local regulatory context for evaluating project-related risks.

These state and local regulations collectively establish expectations that accidental release risks are systematically evaluated, disclosed, and managed, particularly in relation to sensitive receptors and the public. The QRA provides a quantitative characterization of those risks for the CalCapture Project.

3.3 CEC AFC Requirements for Hazards, Hazardous Materials, and Public Health

Title 20 of the California Code of Regulations (CCR), Division 2, Chapter 5, Appendix B describes the information typically required by the CEC to evaluate hazards, hazardous materials, and public health considerations. The CalCapture Project is being reviewed under a Post-Certification PTA, and the CEC continues to rely on Appendix B as the primary framework for identifying the scope and content of information needed to evaluate public safety and environmental impacts.

For hazards and hazardous materials handling, Appendix B includes requirements such as:

- A description and inventory of hazardous materials used or stored on site, including toxicity and physical properties.
- Mapping of schools, hospitals, day care centers, long term care facilities, and other sensitive land uses in the vicinity of the project.
- A description of storage and handling systems and measures proposed to reduce the risk of accidental releases, fires, and explosions.
- Protocols for modeling the potential offsite consequences of accidental releases, including model selection, input assumptions, and meteorological conditions.

For public health, it requires assessment of potential health risks from hazardous air emissions, identification of sensitive receptors within the area that could be exposed, and documentation of modeling inputs and results.

This QRA has been prepared to align with these information requirements and to support the CEC's review of the proposed project changes under the PTA process by:

1. Providing a detailed inventory of CO_2 and other hazardous materials associated with the CalCapture facility, pipeline, and transport activities, as well as a scenario list.
2. Identifying and mapping sensitive receptors within the study area, including residences, schools, and other facilities, consistent with the statutory definition of sensitive receptors.

3. Describing the consequence and risk modeling tools and methodology, input assumptions, and meteorological data used to simulate accidental releases and to estimate the extent and severity of potentially hazardous conditions.
4. Providing the hazard endpoint definitions based on human vulnerability to help in the estimation of severity of potentially hazardous conditions.
5. Confirming that no schools, hospitals, or day care centers are located within the project influence zone; the nearest public exposure location is Elk Hills Road, which is analyzed explicitly.
6. Quantifying individual and societal risk metrics that can be used, together with other project technical evaluations prepared under the PTA, to inform the assessment of public health and safety impacts.

The report, including the Study Basis (as provided in Appendix A), demonstrates that the CalCapture Project has been evaluated using methods consistent with CEC expectations for post-certification review, risk disclosure, and public risk management.

3.4 Industry standards and risk acceptance criteria

The QRA follows ISO 31000 for risk management and ISO 17776 for hazard identification and risk assessment. These standards guide the process from system definition through scenario selection and risk evaluation. This is further discussed in Section 4.

This QRA references international benchmarks for land use planning, as summarized in Section 6.6 of Appendix A: Study Basis. These criteria provide a solid basis for interpreting the magnitude of calculated individual and societal risks and for identifying whether additional risk reduction measures should be considered.

4 METHODOLOGY

This section provides a high-level summary of the key methodology aspects.

The methodology applied for estimation of risk to the public is a standard risk assessment approach. Figure 4-1 shows the main elements and the steps included in a risk assessment process. The assessment follows ISO 31000 [/1/] and aligns with ISO 17776 [/2/], which progresses from system definition and hazard identification through frequency/consequence analysis to risk estimation and evaluation against acceptance criteria. The scope of this risk analysis as performed by DNV is related to the "risk assessment diagram" shown in Figure 4-1.

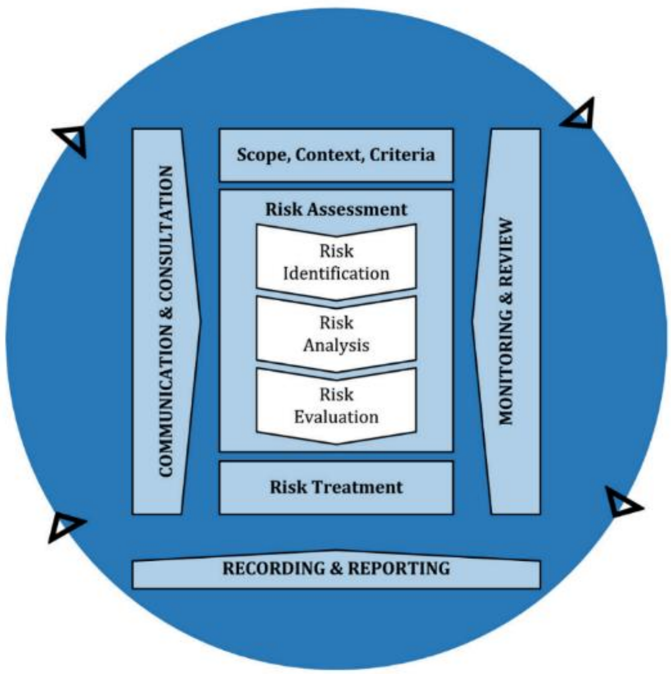


Figure 4-1: Risk management flow diagram [/1/]

Key steps in the risk assessment are:

- Identify potentially hazardous events, and
- Assessment and evaluation of potential consequences of the identified events.

The frequencies and consequences of the identified events are assessed against predefined acceptance criteria.

With basis in the ISO 31000 process [/1/] as presented in Figure 4-1, the QRA has been developed following the main steps further elaborated in subsequent sections.

4.1 System Definition

The initial step in the QRA process is to compile all relevant data to ensure that the analysis is based on the most accurate information available. This includes gathering data for the above-ground facilities and buried pipelines, such as drawings and documentation related to their design and operations.

The QRA model reflects current design drawings and operating data. Assumptions and inputs are compiled in Appendix A.

4.2 Hazard Identification / Failure Case Selection

Scenarios or hazards are defined by using a specific set of conditions to characterize a range of possible failures. It is not practicable or necessary to consider every possible permutation of release size and location, exact inventory at time of failure, temperature, pressure etc. since all of these in practice will vary. Thus, characteristic values of each parameter necessary to model the failure case are selected in such a way as to cover the spectrum of possible values.

Representative failure cases (small/medium/large/rupture) are defined to span credible variability in hole sizes, operating states, and inventories without over-specifying permutations. See Table 5-1 for the full scenario set.

4.3 Frequency Analysis

Release frequencies for the CalCapture facilities are estimated using historical release data from the UK Health and Safety Executive's (UK HSE) Hydrocarbon Release Database (HCRD) for 1992 – 2015, which was reviewed and compiled by the International Association of Oil & Gas Producers (IOGP) [/3/]. An equipment part count was performed to determine the leak frequency, providing representative basis for potential release scenarios.

Although the HCRD is based on offshore installations, it remains a suitable analogue for CalCapture. Offshore facilities typically operate under stricter inspection, maintenance, and integrity management requirements, while also being exposed to more severe environmental loading. These opposing factors tend to balance each other, which is consistent with findings from independent reviews [Ref /18//19//20/]. In addition, CalCapture process equipment, pressure systems, and operational controls are designed in accordance with current U.S. codes and industry standards that are broadly comparable to those used in offshore oil and gas operations. This alignment reduces the likelihood that the HCRD would underestimate equipment-related failure frequencies for this facility.

Since potential releases during unloading, transfer and storage of hazardous chemicals used in the facility are not included in the UK HSE's HCRD, estimation of potential releases of these types are based on the UK HSE Failure Rate and Event Data (FRED).

Assumptions for the pipeline failure frequencies are based on the U.S. DOT PHMSA failure frequency and associated hole size distribution, while the hole size definition is based on European Gas Pipeline Incident Data Group (EGIG). In addition, earthquake-induced failure rates are incorporated into the pipeline release frequencies to account for seismic risks specific to the site location.

Further details of the assumptions used in the failure frequency analysis are provided in Appendix A.

4.4 Consequence Assessment

The type of consequence assessment performed, and the level of detail depends on the actual hazard considered. In general, the consequence calculations for the release events considered in the QRA comprise the following main steps:

- Estimation of release rate and duration
- Gas dispersion calculations
- Ignited consequence
    - Fires and explosion calculations
- Un-ignited consequence calculations

- Toxic exposure calculations

The dispersing cloud is impacted by the weather conditions at the time of the release. A range of weather conditions are applied in the analysis. Additional detail and discussion are provided in Appendix A. The discharge and dispersion modeling are performed using Phast v9.11. The endpoints selected for the consequence assessment are listed in Section 7.2.

4.4.1 Computational Fluid Dynamics

DNV conducted computational fluid dynamics (CFD) analysis of the worst-case buried pipeline rupture scenario in order to strengthen the assessment to account for potential terrain impacts to the dispersion extent. It is important to note that this level of analysis is not explicitly required for the CRC pipeline segment given the absence of nearby sensitive receptors[3] as defined in California Senate Bill 614 (2025) [/4/]. However, it was undertaken to provide more refined results for the worst-case pipeline scenario compared to a simplified free-field model and so that the potential impact zone from the scenario is more accurately represented.

The CFD assessment followed a workflow which started with performing a screening exercise using the free-field Phast modeling software along the buried pipeline segment to identify the rupture location that would produce the longest downwind distances toward Elk Hills Road for a rupture. The discharge results for the specific release location selected was taken directly from Phast and specified as input to KFX for the CFD analysis.

Dispersion was simulated in KFX for the worst-case wind condition from west to east with the CO_2 plume being directed toward the Elk Hills Road. Four representative weather conditions were modeled to cover stability and wind speed combinations considered in the QRA. Both isolation success and isolation failure cases were evaluated. Terrain and surface roughness local to the facility were included and was taken from the U.S. Geological Survey (USGS) National Map Application [/5/], and local grid refinement was applied near the release source.

The resulting lethality output from KFX was then imported into Safeti for the full-bore rupture at the selected location. CFD-based lethality distances were used to define receptor impacts in the QRA calculations for the specific location of rupture.

4.5 Human Vulnerability Criteria

The consequence analysis, as discussed in Section 4.4, predicts the distance to each relevant hazard level, such as toxic cloud, thermal radiation or overpressure. For the risk calculations part of the analysis, these hazard levels must be linked to their expected impact on people. This is done by selecting end-point criteria that represent conditions associated with a defined likelihood of a fatality based on established industry recommendations. In the Safeti software, if the hazard at a location exceeds the chosen end point, exposed individuals are assigned the corresponding fatality probability.

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[3] According to California Senate Bill 614 (2025) [/4/], a *"sensitive receptor" means any of the following:*

(A) An education facility, including a preschool, school with transitional kindergarten, kindergarten, or any of grades 1 to 12, inclusive, daycare center, park, playground, college, or university.
(B) A community resource center, including a youth center.
(C) A health care facility, including a hospital, retirement home, or nursing home.
(D) Live-in housing, including a long-term care hospital, hospice, prison, detention center, or dormitory.
(E) A residence, including a private home, condominium, apartment, and living quarter.
(F) A building that is a business that is open to the public.

A sensitive receptor does not include a facility or building set forth in paragraph (1) that is not certified for occupancy or has been abandoned.

4.5.1 Vulnerability criteria for fires and explosions

The end-point criteria and associated vulnerability parameters for fires and explosions used in this assessment are provided in Table 4-1.

Table 4-1 Summary of Fires and Explosions Vulnerability (Fatality) Criteria for Personnel Outdoors

Fire (jet fire, pool fire, and fireball)	**LSIR**
Flame Zone	1
Heat Radiation > 37.5 kW/m^2	1
Heat Radiation < 37.5 kW/m^2	Probit calculation, 36.38 + 2.56 ln[(W.m^{-2})$^{4/3}$.T], where exposure time T is in seconds and maximum exposure time is 20 seconds.
Flash Fire	**LSIR**
Inside the LFL Envelope	1
Outside the LFL Envelope	0
Explosion	**LSIR**
Overpressure 0.5 psi	0.1
Overpressure 2 psi	0.2
Overpressure 3 psi	0.5
Overpressure > 3 psi	1

4.5.2 Human vulnerability criteria for toxic cloud

4.5.2.1 Probit-based approach

The probability of death (P_E) due to exposure to a toxic cloud is calculated with the use of a probit function as shown below.

The Probit equation used to calculate the probability of fatality is as follows:

$$P_E = a + b \ln(C^n \times t)$$

where C is the concentration (ppm)
t is the time of exposure (minutes)
a is a constant
b is a constant and
n is a constant

The cloud envelope to a specified concentration of interest at its boundary will be determined using Phast/Safeti. The concentration of interest is determined from the toxicology of the material and applied through the probit relationship described above. The exposure time is calculated in the modeling for each location based on the release dynamics and the total inventory available for release in each defined scenario. Phast/Safeti applies a maximum exposure cap of 1 hour; however, this does not imply that releases will persist for full duration.

The probit constants are derived from the UK HSE Specified level of toxicity (SLOT) and Significant likelihood of death (SLOD) values [Ref /21/]. These toxic probit constants are defined in Phast / Safeti as the default parameter values.

Material	**Constants**		
	a	**b**	**n**
CO_2	-90.778	1.01	8
Sulfuric Acid	-8.3959	0.94	2.14

4.5.2.2 Concentration-based risk approach

Another toxic material present at the facility is sodium hydroxide and EFG+. The toxic modeling approach adopted for this material will follow the concentration-based threshold method available in the risk modeling software, Safeti, as no probit constants are available for these materials.

The threshold toxic dose is determined using reference concentration, reference duration, and toxic dose threshold values defined in the material properties. This method calculates the toxic dose by integrating the concentration over the exposure duration and comparing it against the threshold dose. For the case of sodium hydroxide, it would be a concentration of 10 mg/m^3 which the NIOSH provides as the concentration that corresponds to IDLH after 30 minutes exposure time.

Given the low volatility and very limited vapor hazard of sodium hydroxide, the modeling is not expected to predict significant toxic effect distances beyond immediate release points. As such, while this methodology will be applied, the contribution to the offsite toxic risk profile is expected to be limited.

4.6 Risk Calculation

The risk is estimated using Safeti v9.11, which compiles the consequences, the likelihood of each event (based on the frequency analysis and the background data) and the resulting impact to the surrounding area. The key assumptions related to risk modeling are presented in Appendix A.

Individual risk is expressed in terms of geographical variations of annual fatal risk, represented by isopleths, or iso-risk contour plots. The iso-risk contour indicates the extent of the area in which the facility or operation represents a potential hazard. The risk level is estimated for a hypothetical individual who is exposed to the risk at a specific location 24 hours per day, 365 days per year. This location-specific individual risk (LSIR) risk contour is thus independent of the fraction of year a person might actually be at the location and exposed to the hazards.

In evaluating the risks associated with the system, it is important not only to consider the individual risk, but also how many people are affected by an accident, represented by the ‘societal risk’. One way of assessing this is to construct an FN curve, showing the cumulative frequency F with which N or more people are predicted to become fatalities.

The number of predicted fatalities in any one occurrence of an event can be determined from the location specific individual risk values, taking into account the number of people at each location at any one time. The population distributions used in this process are given in Appendix A: Study Basis.

A numerical expression of the societal risk posed by a particular release scenario, or group of scenarios, is the Potential Loss of Life (PLL). The PLL is defined, for each loss of containment scenario, as the product of the frequency and the predicted number of fatalities for that scenario, and it is a measure of the expected number of fatalities per year produced by the scenario.

4.6.1 Transport Incident Data Collection

To quantify risk associated with road transportation of hazardous materials, historical incident data were obtained from PHMSA’s comprehensive database of hazardous material release incidents that meet federal reporting thresholds, documented through the U.S. DOT Hazardous Materials Incident Report Form 5800.1.

For this study, the U.S. DOT “Hazmat Incident Report Search Tool” was used to extract history of incidents [/6/]. The search focused on incidents occurring during highway transit involving the chemicals of interest. A 25-year period was considered, spanning from January 1, 2000, to October 5, 2025.

4.7 Risk Acceptance Criteria

4.7.1 Individual Risk

Risk acceptance criteria are used to determine whether the calculated overall risk level of the facility is within acceptable limits. LSIR is a commonly applied measure for land-use planning and regulatory compliance. While no specific risk criteria have been identified in U.S. Federal, State, or Local regulations that would apply to this project, various jurisdictions, including California, have established individual risk of fatality criteria for public populations. Full details of the individual risk criteria for various jurisdictions are provided in Appendix A.

4.7.2 Societal Risk

Societal risk refers to the potential for an incident to cause harm to multiple individuals within a population. It is typically expressed in terms of the frequency of events resulting in a specified number of fatalities. In a QRA, societal risk is often represented using FN curves, which shows the cumulative frequency (F) of there being N or more fatalities among a population group. It is a way of assessing group risk and the level of risk that a society would tolerate. An FN curve is constructed from a large number of 'FN pairs' where each pair represents a scenario that occurs with frequency F and fatally injures N people.

For this QRA, DNV applied the societal risk threshold used by Santa Barbara County[4] as the primary benchmark as it is one of the few published criteria for societal risk and comes from a neighboring county. This is shown in Figure 4-2. This criterion provides a relevant and regionally appropriate reference for evaluating societal risk and reflects established risk tolerability levels within California. Full details of the societal risk criteria for various jurisdictions are provided in Appendix A.

[4] The Santa Barbara County societal risk criterion is documented in the County's Environmental Thresholds and Guidelines Manual (October 2008) [Ref /9/], and was developed to support environmental review and land use decision-making for projects involving hazardous materials, where quantitative evaluation of potential public risk is required. In the absence of a statewide societal risk standard in California, this criterion has been typically referenced as a regional benchmark for evaluating societal risk.

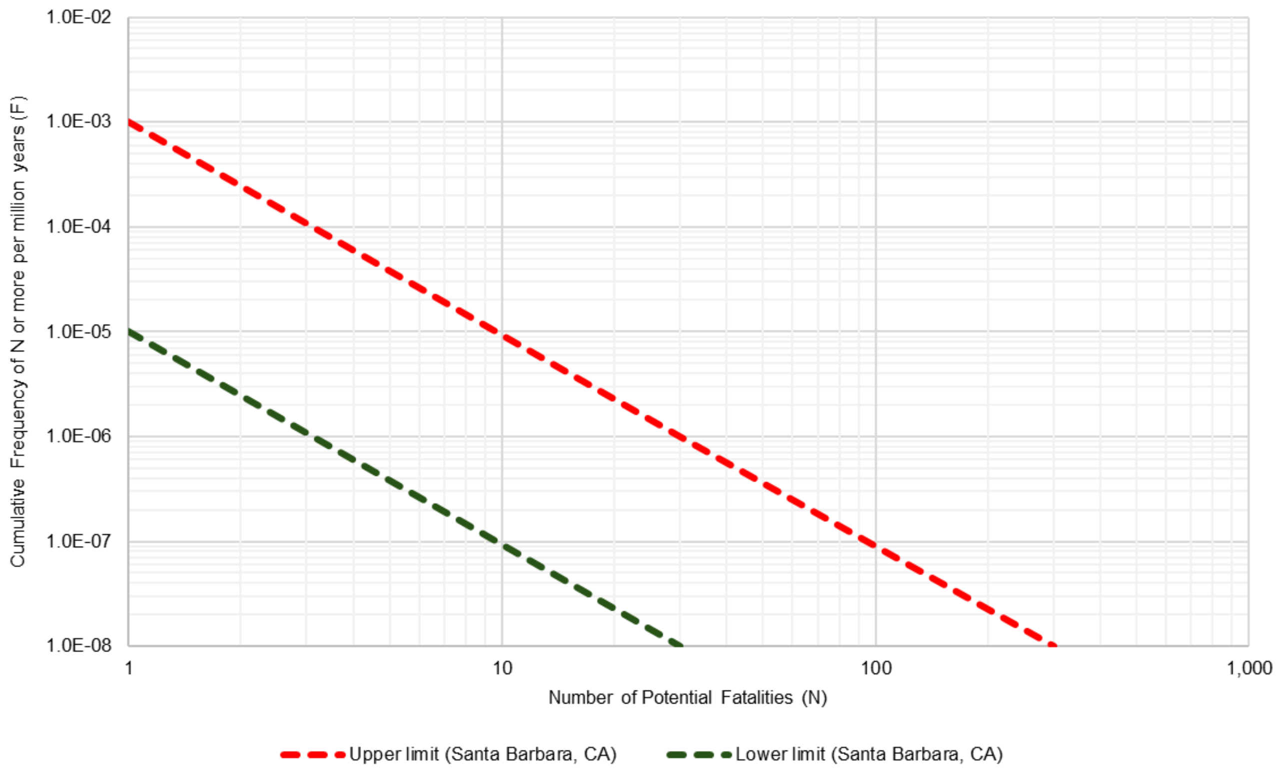


Figure 4-2 Societal Risk Criterion used in the QRA (Santa Barbara, CA)

5 HAZARD IDENTIFICATION

Table 5-1 provides the scenarios considered in the QRA study. The scenarios are grouped based on the main systems listed in Section 1.2.

Table 5-1: List of scenarios considered in the QRA

Scenario ID	Sub-system	Components	Temperature	Pressure	Flowrate (lb/hr)
1A – Release from upstream of Direct Contact Cooler	1. Flue Gas Cooling	H_2O, CO_2, N_2, Ar, O_2, NO, NO_2, NH_3, SO_2	210	Atmospheric	6,062,500
2A – Release from downstream of Blower	2. CO_2 Absorption	H_2O, CO_2, N_2, Ar, O_2, NO, NO_2, NH_3, SO_2	122	Atmospheric	6,019,560
2B – Release from Absorber to Rich Solvent Pump to Solvent Cross Exchanger	2. CO_2 Absorption	H_2O, CO_2, N_2, Ar, O_2, EFG+, HSS	121	Atmospheric	4,978,580
2C – Release from Lean Solvent Cooler and Lean Solvent Filter to Absorber	2. CO_2 Absorption	H_2O, CO_2, EFG+, HSS	100	Atmospheric	4,555,680
2D - Release from Lean Solvent Flash Drum and Lean Solvent Pump and Solvent Cross Exchanger	2. CO_2 Absorption	H_2O, CO_2, EFG+, HSS	225	Atmospheric	4,648,630
3A – Release from Solvent Cross Exchanger to Stripper	3. Solvent Regeneration	H_2O, CO_2, N_2, Ar, O_2, EFG+, HSS	214	60.3	4,978,580
3B – Release from Lean Flash Drum to Lean Vapor Compressor	3. Solvent Regeneration	H_2O, CO_2, EFG+	225	Atmospheric	146,170
3C – Release from Overhead Accumulator to Compressor	3. Solvent Regeneration	H_2O, CO_2, N_2, Ar, O_2,	112	8.8	414,530
3D – Release from Stripper to Solvent maintenance system	3. Solvent Regeneration	H_2O, CO_2, EFG+, HSS, Degradation products	248	11	3,342
3E – Recovered Solvent Release from Solvent Maintenance System to Lean Flash Drum	3. Solvent Regeneration	H_2O, CO_2, EFG+	102	11.5	3,091
4A – Release from hose connection during solvent truck unloading	4. Chemical Storage and Supply	EFG+	Ambient	Atmospheric	140 gpm
4B – Release from hose connection during TEG truck unloading	4. Chemical Storage and Supply	TEG	Ambient	Atmospheric	30 gpm

Scenario ID	Sub-system	Components	Temperature	Pressure	Flowrate (lb/hr)
4C – Release from hose connection during Sulfuric Acid truck unloading	4. Chemical Storage and Supply	Sulfuric Acid	Ambient	Atmospheric	45 gpm
4D – Release during Sodium Hydroxide truck unloading	4. Chemical Storage and Supply	Sodium Hydroxide	Ambient	Atmospheric	85 gpm
4E – Release from solvent storage	4. Chemical Storage and Supply	EFG+	Ambient	Atmospheric	220,000 gal/yr
4F – Release from TEG storage	4. Chemical Storage and Supply	TEG	Ambient	Atmospheric	2,930 gal/yr
4G – Release from hydrogen cylinder storage	4. Chemical Storage and Supply	H_2	70	3,000	0.77 MSCF/yr
4H – Release from Sulfuric Acid storage	4. Chemical Storage and Supply	Sulfuric Acid	Ambient	Atmospheric	6,600 gal/yr
4I – Release from Sodium Hydroxide storage	4. Chemical Storage and Supply	Sodium Hydroxide	Ambient	Atmospheric	30,000 gal/yr
5A – Release from CO2 Product Compressor to CATOX Unit Static Mixer	5. CO2 Compression	H_2O, CO_2, N_2, Ar, O_2	224	700	406,180
5B – Hydrogen from cylinder to CATOX Unit Static Mixer	5. CO2 Compression	H_2	68	700	0.5
6A – Release from Vent during maintenance	6. Vent Stack	CO_2	120	2,100	Full depressurization of 10" pipeline with inventory of 44,783 lb
6B – Release from Vent during compressor blowoff	6. Vent Stack	CO_2	120	2,100	4,800 TPD
6C – Release from Vent during emergency blowdown (small leak)	6. Vent Stack	CO_2	120	2,100	Full depressurization of 10" pipeline with inventory of 44,783 lb
7A – Release from Natural Gas Fired Boiler	7. Fired Boiler	Natural Gas (Methane)	70	200	4 MMSCFD
8A – Release from SDV in the above-ground manifold	8. Measuring Skid	CO_2	120	2,100	404,230

Scenario ID	Sub-system	Components	Temperature	Pressure	Flowrate (lb/hr)
8B – Release from analyzer and flowmeter in the above-ground manifold	8. Measuring Skid	CO_2	120	2,100	404,230
9A – Release from 10” pig launcher in the above-ground manifold	9. Pig Launcher	CO_2	120	2,100	404,230
10A – 10” Above-ground Pipeline (CalCapture area)	10. Pipeline	CO_2	120	2,100	404,230
10B – 10” Buried Pipeline	10. Pipeline	CO_2	120	2,100	404,230
10C – 10” Above-ground Pipeline (Manifold area)	10. Pipeline	CO_2	120	2,100	404,230
11A – Release from 10” pig receiver in the above-ground manifold	11. Pig Receiver	CO_2	120	2,100	404,230
12A – Release of Solvent during road transport	12. Road Transport	EFG+	Ambient	Atmospheric	53 per year (transport frequency)
12B – Release of TEG during road transport	12. Road Transport	TEG	Ambient	Atmospheric	20 per year (transport frequency)
12C – Release of hydrogen during road transport	12. Road Transport	Hydrogen	70	3,000	6 per year (transport frequency)
12D – Release of Sulfuric Acid during road transport	12. Road Transport	Sulfuric Acid	Ambient	Atmospheric	9 per year (transport frequency)
12E – Release of Sodium Hydroxide during road transport	12. Road Transport	Sodium Hydroxide	Ambient	Atmospheric	12 per year (transport frequency)

6 FREQUENCY ANALYSIS

6.1 CalCapture Unit

DNV performed a (Process and Instrumentation Diagram) P&ID-level equipment part count for the CalCapture facility. The calculated frequencies by the various sub-systems, listed in Table 5-1, and broken down by hole size is provided in Table 6-1.

Table 6-1: Failure frequency distribution by hole size

Name	Release Frequency (per year)					Failure frequency (in years)
	Small	Medium	Large	Rupture	Total	
1. Flue Gas Cooling	2.2E-03	2.2E-04	5.6E-05	6.9E-05	2.5E-03	1 in 400 years
2. CO2 Absorption	5.0E-02	4.4E-03	8.8E-04	1.6E-03	5.6E-02	1 in 18 years
3. Solvent Regeneration	4.0E-02	5.2E-03	7.1E-04	1.8E-03	4.7E-02	1 in 21 years
4. Chemical Storage and Supply	3.5E-03	1.6E-04	5.9E-04	3.2E-05	4.2E-03	1 in 240 years
5. CO2 Compression	1.1E-02	1.5E-03	3.1E-04	7.0E-04	1.4E-02	1 in 71 years
7. Fired Boiler	3.2E-04	5.4E-05	1.4E-05	3.6E-05	4.2E-04	1 in 2,400 years
8. Measuring Skid	2.1E-03	1.7E-04	3.2E-05	6.6E-05	2.4E-03	1 in 420 years
9. Pig Launcher	2.0E-03	3.3E-04	6.6E-05	1.7E-04	2.5E-03	1 in 400 years
11. Pig Receiver	1.9E-03	3.3E-04	6.6E-05	1.7E-04	2.4E-03	1 in 410 years
Total	1.1E-01	1.2E-02	2.7-03	4.7E-03	**1.3E-01**	**1 in 8 years**

Table 6-1 presents the estimated failure frequencies for different equipment items categorized by hole size (small, medium, large, and rupture). The total event frequency for all equipment combined is approximately ~1.3E-01 per year, which corresponds to approximately one event every 8 years. Results indicate that the different sub-systems have varying frequencies, with CO_2 Absorption and Solvent Regeneration having relatively higher totals (1 in 18 years and 1 in 21 years, respectively), while others such as the Fired Boiler and Pig Launcher exhibit much lower frequencies (1 in 2,368 years and 1 in 398 years). The higher failure frequencies observed in certain sub-systems are largely attributable to the greater number of equipment items within those systems, which increases the overall likelihood of a release.

However, it is important to emphasize that a higher event frequency does not automatically translate into severe consequences or worst-case scenarios. The distribution of release sizes demonstrates clearly that approximately 85% of all predicted releases are small, 10% are medium, 2% are large, and 4% are rupture. This means that while the likelihood of a release occurring is dominated by small leaks, these events typically have limited consequences compared to larger failures. The consequence of an event depends on multiple factors such as hole size, operating conditions, ignition probability, detection and isolation systems, and emergency response measures. Therefore, while some equipment shows higher frequencies of release, these are predominantly associated with small releases that pose limited risk compared to large-scale failures.

This distinction is important as frequency indicates how often an initiating event might occur, not the severity of its outcome. Section 8 of this QRA report integrates both frequency and consequences to evaluate overall risk for the Project.

Note that the above discussion is for the CalCapture facility only, the pipeline release and road transport incident frequencies are discussed below in Sections 6.2 and 6.3, respectively.

6.2 Pipeline

Table 6-2 summarizes the estimated release frequencies for the pipeline, categorized by hole size (pinhole, leak, and rupture). The total failure frequency for the pipeline is ~1.8E-03 per mile-year, which corresponds to approximately one event every 1,336 years for the entire length of the pipeline. Full details of how these figures have been calculated are discussed in Appendix A.

Note that the pipeline release frequency analysis is based only on the pipeline, as there are no buried flanges or pumps within the scope of the current buried pipeline design.

The assumed release directions differ for above-ground and buried sections: horizontal for above-ground and vertically upward for buried pipelines.

Table 6-2: Failure frequency distribution by hole size

	Release frequency (per mi-year)				Failure frequency (in years for 0.5 mi pipeline)
	Pinhole	Leak	Rupture	Total	
Pipeline	9.5E-04	3.9E-04	4.6E-04	**1.8E-03**	**1 in 1,336 years**

6.3 Road Transport Incidents

6.3.1 Compressed Hydrogen

The U.S. DOT hazmat incident database was searched for incidents related to transport of compressed hydrogen. Over the last 25-year period there were 19 highway-transit incidents reported for compressed hydrogen. As shown in Table 6-3, the majority of incidents relate to vehicle collision or rollover (53%) and 16 of the 19 incidents resulted in a release. Only 1 fatality was reported and it was not related to a release of hydrogen.

Table 6-3 U.S. DOT Compressed Hydrogen Highway Transit Incidents (2000-2025)

Transit incident Type	No. of incidents	No. of incidents resulting in release of hazardous material	No. of fatalities related to the hazardous material	No. of fatalities not related to the hazardous material	No. of injuries related to the hazardous material
Vehicle collision or rollover	10	7	-	1	2
Equipment failure	4	4	-	-	-
Vehicle fire / malfunction	3	3	-	-	-
Unknown	2	2	-	-	-
Total	19	16	0	1	2

6.3.2 Sulfuric Acid

The U.S. DOT hazmat incident database was searched for incidents related to transport of sulfuric acid (including sulfuric acid, solutions with >51% acid, and spent sulfuric acid). Over the last 25-year period there were 208 highway-transit incidents reported for sulfuric acid. As shown in Table 6-4, the majority of incidents relate to operating error (44%) or equipment failure (35%). Vehicle collision or rollover only account for 19% of the incidents. Only 1 fatality related to the hazardous material was reported across the incidents.

The average quantity spilled for the equipment failure and operating error incidents is 23 gallons, and the median value across the incidents is 5 gallons.

Table 6-4 U.S. DOT Sulfuric Acid Highway Transit Incidents (2000-2025)

Transit incident Type	No. of incidents	No. of incidents resulting in release of hazardous material	No. of fatalities related to the hazardous material	No. of fatalities not related to the hazardous material	No. of injuries related to the hazardous material
Equipment failure	72	69	-	-	18
Operating error	92	91	-	-	2
Vehicle collision or rollover	40	33	1	3	5
Unknown	4	4	-	-	-
Total	208	197	1	3	25

6.3.3 Sodium Hydroxide

The U.S. DOT hazmat incident database was searched for incidents related to transport of sodium hydroxide solutions. Over the last 25-year period there were 176 highway-transit incidents reported for sodium hydroxide. As shown in Table 6-5, the majority of incidents relate to equipment failure (36%) or operating error (30%). Vehicle collision or rollover (32%) is also a significant contributor to the incidents. No fatalities were reported related to the release of hazardous material across the incidents.

The average quantity spilled for the equipment failure and operating error incidents is 87 gallons, and the median value across the incidents is 5 gallons.

Table 6-5 U.S. DOT Sodium Hydroxide Highway Transit Incidents (2000-2025)

Transit incident Type	No. of incidents	No. of incidents resulting in release of hazardous material	No. of fatalities related to the hazardous material	No. of fatalities not related to the hazardous material	No. of injuries related to the hazardous material
Equipment failure	63	63	-	-	-
Operating error	53	53	-	-	2
Vehicle collision or rollover	57	49	-	3	6
Unknown	3	3	-	-	-
Total	176	168	0	3	8

6.3.4 Monoethanolamine / Ethanolamine

The U.S. DOT hazmat incident database was searched for incidents related to transport of monoethanolamine or ethanolamine. Over the last 25-year period there were 14 highway-transit incidents reported for bulk (cargo or portable tanks) transport of the chemical. As shown in Table 6-6, the majority of incidents relate to equipment failure. No fatalities or injuries were reported related to the transit incidents. The majority of incidents relate to equipment failure (64%). Operating error and vehicle collision or rollover each contribute 14% to the incident history. No fatalities or injuries were reported related to the release of the hazardous material transit incidents.

Table 6-6 U.S. DOT Monoethanolamine / Ethanolamine Highway Transit Incidents (2000-2025)

Transit incident Type	No. of incidents	No. of incidents resulting in release of hazardous material	No. of fatalities related to the hazardous material	No. of fatalities not related to the hazardous material	No. of injuries related to the hazardous material
Vehicle collision or rollover	2	1	-	-	-
Equipment failure	9	9	-	-	-
Operating error	2	2	-	-	-
Vandalism	1	1	-	-	-
Total	14	13	0	0	0

6.3.5 Transport Release Frequency

There is the potential for hazardous materials to be released while in transit to the facility. Releases may occur due to a variety of causes as indicated by the previous discussion, including vehicle collision, equipment failure or operating error.

The U.S. DOT Federal Motor Carrier Safety Administration (FMCSA) tracks incident data. In 2021, the number of crashes involving large trucks (494,000 crashes) and the number of million vehicle miles traveled (MVMT) (327,026 MVMT) provides the estimation of 1.51 large truck crashes per MVMT [/11/]. This estimate includes both hazardous material and non-hazardous material vehicles.

If a hazardous material carrier is involved in a vehicle incident, there are many factors that influence whether a release of the hazardous material will occur. This can be influenced by the type of vehicle incident which can also be influenced by the roadway type (freeway, multilane, divided or not) and area type (rural or urban). The probability of a hazardous material release given an accident was estimated in a study by Harwood et. al. [/12/] in 1990. The probability of release given an accident ranged from 0.05 to 0.09, depending on the highway class. Harwood outlined a methodology to calculate the hazardous material accident release rate based on the general truck accident rate and application of the probability of release [/13/].

Based on 1.51 large truck crashes per MVMT and conservatively assuming a release probability of 0.09, the general hazardous material release frequency from collision is estimated as 0.136 releases per MVMT. As discussed in the previous incident transport histories for the products, other failure causes such as equipment failure or operating error may also contribute to a release during transit. The historical incident data summarized in the early sections, show that collisions account for 14-53% of the reported hazardous material releases during transport. To ensure that the estimated release frequency reflects the full set of credible failure causes and not only collisions, the calculated collision based frequency is scaled upward so that the total frequency matches the observed distribution of release causes in the historical record. This approach provides a conservative method to incorporate both collision and non-collision contributors when detailed frequency rates are not available for the road transport of hazardous material being analyzed.

Table 6-7 presents the total transit release frequency estimated for each chemical transport. The transportation routes are not evaluated in detail; a 50-mile travel distance is assumed for the transport for each chemical.

Table 6-7 Transit Release Frequency Estimate

Material	Collision Release Frequency, per MVMT	Collision fraction of Historical Incidents	Non-collision fraction of Historical incidents	Total Release Frequency, per MVMT	No. transports per year	Distance travelled, mi per trip	Annual mileage travelled	Total Transit Release Frequency, per year
Solvent (amine)	0.136	0.14	0.86	0.97	53	50	2,650	2.6E-03
Hydrogen	0.136	0.53	0.47	0.26	6	50	300	7.7E-05
Sulfuric Acid	0.136	0.19	0.81	0.72	9	50	450	3.2E-04
Sodium Hydroxide	0.136	0.32	0.68	0.42	12	50	600	2.5E-04

7 CONSEQUENCE ANALYSIS

7.1 Weather Data

Data on wind direction and wind speed are combined to form a set of representative weather categories. The wind speed by direction is based on the hourly average winds extracted for the Meadows Field Airport, Bakersfield [/14/] over the period 2015 to 2025 to generate the site wind rose using this 10-year span.

Four representative weather conditions, as presented in Table 7-1, are defined for the study based on the airport weather data. Note these values incorporated calms (equally distributed) across all the directions in the lowest wind speed range (1.5 m/s or 3.3 mph). The predominant wind direction is from the northwest (14% annually), with an average wind speed in the area of 3.2 m/s (7.2 mph). Additional details are provided in Appendix A.

Table 7-1: Representative Weather Conditions

Weather Case	Atm. Stability	Wind Speed (m/s) [mph]	Total Probability
F1.5	F	1.5 m/s [3.3 mph]	0.3466
B3	B	3 m/s [6.7 mph]	0.3683
E5	E	5 m/s [11.2 mph]	0.2116
D8	D	8 m/s [17.9 mph]	0.0734

7.2 Hazard Endpoints

Hazard types including flammable dispersion, jet fire, explosion and toxic are considered in this QRA study. A comprehensive understanding of these hazard endpoints is crucial for assessing the potential consequences associated with the various release scenarios. The following endpoints are considered in the study.

<table>
<tr><th>Hazardous effect</th><th>Endpoints</th></tr>
<tr><td>Explosion overpressure</td><td>Explosion hazard frequency contours for 0.5 psi (0.03 bar), 2 psi (0.1 bar), and 3 psi (0.2 bar).</td></tr>
<tr><td>Thermal radiation</td><td>Thermal hazard frequency contours as per below [/15/]-
<table>
<tr><th>Thermal Radiation</th><th>Effect</th></tr>
<tr><td>4.7 kW/m^2</td><td>Heat intensity in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing</td></tr>
<tr><td>9.46 kW/m^2</td><td>Pain threshold reached after 8 seconds; second-degree burns after 20 seconds</td></tr>
<tr><td>37.5 kW/m^2</td><td>Significant chance of fatality for people exposed instantaneously. Sufficient to cause damage to process equipment</td></tr>
</table></td></tr>
<tr><td>Flammable gas</td><td>Lower Flammable Limit (LFL) and 50% LFL</td></tr>
</table>

Hazardous effect	Endpoints
Toxic gas concentration – CO_2	CO_2 is a colorless, odorless gas at atmospheric temperatures and pressures. It is heavier than air and may asphyxiate by the displacement of air. Exposure to CO_2 can cause headache, dizziness, difficulty breathing and tremors. Extremely high concentrations, far above typical occupational exposure limits, can be dangerous and may lead to serious health effects. The CO_2 concentrations of interest for the evaluation in the QRA are: • 30,000 ppm – American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for short-term exposure limit (STEL), based on a 15-minute exposure time [/16/]. This limit is used as a reference for modeling purposes and should not be considered as a maximum emergency limit. • 40,000 ppm – National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) after 30 minutes exposure time [/17//]. This limit is used as a reference for modeling purposes and should not be considered as a maximum emergency limit. • 50,000 ppm, 75,000 ppm, and 100,000 ppm. (Note 1) • 110,000 ppm – Estimated CO_2 concentration with potential to cause gasoline engine stall. • 150,000 ppm – Estimated CO_2 concentration with potential to cause diesel engine stall. Note 1: The concentrations of 50,000, 75,000, and 100,000 ppm CO_2 are not linked to specific regulatory thresholds but are included as reference levels to illustrate concentration ranges that may occur close to the source following the release scenarios. These values provide useful visualization to show concentration bands to complement the benchmark levels of 30,000 ppm (short-term exposure limit) and 40,000 ppm (IDLH). They are included solely to aid in interpreting dispersion behavior and plume extent, but not to represent health outcomes or specific regulatory limits.
Toxic gas concentration - Others	Other toxic materials present in the facility include: • Sulfuric Acid • Sodium Hydroxide • EFG+ (represented as Monoethanolamine, MEA) • Nitrogen (asphyxiation hazard due to oxygen displacement) The concentrations of interest for these materials for the evaluation are: • Sulfuric Acid: 15 mg/m^3 – National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) after 30 minutes exposure time [/17/]. This limit is used as a conservative threshold for modeling purposes and should not be considered as a maximum emergency limit. • Sodium Hydroxide: 10 mg/m^3 – National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) after 30 minutes exposure time [/17/]. This limit is used as a conservative threshold for modeling purposes and should not be considered as a maximum emergency limit. • Monoethanolamine: 2,500 mg/m^3 – The U.S. Department of Energy Protective Action Criteria 3 (PAC-3) defines this to be the maximum concentration considered to be potentially life-threatening or fatal after 30 minutes exposure time. • Nitrogen: 76,500 ppm – Calculated concentration threshold at which oxygen displacement becomes a concern for asphyxiation. This value is used for modeling purposes and should not be considered as a regulatory limit. Other materials (e.g. ethylene glycol, triethylene glycol, sodium hypochlorite, citric acid, biocide, and sodium bisulfite) are present onsite; however, these are either stored in very low volumes or are not classified as toxic when inhaled. Since the QRA focuses on potential toxicity effects to personnel from the dispersion of toxic fumes away from the site, they are not included in this assessment.

7.3 Free-field Dispersion and Consequence Results

The tables outlined in Appendix B present the results of atmospheric dispersion and consequence modeling for the scenarios considered in the QRA. These simulations were performed under free-field conditions in Phast. The objective of this analysis is to determine the extent of hazardous concentrations for each release scenario and to use these results to assess potential risks to the public.

The key findings at a height of 3.3 ft are summarized below:

- Among all scenarios, buried pipeline leaks exhibit the greatest toxic impact distances, with downwind concentrations of CO_2 reaching up to 1,540 ft at 30,000 ppm under D8 weather conditions. This significantly exceeds the distances observed in above-ground releases scenarios. The rupture scenarios also show substantial toxic dispersion, particularly for NaOH, with distances exceeding 1,000 ft in some cases.
- Flammable dispersion distances are generally lower than toxic dispersion but still pose a significant hazard. The 7A scenario under rupture conditions show the largest flammable impact zones, with LFL distances reaching up to 89 ft and ½ LFL distances exceeding 220 ft.
- Thermal radiation results indicate that rupture scenarios again dominate in terms of impact. For jet fires, radiation levels of 37.5 kW/m^2 extend up to 136 ft, while pool fires in the same scenarios reach 194 ft. These distances represent zones where thermal exposure could cause serious injury or damage to equipment and infrastructure.
- Overpressure modeling reveals that scenario 3A produces the highest blast wave impact, with 0.5 psi overpressure reaching up to 200 ft and 3 psi up to 94 ft.

7.3.1 Vent Dispersion Results

Three vent release scenarios were modeled which correspond to the following operational conditions:

- Scenario 6A: Vent release during maintenance.
- Scenario 6B: Vent release during compressor blowoff.
- Scenario 6C: Vent release during emergency blowdown (same flowrate as 6A).

For these vent scenarios, the release is oriented vertically upwards, promoting the rise of the plumes and minimizes ground-level concentrations. Figure 7-1 presents the side view snapshots for Scenarios 6A and 6C at time = 1 second, showing results for different atmospheric stability categories, with contours representing CO_2 concentrations at 30,000 ppm, 40,000 ppm, 100,000 ppm, and 150,000 ppm. Similarly, Figure 7-2 illustrates the side view for Scenario 6B at time = 1 second under the same conditions and concentration levels.

Across all cases, the plume remains well above 100 ft from ground level. This indicates that the vented CO_2 is not expected to impact any structures or receptors below 100 ft in height.

The vertical orientation of the vent is a key factor to achieving this dispersion behavior, as it directs the flow away from ground-level and also facilitates dilution. The results confirm that venting during maintenance, emergency blowdown, or compressor blowoff do not pose a hazard receptors below 100 ft.

It is noted in the figures below (Figure 6-1B and Figure 6-2B), which represent the highly turbulent atmospheric conditions, that a noticeably flatter and more lateral spreading plume is observed compared to the profiles under stable conditions. This behavior is driven by the strong turbulence associated with Category B Pasquill stability, which accelerates plume mixing, thereby reducing its vertical rise. The concentration contours for B3 show significant differences in shape, but still well above 100 ft elevation

Figure 7-3 shows the plume progression for the 1.5F case, presented below as an example for Scenario 6B to illustrate the cloud profile following the release. The timesteps are shown only up to five seconds due to the short duration of the release.

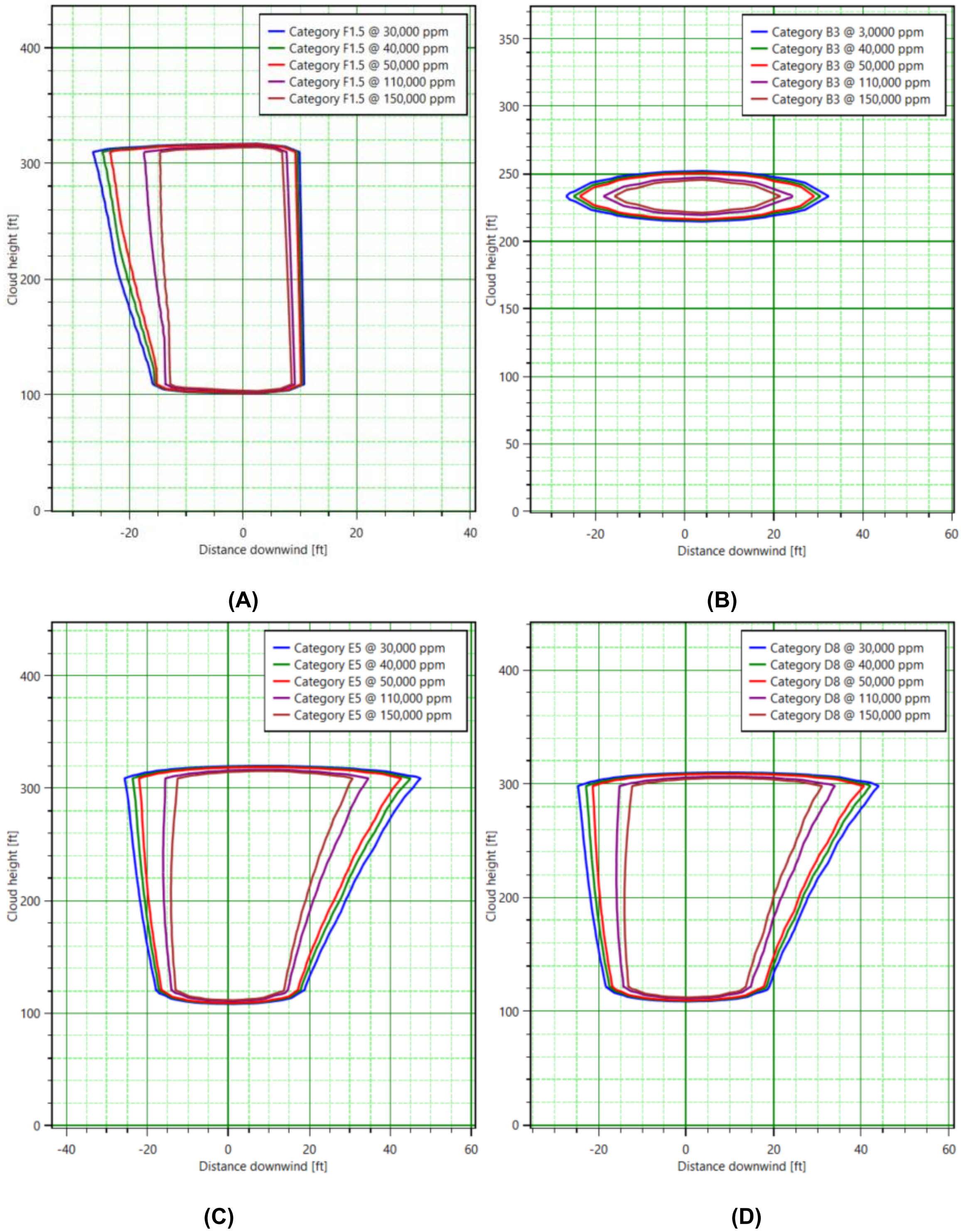


Figure 7-1 6A/6C Vent Release Scenario – Side view at 1s (A: F1.5, B: B3, C: E5, and D: D8 weather conditions)

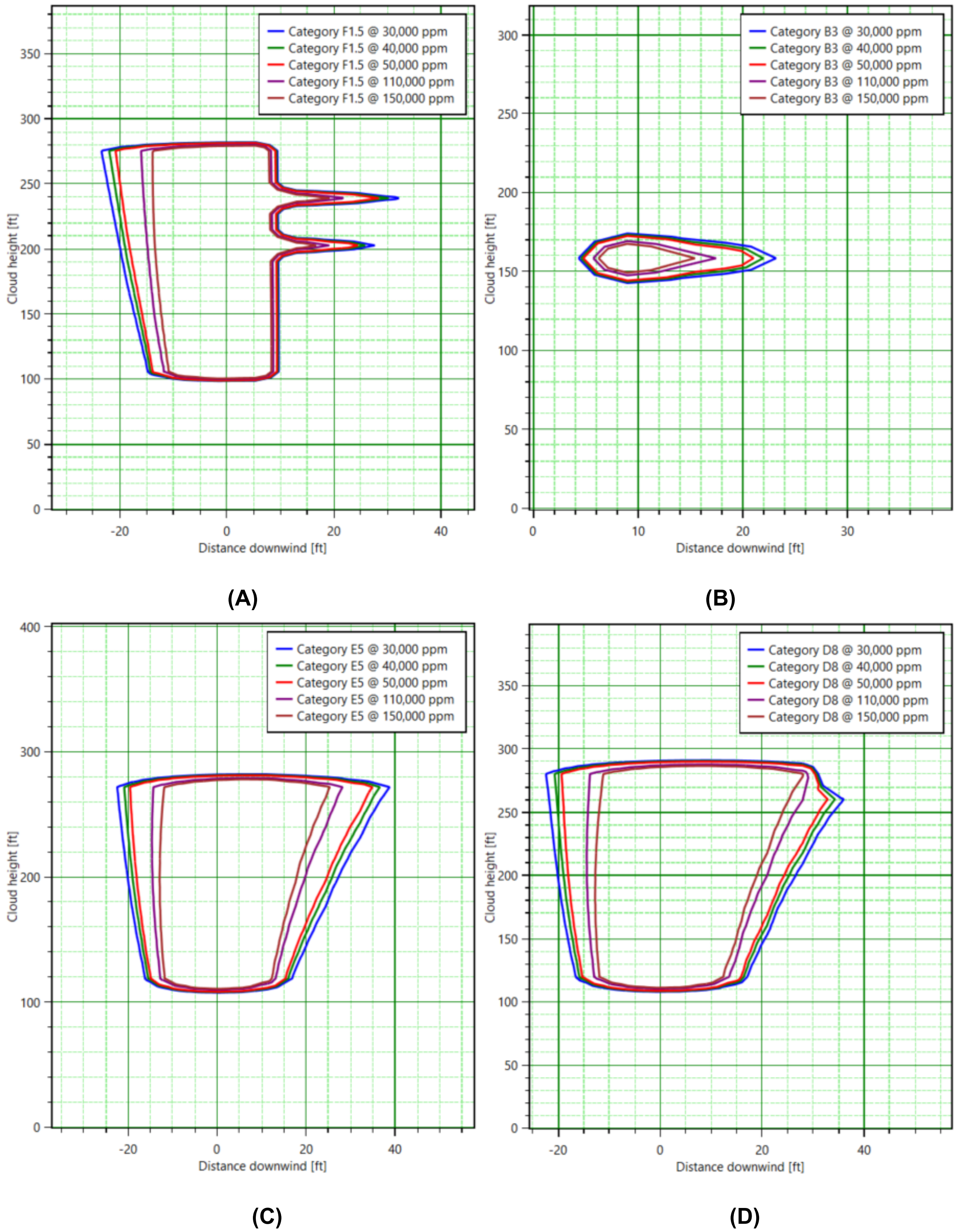


Figure 7-2 6B Vent Release Scenario – Side view at 1s (A: F1.5, B: B3, C: E5, and D: D8 weather conditions)

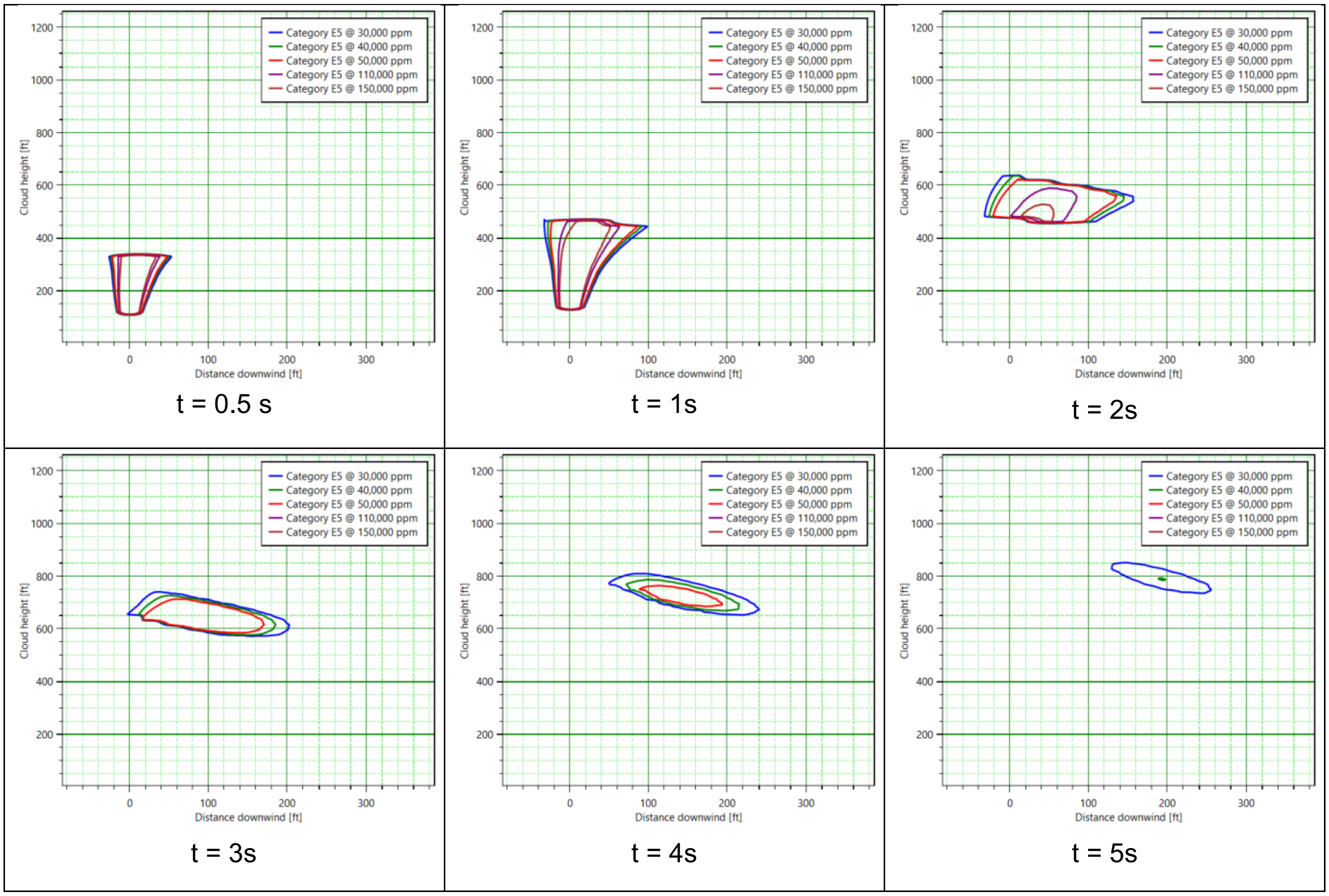


Figure 7-3 Example, 6B Vent Release Scenario – Side view – E5 weather condition

7.4 Computational Fluid Dynamics

The CFD analysis was conducted for the worst-case rupture scenario on the buried CO_2 pipeline segment, with wind direction aligned toward Elk Hills Road to represent a worst-case conservative condition. Four representative weather cases were modeled (F1.5, B3, E5, and D8), covering a range of atmospheric stability and wind speed combinations. For each case, dispersion was simulated for both isolation success and isolation failure conditions to capture the influence of emergency isolation on plume behavior, and these are shown in Table 7-2 and Table 7-3, respectively.

The results show the evolution of CO_2 concentration contours over time, with color bands representing specific concentration endpoints.

Across all scenarios, the plume expands rapidly within the first 30 to 50 seconds, with concentrations above 110,000 ppm remaining close to the source. By 80 to 100 seconds, the 40,000 - 50,000 ppm plume concentrations extend farther downwind, to about 1,000 ft, while the 30,000 ppm represents the outermost footprint at a distance of roughly 1,500 ft.

With isolation success, the plume has dissipated significantly after 120 seconds, with only low-concentration areas remaining at 150 seconds. In contrast, isolation failure results in a more persistent plume. It is also worth noting that, based on the modeling results, most weather conditions do not result in concentration reaching Elk Hills Road, the only location with potential for public exposure. Only under E5 atmospheric stability do lower concentration levels (e.g., 30,000 ppm) briefly extend toward the road, but the plume dissipates rapidly and does not pose a sustained exposure risk.

These CFD-based concentration footprints were imported into Safeti and used in the QRA calculations. Compared to free-field dispersion results, the CFD analysis provides a more realistic representation of plume dynamics with the consideration of local terrain (rather than assuming flat terrain) and confirms that offsite consequences for the worst-case rupture scenario are highly unlikely.

Table 7-2 Isolation Success - Dispersion over time (s = seconds)

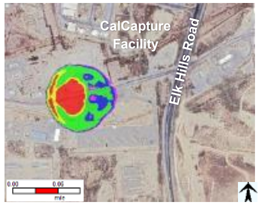
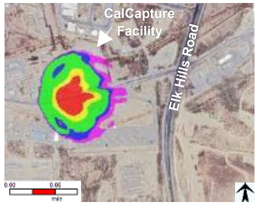
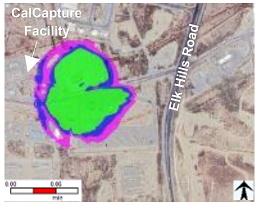
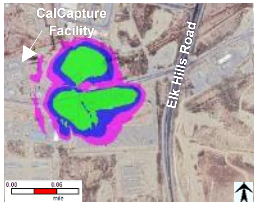
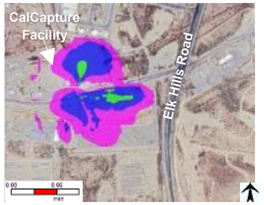
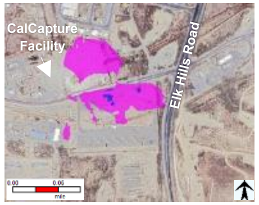
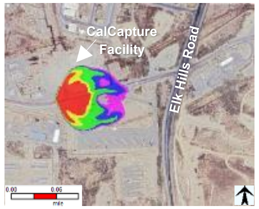
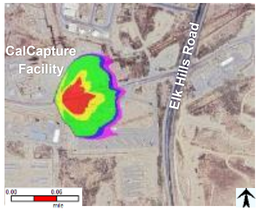
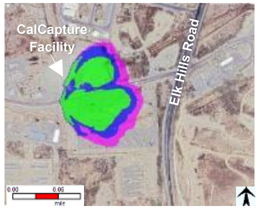
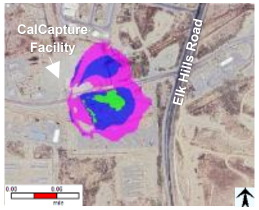
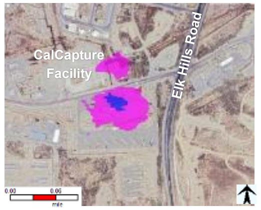
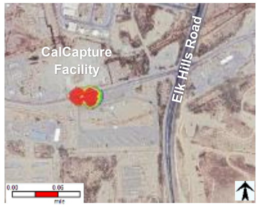
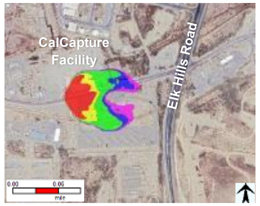
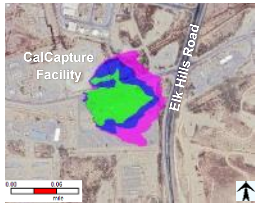
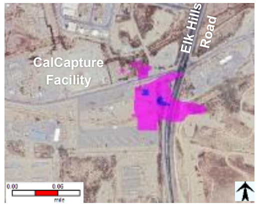
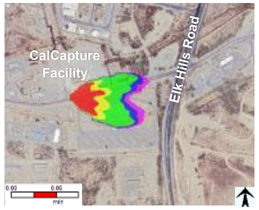
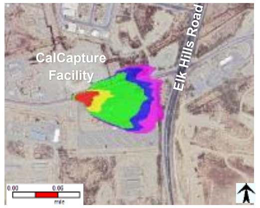
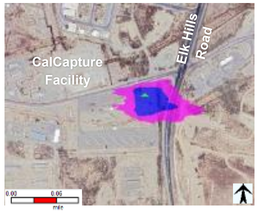
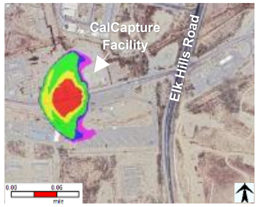
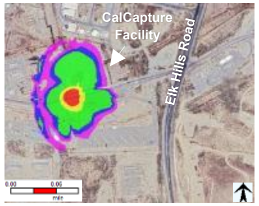
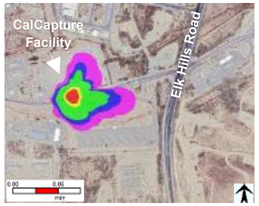
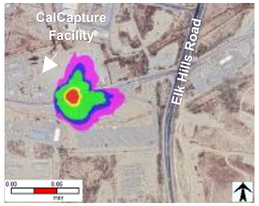
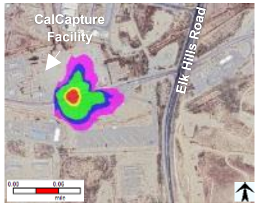
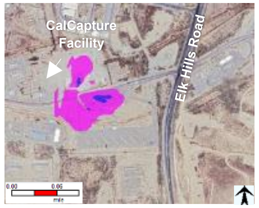
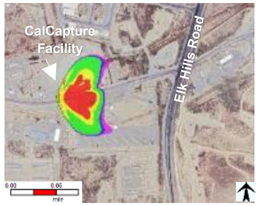
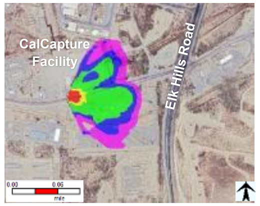
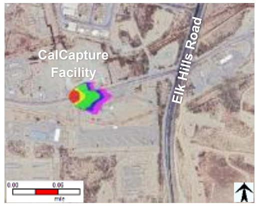
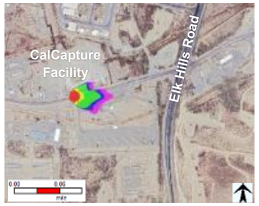
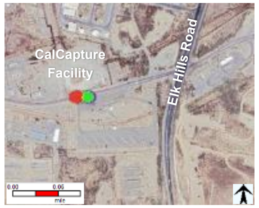
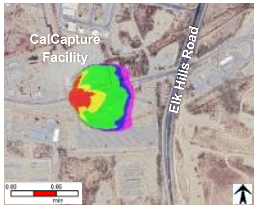
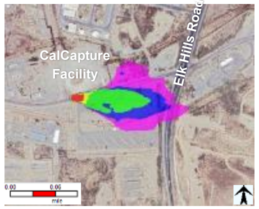
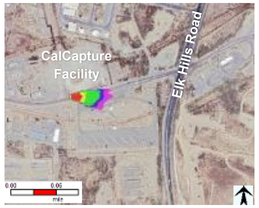
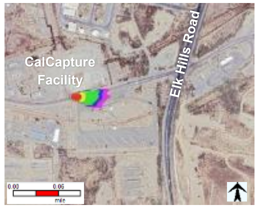
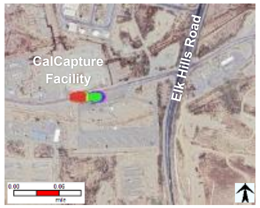
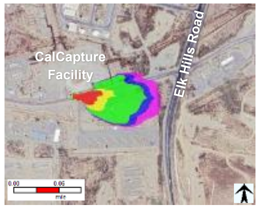
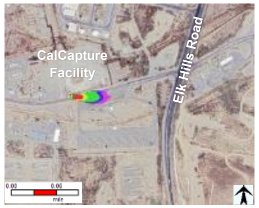
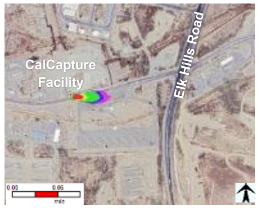
Key 150,000 ppm 110,000 ppm 50,000 ppm 40,000 ppm 30,000 ppm	10s	30s	50s	80s	100s	120s	150s
F1.5							
B3							
E5							
D8							

Table 7-3 Isolation Failure - Dispersion over time (s = seconds)

Key 150,000 ppm (red) 110,000 ppm (yellow) 50,000 ppm (green) 40,000 ppm (blue) 30,000 ppm (magenta)	10s	50s	100s	500s	1000s	1800s	1850s
F1.5							
B3							
E5							
D8							

8 RISK RESULTS

The overall objective of the QRA is to estimate the individual and societal risk of the CRC facility to the public population. Frequencies and consequences of the release events considered are combined for different weather conditions and hazardous scenarios to estimate the overall risk.

8.1 Frequency Contours for Hazard Effects

This section presents the contours corresponding to a frequency of 10^{-6} per year (1 event in 1 million years) to 10^{-4} per year (1 event in 10,000 years) for the different hazard effects considered in the QRA - jet fire, pool fire, toxic and explosion. These contours indicate the maximum extent of areas where exposure to a specified effect level (such as thermal radiation for fires, or overpressure for explosions) could occur with the stated likelihood. They represent only how often a given hazard effect may reach a particular intensity and do not account for the presence of people or their vulnerability. Individual risk is evaluated separately, and results are provided in Section 8.2.

No contours corresponding to frequencies greater than 10^{-3} (1 in 1,000 years) were observed.

For jet fires and pool fires, contours are shown in Figure 8-1 to Figure 8-4 for thermal radiation levels of 4.7 kW/m^2 and 9.46 kW/m^2, representing areas where these thermal radiation levels could be experienced. The 37.5 kW/m^2 level is not shown as it is expected to be experienced at a frequency of less than 10^{-6} per year.

The figures below indicate that the extents of these hazard effects are highly localized, with all footprints remaining within or very close to the facility boundary. In contrast to these frequency contours, the individual risk contours presented later in the report incorporate both the likelihood of the event and the probability that an exposed person could be harmed. This distinction ensures that effect frequency and individual risk are evaluated consistently but interpreted correctly for decision making.

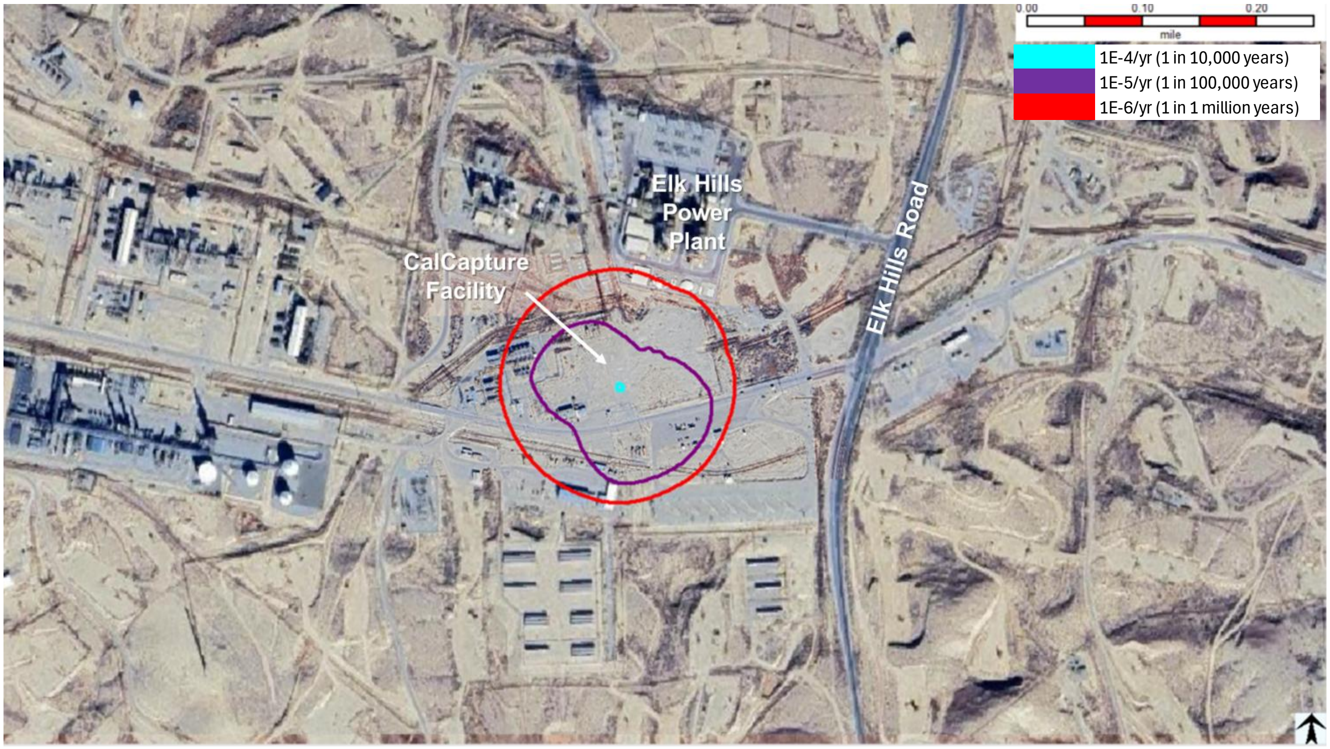


Figure 8-1 Frequency contour – jet fires at 4.7 kW/m^2

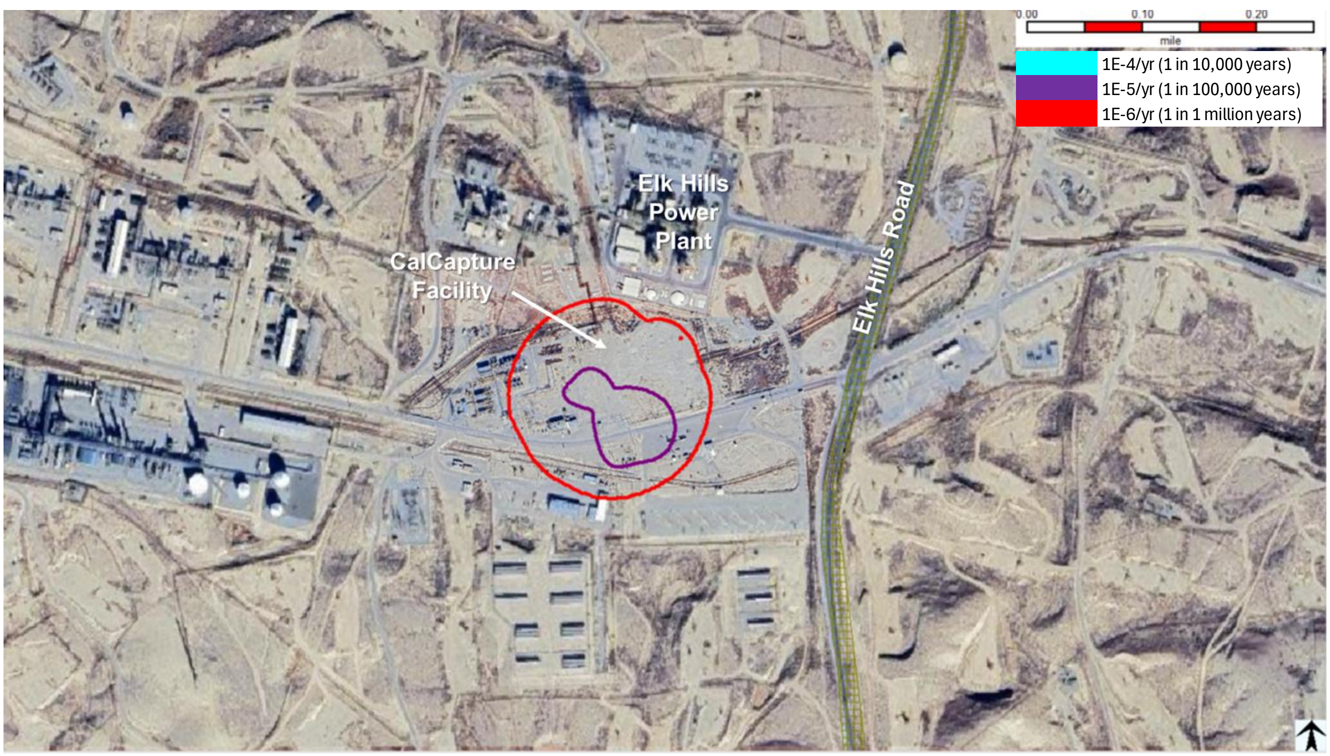


Figure 8-2 Frequency contour – jet fires at 9.46 kW/m^2

Figure 8-3 Frequency contour – pool fires at 4.7 kW/m²

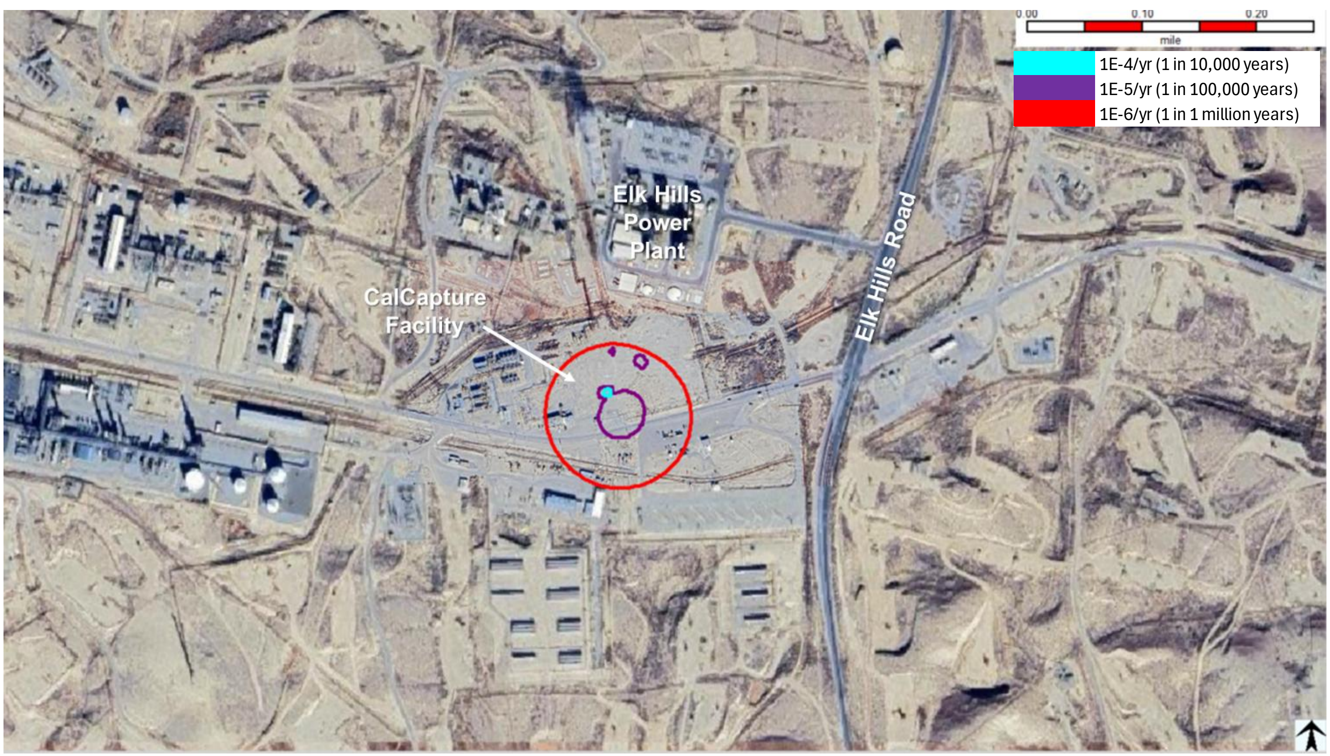


Figure 8-4 Frequency contour – pool fires at 9.46 kW/m²

No contours are presented for explosion overpressure levels because the frequencies of experiencing 0.5 psi, 1 psi, and 2 psi overpressure effects are all below 10^{-6} per year.

Figure 8-5 to Figure 8-7 present the toxic concentration contours for the various systems evaluated in the QRA. The results show that the toxic plumes remain fairly localized within the facility boundary. This behavior is similar to the jet fire scenarios, where the impact zones are confined and do not extend significantly beyond the site perimeter.

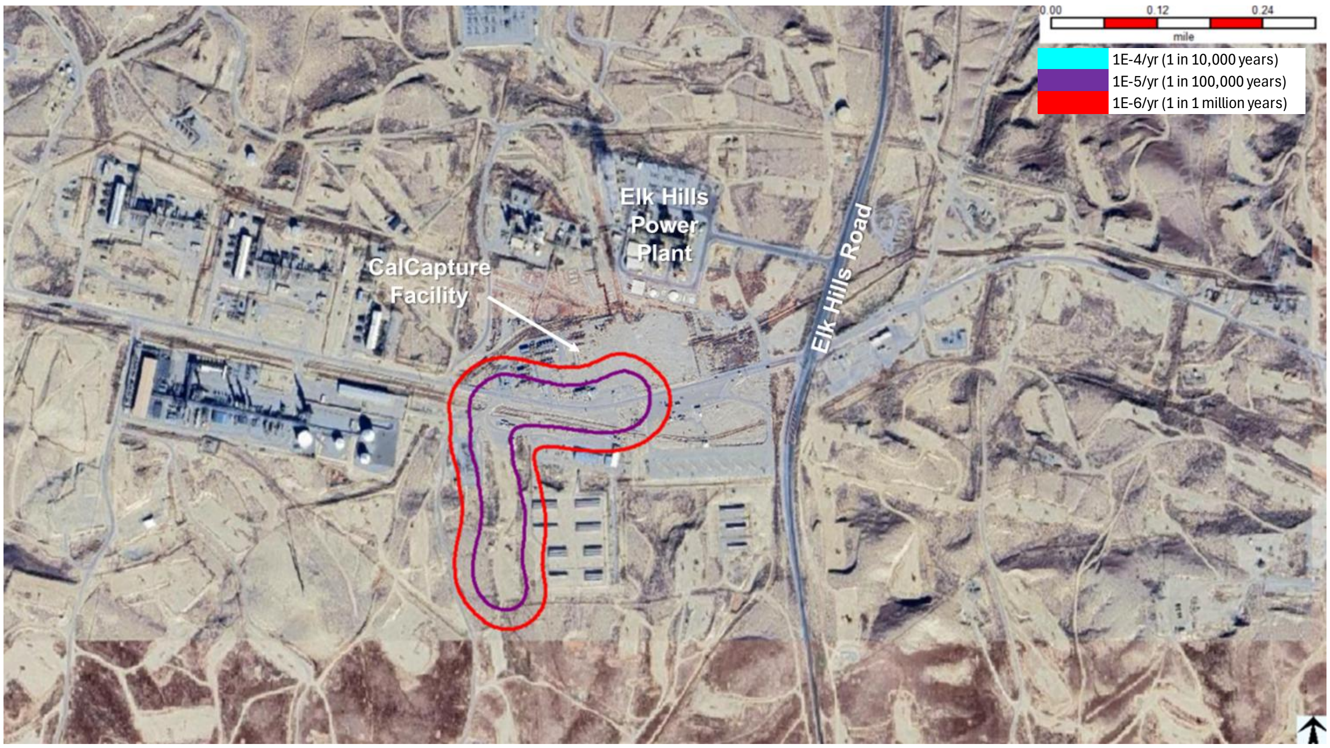


Figure 8-5 Frequency contour – toxic (Pipelines)

Figure 8-6 Frequency contour – toxic (CalCapture)

Figure 8-7 Frequency contour – toxic (MEA-specific scenarios)

8.2 Individual Risk Results

8.2.1 Individual Risk contours

Figure 8-8 illustrates the Location-Specific Individual Risk (LSIR) contours for outdoor areas surrounding the facility. It should be noted that these contours assume continuous presence (100% occupancy), which is a conservative assumption. In reality, public exposure would be intermittent and limited, meaning actual risk levels for the public are significantly lower than indicated. A detailed breakdown of LSIR contributions from all scenarios considered in the QRA is provided in Appendix C.

As shown, the highest risk contour (1E-4 per year, 1 in 10,000 years) is confined within the immediate vicinity of the CalCapture equipment, while the 1E-5 per year and 1E-6 per year risk contours extend slightly farther but remain well within the facility boundary, and do not intersect Elk Hills Road.

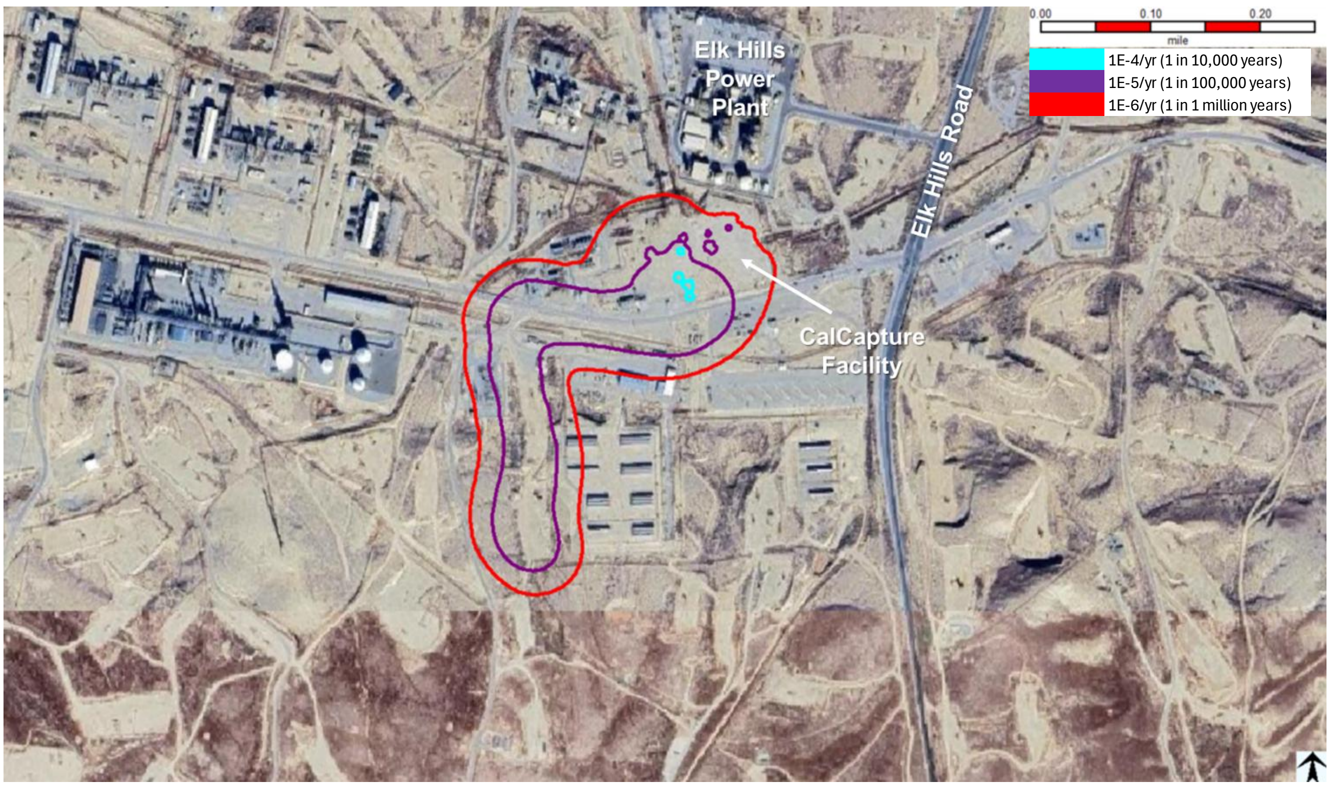


Figure 8-8 Overall Outdoor LSIR (100% presence factor) Contours

8.2.2 Individual Risk at key locations of interest

Table 8-1 summarizes the calculated Individual Risk Per Annum (IRPA) for six representative locations along the Elk Hills Road adjacent to the facility, assuming 100% presence at the given locations, as illustrated in Figure 8-10.

Table 8-1: Individual Risk Results for Key Locations of Interest

Risk Ranking Point Name	Risk Total [/yr]	Comparison against criteria for various jurisdictions (Refer to Appendix A)

1	<1E-08	Acceptable - Below broadly acceptable public risk
2	<1E-08	Acceptable - Below broadly acceptable public risk
3	2.3E-08 (1 in 40 million years)	Acceptable - Below broadly acceptable public risk
4	3.0E-08 (1 in 30 million years)	Acceptable - Below broadly acceptable public risk
5	1.1E-08 (1 in 90 million years)	Acceptable - Below broadly acceptable public risk
6	<1E-08	Acceptable - Below broadly acceptable public risk

In addition to the results presented in the table above, Figure 8-9 illustrates the variation in LSIR along Elk Hills Road between points marked with 1 to 6 (in Figure 8-10). The risk profile shows a gradual increase toward the central section of the transect where it is closest to the CalCapture facility, peaking at approximately 3E-08 per year, before declining toward the end as it moves away from the facility. Even at its highest point, the LSIR remains orders of magnitude below the broadly acceptable public risk criteria applied in many international jurisdictions which ranges between 1E-06 to 1E-04 per year.

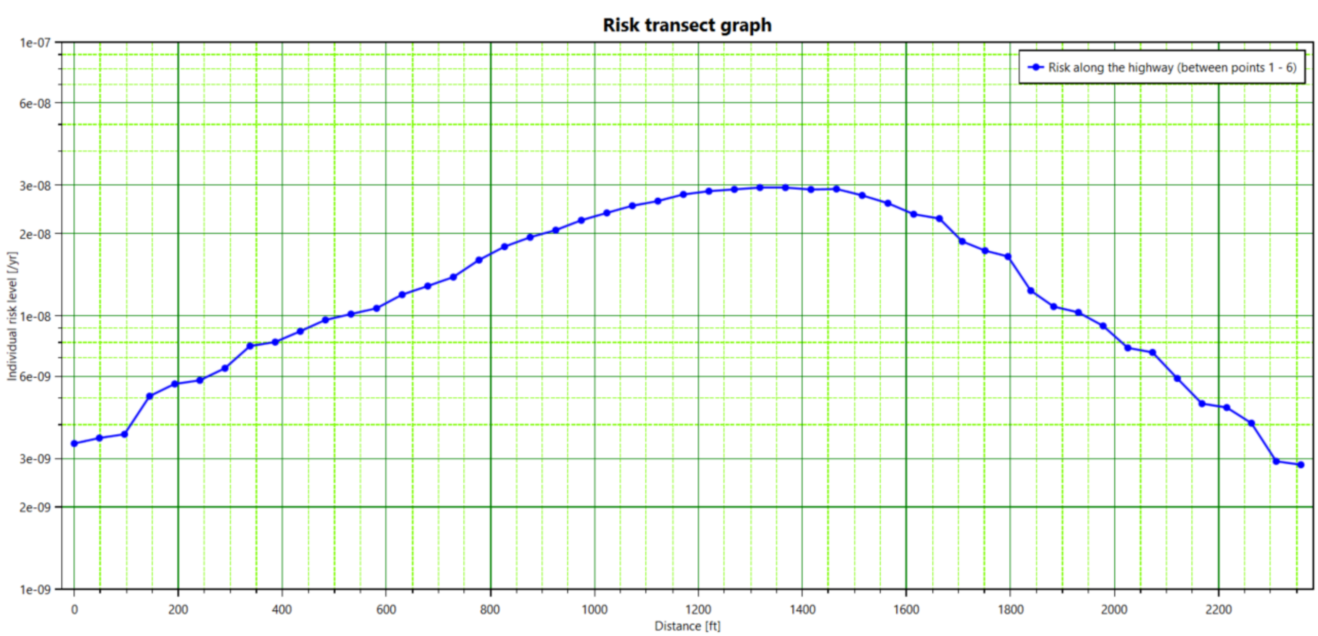


Figure 8-9 LSIR along the highway between points 1-6 (refer to Figure 8-10 for the locations)

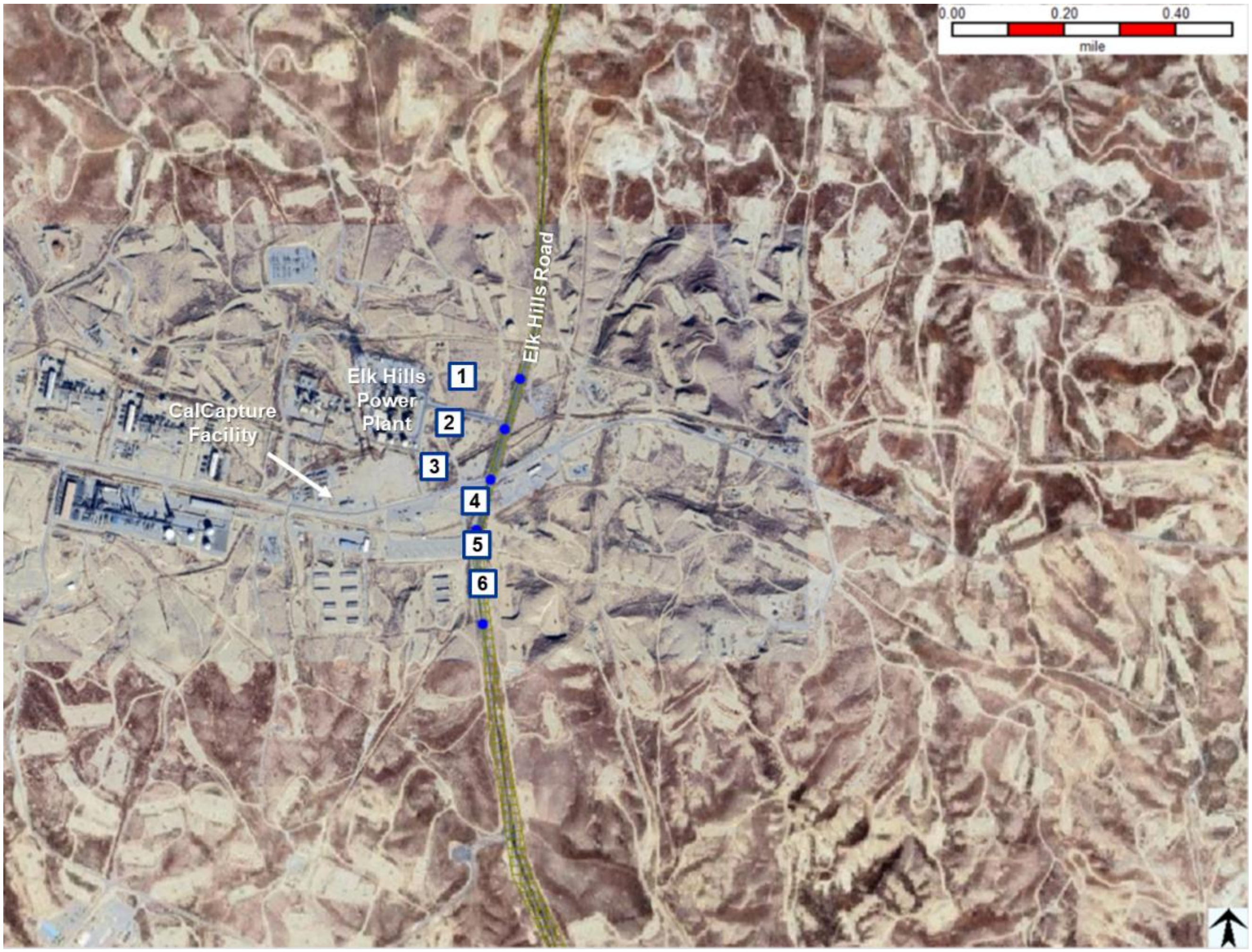


Figure 8-10 Key Locations of Interest Considered in the QRA

The results above show that the individual risk at all these points is well below the broadly acceptable public risk criteria adopted by various jurisdictions. For three of the locations (1, 2 and 6), the risk is so low that it is classified as negligible, while the remaining points (3, 4 and 5) have values in the order of 10^{-8} per year, corresponding to periods of tens of millions of years. Therefore, the risk to members of the public at these locations is extremely low.

It is important to note that IRPA assumes a hypothetical individual remains at the location 100% of the time, which is a highly conservative assumption. In reality, public presence at these locations is intermittent and limited to short durations, such as while driving along Elk Hills Road. When realistic occupancy factors are applied, the actual individual risk to the public becomes almost negligible. This reinforces that the facility poses risk to public safety that is well below broadly acceptable benchmarks at these key locations, and even lower than the probabilities conservatively indicated above.

For this assessment, the highest calculated risk at the evaluated locations is approximately 3E-08 per year. This value is orders-of-magnitude below the upper limit commonly used in Canada and the United Kingdom of 1E-04 per year, and the Netherlands and Hong Kong's upper limit of approximately 1E-05 per year. Additionally, even under worst-case assumptions (of 100% presence), the risk to someone at locations along Elk Hills Road are two orders-of-magnitude below levels considered safe by California Department of Education guidance (1E-06). When considering that people are only present for short periods, the actual risk is even further reduced below broadly acceptable benchmarks.

8.3 Road Transport Individual Risk Evaluation

Incident history from road transport of hazardous materials indicate small release events are far more common with a release frequency split between 75% small and 25% large leaks. The frequency split is estimated upon review of the U.S. DOT hazmat incident database's historical incidents for the various road transports. The reported released quantities less than 25 gallons are approximately 75% of the total number of incidents.

8.3.1 Solvent (amine) and Sodium Hydroxide

Although the solvent (amine) and sodium hydroxide are toxic, their incident history does not indicate transit fatalities related to the hazardous material; but there have been some injuries and fatalities due to vehicle collision (unrelated to the hazardous material).

The historical sodium hydroxide transit incident history (3 fatalities across 176 incidents over 25 yrs) provides a basis to estimate the fatality probability. The past fatal incidents involved large releases events (releases > 2,900 gallons). Large leaks are assumed to have a higher conditional probability of fatality, estimated as 1 in 60. Small leaks are assumed to have a lower conditional probability of causing a fatality, taken as 1 in 600 (assumed a factor of 10 lower).

The historical amine transit incident history does not indicate any fatal incidents (across the 14 incidents over 25 yrs). The same values for sodium hydroxide are applied but factored by 2 as a conservative assumption, given the absence of recorded fatal events. Large leaks are assumed to have a conditional fatality probability of 1 in 120; small leaks are assumed to have a conditional probability of 1 in 1,200.

8.3.2 Hydrogen and Sulfuric Acid

Hydrogen is flammable and transported as a compressed gas. Sulfuric acid releases can result in toxic exposure.

The historical hydrogen transit incident history (1 fatality across 19 incidents over 25 yrs) provides a basis to estimate the fatality probability. Large leaks are assumed to have a higher conditional probability of fatality, estimated as 1 in 20. Small leaks are assumed to have a lower conditional probability of causing a fatality, taken as 1 in 200 (assumed a factor of 10 lower).

The historical sulfuric acid transit incident history (4 fatalities across 208 incidents over 25 yrs) provides a basis to estimate the fatality probability. Large leaks are assumed to have a higher conditional probability of fatality, estimated as 1 in 50. Small leaks are assumed to have a lower conditional probability of causing a fatality, taken as 1 in 500 (assumed a factor of 10 lower).

8.3.3 Transport Risk Results

Table 8-2 presents the estimate of the individual risk for the hazardous material transport. The overall individual risk is 1.2E-05 per year (1 in 85,500 years) which is comparable to established upper risk thresholds for tolerable risks in the Netherlands and Hong Kong (1E-05 per year) and an order of magnitude lower than upper risk thresholds from Canada and the United Kingdom (1E-04 per year). Based on these comparisons, the preliminary road transport risk estimate does not exceed typical international upper-bound criteria, although it highlights the need for a route-specific assessment to determine the final contribution of road transport risk. It is also noted that road transport often represents one of the largest contributors to overall risk in quantitative risk assessments. This is driven by the inherent hazards associated with vehicle operation on public roadways rather than the characteristics of the chemicals transported.

These results should be interpreted as a conservative upper bound. The estimate is based on high level assumptions and does not account for the final transport route, road characteristics, supplier locations, traffic density, or detailed public exposure along the transit corridor. These inputs are not yet defined at this stage of the project.

Table 8-2 Transit Risk Estimate

Material	Total Transit Release Frequency, per year	Small Release Frequency, per year	Large Release Frequency, per year	Impact probability, Small	Impact probability, Large	Individual Risk per year, Small	Individual Risk per year, Large	Individual Risk per year, Overall
Solvent (amine)	2.6E-03	1.9E-03	6.4E-04	0.0008	0.008	1.6E-06	5.4E-06	7.0E-06
Hydrogen	7.7E-05	5.8E-05	1.9E-05	0.005	0.05	2.9E-07	9.6E-07	1.3E-06
Sulfuric Acid	3.2E-04	2.4E-04	8.0E-05	0.002	0.02	4.8E-07	1.6E-06	2.1E-06
Sodium Hydroxide	2.5E-04	1.9E-04	6.4E-05	0.002	0.017	3.2E-07	1.1E-06	1.4E-06
Total	**3.2E-03**	**2.4E-03**	**8.1E-04**	**-**	**-**	**2.7E-06**	**9.0E-06**	**1.2E-05**

8.4 Societal Risk Results

The societal risk assessment considered the presence of public population in areas potentially affected by the facility. For the QRA, the public population included in the analysis is limited to traffic along Elk Hills Road. The nearest sensitive receptors are a residential area located approximately 4.97 miles from the facility, while other residential locations are all at distances greater than 5 miles away. These distances are well outside the zones that could be potentially affected by the hazardous release scenarios considered in the QRA.

8.4.1 Potential Loss of Life

Potential Loss of Life (PLL) is the average number of fatalities per year. It is calculated from the product of the hazard frequency and severity of the hazard in terms of predicted fatalities.

The PLL across the facility is 5.5E-08 per year (1 fatality in 18 million years), which is considered negligible.

8.4.2 FN Curve

Figure 8-11 presents the FN curve, indicating the societal risk associated with the operations of the CalCapture facility. FN curves are used to present the cumulative frequency (F) or there being N or more fatalities.

The figure shows that the societal risk falls well below the societal risk criteria for the different jurisdictions. Unlike typical FN curves that show a line across multiple fatality numbers, the societal risk only appears as a single point. This is due to the fact that all credible scenarios considered in the QRA have the potential for only one fatality at most. There are no scenarios that were predicted to result in multiple simultaneous fatalities.

In addition, the public population considered in the QRA is limited to moving traffic along Elk Hills Road, and no individuals are assumed to be present at any location 100% of the time. For the QRA, a population density approach was used to reflect intermittent presence of the public.

The plotted point falls well below the societal risk criteria for the public. The maximum N value is predicted to be 1, meaning no scenario modeled resulted in more than a single fatality. The predicted overall frequency of such an event is equivalent to 1 fatality in 18 million years, which is considered negligible.

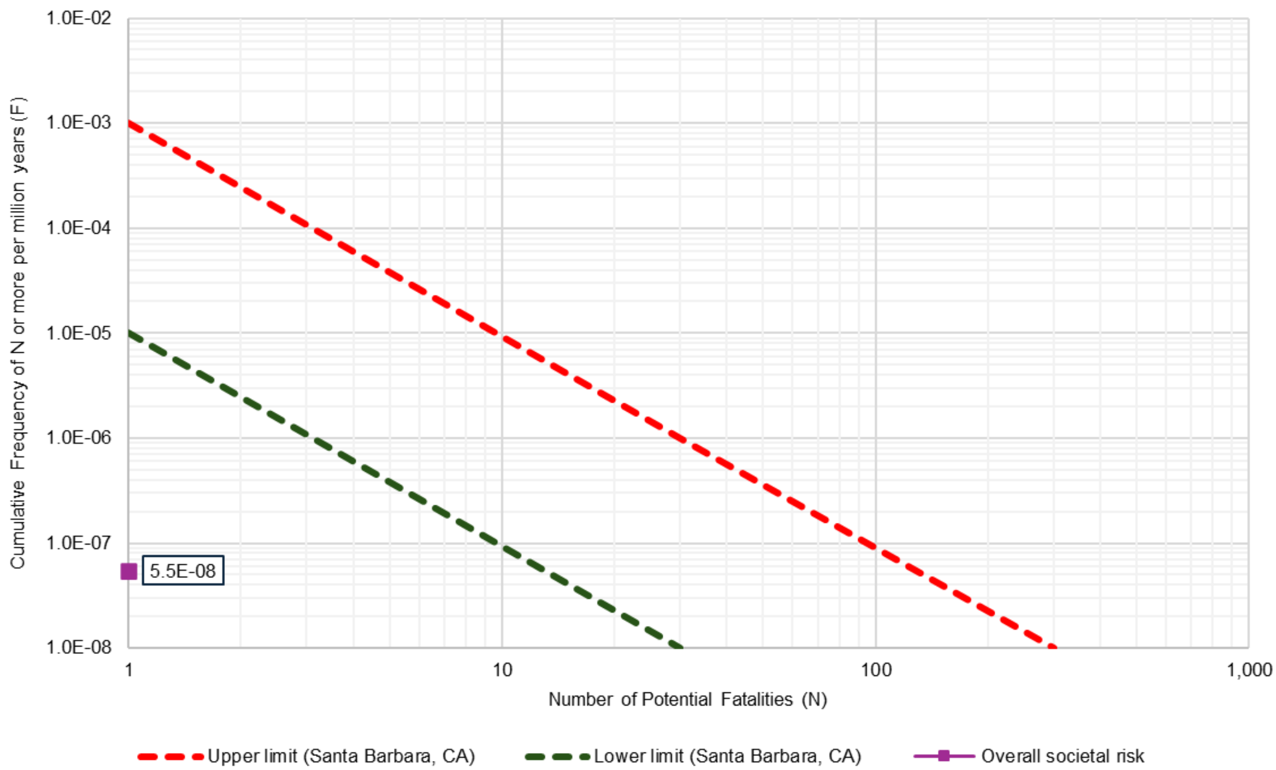


Figure 8-11 FN Curve

9 INTERPRETATION OF RISK RESULTS

This section provides an interpretation of the QRA results in the context of public safety, regulatory risk acceptance criteria, and the project's design and operational features. The intent is to explain how the assessed risks compare to established benchmarks and to clarify whether mitigation measures are required to demonstrate that project impacts are less than significant.

The proposed facility incorporates multiple inherent safety, design, and operational features intended to minimize the likelihood and consequences of accidental releases. These include leak detection systems, emergency isolation and shutdown devices, pressure relief systems, and equipment layouts that reduce escalation potential.

The QRA results demonstrate that these design features are effective in reducing risk to the public to negligible levels. The calculated individual risk of fatality is less than 3.0E-08 per year (or 1 in 30 million years), and the estimated potential for loss of life is approximately 5.5E-08 per year (or 1 in 18 million years). These values are orders of magnitude below commonly applied risk acceptance thresholds and well below typical day-to-day risks experienced by the general public. On this basis, the facility-related risks are considered less than significant.

Risks associated with chemical delivery to the project are dominated by the inherent risks of road transportation rather than by the properties of the materials being transported. The transportation risk assessment shows that these risks fall within established tolerable risk thresholds and are consistent with risk levels typically associated with projects that involve road transportation.

Based on the results of the QRA, mitigation measures are not required, as individual and societal risks remain below applicable acceptance levels. The design and operational controls are sufficient to ensure compliance with applicable regulatory requirements and to support the conclusion that the proposed project changes would not result in a significant impact to public health or safety.

10 CONCLUSIONS

The CalCapture Project QRA study covered the Carbon Capture Unit subsystems, the dense-phase 10-inch buried CO_2 pipeline between the capture unit and the CTV I 35R manifold and well pads, onsite chemical unloading and storage, and chemical transport within a 50-mile area.

Dispersion and consequence modeling were carried out using DNV's proprietary tools: Phast for free-field modeling, KFX for CFD modeling, and Safeti for risk estimation. While the QRA applies flat-terrain, two-dimensional modeling in Safeti, CFD simulations in KFX accounted for local terrain and topography to better model the CO_2 plume dispersion from the worst-case rupture pipeline release that was considered.

Results from the QRA show that the 1E-06 per year (1 in 1 million years) LSIR contour, a threshold used by the California Department of Education specifically for hazardous pipelines [Ref /10/], remains within the immediate CRC facility and does not reach Elk Hills Road. Individual risk at representative points along the highway is in the order of 10^{-8} per year (1 in 100 million years) or negligible, which is far below broadly acceptable public-risk criteria adopted by multiple jurisdictions.

Based on historical data and conservative assumptions, the estimated individual risk from hazardous material transport is approximately 1.2E-05 per year, equivalent to one fatality in 85,500 years. This remains within the upper-bound criteria commonly applied in jurisdictions such as Canada, the United Kingdom, the Netherlands, and Hong Kong. The result reflects the inherent risks associated with vehicle operation on public roadways rather than the specific hazards of the chemicals transported. The current estimate should be interpreted as an upper bound because detailed information that would influence transportation risk, such as final routing, supplier locations, roadway characteristics, and operational controls, is not yet available. Historical U.S. DOT data show that most incidents involve minor releases, and severe outcomes are rare.

Finally, the QRA confirms that the societal risk is minimal, with a calculated PLL of approximately 5.5E-08 per year, equivalent to one fatality in 18 million years, and no credible scenarios resulting in multiple fatalities.

The QRA concludes that the overall risk to the public on Elk Hills Road is very low. All calculated risk metrics are below international referenced benchmarks commonly applied to land-use planning and public safety for similar facilities. To place these values in context, the 2023 National Safety Council (NSC) publishes fatality statistics for everyday activities, showing that common risks such as driving, accidental falls, or pedestrian incidents occur at orders of magnitude higher [Ref /22/]. For example, the NSC estimates the individual causes of death from a motor-vehicle incident at roughly 1 in 95, from accidental falls at roughly 1 in 91, or from cataclysmic storm at roughly 1 in 39,192. By comparison, the CalCapture facility and pipeline risks, in the range of 1 in 100,000 to 1 in 10,000,000 per year, fall far below the risk levels associated with typical daily activities encountered by the public.

Based on the results of the QRA, mitigation measures are not required, as individual and societal risks remain below applicable acceptance levels. The design and operational controls are sufficient to ensure compliance with applicable regulatory requirements and to support the conclusion that the proposed project changes would not result in a significant impact to public health or safety.

DNV

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APPENDIX A
Study Basis

Table of contents

Abbreviations

AADT	Annual Average Daily Traffic
ACGIH	American Conference of Governmental Industrial Hygienists
ACH	Air Changes per Hour
CCPS	Center for Chemical Process Safety
CCU	Carbon Capture Unit
CFD	Computational Fluid Dynamics
CO_2	Carbon Dioxide
CRC	California Resources Corporation
CTV	Carbon Terravault
DCC	Direct Contact Cooler
DDT	Deflagration to Detonation Transition
EFG+	Econamine FG Plus^{SM}
EG	Ethylene Glycol
EGIG	European Gas Pipeline Incident Data Group
EHPP	Elk Hills Power Plant
EOR	Enhanced Oil Recovery
ERPG	Emergency Response Planning Guidelines
ESD	Emergency Shutdown
FN	Frequency-Fatality(N)
FRED	Failure Rate and Event Data
GPM	Gallons Per Minute
H&MB	Heat & Material Balance
HCRD	Hydrocarbon Release Database
ID	Internal Diameter
IDLH	Immediately Dangerous to Life or Health
IOGP	International Association of Oil & Gas Producers
IR	Individual Risk
LFL	Lower Flammability Limit
LPG	Liquefied Petroleum Gas
LSIR	Location Specific Individual Risk
MCE	Maximum Considered Earthquake
ME	Multi-Energy Method

MEA	Monoethanolamine
MTPA	Million Tonnes Per Annum
MWe	Megawatt-equivalent
NIOSH	National Institute for Occupational Safety and Health
MMTPA	Million Metric Tonnes Per Annum
MMTPD	Million Metric Tonnes Per Day
MOP	Maximum Operating Pressure
NPS	Nominal Pipe Size
OD	Outside Diameter
P&ID	Piping & Instrumentation Diagram
PFD	Process Flow Diagram
PGA	Peak Ground Acceleration
PHMSA	Pipeline and Hazardous Materials Safety Administration
QRA	Quantitative Risk Assessment
SDV	Shutdown Valve
SIL	Safety Integrity Level
SLOD	Significant Likelihood of Death
SLOT	Specified Level of Toxicity
SR	Societal Risk
STEL	Short-Term Exposure Limit
TEG	Triethylene Glycol
TLV	Threshold Limit Value
UFL	Upper Flammability Limit
UIC	Underground Injection Control
UK HSE	United Kingdom Health & Safety Executive
UKOOA	United Kingdom Offshore Operators Association
USGS	US Geological Survey
uVCE	Unconfined Vapor Cloud Explosions
VBR	Volume Blockage Ratio
VCE	Vapor Cloud Explosion

1 BACKGROUND

DNV Energy USA, Inc. (DNV) was requested by California Resources Corporation (CRC) to perform a Quantitative Risk Assessment (QRA) for the CalCapture Carbon Capture and Storage (CCS) Project.

The project would capture carbon dioxide (CO_2) which is generated as a by-product by the 550-megawatt-equivalent (MWe) Elk Hills Power Plant (EHPP). The carbon capture unit (CCU) will utilize Fluor's Econamine FG Plus[SM] (EFG+) process to capture and concentrate the CO_2.The EFG+ process is designed to capture 95 percent of the CO_2 from the total flue gas feed to the unit. The project is anticipated to capture approximately 4,400 metric tonnes of CO_2 per day (MTPD), equivalent to 1.6 million metric tonnes per year (MMTPY). The treated flue gas would be vented to the atmosphere directly from the EFG+ CCU plant absorber. The concentrated CO_2 would then be compressed, dehydrated, and stripped of oxygen prior to conveyance to the existing manifold pad permitted as part of the approved Carbon TerraVault I (CTV I) project (State Clearinghouse No. 2022030180). From there, the CO_2 would be directed to U.S. Environmental Protection Agency (U.S. EPA) approved Class VI UIC wells for injection into a dedicated depleted oil and gas reservoir located on the CRC property and approved as part of the CTV I project. As discussed in Section 2.1, the previously approved and constructed CTV I manifold pad, injection wells, reservoir, and related facilities are not part of the CalCapture CCS Project analyzed in this report.

The main objectives of the QRA analysis are to:

- Define release scenarios related to CO_2 capture and storage, and supporting utilities
- Perform consequence modeling of release scenarios
- Perform frequency analysis of release scenarios
- Evaluate the potential individual and societal risk metrics for offsite / public in the vicinity of the facility
- Identify required mitigation measures, to the extent significant impacts are identified, and prioritize design or operational controls

To achieve the objectives of the assessment, DNV will utilize the Phast and KFX software for the consequence modeling (for both free-field and using computational fluid dynamics (CFD)), and Safeti software for the risk modeling.

The main objective of this document is to provide an overview of the assumptions and key information used in this study. These assumptions form the basis for the QRA. These assumptions are based on the best available information at the time of analysis and are determined to be representative of the proposed project. Minor deviations from the study basis assumptions (e.g. small variations in operating parameters) are not expected to materially affect the conclusions to the study.

2 GENERAL ASSUMPTIONS

2.1 QRA Project Boundary

The QRA project scope consists of the following:

1. Carbon Capture Unit (CCU), which is divided into seven primary subsystems or sections [Ref /1/]:
    a. Flue Gas Cooling
    b. CO_2 Absorption
    c. Solvent Regeneration
    d. Solvent Maintenance
    e. Chemical Storage and Supply (This includes releases during transit to the facility within a 50-mile region from the facility, chemical unloading, and storage).
    f. CO_2 Compression and Cooling
    g. Utility Support Systems
2. CO_2 Emitter Pad (at CalCapture Unit Emitter Pad)
3. Transportation of dense phase CO_2 via 10” buried pipeline to the existing 35R manifold facility (pad).
4. CO_2 Emitter Manifold Header (at existing 35R Pad)

The location of the CCU facility, 10” pipeline, and injection manifold are shown in Figure 2-1.

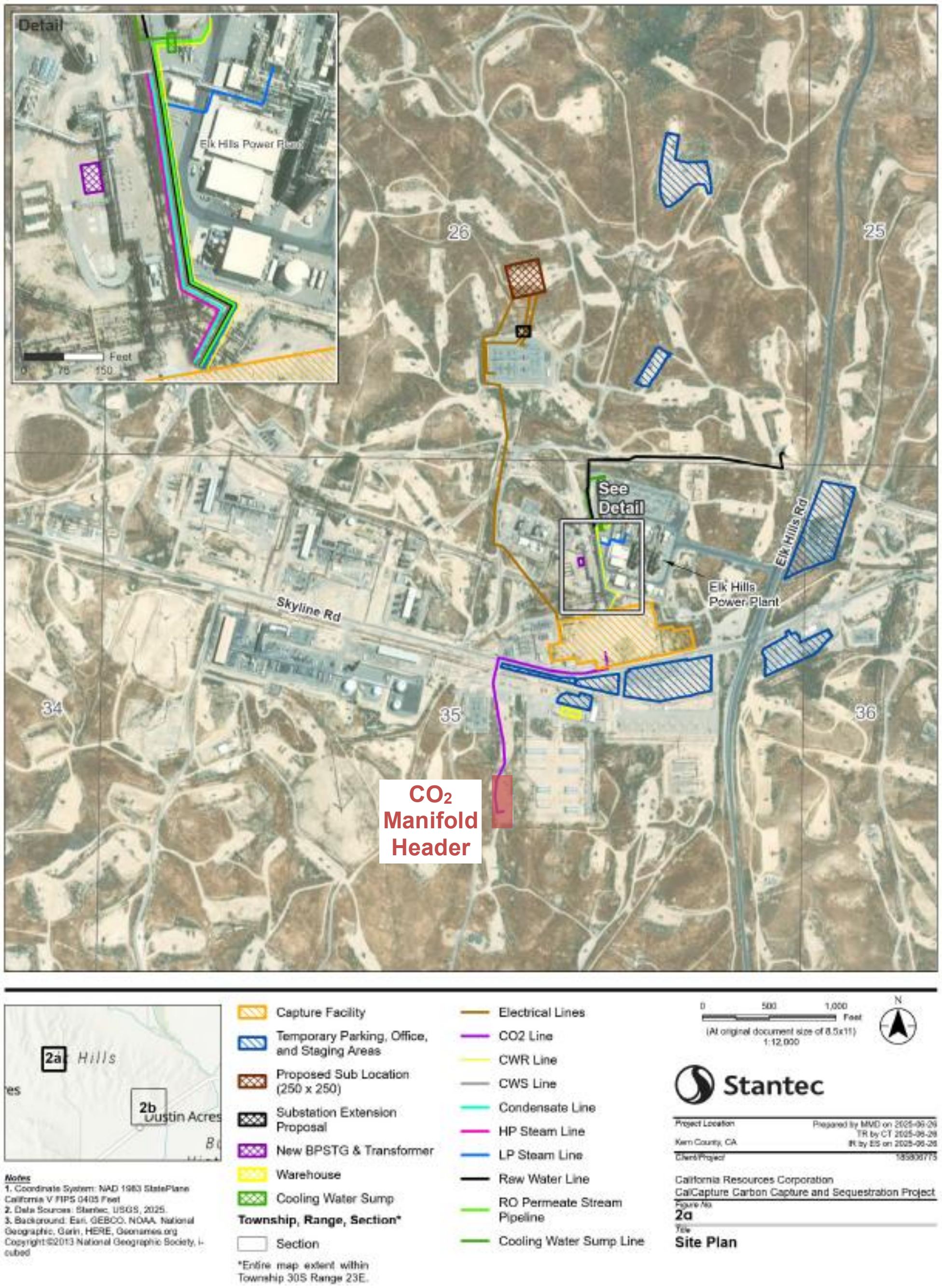

Figure 2-1 Location of CCU Facility and CO_2 Pipeline

2.1.1 CCU Facility

The CCU is designed to recover CO_2 from flue gas through a sequence of cooling, absorption, solvent regeneration, and compression steps. Flue gas from two stacks is combined and routed through a cooling system, where it is contacted with circulating water in a direct contact cooler (DCC) column to condense water vapor and reduce the overall gas volume. The cooled flue gas is then passed through a blower and into the Absorber, where it flows counter-current to a proprietary solvent (EFG+) that selectively absorbs CO_2. A wash section at the top of the Absorber removes residual solvent and cools the treated gas, which is subsequently vented.

The CO_2-rich solvent is regenerated in a Stripper, where steam releases CO_2 from the solvent. The recovered solvent is cooled, filtered, and returned to the Absorber, with a proprietary solvent maintenance system removing contaminants and degradation products. Make-up solvent and triethylene glycol (TEG) are stored and supplied as needed, supported by nitrogen blanketing and other chemical treatment systems. The captured CO_2 is compressed to 2,100 psig, purified, and delivered to a pipeline for injection (refer to Section 2.1.2). Prior to transport, CO_2 goes through the CalCapture Emitter Pad, which consists of isolation valves, metering skid, vent connection and pig launcher. Pig launcher and receiver skids are incorporated to support operational integrity and pipeline maintenance, which will be used once per year, and will be operated at the same conditions as the pipeline (refer to Table 2-4).

The CCU is supported by a range of utility systems, including cooling water, steam, instrument air, nitrogen, and water treatment facilities.

A representative Process Flow Diagram (PFD) of the boundary of the CCU facility is shown in Figure 2-2 [Ref /1/].

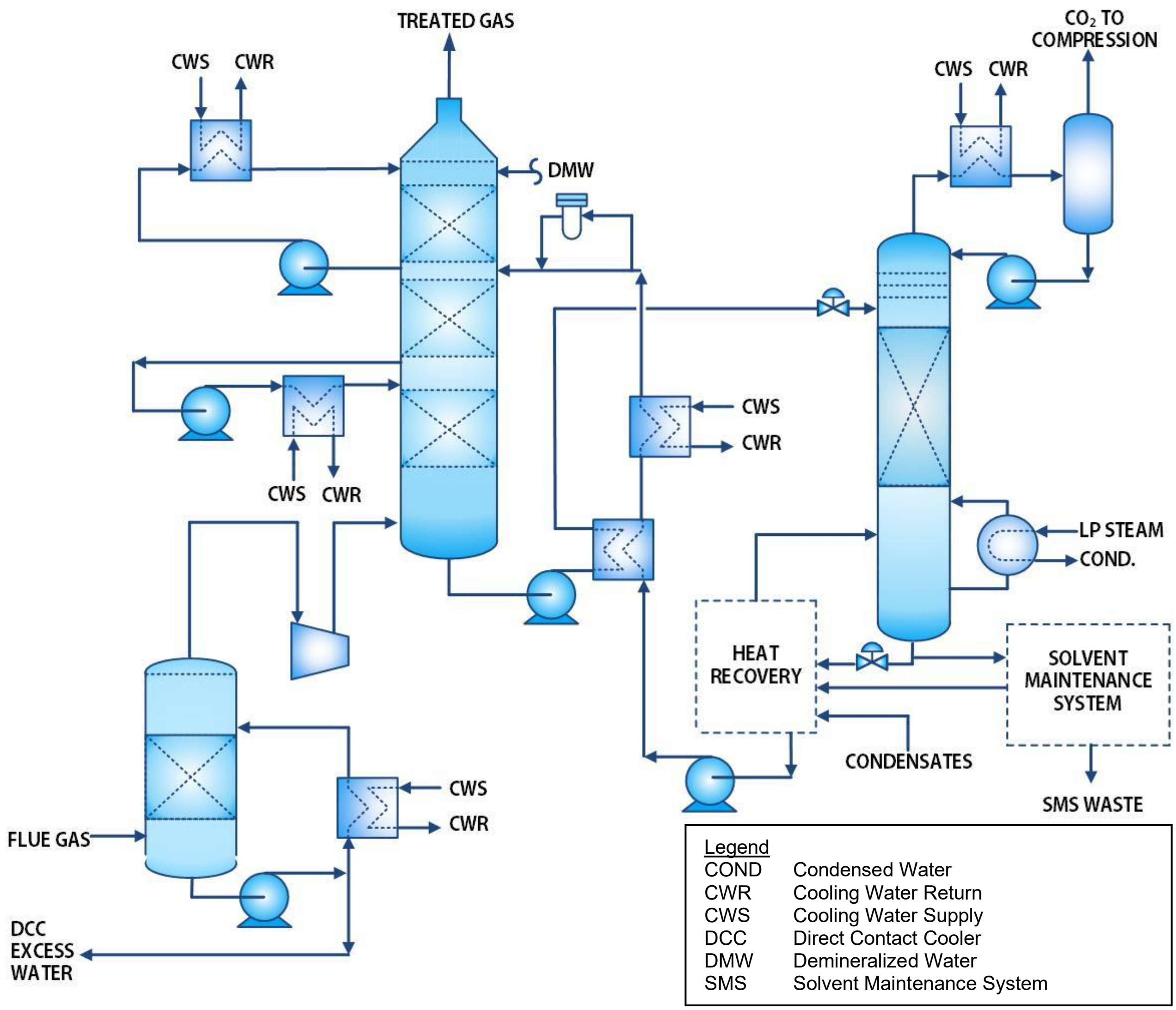

Figure 2-2 Location of CCU Facility and CO2 Pipeline [Ref /1/]

2.1.1.1 Venting Operations

The CCU facility includes several designated venting points, primarily routed to a dedicated CO_2 vent stack. Venting occurs under both normal and upset conditions.

During normal operation, the primary source of CO_2 venting is the Absorber vent stack, which continuously releases treated flue gas to atmosphere. This vent stream consists mainly of nitrogen and oxygen, with small amounts of water vapor, residual CO_2, and trace components such as ammonia, aldehydes, particulates, and minor solvent carryover. Additional routine venting occurs from solvent, glycol, and TEG storage and recovery tanks, which are caused by temperature fluctuations, filling, or draining activities. These short-duration emissions are not expected to pose any risk to the public. Accordingly, normal, routine venting operations are not considered in the QRA.

Intermittent CO_2 venting occurs during start-up, shutdown, or could occur in the event of upset conditions. These venting events are infrequent but may result in high concentrations of CO_2 released to the atmosphere. These non-routine venting scenarios are detailed in Table 2-1.

Table 2-1 Venting Scenarios

Vent scenario description	Temperature / F	Pressure / psig	Flow rate	Vent Duration	Frequency	Fluid	Considered in QRA?
1. CO_2 Compressor Start-up	305	2,030	12,130 lb/hr	30 minutes	Once per month	100% CO_2	No – low flowrate and considered a controlled event
2. CO_2 Compressor discharge piping vent during maintenance	120	2,000	Full depressurization of 10" pipeline with inventory of 44,783 lb		Once per year	100% CO_2	Yes, infrequent but significant flowrate. Vent release considered in QRA.
3. CO_2 Compressor blowoff and emergency venting	120	2,100	4,800 TPD (440,925 lb/hr)	5 minutes	12 blowoff events per year + one emergency vent per year	100% CO_2	Yes, this is an uncontrolled, non-routine release
4. CO_2 pipeline emergency blowdown (following detection of a leak)	120	2,100	Full depressurization of 10" pipeline with inventory of 44,783 lb		See Section 4.2 for pipeline leak frequency	100% CO_2	Yes, this is an uncontrolled, non-routine release

Specification of the CO_2 vent stack is as follows:

- Dimensions: 36-inch internal diameter (ID) by 100 ft high (oriented vertically upward)

2.1.1.2 Chemical Consumption and Unloading Operations

A range of solvents and treatment chemicals are used to support the CO_2 capture, solvent regeneration, dehydration, and utility systems. Table 2-2 summarizes the expected consumption rates and initial fill requirements for the chemicals that are assessed as part of this QRA.

Table 2-2 CCU Chemical Consumption Data [Ref /1/]

EFG+ Plant Chemicals	Notes	Initial Charge	Annual Consumption (Note 1)
EFG+ Solvent (100 weight percent [wt%] basis)	An aqueous amine solution blend	837 tons (Note 2)	800 tons
Hydrogen (100 vol%)	Supplied via tube trailers, and is consumed in relatively small quantities for catalytic oxidizer operation	120,000 standard cubic feet (Note 6)	0.77 million standard cubic feet

EFG+ Plant Chemicals	Notes	Initial Charge	Annual Consumption (Note 1)
Ethylene Glycol (100 wt% basis)	Used in a closed-loop cooling system, with only minor annual losses expected	15,900 gallons	(Note 3)
TEG (100 wt% basis)	Used in the CO_2 Dehydration Package to remove water vapor from the CO_2 product stream	3,200 gallons (Note 4)	2,930 gallons (Note 5)
WSAC Water Treatment Chemicals			
Sulfuric Acid		4,200 gallons (max storage capacity)	4,400 gallons per yr
Sodium Hypochlorite (Biocide)		12,600 gallons (max storage capacity	30,000 gallons per yr
RO System Treatment Chemicals			
Sodium Hypochlorite (12%)		4,200 gallons (max storage capacity	10,000 gallons per yr
Sulfuric Acid		2,100 gallons (max storage capacity	2,200 gallons per yr
Sodium Hydroxide		12,600 gallons (max storage capacity	30,000 gallons per yr

Notes:
1) Annual consumptions are based on 350 days of EFG+ plant operations per year.
2) Initial solvent charge includes working inventory (711 tons), Solvent Storage Tank (CCU1-T-501) inventory (82 tons), and solvent required for degreasing during commissioning (44 tons).
3) Annual consumption of ethylene glycol is based on losses due to leaks and drains. As such, the annual consumption is dependent on plant operation and maintenance.
4) Initial TEG requirement based on 2,200 gallons for skid inventory plus 1,000 gallons for TEG make-up storage tank.
5) TEG annual consumption is a preliminary estimate. To be confirmed by selected vendor in the detailed engineering phase.
6) Hydrogen would be stored in rented jumbo trailers with an assumed capacity of 120,000 standard cubic feet

Unloading operations are planned to accommodate the periodic delivery of the chemicals described in Table 2-2. Details of unloading activities to the facility are shown in Table 2-3. These unloading operations provide the necessary chemical make-up to maintain continuous operation of the CCU facility while accounting for process consumption and system losses.

Table 2-3 Unloading Operations [Ref /8/]

Chemical	Annual Consumption	Loading Frequency	Load Amount	Loading Rate
Solvent	800 tons / 220,000 gal	53 per year	4,200 gal	140 gpm
TEG	2,930 gal	20 per year	150 gal	10 gpm
Hydrogen	0.77 million SCF	1 trailer every 2 months	600 lbs	N/A

Chemical	Annual Consumption	Loading Frequency	Load Amount	Loading Rate
Sulfuric acid	6,600 gallons	9 per year	750 gallons	45 gpm
Sodium hydroxide	30,000 gallons	12 per year	2,500 gallons	85 gpm

2.1.2 CO_2 Pipeline and Manifold

2.1.2.1 10" Buried Pipeline

The data presented in Table 2-4 applies to the 10-inch pipeline segment. The pipeline route is shown in Figure 2-3.

Table 2-4 Pipeline data

Parameter	Input
Nominal pipe diameter (in) (OD)	10" pipeline (flow line from Capture Facility to Injection Manifold) (Note 1)
Pipeline total length (mile)	~0.5 mile The route is provided in KMZ file [Ref /2/].
Wall thickness (in)	NPS 10" X65 Schedule 80: 15.09 mm
Service	Dense phase CO_2
Operating pressure (psig)	2,100 (maximum operating pressure, MOP)
Operating temperature (°F)	120 (maximum operating temperature)
Flowrate (million metric tonnes per annum, MMTPA)	1.61 (Note 2)
Burial depth (ft)	4 ft, measured from top of pipe Pipeline is buried along its length but is above-ground at both ends

Note 1: The final pipeline specifications (diameter and burial depth) had not been confirmed. CRC indicated the pipeline may be 8-inch or 10-inch. For conservatism, DNV will model a 10-inch pipeline at 4 ft burial depth, representing a worst-case scenario. An 8-inch pipeline would have lower flow and reduced impacts, so the 10-inch analysis conservatively bounds both options.

Note 2: The QRA will be conducted based on an average flowrate of 1.61 MMTPA. However, it is anticipated that, at times, the flowrate may increase up to 1.75 MMTPA. A sensitivity analysis has been carried out to assess the impact of this potential increase, and results indicate it does not produce a noticeable effect on the dispersion profile. This is primarily due to the fact that a potential release from the pipeline will be driven by the line pressure at the breach rather than the flowrate through the line. Therefore, the QRA will remain valid and applicable for the anticipated flowrate increase, and no update to the QRA is deemed necessary should this increase occur.

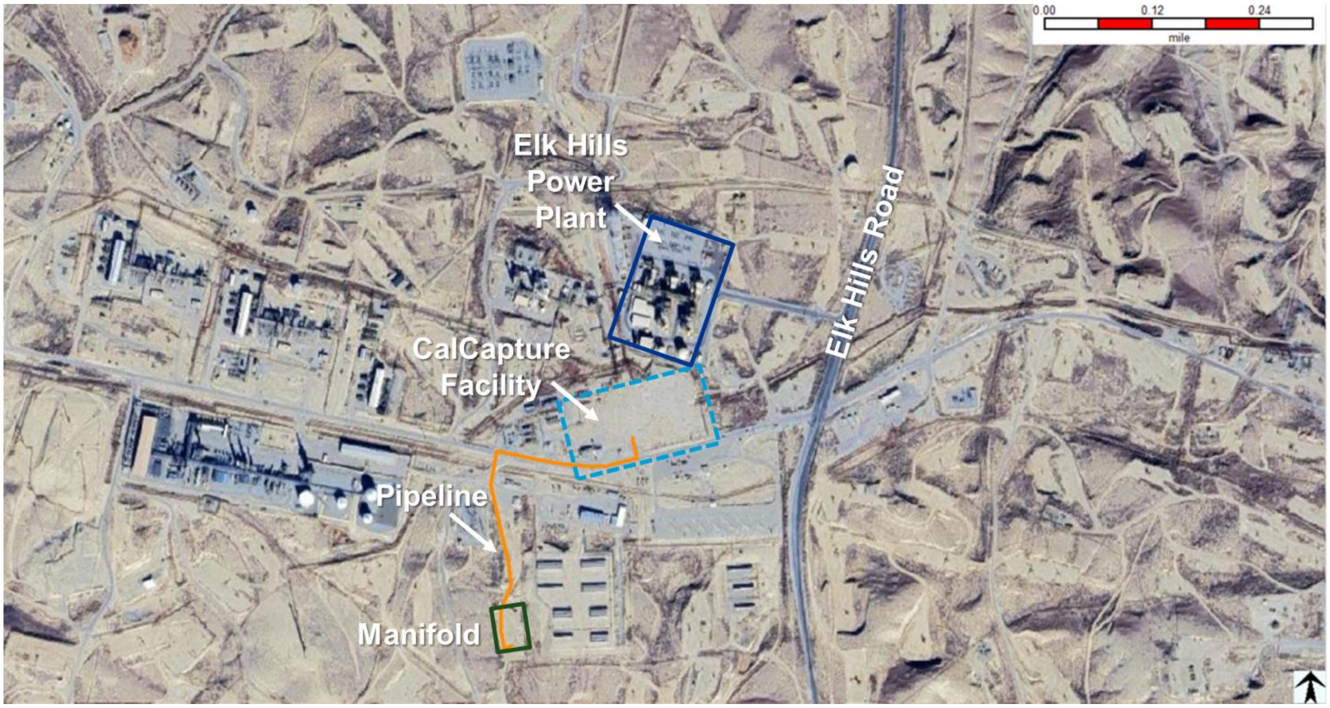

Figure 2-3 10" Pipeline Route

2.1.2.2 Injection Manifold

The existing CO_2 injection manifold at the Elk Hills CTV I emitter pad site is designed to receive compressed CO_2 from the CCU and route it toward the Class VI injection wells. The 35R manifold consists of various equipment; however, those are out of scope for the QRA. The only equipment in the manifold that is part of the CalCapture project are isolation valves and the pig receiver, which will be used once per year, and operated under the same conditions as the pipeline (refer to Table 2-4), but will be de-inventorized and not pressurized for the rest of the year.

2.2 Software Used for Modeling

Phast (version 9.11), KFX (version 7.0), and Safeti (version 9.11) are used for the consequence and risk modeling.

Phast and Safeti are free-field models, which simulate leaks or ruptures on a flat plain with varying levels of obstruction based on the surface roughness. The primary modeling will be performed under free-field conditions and assumes a flat terrain. However, for the worst-case pipeline release scenario, CFD modeling (using the KFX software) will be considered to account for the potential influence of complex terrain and slope to assess possibility of a release reaching the Elk Hills Road. By considering this, the modeling will reflect the most realistic and conservative outcomes for areas where terrain could influence dispersion behavior. The approach is discussed further in Section 5.4.

Although Skyline Road is present in the area, it is a private, restricted-access road. Public vehicles are not expected to travel on this road under normal conditions, and the area is not designated for general public use. Given that the pipeline is buried along this route and located within a controlled corridor, and that the surrounding terrain is relatively flat, the use of CFD modeling will be limited to the worst-case scenario rather than all cases.

For areas with these attributes, the Phast dispersion modeling (version 9.11) provides a reliable method for estimating dispersion distances and characterizing the extent of potential hazardous zones.

2.3 Representative Weather and Atmospheric Data

2.3.1 Weather Data

Data on wind direction and wind speed are combined to form a set of representative weather categories.

The wind speed by direction is based on the hourly average winds extracted for the Meadows Airport, Bakersfield over the period 2015 to 2025 to generate the site wind rose using this 10-year span as shown in Table 2-5 and Figure 2-4 [Ref /3/].

Table 2-5 Bakersfield Wind Rose Data

Wind Direction		Wind Speed Categories (m/s)				
	Calm (<1.3)	1.3 - 1.6	1.6 - 3.4	3.4 - 5.5	>5.5	Total
N	0.0132	0.0118	0.0456	0.0291	0.0079	0.1075
NNE	0.0132	0.0077	0.0177	0.0048	0.0005	0.0439
NE	0.0132	0.0073	0.0175	0.0027	0.0003	0.0410
ENE	0.0132	0.0097	0.0141	0.0009	0.0001	0.0380
E	0.0132	0.0184	0.0416	0.0040	0.0004	0.0776
ESE	0.0132	0.0153	0.0279	0.0030	0.0018	0.0613
SE	0.0132	0.0114	0.0272	0.0046	0.0030	0.0594
SSE	0.0132	0.0086	0.0165	0.0028	0.0027	0.0437
S	0.0132	0.0070	0.0099	0.0013	0.0005	0.0320
SSW	0.0132	0.0027	0.0043	0.0005	0.0002	0.0209
SW	0.0132	0.0032	0.0060	0.0007	0.0001	0.0232
WSW	0.0132	0.0033	0.0090	0.0016	0.0002	0.0273
W	0.0132	0.0069	0.0256	0.0155	0.0021	0.0634
WNW	0.0132	0.0059	0.0283	0.0459	0.0141	0.1074
NW	0.0132	0.0084	0.0378	0.0563	0.0242	0.1399
NNW	0.0132	0.0081	0.0391	0.0378	0.0155	0.1137
Total	**0.2111**	**0.1356**	**0.3683**	**0.2116**	**0.0734**	**1.0000**

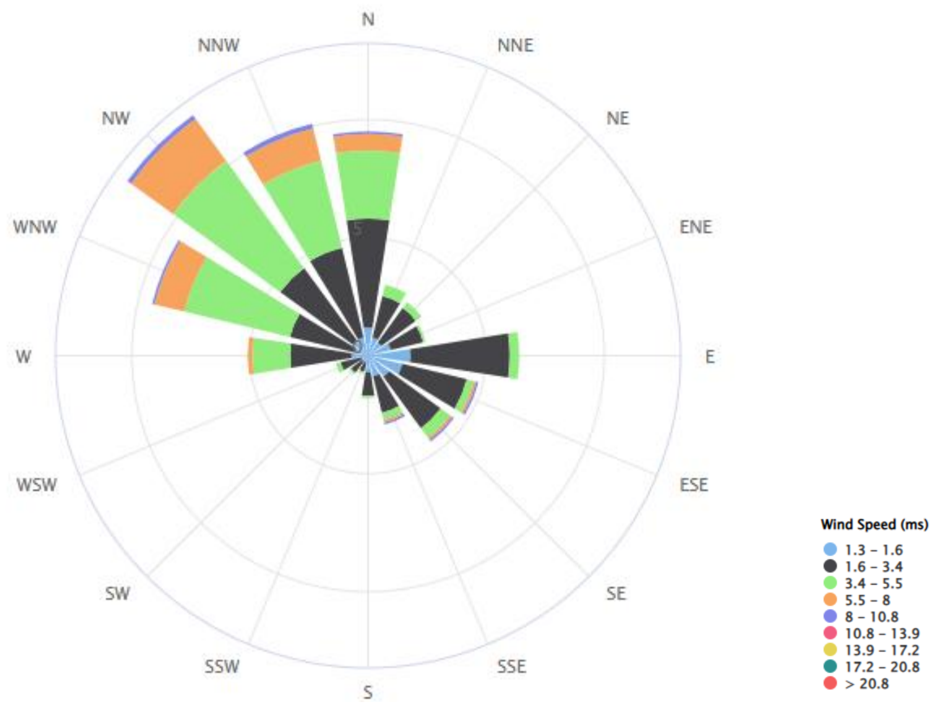

Figure 2-4 Bakersfield Wind Rose [Ref /3/] (indicates direction *from*)

The wind speed data is then simplified into four representative weather conditions, as presented in Table 2-6.

Table 2-6 Representative Weather Conditions

Weather Case	Atm. Stability	Wind Speed (m/s) [mph]	Total Probability
F1.5	F	1.5 m/s [3.3 mph]	0.3466
B3	B	3 m/s [6.7 mph]	0.3683
E5	E	5 m/s [11.2 mph]	0.2116
D8	D	8 m/s [17.9 mph]	0.0734

Note these values incorporated calms (equally distributed) across all the directions in the lowest wind speed range (1.5 m/s). The predominant wind direction is from the northwest (14% annually), with an average wind speed in the area of 3.2 m/s.

In addition to the weather categories, certain meteorological constants are defined as inputs to the QRA for Meadows Airport, Bakersfield over the period 2015 to 2025 [Ref /3/]:

- Atmospheric Temperature (°F) – 67.5
- Relative humidity – 47.8%
- Surface Temperature (°F) – 67.5 (assumed same as the atmospheric temperature)
- Wind speed reference height (ft) – 32.8, standard for meteorological parameters

2.3.2 Topography

The Elk Hills Power Plant is located near Skyline Road and Elk Hills Road in western Kern County. Although the broader Elk Hills area is characterized by rolling uplands, the immediate area around the plant and adjacent roadways is relatively level. Based on available Google Earth elevation profile mapping tool and site context, local elevation differences are modest, generally less than 50 feet across the plant footprint and surrounding road corridor. This describes the terrain in the area that could reasonably be affected by the release scenarios considered.

Given that the consequence and risk modeling tools used in this study assume flat, two-dimensional terrain, this assumption is consistent with the model characteristics. It describes the relatively flat terrain in and around the project area.

2.3.3 Surface Roughness

Low congestion level with moderate surface roughness (30 mm (1.2 in), open flat terrain; grass, few isolated objects) is applied in the modeling.

This roughness value reflects the inland location of the site, which lacks nearby bodies of water and is characterized by relatively flat terrain around the plant and the 0.42 mile pipeline corridor.

2.4 Fluid Composition

A representative amine, monoethanolamine (MEA), will be used to represent the amine solvent EFG+.

The fluid transported through the buried pipeline consists mainly of CO_2 at concentrations greater than 99%. For the purposes of the QRA, this will be assumed to be 100% CO_2.

The fluid released during the CO_2 venting scenarios will also be assumed to be 100% CO_2.

2.5 Receptor Height

The reporting of the hazard zones and risk impact is assumed at 3.3 ft (1 m) above ground level.

Side views of the dispersion will be provided to understand the concentration variation by height.

3 FAILURE CASE DEFINITION ASSUMPTIONS

The major accident hazards, or failure cases, are defined based on scenarios with the potential to impact the people, specifically the public. This assessment identifies representative releases from each of the primary subsystems within the CCU facility (as described in Section 2.1), as well as from the pipeline and the manifold. The aim is to ensure that scenarios considered in the QRA are both representative of the system and relevant to public risk.

3.1 Representative Parameters

For each failure case, the key inputs to determining the release parameters are the material, phase, process conditions, flowrate, and section volume / inventory, as described below.

- Material: Where applicable, releases are modeled as a mixture using a representative mixture composition (of up to 10 components), although a single representative material will be defined wherever a dominant material applies. This is defined as part of the analysis, noting that as a rule:
    - Where possible, the mixture is simplified to include the components with the largest fractions and those that are highly hazardous even at low concentrations.
- Phase: The phase of the material at the process conditions, and subsequently upon discharge, is a key factor influencing the consequences of the release event.
- Process conditions (temperature and pressure): Taken from the information provided by CRC, using the representative operating case. Where the conditions vary within a section, those associated with the main inventory are used. Where there is no 'main' inventory, the stream with the highest pressure is taken as representative. This will ensure that all foreseeable scenarios are addressed by conservatively representing the release cases with the greatest potential impact to the public.
- Flowrate: The normal flowrate through each of the representative streams has also been confirmed by CRC.
- Volume / inventory: The section volume is derived from the vessel volumes, together with the fill fraction of each vessel and estimates of the piping inventory. Refer to Section 3.2 for further details.

3.2 Inventory and Release Duration

The quantity of material available for release in the event of a leak or rupture depends on both static and dynamic inventory. Static inventory is defined as the mass within vessels and piping under normal operating conditions, while dynamic inventory accounts for the additional mass discharged until isolation. Static inventories can be conservatively estimated using equipment package volumes and normal operating fill levels where available.

Key assumptions that apply to the analysis in general are the following:

- The static inventory associated with each isolatable segment is defined as the mass within each segment under normal operating conditions.
- Total inventory is calculated as a sum of static inventory and dynamic inventory of isolatable segments. Static inventory is based on vessel dimensions. Dynamic inventory is based on the discharge rate of the representative scenario for the duration until isolation.
- The normal operation fill levels from each vessel are taken from facility documents.

- Estimates of the inventory associated with pipework, filters, and heat exchangers are included.

3.3 Hole Size Category

3.3.1 Hole Sizes – Above-ground Facilities

Leak data is presented in most databases as a distribution. For use in a QRA, the distribution is split into representative hole sizes and ranges. Several approaches exist for doing this with the most common being where each range is represented by the upper limit of the range, or by a representative size within the range. For this study, the upper limit of the hole diameter range is conservatively applied as the representative hole size diameter.

To define the hazardous release events applied to each release scenario, four hole-size distributions with representative hole sizes are modeled for all above-ground facility releases as listed below. This split is based on the methodology described in Modeling of Accidental Hydrocarbon Releases in QRAs: Hole Size Versus Initial Release Rate Basis [Ref /9/].

Table 3-1 Above-ground Facilities Hole Size Categories

Size Category	Hole Size Range	Representative Hole Size Diameter
Small	3 mm – 25 mm (0.1 in – 1 in)	10 mm (0.4 in)
Medium	25 mm – 75 mm (1 in – 3 in)	50 mm (2 in)
Large	75 mm – 125 mm (3 in – 5 in)	100 mm (4 in)
Rupture	125 mm (5 in) – Line diameter	Line diameter

3.3.2 Hole Sizes - Pipeline

A hole size approach is used to calculate the release frequencies for the buried pipelines.

The EGIG report [Ref /4/] categorizes leaks into the following hole size categories:

- Pinhole/crack: diameter of hole ≤ 20mm (0.7 in)
- Hole: diameter > 20mm (0.7 in) ≤ pipeline diameter
- Rupture: diameter > pipeline diameter

The “hole” category is equally divided between “medium” and “large” leaks. The representative hole sizes for the different pipeline segments are shown in Table 3-2.

Table 3-2 Buried Pipeline Hole Size Categories

Hole Size	Hole size range	Representative 10” pipeline hole size
Pinhole	< 20 mm (<0.78 in)	10 mm (0.4 in)
Leak	20 mm (0.78 in) to pipe diameter	127 mm (5 in)
Rupture	Full bore (Note 1)	Pipe diameter

Note 1: Full bore rupture refers to a complete cross-sectional failure of the pipeline. In some cases, high-pressure pipelines may experience ductile fracture propagation, sometimes described as a zipper rupture. This phenomenon can cause the failure to extend along the pipeline until it naturally arrests. This is not modeled explicitly in this QRA. If such a fracture were to occur, the section of pipeline between fracture endpoints would de-inventorize rapidly and would behave as two independent release points. If a running ductile fracture were to occur for this pipeline, as it is relatively short in length the potential release locations are all in the same area already under evaluation in the study. The QRA will evaluate a rupture release at discrete points along the pipeline to consider all potential impact locations. The pipeline release scenarios evaluated in this QRA are considered

sufficient to represent the consequences associated with this type of behavior and reflect how such conditions would be modeled in the software. The overall risk results remain conservative without modeling ductile fracture propagation directly.

3.3.3 Hole Sizes – Unloading Hose / Connections

The hole size categories used for hoses and couples used in road tankers are taken from the UK Failure Rate and Event Data document [Ref /20/]. These are split into: 5 mm (0.2 in) diameter hole, 15 mm (0.6 in) diameter hole, and guillotine failure. The associated failure rates for each hole category are discussed in Section 4.3.

3.3.4 Hole Sizes – Storage Systems

The hole size categories used for the atmospheric tanks used to store the hazardous chemicals are taken from the UK Failure Rate and Event Data document [Ref /20/]. These are split into: 75 mm (3 in) diameter hole, 250 mm (10 in) diameter hole, and catastrophic failure. For the catastrophic failure, it will be assumed that the entire inventory will be released within 10 minutes, which the U.S. EPA [Ref /28/] assumes for the worst case scenario. The associated failure rates for each hole category are discussed in Section 4.5.

Cylinder for hydrogen storage up to 20 MPa (3,000 psig) may be made of steel, while cylinders at pressures over 35 MPA are typically IV hydrogen tanks made of carbon fiber with polymer liner. There has been no hydrogen cylinder leaks in approximately 1.7 million cylinder operational years. Due to the limited data, DNV has developed a model based on steel liquefied petroleum gas (LPG) cylinders, which assumes the hole sizes of 0.4 in (1mm), 4 in (10mm) and rupture.

3.4 Release Location, Height, Direction

Location

A representative release location for each release scenario is based on information provided by CRC. The location is generally selected as that of the vessel containing the main inventory of the isolatable section or, where a number of vessels apply, as the center of the section.

Height

Since it is considered that most of the equipment / fittings are located close to ground level, the representative release height from standard equipment has a default value of 3.3ft (1 m) above grade. A release height of 100 ft will be used for the CO_2 vent stack.

Direction

Releases in the CCU facility, unloading activities, manifold are modeled as unobstructed, horizontal releases.

Release from the atmospheric vent will be modeled as vertical upwards.

Release from the 10” buried pipeline will be modeled as vertical upwards[1].

[1] While it is not feasible to fully represent the complex transient behavior associated with a buried-pipeline release (and a release possibly being directed in varying directions), experimental studies show that buried releases typically form a crater at ground. As the high-pressure inventory releases through the soil, the initial jet is directed predominantly upward into the atmosphere, where it expands and begins to disperse. After crater formation, the release behavior transitions to what is commonly referred to as a “gas-blanket” phase, during which the dense CO_2 travels outward close to the ground surface. The initial release is represented as an upward discharge followed by dense-gas dispersion at ground level; therefore, horizontal releases are not modeled explicitly.

3.5 Scenario List

An initial screening has been carried out to determine failure cases to be used in the QRA. Any streams and equipment handling steam, reverse osmosis (RO) water, potable water, reject water, raw water, instrument air, and plant air are screened out from further consideration as these are considered non-hazardous to the public.

The final list of scenarios that result from the consequence screening will be detailed in the QRA report.

4 FREQUENCY ANALYSIS ASSUMPTIONS

4.1 Leak Frequency – Facility

Generic leak frequencies

The failure data used as the basis for the frequency analysis for the CCU facility is the UK HSE's Hydrocarbon Release Database, or HCRD for 1992 – 2015 [Ref /10/]. This dataset is the most comprehensive and widely used source of leak frequency data for process equipment. The generic leak frequency correlations derived from analysis of the historical data set are documented in the International Association of Oil & Gas Producers (IOGP) Risk Assessment Data Directory [Ref /11/].

Justification for using the source:
Although the HCRD data is compiled from offshore North Sea facilities, it remains the most appropriate and technically robust dataset for estimating equipment-based leak frequencies, including for onshore facilities. Firstly, there is no public domain dataset for onshore facilities that matches the scale, equipment coverage, and completeness of the HCRD. Secondly, while offshore facilities operate in a more challenging environment, this is compensated by more stringent design, inspection, and maintenance requirements. Consequently, there is no evidence to suggest that release frequencies for onshore facilities should differ significantly from those derived from offshore data.

The CalCapture facility shares key characteristics, such as equipment types, and pressure systems, with offshore installations covered by the HCRD. While offshore facilities often follow more stringent inspection and maintenance protocols, they also face harsher environmental stressors. Independent reviews indicate that the use of HCRD correlations remains appropriate for onshore applications such as CalCapture, provided that the data are applied with suitable context [Ref /33//34//35/].

Parts-count

When release scenarios and the associated isolatable sections are identified, a parts count is conducted for each of the isolatable sections using the available drawings, e.g. process flow diagrams (PFDs) and process and instrumentation diagrams (P&IDs). Combining the number of parts identified within each section with the generic failure data for each associated part, produces the basic failure frequency for each release scenario.

The failure frequency for process piping is calculated by applying a general 1.34 factor to the calculated total equipment failure frequencies to account for process piping failure frequencies within the process units. This approach assumes that approximately 25% of the total leak frequency is attributable to process piping, which is reflective of the historical incident record [Ref /11//36/].

Justification for using the factor:
In the absence of detailed, site-specific piping data at this stage of the project, this assumption provides a reasonable and conservative basis. The factor is derived from DNV's experience on comparable QRA projects, where similar proportions of piping-related failures were observed when detailed equipment inventories were available. This methodology ensures that piping contributions are represented in the analysis without overstating their relative contribution.

4.2 Leak Frequency – Pipelines

Understanding CO_2 pipeline failure frequency is important for CCS projects as they rely mainly on pipelines to transport the CO_2. Failure frequency is typically measured in incidents per mile (or km) per year of pipeline operation. Historical data from PHMSA [Ref /12/] and EGIG [Ref /13/] provide information relating to the frequency of such events based on reported incidents.

Table 4-1 shows the pipeline failure rate per 1,000 mi-years which are obtained from various sources.

Table 4-1 Failure rates obtained from various databases

Source	Failure rate per 1,000 mile- years	Reporting Criteria
U.S. DOT – PHMSA CO_2 Transmission 2010-2024[2][Ref /12/]	0.518	> 5 gallons or > $50,000
U.S. DOT - PHMSA Gas Transmission 2005-2024 [Ref /12/]	0.201	> 3 MMSCF or > $50,000
EGIG Gas Transmission 2013-2022 [Ref /13/]	0.190	All Leaks

Between 2010 and 2024, PHMSA recorded 40 reportable incidents involving CO_2 pipelines, primarily in the context of Enhanced Oil Recovery (EOR) (Note that this process is not the proposed intent of this pipeline used in the proposed Project). This corresponds to an average failure frequency of 5.18×10^{-4} per mi-year, i.e. roughly 1 incident per 1,932 mile-years of pipeline operation annually. For comparison, natural gas transmission pipelines in the U.S. experienced 1,199 reportable incidents between 2005 – 2024, with an estimated failure frequency of 2.01×10^{-4} per mi-year. On the other hand, the natural gas pipeline failure frequency reported in the 12th EGIG Report for the basis of “all leaks” is 1.90×10^{-4} per mi-year.

These figures suggest that CO_2 pipeline incident frequencies obtained from PHMSA are modestly higher than the Gas Transmission frequencies from the U.S. DOT and EGIG, but differences are influenced by infrastructure age, sample size or reporting thresholds, and are not necessarily indicative of newly constructed pipelines such as those proposed for the Project.

It is important to note that PHMSA reporting criteria include only “significant incidents” (i.e. releases exceeding five gallons for CO_2 and three MMSCF for natural gas, causing injury or death, or costing more than $50,000). By contrast, the EGIG database includes all reported leaks, and therefore provides a fuller view of size distribution that is more reflective of modern, high-integrity gas transmission practice.

For this QRA, to be conservative, the PHMSA CO_2 failure rate of 0.518 per 1,000 mi-years is adopted as the base failure frequency. PHMSA is the main U.S. source for pipeline incidents, and its ‘significant incident’ cutoff skews the data toward bigger, higher-impact events, which is conservative for the study.

Failure leak size distributions

A review of PHMSA CO_2 incidents indicated that ruptures are uncommon, while most events are leaks. These are summarized in Table 4-2 below. Given that the PHMSA database does not report numeric diameters for hole / leak and pinhole, the hole size definitions will be based on the EGIG definition (see Table 3-2).

[2] It should be noted that the total pipeline mileage reported under PHMSA's CO2 category may include a subset of pipelines classified as “other gases.” The specific allocation between pure CO2 and mixed or unspecified gas streams is not always clearly delineated in the available data.

Table 4-2 PHMSA CO_2 pipeline incident distribution (period of 2010 – 2024)

Category	Share of pipeline incidents	Notes
Pinhole / crack	(9 out of 40) 22.5%	PHMSA leak subtype
Hole (all other leaks)	(28 out of 40) 70.0%	This category aggregates seal/packing, connection failure, crack, other, and unknown leak types.
Rupture	(3 out of 40) 7.5%	Rupture records included reported width and length.

On the other hand, a review of the EGIG dataset [Ref /13/] is provided below and it shows that most pipeline incidents are minor leaks, with rupture being relatively low in comparison, which is of similar trend to the PHMSA category distribution. Table 4-3 summarizes the distribution of leak sizes based on EGIG data from 2013 to 2022. Based on this, only about 11% of the pipeline releases are rupture, with the majority being small or pinhole-sized leaks.

Table 4-3 EGIG distribution of leaks based on hole sizes

Hole size	Release frequency per 1000 mi-yr (2013-2022)	Share of total (%)
Unknown[3]	0.005	2.4
Pinhole / crack (<0.78 in)	0.133	70.1
Leak (0.78 in to pipe diameter)	0.031	16.4
Rupture	0.021	11.2

Pipelines used for EOR encompass a broader range of pipeline infrastructure types that likely overstates the release frequency because EOR infrastructure in the PHMSA CO_2 dataset encompasses, in part, older pipelines with less stringent materials and design standards than the modern, CCS-dedicated infrastructure in California which must meet current seismic and pipeline safety standards, and which are constructed in accordance with modern engineering standards with robust materials, welding practices, and quality control measures. Nonetheless, newer CCS pipelines can still experience early-stage failures. As such, the PHMSA-derived rate provides a reasonable, but conservative, estimate to use for CCS applications.

For the purposes of the QRA, the PHMSA failure frequency and associated hole size distribution, as well as the EGIG hole size definitions, will be utilized. In addition, earthquake-induced failure rates will be incorporated into the pipeline release frequencies to account for seismic risks specific to the site location. This is discussed in Section 4.2.1.

4.2.1 Earthquake-Induced Failure Rates

The proposed CalCapture project is located in the Elk Hills Oilfield, near Tupman, Kern County California, which is in the southern portion of California's seismically active San Joaquin Valley, a region influenced by numerous active fault systems capable of producing strong ground movement.

[3] The Unknown category is referring to the incidents where the hole size could not be established during investigation or reporting to the EGIG dataset.

Given the area's tectonic setting, there is a credible potential for significant seismic events that could impact the infrastructure that is part of the CalCapture Project. Earthquake-induced ground shaking may compromise the integrity of the CO_2 pipeline, potentially resulting in loss of containment and a hazardous release. As such, seismic hazard has been investigated and discussed in this section.

The likelihood of ground movement is reported as hazard areas by the U.S. Geological Survey (USGS) [Ref /24/]. These hazard areas are expressed in terms of probability of exceeding a calculated ground motion value. Recent USGS data specific to the project location are provided in Table 4-4. The data indicates a 2% probability of exceeding a peak ground acceleration (PGA) of 0.54 g in 50 years, which equates to an annual exceedance probability of approximately 1 in 2,500 years (or 4×10^{-4} per year). An earthquake producing a PGA of 0.8 g or greater remains a rare event, with an estimated frequency of less than 1 in 10,000 years (1×10^{-4} per year).

Table 4-4 USGS data on likelihood of peak ground acceleration at site location

Probability of Exceedance	Annual Frequency of Exceedance	PGA (g)
10% in 50 years	2×10^{-3} /year (1 in 500 years)	0.29 g
5% in 50 years	1×10^{-3} /year (1 in 1,000 years)	0.39 g
2% in 50 years	4×10^{-4} /year (1 in 2,500 years)	0.54 g
0.5% in 50 years	1×10^{-4} /year (1 in 10,000 years)	0.80 g
0.05% in 50 years	1×10^{-5} /year (1 in 100,000 years)	1.25 g

Where: PGA = peak ground acceleration and

g = acceleration due to gravity

Katayama et al. [Ref /25/] developed one of the first relations, primarily for segmented cast iron pipelines, in which it provides an estimate of buried pipeline repair rates as a function of PGA. For buried welded steel pipelines in modern (well-constructed) conditions, the estimated earthquake-induced rupture rate for a PGA of 0.54 g (which corresponds to a 2% in 50-year event, which is commonly used as the Maximum Considered Earthquake (MCE) for critical infrastructure) is conservatively on the order of 3.2 repairs per mile, or equivalently, 320 leakages per 100 miles of pipeline exposed to that level of shaking.

These rates quoted above reflect total damage (including both leaks and breaks), but the breakdown by leak size is not available. Therefore, the breakdown of leak size due to ground movement presented in the EGIG Report [Ref /13/] will be applied to the study. It is assumed that 31% of releases result in full breaks/ruptures, 24% result in holes, and 45% result in pinholes/cracks.

4.3 Leak Frequency – Unloading / Transfer

There is potential for the hose and couplings of trucks to fail during unloading operations. This could occur due to an unloading error, hose failure, or failure of connecting equipment. The failure frequencies are taken from the UK HSE Failure Rate and Event Data (FRED) [Ref /20/] and are provided in Table 4-5. DNV will use the failure rates associated with "average" facilities.

Table 4-5 Failure Frequency Rates for Unloading Hose and Connections

Facility	Failure Frequency per transfer $\times10^{-6}$		
	5 mm (0.2 in) hole	15 mm (0.5 in) hole	Guillotine failure (hose diameter)
Basic facilities	13	1	40

Facility	Failure Frequency per transfer ×10^{-6}		
	5 mm (0.2 in) hole	15 mm (0.5 in) hole	Guillotine failure (hose diameter)
Average facilities	6	0.4	4
Multi safety system facilities	6	0.4	0.2

Table 4-6 shows the frequency of unloading, based on the transfer frequency, as well as the unloading rate.

Table 4-6 Transfer frequency and truck unloading rate

Chemical	Truck Unloading Frequency (per year)	Unloading Rate
Solvent (EFG+)	53 per year	140 gallons per minute
TEG	20 per year	10 gallons per minute
Hydrogen	1 trailer every two months (6 per year)	600 lbs per cylinder
Sulfuric Acid	9 per year	45 gallons per minute
Sodium Hydroxide	Once every month (12 per year)	85 gallons per minute

Justification for using the source:
Unloading hose and coupling failure frequencies are taken from the UK HSE Failure Rate and Event Data (FRED). FRED is a set of generic failure rates for Land Use Planning and is recommended as the basis when site-specific statistics are unavailable. It provides per-transfer probabilities derived from panel-reviewed fault trees and incident data for tanker unloading and defines safeguard-based facility classes.

There are no equivalent U.S. or international databases that provide per-transfer probabilities with the same level of detail for hose failures, coupling failures, or operator-based unloading errors. As a result, FRED is widely used in both U.S. and international QRAs when site-specific transfer statistics are unavailable.

The transfer operations of hazardous materials for the Project, which includes road tanker connections, flexible hoses, and mechanical couplings, are consistent with those covered by FRED. The use of FRED failure rates is therefore appropriate and conservative and aligns with established land-use planning practice and industry guidance for modeling unloading risks.

Justification for using specific facility type:
“Average facilities” type is selected because the unloading bays are expected to employ two pull-away prevention measures (including wheel chocks) with inspection and pressure/leak tests, and do not include an effective pull-away controls, such as a short airline or movement detector tied to automatic shutoff. This choice avoids taking unwarranted credit for non-redundant systems.

4.4 Leak Frequency – Road Transportation

Once the CalCapture facility is in operation, the chemicals that will be used are going to be delivered to the CalCapture facility from the supplier storage location. The chemicals will be transported using trucks. Table 4-7 below provides the anticipated frequency of delivery of the various chemicals.

Table 4-7 Volume / Capacity of Chemicals Transported

Chemical	Transport Volume / Capacity
Solvent (EFG+)	4,200 gallons
TEG	150 gallons

Chemical	Transport Volume / Capacity
Hydrogen	600 lbs
Sulfuric Acid	750 gallons
Sodium Hydroxide	2,500 gallons

The QRA will use published accident rates for hazardous material cargo vehicles reported per million vehicle miles traveled (MVMT), e.g. from the Federal Motor Carrier Safety Administration (FMCSA). The analysis will account for both collision events and non-collision events such as non-collision rollovers, equipment failures in transit, and operating error.

Publicly available incident records in the U.S. DOT PHMSA incident database will be reviewed to establish the distribution of transportation release sizes or volumes.

This study will assume that each delivery will travel 50 miles one way from supplier to facility. Trip counts for each material are taken from Table 4-7, and each delivery is treated as one exposure of cargo to in-transit hazards.

Trucks are assumed to meet U.S. DOT specifications and be operated by licensed carriers. No credit is taken for route avoidance, time-of-day restrictions, or telematics. These measures can reduce transportation risk in practice, but they are not included here as this assessment is of a high level and uses conservative assumptions.

4.5 Leak Frequency – Storage

This section covers the leak frequency assumption for fixed storage at the facility for the chemicals used. These tank sizes, as listed in Table 4-8, fall within the Small and Medium Atmospheric Tank (SMAT) range for tanks with capacity less than 450 m^3.

Table 4-8 Failure Frequency Rates for Unloading Hose and Connections

Chemical	Storage Capacity	Storage tank pump rate
Solvent (EFG+)	26,810 gallons	220,000 gallons per year
TEG	1,040 gallons	2,930 gallons per year
Hydrogen	600 lbs	0.77 million standard cubic feet per year
Sulfuric Acid	6,300 gallons	6,600 gallons per year
Sodium Hydroxide	12,600 gallons	30,000 gallons per year

The UK HSE FRED provides generic failure rates per vessel-year that distinguish catastrophic, large, and small releases and separate flammable and non-flammable contents, and these are presented below in Table 4-9.

Table 4-9 Failure Frequency Rates for Small and Medium Atmospheric Tanks

Type of release	Non-flammable contents (per vessel year)	Flammable contents (per vessel year)
Small, 75 mm (3 in) diameter hole	5×10^{-4}	1×10^{-3}
Large, 250 mm (10 in) diameter hole	5×10^{-5}	1×10^{-4}
Catastrophic	8×10^{-6}	1.6×10^{-5}

Justification for using the source:
As the facility's storage tanks are in fixed, atmospheric tanks below 450 m^3 (<120,000 gallons), and the FRED is maintained by the UK safety regulator (UK HSE), it serves as the default basis in the absence of site-specific data. The database failure rates reflect the sensitivity to substance class (whether flammable or non-flammable), and the dominance of corrosion in catastrophic and large releases. FRED provides explicit release-category definitions and hole-sizing rules, which enables mapping frequencies directly to hole size categories. Using FRED enables traceability to a publicly documented method which is widely applied in land-use planning and prior DNV QRAs. It is conservative especially where design and inspection practices meet or exceed the baseline assumptions.

Leak frequency assumption for the hydrogen cylinders are provided in Table 4-10 below. DNV's model aligns with Germany's Federal Institute for Materials Research and Testing's acceptable lifetime failure rates for Type IV cylinders.

Table 4-10 Failure Frequency Rates for Hydrogen Cylinders

Type of release	Flammable contents (per vessel year)
Small, 1 mm (0.04 in) diameter hole	1×10^{-6}
Large, 10 mm (0.4 in) diameter hole	3×10^{-7}
Rupture	1×10^{-7}

4.6 Isolation and Detection Philosophy

4.6.1 Isolation Failure

Isolation failure refers to the inability to successfully isolate a release source, either due to equipment malfunction or human error. The probability of isolation failure is calculated based on the reliability of emergency shutdown systems and, where applicable, human intervention.

To account for the possibility of failure to isolate occurring either due to failure of the emergency shutdown valves (P_{ESD}) or due to human error (P_{human}), the probability of isolation failure is determined as:

$$P_{isolation\ failure} = 1 - (1 - P_{human}) * (1 - P_{ESD})$$

Where:

$$P_{ESD} = 1 - (1 - PFD_{ESD})^N$$

And:

PFD_{ESD} is the probability of failure on demand of the ESD(s); the ESD system is assumed to comply with SIL2 (safety integrity level), this is defined as 1%.

N is the number of ESDs required for isolation and on average, 2 valves are assumed to be required to isolate a segment, hence N = 2.

P_{human} = Probability of human failure, set to a generic value of 10%[4].

Blowdown failure is assumed to be linked to isolation failure (i.e. un-isolated releases do not have blowdown). If there is isolation failure, the release discharge is assumed to continue for a conservative, maximum duration of 3,600s (60 minutes). This duration assumes one hour as the time required for personnel to recognize alarms, operators to diagnose, access and perform manual actions.

4.6.1.1 CO_2 systems

This includes the CCU systems in the CalCapture facility and the CO_2 pipeline. These systems are safeguarded by automated leak detection and isolation systems, and therefore human error is not considered in the isolation failure probability calculation.

Detection systems include:

- Above-ground: 2 out of 3 of the thermal camera, ultrasonic camera, and flow detection sensors successfully triggers.
- Below-ground: 2 out of 3 of fiber optic distributed temperature sensing (DTS), fiber optic distributed acoustic sensing (DAS), and flow detection sensors successfully triggers.
- Low pressure detection: Independent detection system.

Isolation systems include:

- Upstream Isolation (3 independent systems):
  - Compressor discharge ESD
  - Meter station ESD
  - Compressor shutoff
- Downstream Isolation (2 systems):
  - Check valve (passive)
  - Manifold ESD

Given the presence of a passive check valve downstream, only one active isolation is assumed necessary. Therefore, N = 1. As a result, the probability of isolation failure applied within the study is calculated as follows:

$$P_{ESD} = 1 - (1 - 0.01)^1 = 0.01$$

$$P_{isolation\ failure} = 0.01$$

[4] Human failure probability is often determined by site-specific Human Reliability Analysis (HRA). In the absence of this data, this generic value is based on Swain and Gutman's 1984 validation work [Ref /30/], which has also been adopted by the CCPS [Ref /31/].

Blowdown failure is assumed to be linked to isolation failure (i.e. un-isolated releases do not have blowdown). If there is isolation failure, the release discharge is assumed to continue for a conservative, maximum duration of 1,800s (30 minutes) to account for the following:

- Multiple automated detection and isolation systems
- 24/7 manned and monitored facility
- Additional surveillance via security cameras

4.6.1.2 Other systems in CalCapture Unit

For systems outside the CO2 pipeline and CCU, isolation is manually activated by operators in response to alarms or observed process upsets. The general ruleset adopted is that two ESD valves are required for isolation of a segment. Human intervention is required to activate the isolation. As a result, the probability of isolation failure applied within the study is calculated as follows:

$$P_{isolation\ failure} = 0.12$$

Blowdown failure is assumed to be linked to isolation failure (i.e. un-isolated releases do not have blowdown). If there is isolation failure, the release discharge is assumed to continue for a maximum duration of 3,600s (60 minutes).

4.6.2 Detection and Isolation Success and Duration

Detection and isolation times represent the time from release initiation to successful isolation. These times vary based on system type and event severity.

4.6.2.1 CO2 systems

The assumed isolation time is 10 seconds, as defined in the Caltrol Inc. Elk Hills CO2 Pipeline Specification Sheet [Ref /26/].

4.6.2.2 Other systems in CalCapture

Local emergency isolation valves are specified in the CCU facility drawings. The activation of ESD is designed to be triggered manually due to process upset by the operators in the control room.

The times required to detect a release and then to initiate isolation and blowdown are summarized in the table below, which gives the representative times assumed for isolation events. Longer detection and isolation times are required for relatively “smaller” events assuming that “smaller” events may take time to investigate before activating isolation versus “larger” events, which would bring immediate attention and response to activate isolation.

The table below presents the assumed isolation time for above-ground release scenarios.

Leak Size	Response Time (min) *		Cumulative Time to Isolation (min
	Detection	Isolation	
Small	10	5	15
Medium	5	5	10
Large/Rupture	2	1	3

* Definition of response time categories

A release event occurs at time = 0s

Detection: This is the time from when the release event starts until someone (or detector) becomes aware of the release event. This may be the time for an operator in the field to detect the release or for the release cloud to trigger the gas detector alarms in the control room, further alerting the operator in the control room.

Isolation: This is the time from detection until the segment is isolated, and the shutdown valves are closed. This period of time includes the time for operators to discuss the situation and decide whether to activate isolation and shutdown. This also includes the time for the valves to close.

Justification for assumed times:
Given that ESDs are designed to be activated manually, the key factor in determining whether and when isolation occurs is the human factor aspect of the operator's response to the alarm. This can only be quantified as a representative detection and isolation time.
Smaller leaks may take longer to detect and confirm before isolation is initiated. Larger events are more immediately apparent and prompt faster response. The times shown above include detection, decision-making, and valve actuation.

5 CONSEQUENCE ANALYSIS ASSUMPTIONS

5.1 Ignition Probability

Immediate ignition takes place when there is an active ignition source present at where the release happens. In this study, the immediate ignition probability is calculated from the total estimated ignition probability from the UKOOA (United Kingdom Offshore Operators Association) look-up correlations, published in the IOGP Risk Assessment Data Directory [Ref /14/].

Justification for using the source:
This source is widely used in industry QRAs, as it provides a transparent mapping of release type and plant scale to ignition probability. It is implemented consistently in standard tools such as Phast/Safeti. The UKOOA look-up also offers a comprehensive set of correlations derived from a large incident base. Therefore, its use supports traceability, benchmarking against accepted practice, and reproducibility of results. As site-specific data on ignition sources are not readily available, the IOGP values are applied as a conservative, documented baseline.

From the 30 scenarios listed in the IOGP Data Directory, scenario 5 – small plant gas LPG (gas or LPG release from small onshore plant), is used in this study. IOGP Scenario 5 is related to releases of flammable gases, vapor, or liquids significantly above their normal boiling point from small onshore plants (plant area up to 1,200 m^2 (1,435 yd^2), site area up to 35,000 m^2 (41,860 yd^2)).

The IOGP approach relates the mass release rate of the hydrocarbon to ignition probability, which tends to give very low values for Hydrogen. Although the ignition probabilities will still follow the IOGP Curve Model, the ignition probability will be used in terms of 'volume-based' and not 'mass-based' for release scenarios containing hydrogen, while release scenarios containing methane will follow the mass-based ignition probabilities.

Table 5-1 UKOOA Ignition Probabilities [Ref /14/]

Mass Release Rate (kg/s)	Volumetric Release Rate (m^3/s) (Note 1)	Ignition Probability
0.1	0.05	0.0011
0.2	0.11	0.0014
0.5	0.26	0.0020
1	0.53	0.0025
2	1.05	0.0074
5	2.63	0.0204
10	5.27	0.0339
20	10.54	0.0564
50	26.34	0.1107
100	52.69	0.1842
200	105.37	0.3065
500	263.44	0.6000
1,000	526.87	0.6000

Note 1: The volumetric release rate is calculated assuming that the density of LPG is 1.898 kg/m^3

In the event of a release, the probability of ignition is further divided into immediate ignition and delayed ignition. A 40:60 distribution is taken for immediate and delayed ignition distribution. Delayed ignition of flammable gas cloud will either result in flash fire or explosion, depending on confinement and congestion of the area.

5.2 Explosion Modeling

5.2.1 Congested regions

Within the facility areas, obstructed regions are defined as areas with the potential for confinement and congestion of a flammable cloud, which may promote explosion hazards.

Overpressures are calculated using the TNO Multi-Energy (ME) method. To apply this method, regions of congestion are to be defined. The congested regions are defined in terms of location, geometry, and the degree of congestion/confinement. The amount of obstruction within each volume is further defined by using a Volume Blockage Ratio (VBR), i.e., the amount of the volume occupied by piping/equipment. For each obstructed region in Safeti, the user specifies the ME curve number and the volume blockage ratio to estimate overpressures.

In the definition and application of the method, it is assumed that:

- All congested areas are defined as regions of congestion / confinement, and the site layout used to define the x and y dimensions of the congestion. Vertical dimensions are estimated from site plot plans and elevation drawings.
- The cloud volume used in the explosion calculations is determined by the overlap of the cloud LFL envelope and the congestion, up to the maximum dimensions of the respective congested volume.

The correlation of the TNO's ME curve number to peak side-on-overpressure is displayed as curves in Figure 5-1.

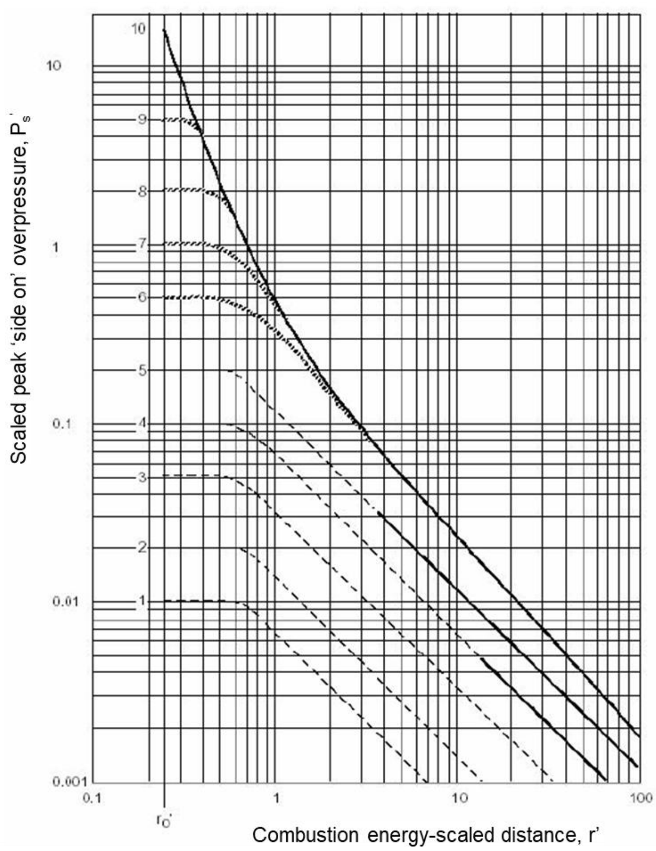

Figure 5-1 TNO Multi-Energy Curves [Ref /29]

The following assumptions are adopted for the explosion modeling of this study:

- The ME curve number that will be applied for modeling of confined hydrogen explosions is curve 10. Note that explosions originating in congested regions will inherently entail the full volume of the cloud. In addition, having a curve strength of 10 means that the effects are equivalent to detonation.
- A VBR of 0.15 will be applied since it is typically used to represent medium congestion.

5.2.2 Unconfined regions

Releases of flammable gas from the piping or equipment in the open can drift and ignite in the presence of an ignition source. This can potentially produce an unconfined vapor cloud explosions (uVCE). The unconfined explosions are characterized by two input parameters:

- Explosion strength: A scale from the ME method that sets blast severity. For this study, explosion strengths 4, 5 and 6 are used, and these correspond to peak overpressures of about 100 mbar (1.5 psi), 200 mbar (2.9 psi), and 500 mbar (7.3 psi), as shown below in Table 5-2.
- Explosion efficiency: This corresponds to the fraction of the gas cloud that participates in the explosion. An assumption of 100% is used for unconfined explosions to be conservative.

The following parameters (Table 5-2) define the strength of unconfined explosions that will be modeled for delayed ignition of any releases that do not overlap with any congested or obstructed areas, i.e., that do not have VCE effects.

Table 5-2 Parameters Used for Unobstructed Explosion [Ref /15/]

Unobstructed Explosion Parameter	Release Rates		
	<0.1 kg/s	0.1-1 kg/s	>1 kg/s
Explosion strength	4	5	6
Efficiency	100%		

Hydrogen releases that are greater than 1 kg/s and where the flammable cloud is larger than about 300 m^3 volume, there is potential for a Deflagration to Detonation Transition (DDT), even in open areas. In those cases, detonation is tested and, when applicable, represent the release using an Explosion Curve Strength of 10 in the ME Method. Some judgement may be needed on the probability assigned to such an outcome, noting that:

- In a relatively small but congested process plant, it is likely that congestion will be encountered, as such detonation becomes more credible. In wide, open areas or when cloud volumes only slightly exceed 300 m^3, a lower probability may be justified.

5.3 Hazard Endpoints

Hazard types including flammable dispersion, jet fire, explosion and toxic are considered in this study. A comprehensive understanding of these hazard endpoints is crucial for assessing the potential consequences associated with the various release scenarios. The following endpoints will be considered in the study:

<table>
<tr><th>Hazardous effect</th><th>Endpoints</th></tr>
<tr><td>Explosion overpressure</td><td>Explosion hazard frequency contours for 0.5 psi (0.03 bar), 2 psi (0.1 bar), and 3 psi (0.2 bar) [Ref /9/].</td></tr>
<tr><td>Thermal radiation</td><td>Thermal hazard frequency contours as per below [Ref /23/]-
<table>
<tr><th>Thermal Radiation</th><th>Effect</th></tr>
<tr><td>4.7 kW/m^2</td><td>Heat intensity in areas where emergency actions lasting several minutes may be required by personnel without shielding but with appropriate clothing</td></tr>
<tr><td>9.46 kW/m^2</td><td>Pain threshold reached after 8 seconds; second-degree burns after 20 seconds</td></tr>
<tr><td>37.5 kW/m^2</td><td>Significant chance of fatality for people exposed instantaneously. Sufficient to cause damage to process equipment</td></tr>
</table></td></tr>
<tr><td>Flammable gas</td><td>Lower Flammable Limit (LFL) and 50% LFL</td></tr>
<tr><td>Toxic gas concentration – CO_2</td><td>CO_2 is a colorless, odorless gas at atmospheric temperatures and pressures. It is heavier than air and may asphyxiate by the displacement of air. Exposure to CO_2 can cause headache, dizziness, difficulty breathing and tremors. Extremely high concentrations, far above typical occupational exposure limits, can be dangerous and may lead to serious health effects.
The CO_2 concentrations of interest for the evaluation are:

30,000 ppm – American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for short-term exposure limit (STEL), based on a 15-minute exposure time [Ref /16/]. This limit is used as a reference for modeling purposes and should not be considered as a maximum emergency limit.
40,000 ppm – National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) after 30 minutes exposure time [Ref /17/]. This limit is used as a reference for modeling purposes and should not be considered as a maximum emergency limit.
50,000 ppm, 75,000 ppm, and 100,000 ppm. (Note 1)
110,000 ppm – According to a DNV study, concentrations between 11-25 vol% CO_2 is understood to cause gasoline engine stall. Lower range will be used.
150,000 ppm - According to a DNV study, concentrations between 15-26 vol% CO_2 is understood to cause diesel engine stall. Lower range will be used.

Note 1: The concentrations of 50,000, 75,000, and 100,000 ppm CO_2 are not linked to specific regulatory thresholds but are included as reference levels to illustrate concentration ranges that may occur close to the source following the release scenarios. These values provide useful visualization to show concentration bands to complement the benchmark levels of 30,000 ppm (short-term exposure limit) and 40,000 ppm (IDLH). They are included solely to aid in interpreting dispersion behavior and plume extent, but not to represent health outcomes or specific regulatory limits.</td></tr>
</table>

Hazardous effect	Endpoints
Toxic gas concentration - Others	Other toxic materials present in the facility include: • Sulfuric Acid • Sodium Hydroxide The concentrations of interest for these materials for the evaluation are: • Sulfuric Acid: 15 mg/m^3 – National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) after 30 minutes exposure time [Ref /17/]. This limit is used as a conservative threshold for modeling purposes and should not be considered as a maximum emergency limit. • Sodium Hydroxide: 10 mg/m^3 – National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life or health (IDLH) after 30 minutes exposure time [Ref /17/]. This limit is used as a conservative threshold for modeling purposes and should not be considered as a maximum emergency limit. Other materials (e.g. ethylene glycol, triethylene glycol, sodium hypochlorite, citric acid, biocide, and sodium bisulfite) are present onsite; however, these are either stored in very low volumes or are not classified as toxic when inhaled. Since the Quantitative Risk Assessment focuses on potential toxicity effects to personnel from the dispersion of toxic fumes away from the site, they are not included in this assessment.

5.4 Computational Fluid Dynamics (CFD) Modeling

For the CFD analysis, DNV will use the KFX software (version 7.0) and will model a CO_2 pipeline release. The pipeline release location and scenario to be modeled will be selected based on the Phast dispersion which results in the highest predicted concentration at Elk Hills Road for a full-bore rupture scenario.

The release characterization, including release rate, temperature, and density, will be derived from Phast calculations to be consistent with the consequence modeling assumptions.

The local terrain will be incorporated into the CFD model to capture the influence of topography on dispersion behavior. This will be extracted from publicly available sources [Ref /32/]. The release will be modeled as vertical upwards with a release elevation at ground level, i.e. post crater formation. The weather conditions described in Table 2-6 will be applied, including ambient temperature of 67.5 ˚F. Wind direction will be assumed from west to east, as this is assumed to represent the worst-case scenario where the released gas plume disperses along the Elk Hills Road. Based on these inputs, four CFD scenarios will be modeled, as summarized in Table 5-3 below.

Table 5-3 Scenario information

Scenario No.	Pipeline Characteristics	Composition	Release Size	Weather Condition	Wind Direction from
1	10”, 2,100 psig, 0.42 mi	100% CO_2	Rupture (10”)	F1.5	West
2	10”, 2,100 psig, 0.42 mi	100% CO_2	Rupture (10”)	B3	West
3	10”, 2,100 psig, 0.42 mi	100% CO_2	Rupture (10”)	E5	West

Scenario No.	Pipeline Characteristics	Composition	Release Size	Weather Condition	Wind Direction from
4	10”, 2,100 psig, 0.42 mi	100% CO_2	Rupture (10”)	D8	West

The CFD results will then be integrated into the QRA, taking into account the leak frequency associated with a full-bore rupture as described in Section 4.2. In addition to contributing to the overall risk estimates, key outputs from the CFD study will be reported, including:

- Maximum dispersion cloud footprint and side-view concentration profiles
- Maximum downwind distances for concentrations of interest
- Screen captures and figures to illustrate model results, including potential impact distances, cloud heights, and duration of elevated concentrations

This approach ensures that the QRA reflects the influence of local terrain under worst-case conditions and provides a robust basis for assessing potential impacts to Elk Hills Road.

6 IMPACT AND RISK ANALYSIS

6.1 Population

6.1.1 Onsite Population

The Elk Hills Power Plant facility includes onsite CRC personnel responsible for plant operations and maintenance activities. However, the scope of the QRA is limited to assessing risks to the public outside the facility boundary, with a specific focus on the nearby public county roadway, Elk Hills Road, and surrounding areas.

Onsite personnel are not included in this assessment because they are covered under occupational safety regulations, receive emergency response training, use appropriate personnel protective equipment (PPE), and have a working understanding of the hazards associated with their duties. Furthermore, these workers operate under a voluntary risk environment. In contrast, members of the public are considered involuntary receptors and are typically not trained, equipped, or informed to manage the risks evaluated in this study. This distinction aligns with CEQA requirements, which focus on public health impacts and the protection of the broader community, including disadvantaged communities.

6.1.2 Offsite Population

This study will assess the offsite impact in the event of hazardous releases.

The nearest residential area is located approximately 4.97 miles from the facility. The locations of the nearest residence and additional nearby residential areas, which consist of residential houses and one school (Tupman), are provided in Figure 6-1. Figure 6-1 also shows other sensitive receptors within a 10-mile buffer region.

Based on the distance of the closest residential areas and the volumes of hazardous materials considered onsite, these locations are not anticipated to be impacted. Elk Hills Road county roadway, which lies approximately 600 ft from the facility, represents the primary public exposure point of concern.

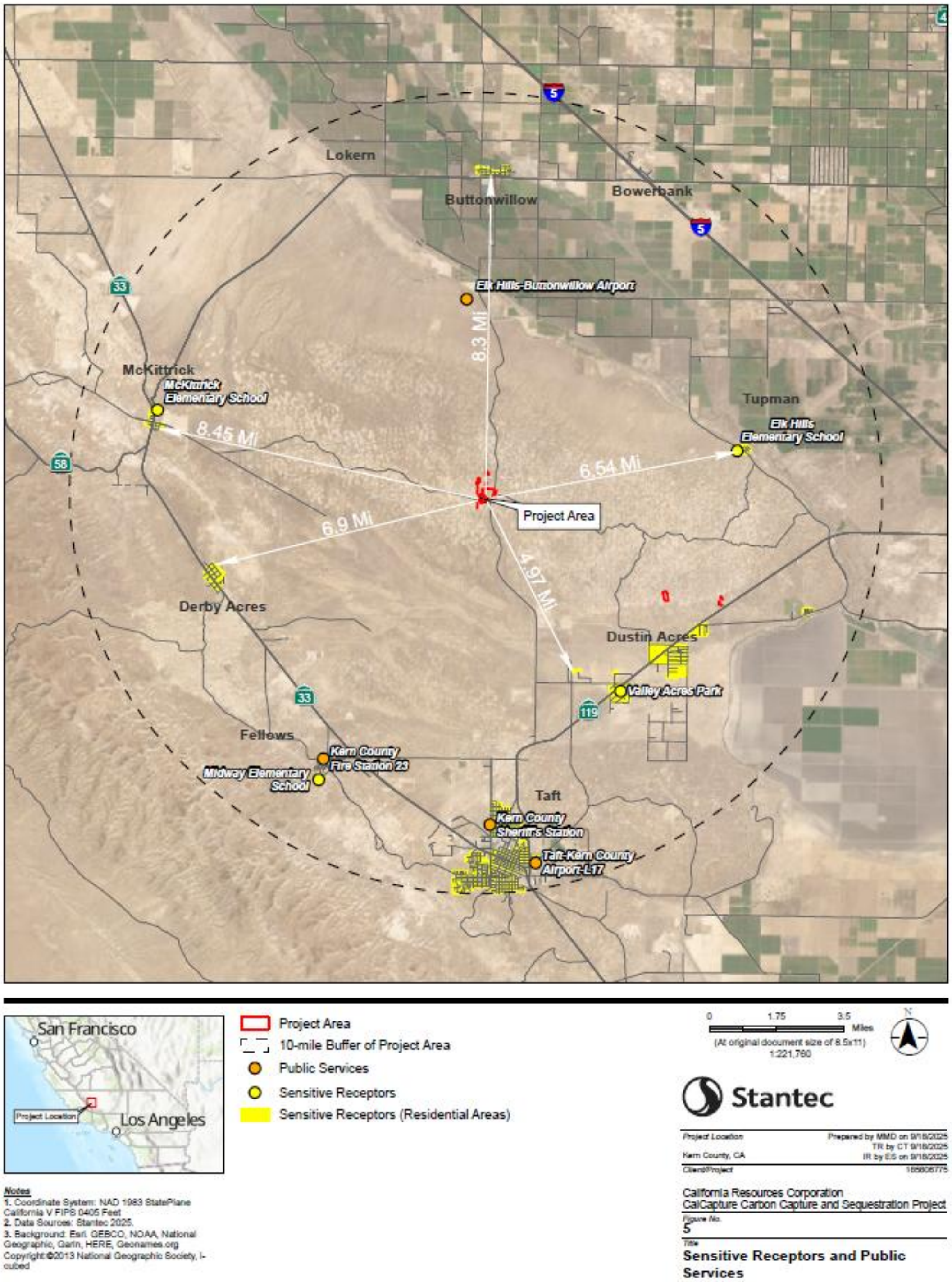

Figure 6-1 Location of Sensitive Receptors Around the Site (Note that the nearest area is approx. 4.97 miles from the proposed CCU facility)

6.1.3 Traffic Data and Methodology

Population estimates for the Elk Hills Road, which will be incorporated into the model, are based on the 2025 Stantec Transportation Impact Analysis traffic survey [Ref /5/]. These estimates represent the transient population of motorists crossing the road segment, which are as follows:

- Elk Hills Road, north of Skyline Road: annual average daily traffic of 1, 548 trips
- Elk Hills Road, south of Skyline Road: annual average daily traffic of 1, 963 trips.

These figures were obtained as Stantec conducted 24-hour traffic counts north and south of Skyline Road, along with peak-hour intersection counts at Elk Hills Road and Skyline Road (private road).

CRC gate entry and exit data were also analyzed for the same period to determine daily traffic volumes associated with CRC operations. These data sets were combined to distribute total traffic along Elk Hills Road and to differentiate between CRC and non-CRC (public) vehicles. Adjustments were made to account for CRC traffic movements that occur between internal gates without entering Elk Hills Road. The resulting analysis indicates that approximately 409 daily trips are attributable to the public, representing the relevant population segment for this QRA.

The QRA model will use a population density approach, with a conservative assumption of 100% outdoor exposure[5] for the public road population, which refers to motor vehicles, including cars and motorcycles, traveling along the Elk Hills Road. Key assumptions presented below include using a 10-foot width per lane and two lanes per county roadway. The estimated public county roadway population and the underlying assumptions are detailed in Table 6-1 [Ref /5/].

Additionally, a point population at the intersection of Elk Hills Road and Skyline Road is also included in the QRA. Motorists are required to stop at this location (4-way STOP sign), and a conservative assumption has been applied that vehicles (with two people per car) may remain at the stop sign for up to one minute. This accounts for the brief increase in exposure time at the intersection and is incorporated into the overall population modeling to be considered in the QRA.

Table 6-1 Density Calculation based on Annual Average Daily Traffic (AADT) Counts

Road	2024 AADT [Ref /5/]	Traffic / hr	Speed, mph	Length, mi	Time on road, hr	Facto-red traffic on length	2 people /car	Area, mi^2	Density, people/ mi^2	Area, m^2	Density, people/ m^2
Elk Hills, north of Skyline Road (2 miles)	409	17	55	2	0.0364	0.62	1	0.0189	65	49053	0.00003
Elk Hills, south of Skyline Road (2 miles)	409	17	55	2	0.0364	0.62	1	0.0189	65	49053	0.00003

5 This assumption is based on treating all individuals traveling along the roadway as if they are fully exposed outdoors, equivalent to driving with windows open. This is a conservative basis, as in reality vehicle cabins would provide some level of protection against potential external toxic concentrations.

6.1.3.1 Consideration of Risk to Motorists on Elk Hills Road

The risk to motorists traveling along Elk Hills Road will be assessed based on predicted CO_2 concentrations from the release scenarios considered.

The analysis will initially apply a population density approach (as described above) using the traffic data in Table 6-1 and a conservative assumption of 100% outdoor exposure for vehicle occupants. Based on the dispersion modeling, the maximum CO_2 concentrations that could occur along the roadway will be determined. If concentrations remain below the CO_2 concentration that motor vehicles are expected to stall (approximately 11 vol%), DNV will assume that motorists can safely continue driving and escape the area of concern, and the base population density approach remains valid. However, if concentrations reach or exceed levels that could cause internal combustion engine (ICE) vehicles to stall (typically in the range of 11–15%), a conservative assumption will be applied such that motorists could become immobilized on the road, and the population assumption will be revised to reflect a worst-case scenario where all motorists present during the event remain on the roadway for the duration of the release.

In addition, for conservatism, it will be assumed that CO_2 concentrations inside vehicles are equivalent to outdoor concentrations (as reflected by the 100% outdoor exposure assumption described above), even though actual in-vehicle concentrations may be lower due to partial sealing and ventilation. This approach ensures that the QRA accounts for both normal driving conditions and the potential immobilization of vehicles under high CO_2 concentrations.

6.2 Human Vulnerability Criteria for Fires and Explosions

The consequence assessments conducted within the risk analysis are used to predict the distance to (or strictly, the area covered by) any desired hazard level, such as specific toxic cloud concentrations. However, for risk calculations, it is necessary to associate hazard levels with their effect, or impact, on personnel.

This is done by setting the modeling end point (i.e., impact) criteria for the various consequences to correspond to levels at which the likelihood of fatality is estimated (for example, based on established best practice). With a simple cut-off model, as possible in Safeti, the assumption is that if the hazard exceeds the specified level (the “end-point criterion”) at that location, any exposed people suffer fatality with the defined probability (the “vulnerability criterion”).

The end-point criteria, used to determine the impacts at a given location, and the corresponding vulnerability parameters, defining the probability of fatality of any exposed people, are summarized in the tables below. These criteria are based on the Bevi Manual (formally known as the Purple Book) [Ref /18/].

Table 6-2 Summary of Fires and Explosions Vulnerability (Fatality) Criteria for Personnel Outdoors

Fire (jet fire, pool fire, and fireball)	**LSIR**
Flame Zone	1
Heat Radiation > 37.5 kW/m^2	1
Heat Radiation < 37.5 kW/m^2	Probit calculation, $36.38 + 2.56 \ln[(W.m^{-2})^{4/3}.T]$, where exposure time T is in seconds and maximum exposure time is 20 seconds.
Flash Fire	**LSIR**
Inside the LFL Envelope	1
Outside the LFL Envelope	0

Explosion[6] [Ref /9/]	LSIR
Overpressure 0.5 psi	0.1
Overpressure 2 psi	0.2
Overpressure 3 psi Overpressure > 3 psi	0.5 1

6.3 Toxic Risk

6.3.1 Probit-based approach

The probability of death (P_E) due to exposure to a toxic cloud is calculated with the use of a probit function as shown below.

The Probit equation used to calculate the probability of fatality is as follows:

$P_E = a + b \ln(C^n \times t)$

where C is the concentration (ppm)
t is the time of exposure (minutes)
a is a constant
b is a constant and
n is a constant

The cloud envelope to a specified concentration of interest at its boundary will be determined using Phast/Safeti. The concentration of interest is determined from the toxicology of the material and applied through the probit relationship described above. The exposure time is calculated in the modeling for each location based on the release dynamics and the total inventory available for release in each defined scenario. Phast/Safeti applies a maximum exposure cap of 1 hour; however, this does not imply that releases will persist for the full duration.

The probit constants are derived from the UK HSE Specified level of toxicity (SLOT) and Significant likelihood of death (SLOD) values [Ref /19/]. These toxic probit constants are defined in Phast / Safeti as the default parameter values.

Material	Constants		
	a	b	n
CO_2	-90.778	1.01	8
Sulfuric Acid	-8.3959	0.94	2.14

Table 6-3 presents the concentrations and exposure duration combinations predicted by the defined CO_2 probit function for different lethality values.

Table 6-3 Probit CO_2 Concentrations versus Lethality

Lethality	CO_2 concentration (ppm) equivalent to lethality predicted by probit with given exposure time		
	10 min	30 min	60 min
1%	79,000	69,000	63,000

[6] This is the explosion vulnerability which conservatively assumes that the road population is 100% outdoors. Refer to discussion in Section 6.1.2.

Lethality	CO_2 concentration (ppm) equivalent to lethality predicted by probit with given exposure time		
	10 min	**30 min**	**60 min**
10%	90,000	78,000	72,000
50%	105,000	92,000	84,000
90%	124,000	108,000	99,000

6.3.2 Concentration-based risk approach

Another toxic material present at the facility is sodium hydroxide and EFG+. The toxic modeling approach that will be adopted for this material will follow the concentration-based threshold method available in the risk modeling software, Safeti, as no probit coefficients are available for these materials.

The threshold toxic dose is determined using a reference concentration, reference duration, and toxic dose threshold values defined in the material properties. This method calculates the toxic dose by integrating the concentration over the exposure duration and comparing it against the threshold dose. For the case of sodium hydroxide, it would be a concentration of 10 mg/m^3 which the NIOSH provides as the concentration that corresponds to IDLH after 30 minutes exposure time.

Given the low volatility and very limited vapor hazard of sodium hydroxide, the modeling is not expected to predict significant toxic effect distances beyond immediate release points. As such, while this methodology will be applied, the contribution to the offsite toxic risk profile is expected to be limited.

6.4 Locations of Interest

Several locations of interest are considered for the QRA. These correspond to representative points along the Elk Hills Road as shown in Figure 6-2.

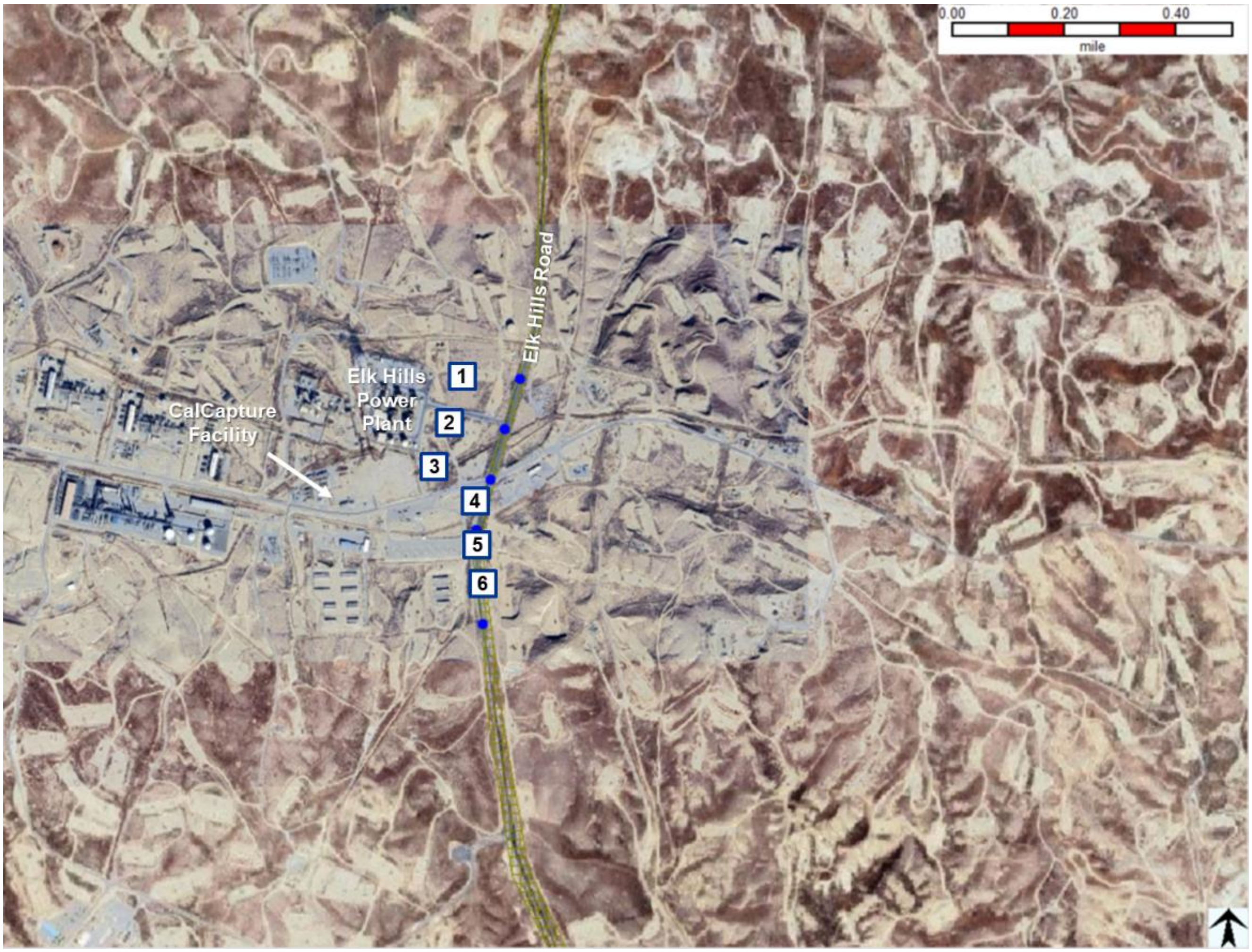

Figure 6-2 Representative locations along Elk Hills Road that will be taken into consideration

6.5 Risk Results

The following risk results are reported in the QRA:

Individual Risk

- Location Specific Individual Risk (LSIR) contours, indicating potential offsite exposure
- LSIR at point locations

Societal/Group Risk

- FN (cumulative frequency vs. number of fatalities) curve for offsite populations

Hazard Frequency Contours

- Overpressure frequency contours
- Radiation frequency contours

- Toxic cloud frequency contours
- Flammable cloud frequency contours

In addition to the above, the QRA will address potential internal combustion engine failure scenario and its implications to personnel by producing frequency of concentration contours for relevant concentration thresholds, illustrating how far these extend at different risk levels. This discussion will review the toxic cloud frequency contours in relation to the Elk Hills Road, where personnel in cars may be present.

6.6 Risk Criteria

6.6.1 Development of Risk Criteria

The development of process industry risk criteria began in the United Kingdom and the Netherlands during the 1970s and 1980s, when the first comprehensive risk analyses were carried out. These studies led to the creation of the earliest risk tolerability criteria, and their approaches have since been used as the foundation for many other countries, regulators, and companies in developing their own risk criteria. Guidance on this subject is described in the 2009 CCPS publication Guidelines for Developing Quantitative Safety Risk Criteria [Ref /6/], which focuses on the application of risk criteria to fixed facilities. The U.S. has largely drawn upon these international precedents, with CCPS serving as a key reference for industry practice.

6.6.2 Judgement of Acceptability

The fundamental principle of risk-based hazard management is that whilst risks cannot always be completely eliminated, it should be possible to reduce them to a level that is As Low As Reasonably Practicable (ALARP). If this is the case, they are viewed as tolerable to society because all reasonably practicable risk reduction measures have been implemented and the benefit that the facility confers on the local community and more widely is regarded as outweighing the risks. A framework for the tolerability of risk developed by the UK HSE [Ref /8/] is illustrated in Figure 6-3.

The triangle represents an increasing level of cumulative risk from a low risk situation, represented by green at the base of the triangle, to a high risk situation, represented by red at the top of the triangle.

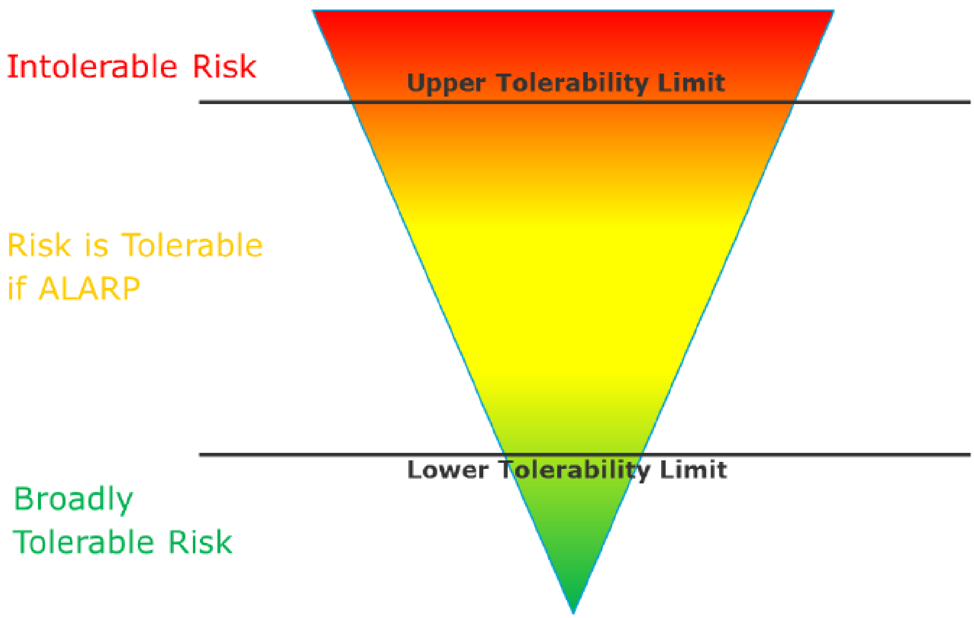

Figure 6-3 Diagram to illustrate the ALARP principle

The typical definitions for the risk levels are as follows:

- Intolerable risk – For practical purposes, a particular risk falling into that region is regarded as unacceptable whatever the level of benefits associated with the activity. Any activity or practice giving rise to risks falling in that region would, as a matter of principle, be ruled out unless the activity or practice can be modified to reduce the degree of risk so that it falls in one of the regions below, or there are exceptional reasons for the activity or practice to be retained.
- Risk is tolerable if ALARP – Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits.
- Broadly tolerable risk – Risks falling into this region are generally regarded as insignificant and adequately controlled by applying all relevant standards and existing industry guidance.

6.6.3 Individual Risk (IR) Criteria

Individual Risk (IR) is the risk experienced by a single individual in a given time period. It reflects the severity of the hazards and the amount of time the individual is in proximity to them. Thus, the total number of people present does not affect the IR. The IR is defined as the frequency at which an individual may be expected to sustain a given level of harm from the realization of specified hazards. It is usually taken to be the risk of fatality and is normally expressed as a risk per year.

IR is expressed in terms of geographical variations of annual risk of death, represented by isopleths, or iso- risk contour plots. The iso-risk contour indicates the extent of the area in which the facility or operation represents a potential hazard. The risk level is estimated for a hypothetical individual who is exposed to the risk at a specific location 24 hours per day, 365 days per year. The Location-Specific Individual Risk (LSIR) contours are thus independent of the fraction of year a person might be exposed to the hazards.

LSIR is widely used for land-use planning and for regulatory criteria. There is not a specified IR criteria for use in the U.S. Various jurisdictions have established individual risk of fatality criteria for public populations. A summary of these individual risk criteria is listed in Table 6-4. DNV will compare the individual risk results for the facility against these different individual risk criteria.

Table 6-4 Individual Risk Criteria for Various Jurisdictions

Jurisdiction	Upper Tolerable Limit for Public Risk of Fatality per year		Lower Tolerability Limit for Public Risk of Fatality per year	
Canada [Ref /21/]	1×10^{-4} per year	1 in 100 million years	1×10^{-6} per year	1 in 1 million years
United Kingdom [Ref /6/]	1×10^{-4} per year	1 in 100 million years	1×10^{-6} per year	1 in 1 million years
Hong Kong [Ref /6/]	1×10^{-5} per year	1 in 10 million years		
Netherlands [Ref /6/]	1×10^{-5} per year	1 in 10 million years	1×10^{-6} per year	1 in 1 million years
California Department of Education [Ref /22/] (criteria specifically for hazardous liquid pipelines)	1×10^{-6} per year	1 in 1 million years		

6.6.4 Societal Risk (SR) Criteria

Societal risk refers to the potential for an incident to cause harm to multiple individuals within a population. It is typically expressed in terms of the frequency of events resulting in a specified number of fatalities. In a QRA, societal risk is often represented using FN curves, which shows the cumulative frequency (F) of there being N or more fatalities among a population group. It is a way of assessing group risk and the level of risk that a society would tolerate. An FN curve is constructed from a large number of 'FN pairs' where each pair represents a scenario that occurs with frequency F and fatally injures N people.

DNV has compiled several group / societal safety risk criteria as shown in Figure 6-4. Various jurisdictions have established societal risk of fatality criteria for public populations.

DNV will apply the societal risk threshold used by Santa Barbara County as the primary benchmark [Ref /27/]. This criterion, as shown in Figure 6-5, provides a relevant and regionally appropriate reference for evaluating societal risk and reflects established risk tolerability levels within California.

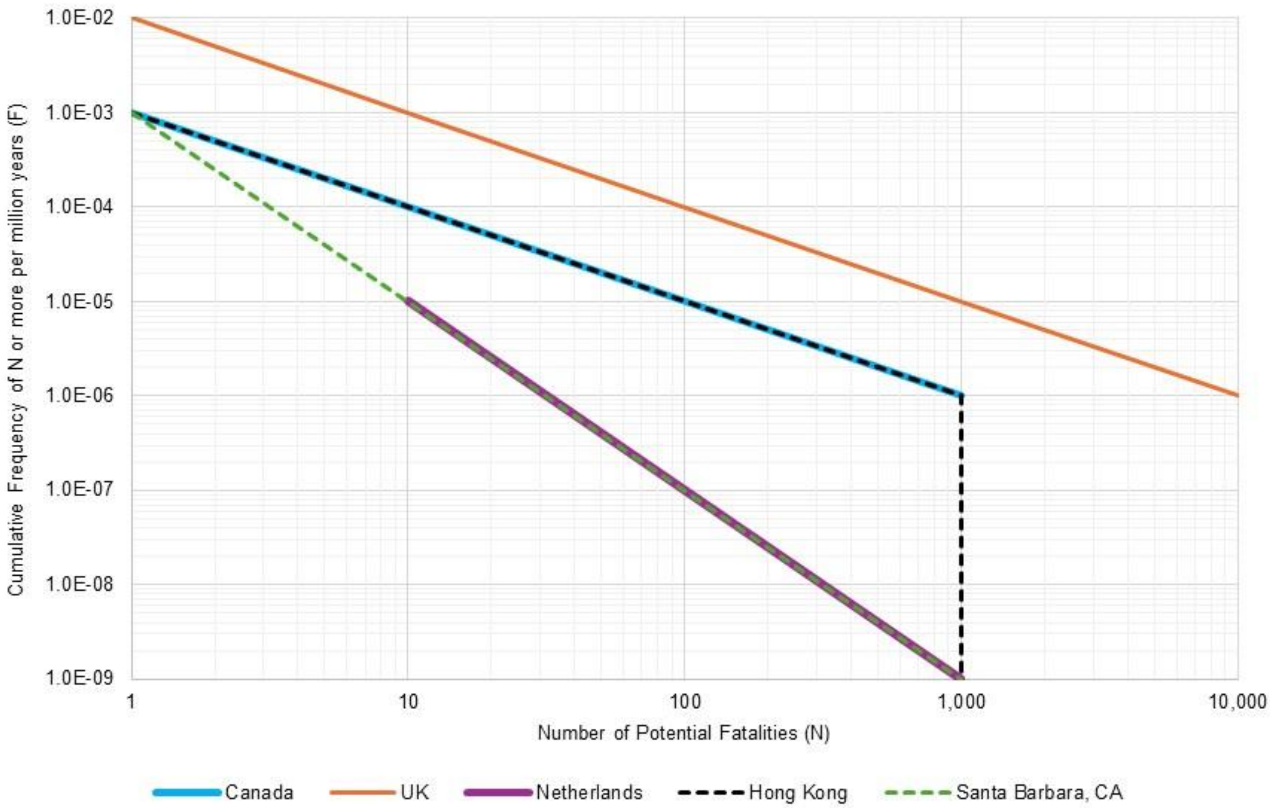

Figure 6-4 Upper Tolerable Limit for Societal Risk [Ref /6/][Ref /22/][Ref /27/]

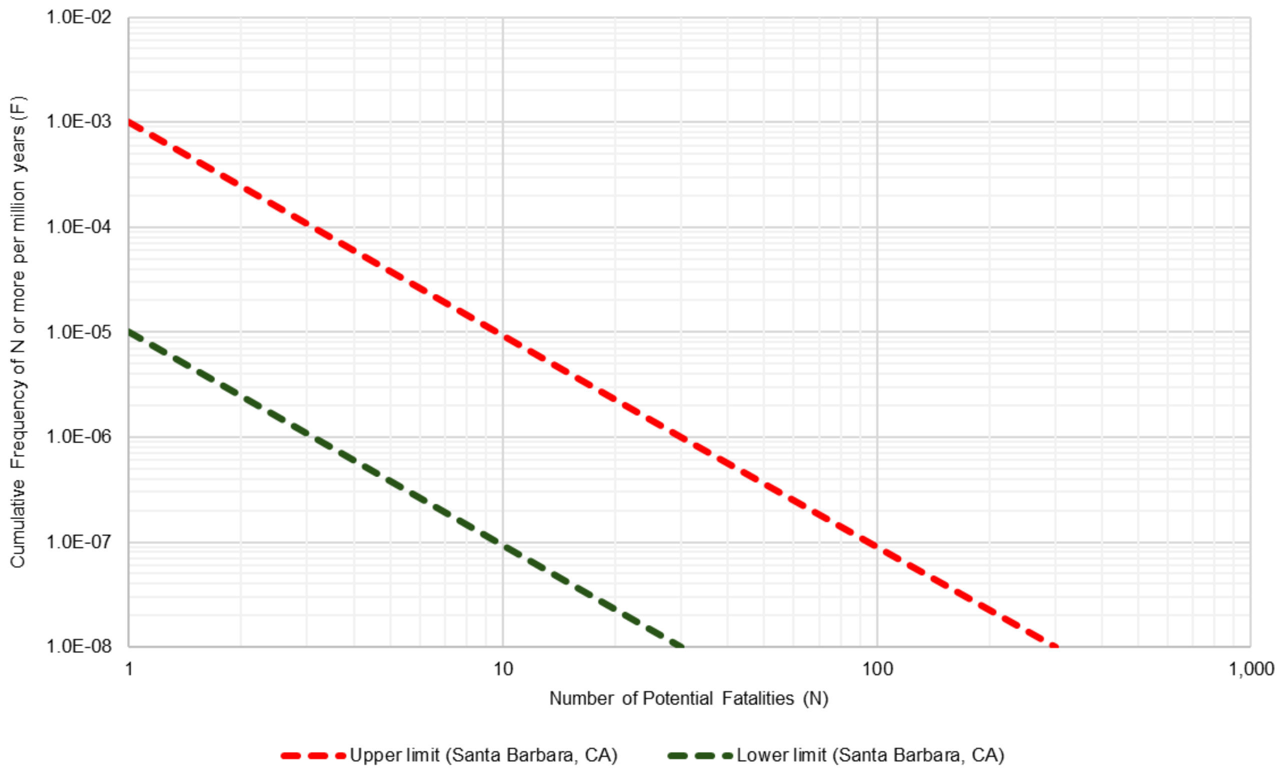

Figure 6-5 Santa Barbara Societal Risk Thresholds [Ref /27/]

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APPENDIX B
Downwind Distances to Hazard Endpoints

Table B-1 Maximum downwind distance (ft) to the various CO_2 concentrations of interest at 3.3ft elevation

Scenario ID	Hole Size	Weather	30,000 ppm	40,000 ppm	50,000 ppm	110,000 ppm	150,000 ppm
3C	S	F1.5	4	4	4	2	1
		B3	4	3	2	2	1
		E5	4	3	2	2	1
		D8	4	3	2	2	2
	M	F1.5	18	14	11	5	5
		B3	17	13	11	5	4
		E5	16	13	10	5	4
		D8	15	12	10	5	4
	L	F1.5	36	27	22	10	7
		B3	33	25	21	10	7
		E5	32	25	20	10	7
		D8	28	23	19	9	7
	R	F1.5	216	158	123	49	34
		B3	224	159	122	47	32
		E5	237	167	126	47	32
		D8	249	169	126	45	31
5A	S	F1.5	16	12	10	6	5
		B3	16	12	10	5	4
		E5	15	12	10	5	5
		D8	15	12	9	5	4
	M	F1.5	88	66	52	22	16
		B3	91	65	50	22	16
		E5	91	65	50	22	16
		D8	90	63	48	21	16
	L	F1.5	144	106	83	35	25
		B3	151	107	83	34	24
		E5	152	109	83	34	24
		D8	155	108	82	33	24
	R	F1.5	144	106	83	35	25
		B3	151	107	83	34	24
		E5	152	109	83	34	24
		D8	155	108	82	33	24
8A	S	F1.5	66	50	40	19	14
		B3	62	45	36	18	13
		E5	64	46	36	18	13
		D8	59	41	33	17	13
	M	F1.5	226	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	L	F1.5	226	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	R	F1.5	226	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
8B	S	F1.5	213	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	M	F1.5	213	164	131	56	40

Scenario ID	Hole Size	Weather	30,000 ppm	40,000 ppm	50,000 ppm	110,000 ppm	150,000 ppm
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	L	F1.5	213	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	R	F1.5	213	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
9A	S	F1.5	66	50	40	19	14
		B3	62	45	36	18	13
		E5	64	46	36	18	13
		D8	59	41	33	17	13
	M	F1.5	213	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	L	F1.5	213	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	R	F1.5	226	169	133	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
Pipeline - above-ground	Pinhole	F1.5	1	1	1	1	0
		B3	1	1	1	1	1
		E5	1	1	1	1	1
		D8	1	1	1	1	1
	Leak	F1.5	6	5	5	4	4
		B3	6	5	5	4	4
		E5	5	5	5	4	4
		D8	5	5	5	4	4
	R	F1.5	9	9	8	7	6
		B3	9	9	9	7	7
		E5	9	8	8	7	6
		D8	9	8	8	7	6
Pipeline - buried	Pinhole	F1.5	2	2	2	2	2
		B3	3	3	2	2	2
		E5	3	3	3	2	2
		D8	6	5	4	3	2
	Leak	F1.5	833	714	624	319	210
		B3	1097	938	816	409	267
		E5	815	652	544	250	168
		D8	965	752	609	236	118
	R	F1.5	563	499	449	269	191
		B3	969	835	734	358	234
		E5	1051	911	814	451	306
		D8	1541	1238	1030	453	290
11A	S	F1.5	66	50	40	19	14
		B3	62	45	36	18	13
		E5	64	46	36	18	13
		D8	59	41	33	17	13

Scenario ID	Hole Size	Weather	30,000 ppm	40,000 ppm	50,000 ppm	110,000 ppm	150,000 ppm
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	L	F1.5	226	169	133	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37
	R	F1.5	213	164	131	56	40
		B3	229	167	129	54	39
		E5	245	179	137	54	39
		D8	257	181	137	52	37

Table B-2 Maximum downwind distance (ft) to the various toxic concentrations of interest at 3.3ft elevation

Scenario ID	Hole Size	Weather Condition	Max downwind distance (ft)
1A (N2 at 76,500ppm)	S	F1.5	1
		B3	1
		E5	1
		D8	1
	M	F1.5	4
		B3	3
		E5	3
		D8	3
	L	F1.5	6
		B3	5
		E5	5
		D8	5
	R	F1.5	82
		B3	86
		E5	95
		D8	112
2A (N2 at 76,500ppm)	S	F1.5	1
		B3	1
		E5	1
		D8	1
	M	F1.5	4
		B3	3
		E5	4
		D8	3
	L	F1.5	7
		B3	6
		E5	6
		D8	5
	R	F1.5	121
		B3	130
		E5	150
		D8	169
2B (MEA at 1000 ppm)	S	F1.5	0
		B3	2
		E5	4
		D8	6
	M	F1.5	0

Scenario ID	Hole Size	Weather Condition	Max downwind distance (ft)
		B3	1
		E5	3
		D8	5
	L	F1.5	0
		B3	1
		E5	1
		D8	4
	R	F1.5	39
		B3	78
		E5	106
		D8	93
2C (MEA at 1000 ppm)	S	F1.5	0
		B3	2
		E5	3
		D8	6
	M	F1.5	0
		B3	1
		E5	3
		D8	5
	L	F1.5	0
		B3	1
		E5	1
		D8	4
	R	F1.5	27
		B3	29
		E5	39
		D8	13
2D (MEA at 1000 ppm)	S	F1.5	11
		B3	9
		E5	8
		D8	7
	M	F1.5	39
		B3	30
		E5	28
		D8	23
	L	F1.5	56
		B3	61
		E5	70
		D8	48
	R	F1.5	115
		B3	141
		E5	177
		D8	204
3A (MEA at 1000 ppm)	S	F1.5	83
		B3	84
		E5	94
		D8	84
	M	F1.5	163
		B3	168
		E5	203
		D8	236
	L	F1.5	179
		B3	198
		E5	240

Scenario ID	Hole Size	Weather Condition	Max downwind distance (ft)
		D8	276
	R	F1.5	202
		B3	233
		E5	282
		D8	327
3B (MEA at 1000 ppm)	S	F1.5	1
		B3	1
		E5	1
		D8	1
	M	F1.5	4
		B3	3
		E5	3
		D8	2
	L	F1.5	5
		B3	4
		E5	5
		D8	4
	R	F1.5	18
		B3	19
		E5	20
		D8	20
3D (MEA at 1000 ppm)	S	F1.5	54
		B3	42
		E5	41
		D8	26
	M	F1.5	54
		B3	42
		E5	39
		D8	26
	L	F1.5	53
		B3	40
		E5	38
		D8	25
	R	F1.5	53
		B3	40
		E5	38
		D8	25
3E (MEA at 1000 ppm)	S	F1.5	16
		B3	14
		E5	16
		D8	15
	M	F1.5	16
		B3	14
		E5	16
		D8	15
	L	F1.5	16
		B3	14
		E5	16
		D8	15
	R	F1.5	16
		B3	14
		E5	16
		D8	15
	S	F1.5	0

Scenario ID	Hole Size	Weather Condition	Max downwind distance (ft)
4A (MEA at 1000 ppm)		B3	2
		E5	4
		D8	6
	M	F1.5	0
		B3	2
		E5	3
		D8	5
	R	F1.5	4
		B3	1
		E5	1
		D8	4
4C (H2SO4 at 15 mg/m3)	S	F1.5	5
		B3	2
		E5	5
		D8	6
	M	F1.5	0
		B3	3
		E5	5
		D8	6
	R	F1.5	5
		B3	0
		E5	0
		D8	4
4D (NaOH at 10 mg/m3)	S	F1.5	614
		B3	149
		E5	298
		D8	172
	M	F1.5	1272
		B3	303
		E5	665
		D8	360
	R	F1.5	1554
		B3	395
		E5	985
		D8	523
4E (MEA at 1000 ppm)	S	F1.5	7
		B3	7
		E5	9
		D8	10
	M	F1.5	7
		B3	7
		E5	9
		D8	10
	R	F1.5	12
		B3	15
		E5	14
		D8	17
4H (H2SO4 at 15 mg/m3)	S	F1.5	7
		B3	6
		E5	9
		D8	10
	M	F1.5	7
		B3	6
		E5	9

Scenario ID	Hole Size	Weather Condition	Max downwind distance (ft)
		D8	10
	R	F1.5	25
		B3	25
		E5	27
		D8	25
4I (NaOH at 10 mg/m3)	S	F1.5	13
		B3	9
		E5	11
		D8	11
	M	F1.5	13
		B3	9
		E5	12
		D8	11
	R	F1.5	1753
		B3	552
		E5	803
		D8	982

Table B-3 Maximum downwind distance (ft) to the various flammable concentrations at 3.3ft elevation

Scenario ID	Hole Size	Weather Condition	½ LFL	LFL	UFL
2B	S	F1.5	0	0	0
		B3	0	0	0
		E5	0	0	0
		D8	3	1	0
	M	F1.5	0	0	0
		B3	1	1	0
		E5	1	1	0
		D8	4	2	1
	L	F1.5	1	1	0
		B3	1	1	0
		E5	1	1	0
		D8	3	3	1
	R	F1.5	1	1	1
		B3	2	2	1
		E5	2	2	1
		D8	7	2	1
2C	S	F1.5	0	0	0
		B3	0	0	0
		E5	0	0	0
		D8	2	1	0
	M	F1.5	0	0	0
		B3	1	0	0
		E5	1	1	0
		D8	4	2	0
	L	F1.5	1	0	0
		B3	1	1	0
		E5	1	1	0
		D8	3	2	1
	R	F1.5	1	1	1
		B3	1	1	1
		E5	1	1	1
		D8	6	5	1
2D	S	F1.5	2	1	0

Scenario ID	Hole Size	Weather Condition	½ LFL	LFL	UFL
		B3	1	1	-
		E5	1	1	0
		D8	1	1	-
	M	F1.5	7	4	-
		B3	6	3	0
		E5	6	4	0
		D8	5	3	0
	L	F1.5	13	7	0
		B3	11	6	0
		E5	11	6	0
		D8	10	6	0
	R	F1.5	50	30	5
		B3	48	28	4
		E5	50	27	4
		D8	48	23	4
3A	S	F1.5	21	17	7
		B3	18	16	7
		E5	19	16	7
		D8	17	16	7
	M	F1.5	41	26	14
		B3	37	21	16
		E5	39	23	15
		D8	34	20	16
	L	F1.5	72	40	17
		B3	77	38	17
		E5	79	39	17
		D8	82	36	17
	R	F1.5	102	67	19
		B3	105	74	18
		E5	113	76	18
		D8	120	79	18
3D	S	F1.5	16	11	3
		B3	15	11	3
		E5	15	11	3
		D8	15	10	3
	M	F1.5	16	11	3
		B3	15	11	3
		E5	15	11	3
		D8	15	10	3
	L	F1.5	16	11	3
		B3	15	11	3
		E5	15	11	3
		D8	15	10	3
	R	F1.5	16	11	3
		B3	15	11	3
		E5	15	11	3
		D8	15	10	3
3E	S	F1.5	10	8	4
		B3	11	9	4
		E5	11	9	4
		D8	12	10	4
	M	F1.5	10	8	4
		B3	11	9	4
		E5	11	9	4
		D8	12	10	4

Scenario ID	Hole Size	Weather Condition	½ LFL	LFL	UFL
	L	F1.5	10	8	4
		B3	11	9	4
		E5	11	9	4
		D8	12	10	4
	R	F1.5	10	8	4
		B3	11	9	4
		E5	11	9	4
		D8	12	10	4
4A	S	F1.5	0	0	0
		B3	1	0	0
		E5	2	1	0
		D8	3	2	1
	M	F1.5	0	0	0
		B3	0	0	0
		E5	0	0	0
		D8	4	3	1
	R	F1.5	0	0	0
		B3	1	1	0
		E5	1	1	1
		D8	4	3	2
4E	S	F1.5	5	4	2
		B3	6	5	2
		E5	6	5	3
		D8	7	5	3
	M	F1.5	5	4	2
		B3	6	5	2
		E5	6	5	3
		D8	7	5	3
	R	F1.5	9	8	6
		B3	10	9	7
		E5	10	9	7
		D8	15	13	9
4G	S	F1.5	19	10	1
		B3	16	9	1
		E5	15	9	1
		D8	13	8	1
	M	F1.5	21	11	1
		B3	17	10	1
		E5	16	10	1
		D8	15	9	1
	R	F1.5	131	78	-
		B3	134	76	2
		E5	144	78	-
		D8	149	72	2
5B	S	F1.5	2	1	0
		B3	2	1	0
		E5	2	1	0
		D8	2	1	0
	M	F1.5	2	1	0
		B3	2	1	0
		E5	2	1	0
		D8	2	1	0
	R	F1.5	2	1	0
		B3	2	1	0
		E5	2	1	0

Scenario ID	Hole Size	Weather Condition	½ LFL	LFL	UFL
		D8	2	1	0
7A	S	F1.5	18	9	4
		B3	17	9	3
		E5	16	9	4
		D8	15	8	3
	M	F1.5	106	48	14
		B3	108	45	14
		E5	109	45	14
		D8	106	42	13
	L	F1.5	197	89	24
		B3	210	87	23
		E5	215	88	23
		D8	223	86	22
	R	F1.5	197	89	24
		B3	210	87	23
		E5	215	88	23
		D8	223	86	22

Table B-4 Maximum downwind distance (ft) to the jet fire thermal radiation levels at 3.3ft elevation

Scenario ID	Hole Size	Weather Condition	4.7 kW/m^2	9.46 kW/m^2	37.5 kW/m^2
2B	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	L	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	16	-	-
	R	F1.5	-	-	-
		B3	47	-	-
		E5	47	-	-
		D8	57	54	-
2C	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	L	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	R	F1.5	-	-	-
		B3	-	-	-
		E5	34	-	-
		D8	40	-	-

Scenario ID	Hole Size	Weather Condition	4.7 kW/m^2	9.46 kW/m^2	37.5 kW/m^2
2D	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	5	-	-
	M	F1.5	-	-	-
		B3	26	-	-
		E5	23	-	-
		D8	22	-	-
	L	F1.5	54	-	-
		B3	46	-	-
		E5	42	-	-
		D8	39	-	-
	R	F1.5	210	-	-
		B3	181	173	-
		E5	162	152	-
		D8	154	141	-
3A	S	F1.5	76	-	-
		B3	66	-	-
		E5	60	57	-
		D8	57	52	-
	M	F1.5	236	-	-
		B3	206	196	-
		E5	188	173	-
		D8	182	162	-
	L	F1.5	369	359	-
		B3	327	305	-
		E5	302	271	-
		D8	294	255	-
	R	F1.5	559	536	-
		B3	506	463	-
		E5	469	410	-
		D8	459	393	-
3D	S	F1.5	-	-	-
		B3	45	-	-
		E5	41	-	-
		D8	38	-	-
	M	F1.5	-	-	-
		B3	45	-	-
		E5	41	-	-
		D8	38	-	-
	L	F1.5	-	-	-
		B3	45	-	-
		E5	41	-	-
		D8	38	-	-
	R	F1.5	-	-	-
		B3	45	-	-
		E5	41	-	-
		D8	38	-	-
3E	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	9	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-

Scenario ID	Hole Size	Weather Condition	4.7 kW/m²	9.46 kW/m²	37.5 kW/m²
		D8	9	-	-
	L	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	9	-	-
	R	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	9	-	-
4A	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	0	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	0	-	-
	R	F1.5	-	-	-
		B3	2	-	-
		E5	2	-	-
		D8	2	2	-
4E	S	F1.5	-	-	-
		B3	-	-	-
		E5	0	-	-
		D8	0	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	0	-	-
		D8	0	-	-
	R	F1.5	11	-	-
		B3	11	10	-
		E5	10	9	-
		D8	10	9	-
4G	S	F1.5	9	8	7
		B3	9	8	7
		E5	9	8	7
		D8	9	8	7
	M	F1.5	11	9	8
		B3	11	9	8
		E5	11	9	8
		D8	11	9	8
	R	F1.5	71	59	44
		B3	71	59	44
		E5	71	59	44
		D8	71	59	44
5B	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	R	F1.5	-	-	-
		B3	-	-	-

Scenario ID	Hole Size	Weather Condition	4.7 kW/m²	9.46 kW/m²	37.5 kW/m²
		E5	-	-	-
		D8	-	-	-
7A	S	F1.5	20	19	17
		B3	20	19	17
		E5	19	18	16
		D8	19	18	14
	M	F1.5	109	95	77
		B3	108	96	78
		E5	107	96	80
		D8	106	95	81
	L	F1.5	188	162	126
		B3	187	162	129
		E5	187	163	132
		D8	185	164	136
	R	F1.5	188	162	126
		B3	187	162	129
		E5	187	163	132
		D8	185	164	136

Table B-5 Maximum downwind distance (ft) to the pool fire thermal radiation levels at 3.3ft elevation

Scenario ID	Hole Size	Weather Condition	4.7 kW/m²	9.46 kW/m²	37.5 kW/m²
2B	S	F1.5	5	-	-
		B3	5	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	15	11	-
		B3	17	13	-
		E5	17	15	-
		D8	19	18	-
	L	F1.5	17	12	-
		B3	18	14	-
		E5	18	15	-
		D8	19	18	-
	R	F1.5	31	23	-
		B3	33	24	-
		E5	34	24	-
		D8	34	25	-
2C	S	F1.5	4	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	14	-	-
		B3	16	-	-
		E5	17	-	-
		D8	18	-	-
	L	F1.5	15	12	-
		B3	17	14	-
		E5	17	15	-
		D8	18	18	-
	R	F1.5	29	21	-
		B3	30	22	-
		E5	31	23	-
		D8	31	24	-

Scenario ID	Hole Size	Weather Condition	4.7 kW/m²	9.46 kW/m²	37.5 kW/m²
2D	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	L	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	R	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
3A	S	F1.5	30	22	-
		B3	31	23	-
		E5	32	23	-
		D8	32	24	-
	M	F1.5	31	23	-
		B3	33	24	-
		E5	34	24	-
		D8	34	25	-
	L	F1.5	31	23	-
		B3	33	24	-
		E5	34	24	-
		D8	34	25	-
	R	F1.5	31	23	-
		B3	33	24	-
		E5	34	24	-
		D8	34	25	-
3D	S	F1.5	23	-	-
		B3	24	-	-
		E5	24	-	-
		D8	24	-	-
	M	F1.5	22	-	-
		B3	23	-	-
		E5	23	-	-
		D8	24	-	-
	L	F1.5	20	-	-
		B3	20	-	-
		E5	20	-	-
		D8	20	-	-
	R	F1.5	20	-	-
		B3	20	-	-
		E5	20	-	-
		D8	20	-	-
3E	S	F1.5	24	20	-
		B3	24	21	-
		E5	25	23	-
		D8	25	24	-
	M	F1.5	22	-	-
		B3	23	-	-
		E5	24	-	-

Scenario ID	Hole Size	Weather Condition	4.7 kW/m^2	9.46 kW/m^2	37.5 kW/m^2
		D8	24	-	-
	L	F1.5	19	-	-
		B3	19	-	-
		E5	20	-	-
		D8	21	-	-
	R	F1.5	19	-	-
		B3	19	-	-
		E5	20	-	-
		D8	21	-	-
4A	S	F1.5	5	4	-
		B3	6	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	12	10	-
		B3	14	12	-
		E5	15	13	-
		D8	15	15	-
	R	F1.5	56	43	21
		B3	58	46	23
		E5	59	48	24
		D8	60	49	26
4E	S	F1.5	15	13	-
		B3	15	14	-
		E5	15	15	-
		D8	18	17	-
	M	F1.5	15	13	-
		B3	15	14	-
		E5	15	15	-
		D8	18	17	-
	R	F1.5	430	332	177
		B3	436	345	184
		E5	441	349	190
		D8	440	354	194

Table B-6 Maximum downwind distance (ft) to the overpressure levels at 3.3ft elevation

Scenario ID	Hole Size	Weather Condition	0.5 psi	1 psi	3 psi
3A	S	F1.5	99	52	47
		B3	99	53	47
		E5	99	52	47
		D8	97	52	47
	M	F1.5	200	105	94
		B3	195	104	93
		E5	197	105	94
		D8	195	104	93
	L	F1.5	101	53	47
		B3	100	53	47
		E5	100	53	47
		D8	97	52	46
	R	F1.5	199	105	94
		B3	196	104	93
		E5	198	105	94
		D8	198	105	94
4G	S	F1.5	-	-	-

Scenario ID	Hole Size	Weather Condition	0.5 psi	1 psi	3 psi
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	R	F1.5	153	93	86
		B3	146	91	84
		E5	147	91	84
		D8	142	89	83
7A	S	F1.5	-	-	-
		B3	-	-	-
		E5	-	-	-
		D8	-	-	-
	M	F1.5	112	56	50
		B3	107	55	49
		E5	109	55	49
		D8	104	54	48
	L	F1.5	200	105	94
		B3	202	106	95
		E5	202	106	95
		D8	200	106	94
	R	F1.5	200	105	94
		B3	202	106	95
		E5	202	106	95
		D8	200	106	94

APPENDIX C
Breakdown of Outdoor LSIR Contours

Figure C-1 LSIR Contour due to the CO_2 Pipeline

Figure C-2 LSIR Contour due to the NaOH and MEA Storage and Transfer Operations

Figure C-3 LSIR Contour due to the other MEA Releases

Figure C-4 LSIR Contour due to the CalCapture releases (incl. CO_2 scenarios, and H_2SO_4 storage and transfer operations)

About DNV

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