Appendix H.1 - Risk Assessment Methodology

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Risk assessment involves evaluating risks presented to the public by the facility in the form of hazardous materials releases resulting in explosions, flammable vapors, or toxic material impacts. The risk assessment methodology used to evaluate the risks associated with the Rail Spur Project, including transport of crude by rail along the mainlines between the SMR and Roseville and Colton, involved the use of a Quantitative Risk Assessment (QRA). The tools, assumptions, and industry standards associated with implementing QRAs described below.

The worst case hazard zones for the Santa Maria Refinery (SMR) did not extend off of the refinery property and would not impact sensitive receptors in the vicinity of the refinery. Therefore, no QRA was needed for the SMR impacts. The worst case mainline rail hazard zones would impact sensitive populations so a QRA was conducted for a number of rail routes as discussed below.

A QRA analyzes the risks of immediate human safety impacts presented by industrial operations on nearby populations. The assessment follows commonly accepted industry standards including the recommendations of the Center for Chemical Process Safety (CCPS), the Health and Safety Executive of the United Kingdom.

The main objective of the QRA is to assess the project's risk of generating serious injuries or fatalities to members of the public, to assess the risks of spill events, and to develop mitigation measures that could reduce these risks. The development of the serious injury and fatality aspects of the QRA involves five major tasks:

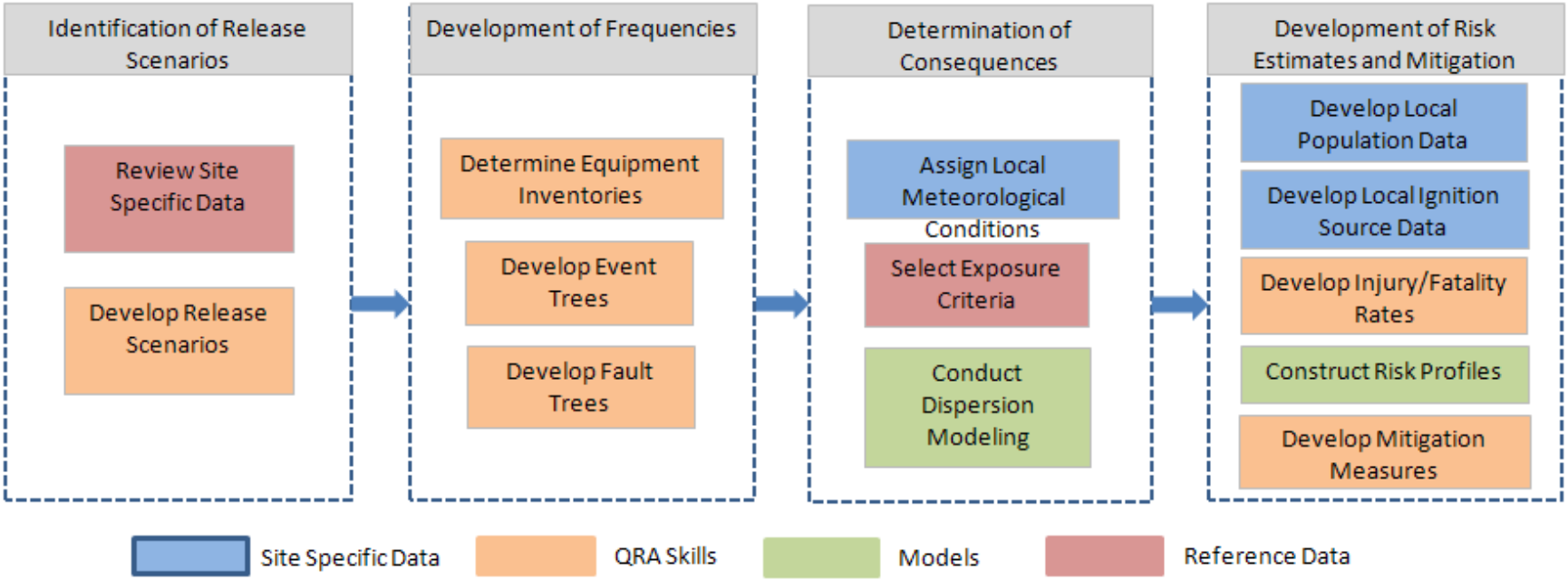
- Identifying release scenarios;
- Developing frequencies of occurrence for each release scenario;
- Determining consequences of each release scenario;
- Developing estimates of risk, including risk profiles; and
- Developing risk-reducing mitigation measures.

Figure 1 shows the steps in developing a QRA.

A QRA computer model, developed by Marine Research Specialists, is used to calculate the risk profiles and, in conjunction with Geographic Information System software, to manage the data in accordance with CCPS guidelines for hazard assessments (CCPS 1989). The model is based on a polar coordinate grid of cells. The grid extends at least 0.5 mile from in all directions and has varying cell sizes depending on the populations and ignition sources. Hazard zones are then laid over the grid to determine populations impacted. The following sections discuss information developed as inputs to the model and whether they were used in the case of the Rail Spur project or not.

Meteorological conditions at the site are represented by two stability classes: F stability/2 meters per second (m/s) and D stability/4 m/s. Wind conditions are divided into 16 directions and the probability of wind in each direction, at each stability class and speed, is entered.

Figure 1 Steps Involved in Developing a Quantitative Risk Assessment



Fatality and serious injury probabilities are entered for each type of scenario (i.e., flame jets, fires, vapor clouds, including flammable and toxic clouds, explosions, and boiling liquid expanding vapor explosions), indicating the percentage of persons who are exposed to a scenario that would suffer serious injuries or fatalities.

Population density information developed for each receptor includes the number of persons present at each location, the area over which the persons are distributed, and the maximum number of persons that could be exposed. If a cloud covers only a portion of the area, the population density is used to determine the number of persons exposed.

A use factor is applied to each receptor based on the hours per day that persons are at the location. For example, a receptor that has persons at it 12 hours per day would have a use factor of 0.5. This factor reduces the frequency of a release scenario impacting persons.

An ignition probability at each receptor is applied, which defines the probability that a flammable cloud would reach the receptor and ignite and affect the receptor location. For example, if there are no ignition sources between the receptor and the release point and there is an ignition point at the receptor, such as a campfire, which has a high probability of igniting the cloud, then the ignition probability would be 1.0 at the receptor.

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This would mean that any receptor farther from the release point would not be impacted. If there are ignition sources at the release location (such as flares or heaters), the ignition probability would be less than 1.0, meaning that part of the time the flammable cloud would not reach the receptors at all. The sum of ignition probabilities along any one path is equal to or less than 1.0.

A shielding factor is also applied to receptor locations. The shield factor is applicable to thermal scenarios only, such as flame jets, fires, or boiling liquid expanding vapor explosions. Thermal scenarios only produce impacts if the receptor is directly exposed to the flame and has a "line of sight." Buildings, vegetation, terrain, and other types of obstructions would prevent persons exposed to the fire from experiencing the full effects, and would reduce the probability that the person would suffer a serious injury or fatality.

Release scenario frequencies are determined though failure rate analysis and fault trees, which detail the general conditions and equipment-specific frequencies that could lead to a release. Event trees evaluate post-release behavior of the released material, such as whether it forms a flammable cloud, flame jet, toxic cloud, explosion, or a boiling liquid expanding vapor explosion.

The end products for the serious injury and fatality analysis are "risk profile" curves, one for fatalities and one for serious injuries, developed from the scenario frequencies and effected populations for each scenario. The risk profile curves estimate the risk that any existing population would suffer fatalities or serious injuries.

A. Release Scenarios

Release at the SMR could occur manly from the unloading operations and the new pipeline to the existing crude oil storage tanks. The worst case spill volume was determined to be from a pipeline spill. Spill volumes from a pipeline system rupture are based on the pipeline diameter and the terrain profile, which would limit the amount of oil that could drain out of the pipeline. In addition, the pumping rate also affects the size of a release since oil pumped into the pipeline would contribute to the release size until the pumps are shut down.

Spills at the Santa Maria Refinery (SMR) that would be contained by the berms and drainage system valves and, for areas outside of berms, would be directed to the drainage basins (tertiary containment). A spill would only be directed outside of the these areas after a subsequent failure in the drainage basin discharge procedure or equipment.

Spill volumes from rail cars were assumed to include multiple rail car releases (the full volume of about six rail cars) for train derailment scenarios. No containment system was assumed for railroad spills.

B. Failure Frequencies

Once the scenarios have been identified, the analysis attempts to estimate the frequency of each scenario. The worst case hazard zones for the Santa Maria Refinery (SMR) did not extend off of the refinery property so it was not necessary to estimate failure frequencies of the events at the SMR. The remainder of this section focuses on the mainline rail failure events.

Rail Type

Rail track is classified into six categories with Class 6 having the most stringent track tolerances and maintenance schedules. With the advent of higher speed trains additional classifications have

been defined for Class 7 and 8. Mainline track is generally Class 4 or 5 and typically have lower accident rates per million miles. Class 6 track is used for high speed trains up to 110 mph, and are found in the Northeast Corridor between Washington D.C. and New York. Class 4 track is the dominant class for mainline track used in passenger and long-haul freight service. The Class of a track determines the maximum speed that freight and passenger trains can travel. Higher class tracks have higher allowable speeds.

The Federal Railroad Administration (FRA) establishes minimum design standards for each of the various track classes. Each railroad establishes their own design standards for their tracks that meet or exceed the FRA standards. The FRA standards cover the track roadbed, track geometry, track structure (ballast, cross-ties, joints, switches, etc.). These minimum track safety standards are specified in 49 CFR 213.

Tank Car Type

Rail car types for crude oil are DOT-111 non-pressurized tank cars (DOT 111A60W1). DOT-111 tank cars for crude oil service have a maximum capacity of 30,000 gallons. Following an accident in Illinois in 2009, the NTSB made a number of safety recommendations to both the American Association of Railroads (AAR) and the DOT Pipeline and Hazardous Materials Safety Administration (PHMSA) regarding DOT-111 tank cars. The NTSB recommended to PHMSA that it require modifications be made on all existing and new DOT-111s. PHMSA did not mandate a fleet retrofit, nor has it published new standard designs for crude and ethanol tank cars. The AAR-North American Tank Car Committee, independent of a federal mandate, implemented nearly all of the recommendations made to PHMSA in its design standards for new crude oil and ethanol tank cars ordered after October 2011. Specifically, all new DOT-111 tank cars for ethanol and crude oil service beginning October 1, 2011 are required to have:

- Increase head and shell thickness;
- Normalized steel;
- ½-inch thick ½-height head shields; and
- Top fitting protection.

The NTSB also recommended the AAR review the design requirements for attaching center sills or draft sills for all tank cars. The AAR-North American Tank Car Committee has studied the stub sill issue and will revise those standards as recommended. Nearly 25 percent of the DOT-111 fleet carrying crude today meets the higher design standards, as outlined above.

On July 23, 2014 the DOT issued a notice of proposed rulemaking covering enhanced tank car standards and operational controls for high-hazard flammable trains, which included crude oil trains. As part of the proposed DOT rulemaking, the PHMSA, in coordination with the Federal Railroad Administration (FRA), is proposing: (1) new operational requirements for certain trains transporting a large volume of Class 3 flammable liquids; (2) improvements in tank car standards; and (3) revision of the general requirements for offerors to ensure proper classification and characterization of mined gases and liquids. These proposed requirements are designed to lessen the frequency and consequences of train accidents/incidents (train accidents) involving certain trains transporting a large volume of flammable liquids.

The PHMSA is proposing revisions to the Hazardous Materials Regulations (HMR; 49 CFR Parts 171-180) that establish requirements for "high-hazard flammable train" (HHFT). This proposed rule defines a HHFT as a train comprised of 20 or more carloads of a Class 3 flammable liquid and ensures that the rail requirements are more closely aligned with the risks posed by the operation of these trains. This rule primarily impacts unit train shipments of ethanol and crude oil; because ethanol and crude oil are most frequently transported in high volume shipments, typically in trains with 20 or more cars of those commodities. Currently, as shipped, crude oil and ethanol are typically classified as Class 3 flammable liquids. The primary intent of this rulemaking is to propose revisions to the HMR that update and clarify the regulations to prevent and mitigate the consequences of a train accident involving flammable liquids, should one occur. Table 1 identifies those affected by this NPRM and describes the regulatory changes.

Table 2 further summarizes the three options that DOT is considering for use with HHFT. As noted in Table 1, PHMSA proposes to require one of these options for new tank cars constructed after October 1, 2015, if those tank cars are used as part of HHFT. In addition, for all three Options, PHMSA proposes the following timelines for tank cars used as part of HHFT: (1) for Packing Group I, DOT Specification 111 tank cars are not authorized after October 1, 2017; (2) for Packing Group II, DOT Specification 111 tank cars are not authorized after October 1, 2018; and (3) for Packing Group III, DOT Specification 111 tank cars are not authorized after October 1, 2020. The crude transported to the SMR could be in Packing Group I.

Accident Rates

In order to identify the probability of an accident (i.e., accident rate or derailment rate) and oil spill (i.e., spill rate) from a crude oil train on each of the possible routes, Dr. Christopher Barkan was retained to conduct a quantitative assessment. Dr. Barkan is Professor and Executive Director of the Rail Transportation and Engineering Center at the Department of Civil and Environmental Engineering at the University of Illinois at Urbana- Champaign. He and his colleagues prepared a report (see Appendix H.2) that looked at route specific accident rates and spill rates based upon the tank car design proposed by the Applicant. The analysis took into account major risk factors, including route specific FRA track class, method of operation, tank car safety design, and the proposed volume of crude oil trains over the route.

C. Consequence Analysis

The consequence analysis and hazard modeling consider the physical effects of a release and its damage to people. The analysis judges the severity of potential hazards associated with accidents and their possible consequences.

Risk assessments typically evaluate fire, flammability, explosion, and toxicity. Fire and flammability hazards are relevant for flammable vapors with relatively low flash points, such as propane and methane; their hazard is usually thermal radiation from vapor jet or pool fires. In addition, larger vapor jet fires can also lead to a loss of structural integrity of other storage or process vessels. The temperature in flame jets is usually high, and flame impingement onto nearby equipment is of the greatest concern.

Table 1 Proposed Regulatory Requirements for HHFT (USDOT July 23, 2014)

Proposed Requirement	Effected Entity
Better classification and characterization of mined gases and liquids. • Written sampling and testing program for all mined gases and liquids, such as crude oil, to address: (1) frequency of sampling and testing; (2) sampling at various points along the supply chain; (3) sampling methods that ensure a representative sample of the entire mixture; (4) testing methods to enable complete analysis, classification, and characterization of material; (5) statistical justification for sample frequencies; and, (6) duplicate samples for quality assurance. • Require offerer to certify that program is in place, document the testing and sampling program, and make program information available to DOT personnel, upon request.	Offerors / Shippers of all mined gases and liquids
Rail routing risk assessment. • Requires carriers to perform a routing analysis that considers 27 safety and security factors. The carrier must select a route based on findings of the route analysis. These planning requirements are prescribed in 49 CFR 172.820 and would be expanded to apply to HHFTs. Notification to SERCs. • Require trains containing one million gallons of Bakken crude oil to notify State Emergency Response Commissions (SERCs) or other appropriate state delegated entity about the operation of these trains through their States. Reduced operating speeds. • Restrict all HHFTs to 50-mph in all areas • PHMSA is requesting comment on three speed restriction options for HHFTs that contain any tank cars not meeting the enhanced tank car standards proposed by this rule: (1) a 40-mph maximum speed restriction in all areas (2) a 40-mph speed restriction in high threat urban areas; and, (3) a 40-mph speed restriction in areas with a 100K+ population. • PHMSA is also requesting comment on a 30-mph speed restriction for HHFTs that do not comply with enhanced braking requirements. Enhanced braking. • Require all HHFTs be equipped with alternative brake signal propagation systems. Depending on the outcome of the tank car standard proposal and implementation timing, all HHFTs would be operated with either electronic controlled pneumatic brakes (ECP), a two-way end of train device (EOT), or distributed power (DP).	Rail Carriers, Emergency Responders
Enhanced standards for both new and existing tank cars. • Require new tank cars constructed after October 1, 2015 (that are used to transport flammable liquids as part of a HHFT) to meet criteria for a selected option, including specific design requirements or performance criteria (e.g., thermal, top fittings, and bottom outlet protection; tank head and shell puncture resistance). PHMSA is requesting comment on the following three options for the DOT Specification 117: 1. FRA and PHMSA Designed Car, or equivalent 2. AAR 2014 Tank Car,or equivalent 3. Jacketed CPC-1232, or equivalent • Require existing tank cars that are used to transport flammable liquids as part of a HHFT, to be retrofitted to meet the selected option for performance requirements, except for top fittings protection. Those not retrofitted would be retired, repurposed, or operated under speed restrictions for up to five years, based on packing group assignment of the lading.	Tank Car Manufacturers, Tank Car Owners, Shippers and Rail Carriers

HHFT-High-Hazard Flammable Trains
Source: USDOT, 2014.

Table 2 Proposed Safety Features by Tank Car Option (USDOT July 23, 2014)

Tank Car	Bottom Outlet Handle	GRL (lbs)	Head Shield Type	Pressure Relief Valve	Shell Thickness	Jacket	Tank Material	Top Fittings Protection	Thermal Protection System	Braking
Option 1: PHMSA and FRA Designed Tank Car	Bottom outlet handle removed or designed to prevent unintended actuation during a train accident	286k	Full- height, 1/2 inch thick Head shield	Reclosing pressure relief device	9/16 inch Minimum	Minimum 11-gauge jacket constructed from A1011 steel or equivalent. The jacket must be weather-tight	TC-128 Grade B, normalized steel	TIH Top fittings protection system and nozzle capable of sustaining, without failure, a rollover accident at a speed of 9 mph	Thermal protection system in accordance with §179.18	ECP brakes
Option 2: AAR 2014 Tank Car	Bottom outlet handle removed or designed to prevent unintended actuation during a train accident	286k	Full- height, 1/2 inch thick head shield	Reclosing pressure relief device	9/16 inch Minimum	Minimum 11-gauge jacket constructed from A1011 steel or equivalent. The jacket must be weather-tight	TC-128 Grade B, normalized steel	Equipped per AAR Specifications Tank Cars, appendix E paragraph 10.2.1	Thermal protection system in accordance with §179.18	In trains with DP or EOT devices
Option 3: Enhanced CPC 1232 Tank Car	Bottom outlet handle removed or designed to prevent unintended actuation during a train accident	286k	Full Height 1/2 inch thick head shield	Reclosing pressure relief device	7/16 inch-Minimum	Minimum 11-gauge jacket constructed from A1011 steel or equivalent. The jacket must be weather-tight	TC-128 Grade B, normalized steel	Equipped per AAR Specifications Tank Cars, appendix E paragraph 10.2.1	Thermal protection system in accordance with §179.18	In trains with DP or EOT devices
DOT 111A100 W1 Specification (Currently Authorized)[1]	Bottom Outlets are Optional	263K	Optional; Bare Tanks half height; Jacket Tanks full height	Reclosing pressure relief valve	7/16 inch-Minimum	Jackets are optional	TC-128 Grade B, normalized steel	Not required, but when Equipped per AAR Specifications Tank Cars, appendix E paragraph 10.2.1	Optional	Not required

1. A CPC-1232 tank car is with all of the options included in the design. This is referred to as a post October 1, 2011 tank car and is the tank car design proposed for use by the Applicant.

Source: USDOT 2014.

The release and ignition of flammable vapors may also cause an explosion. The blast overpressure hazard depends on the nature of the chemical, the strength of the ignition source, and the degree of confinement. Finally, toxic chemicals can produce adverse effects to humans. The degree of these effects depends on the toxicity of the material and the duration of the exposure.

Performing state-of-the-art hazard assessment requires a combination of sophisticated analytical techniques and extensive professional experience. The consequence models used in this analysis are the result of more than two decades of development, and they have been validated using large-scale field tests. While a large number of consequence models are available, only a few specific models were needed to assess the hazards identified as part of this study. The hazard assessment models used as part of this analysis can be categorized into two groups:

- Release rate models; and
- Vapor dispersion models.

The following sections discuss the general characteristics of each of the models used for the consequence analysis. Specific models used in the consequence analysis were selected based on the scenarios identified in the hazard identification task.

Release Rate Models

Several models were utilized to simulate potential releases of gas, liquefied petroleum gas, natural gas liquids, and crude vapor, and two-phase releases from pipes, vessels and tanks cars.

One of the first steps in consequence modeling is to establish the source terms (i.e., release rate, temperature, pressure, and velocity) associated with each scenario. The release rate is the rate at which the material is released from the pipe, vessel, or tank car to the atmosphere. Before the source terms can be estimated for each scenario identified in the hazard analysis, the thermodynamic and physical properties of each hydrocarbon stream must be characterized. The thermodynamic and physical properties of the hydrocarbon streams were estimated using the IoMosaic SuperChems™ model, which utilizes numerous thermodynamic and physical property estimation techniques.

The SuperChems™ model simulates the release of multi-component liquid and vapor streams characteristic of the potential releases associated with the facility. For this study, these models are useful in assessing the effect of multi-component streams on vapor cloud flammability characteristics.

Steady and Non-Steady Release from a Pressurized Vessel or Pipeline

These numerical steady and non-steady state flow models are used to compute multi-component liquid and vapor release rates from a ruptured valve or pipeline. The steady-choked and un-choked flow models compute a single release rate assuming uniform pressure and temperature in the vessel; in most blow-down processes from pressure vessels, the pressure inside is sufficiently high that choked flow (i.e., releases at sonic velocity) conditions exist during most of the blow-down period. However, in smaller pressure vessels, or for relatively larger release rates, the conditions inside the vessel are not steady. The pressure drop influences the flow velocity and, thus, the mass flow rate. In addition, the density and temperature inside the vessel are also

changing. The unsteady state models compute a time-dependent release rate profile based on the chemical component properties.

The modeling method for release rate is to simulate the initial and the average release rate from a pipe or vessel rupture based on the operating conditions: the temperature, pressure, and composition. The initial release rate is then assumed to be steady for the duration of a flammable release (the average release rate is used for a toxic release) until the process inventory is expelled or a system shutdown intervenes. This model was used to estimate tank car spill rates.

Pool/Tank Fire Modeling Methodology

The thermal radiation hazards from hydrocarbon pool fires depend on a number of parameters, including the composition of the hydrocarbon mixture, the size and shape of the fire, the duration of the fire, its proximity to the object(s) at risk and the thermal characteristics of the object exposed to the fire. Estimating the thermal radiation field surrounding a fire involves the following three major steps:

- Geometric characterization of the pool fire which involves the determination of the burning rate and the physical dimensions of the fire. In calculating thermal radiation, the size/shape of the fire implies the time-averaged size of the visible flame envelope (i.e., not obstructed by smoke). Field experiments have shown that the non-visible parts of the fire radiate less than 10% of the total radiation from a hydrocarbon pool fire.
- Characterization of the radiative properties of the fire which involves the estimating the average irradiance of the flames. The intensity of thermal radiation emitted by pool fires depends on a host of parameters including fuel type, fire size, flame temperature, and composition. The major sources of radiative emissions in large pool fires are water vapor, carbon dioxide and soot.
- Calculation of radiant intensity at a given location. This is accomplished once the geometry of the fire, its radiation characteristics and the location, geometry and orientation of the receiver are known. For large distances (hundreds of meters), the absorption of thermal radiation in the intervening atmosphere becomes appreciable. This is dependent on the path length, flame temperature and atmospheric relative humidity.

Several pool fire scenarios were considered in the analysis including; a fire in the oil storage tank, a fire in the diked area surrounding the storage tank resulting from storage tank failure and ignition and a fire following the derailment of a tank car. These scenarios were simulated using the SuperChems™ consequence modeling.

Fires in blended hydrocarbon mixtures, especially those whose components differ widely in their volatility, do not burn at a uniform rate. In the beginning, the burning rate is characteristic of the high volatile component. During the middle portion of the burning, the less volatile component still must be brought to the boiling point of the blend. Finally, as the fractionation proceeds, the burning rate becomes characteristic of the higher boiling fraction.

Radiative properties of the fire were based on a detailed analysis of typical crude oil that would be delivered via rail. This information was used to simulate the fractionation of the burning hydrocarbon mixture, and the progressive decrease in thermal radiation intensity over time. The

initial pool geometry for each model simulation was based on the area and shape of the storage tank and diked area. Several meteorological conditions were also simulated to obtain a worst-case estimate of thermal radiation hazards.

Several pool fire scenarios were considered in the analysis which included potential spill sizes of to 30,000 gallons. These scenarios were simulated using the SuperChems consequence modeling package. It should be noted that any fire that occurs would be likely to be restricted to the location of the spill. A flammable vapor cloud moving downwind from a crude oil spill is not expected to arise since the small quantities of flammable vapors evolving would disperse very rapidly. Calculations were made based on the following assumptions:

- Ambient temperature 305 K
- Discharge temperature of 350 K
- Unlimited pool radius
- Average flame temperature of 1,000 K
- Burning rate of 0.228 mm/s for light crude oil.

Boiling Liquid Expanding Vapor Explosion Model

A boiling liquid expanding vapor explosion is a sudden loss of containment of a liquid that is above its boiling point (at atmospheric conditions). A boiling liquid expanding vapor explosion results in a sudden, vigorous liquid boiling and the production of a shock wave. Liquids stored under pressure (such as the gas liquids) fall into this category as well as any liquid that is stored at an elevated temperature above its boiling point. The main hazards presented by liquids stored under pressure are fireball and radiation.

Boiling liquid expanding vapor explosions were modeled using the SuperChems™ model for fireballs. The approach estimates the total energy that could be produced by the material combustion and the duration of the explosion. Impacts are estimated by integrating the energy flux over the time that the explosion occurs at different distances from the source of the explosion. Overpressure due to boiling liquid expanding vapor explosion was also estimated assuming the tank car fails due to overpressure, and the resulting shockwave is dissipated into the environment. The larger of the hazard zones pertaining to boiling liquid expanding vapor explosions (either overpressure or thermal radiation) was used to estimate risk.

A recent crude oil incident in Lac-Mégantic, Canada occurred when an uncontrolled crude oil unit train derailed. On July 6, 2013 an unattended crude oil unit train consisting of 72 loaded tank cars and five locomotives ran eight miles downgrade (1.2 percent grade) into downtown Lac-Mégantic. 63 tank cars derailed, resulting in approximately 1.5 million gallons of crude oil being spilled and subsequently ignited. Several derailed tank cars released product resulting in multiple explosions and fires causing 47 fatalities, extensive damage to the town centre and precipitated the evacuation of about 2,000 people from the surrounding area. While non-pressurized tank cars typically do not pose a significant explosion hazard, several of the DOT-111 tank cars that did not fail as a result of the derailment, subsequently failed due to overheating and over-pressurization caused by the spilled crude oil pool fire.

D. Damage Criteria

Since the release streams are flammable, releases could potentially result in thermal radiation exposure from a fire, and also present an overpressure hazard due to explosions from flammable vapor clouds or boiling liquid expanding vapor explosions. Damage criteria were developed in order to quantify the potential consequences of an accidental release. Damage criteria are defined as the levels of exposure that could produce fatalities and produce serious injuries.

Serious injury is defined as an impact from the exposure that could require medical intervention and could produce effects that last significantly longer than the duration of the exposure. An injury such as lung damage that would require hospitalization and/or other types of therapy would be considered a serious injury.

D.1 Thermal Radiation Damage Criteria

The potential concern associated with large-scale fires is thermal radiation intensity, and its effects on persons, the surrounding structures, processes, and fire suppression equipment. Table 3 presents an overview of thermal radiation intensity and observed effects.

Table 3 Thermal Radiation Serious Injury and Impacts

Intensity (kW/m^2)	Impact
1	Time for severe pain - 115 seconds Time for second-degree burns - 663 seconds [a]
1.6	No discomfort for long exposure [b]
2	Time for severe pain - 45 seconds Time for second-degree burns – 187 seconds [a]
3	Time for severe pain - 27 seconds Time for second-degree burns - 92 seconds [a]
4	Time for severe pain - 18 seconds Time for second-degree burns - 57 seconds [a]
5	Time for severe pain - 13 seconds Time for second-degree burns - 40 seconds [a]
10	Time for severe pain - 5 seconds Time for second-degree burns - 14 seconds Time for 100% fatality - 270 seconds [a c]
12.5	Melting of plastic tubing [b]
25	Minimum energy to ignite wood [b]
37.5	Damage to process equipment [b]
100	Time for severe pain - <1 seconds Time for second-degree burns - 1 sec Time for 100% fatality - 11 seconds [c]

a. Based on Handbook of Chemical Hazard Analysis Procedures, FEMA. b. CCPS Chemical Process Quantitative Risk Analysis. c. CCPS Chemical Process Quantitative Risk Analysis using probit equation by Eisenberg

Data presented in this table shows that no considerable physical effect would result from exposure to a radiation intensity between 1 and 1.6 kW/m^2 over extended periods. Exposure to a radiation intensity of 5 kW/m^2 would result in pain if the exposure period were to exceed 13

seconds, and it would result in second-degree burns after 40 seconds. Exposure to a radiation intensity of 10 kW/m^2 would result in pain (5 seconds) and second-degree burns after short exposure periods (i.e., 14 seconds), and death after longer periods. The time required to reach pain, second-degree burn, and fatality thresholds were used to estimate radiation levels that would result in serious injury or fatality. Persons exposed to thermal radiation have the opportunity to move away from the hazard, unlike overpressure effects or vapor cloud fires and explosions, which are instantaneous. It was assumed in this analysis that some people not within the flame area would move away from the flame to get away from the heat. Analysis of the distances to various radiation levels indicates that this is feasible. Therefore, a less than 1 minute exposure was used as the basis for determining the damage criteria. Exposure to a thermal radiation level of 10 kW/m^2 could result in a serious injury (at least second-degree burns) if exposed for less than 1 minute, and it was, therefore, assumed that all persons exposed to 10 kW/m^2 would suffer serious injuries. Serious injuries would start to be realized at and above 5 kW/m^2. Exposure to thermal radiation levels in excess of 10 kW/m^2 would likely begin to generate fatalities in less than 1 minute. All persons exposed to thermal radiation within the flame area were assumed to suffer fatalities regardless of exposure duration.

D.2 Flammable Vapor Criteria

A release of flammable material can produce impacts by producing a cloud of the flammable material that, if it encounters an ignition source, either explodes or burns (deflagration) back to the material source. Persons located within the cloud when it explodes or burns could be seriously impacted. Whether the cloud explodes or burns is a function of the material and the level of confinement in the environment in which the cloud is located (e.g., within pipe racks, between buildings). All release scenarios from the Rail Spur Project could contain flammable vapors.

Several biological and structural explosion damage criteria were reviewed, specifically the Center for Chemical Process Safety "Evaluating Process Plant Buildings for External Explosions and Fires" and Center for Chemical Process Safety "Chemical Process Quantitative Risk Analysis." This reference indicates that persons within a structure suffer considerably more damage than persons in the open due to overpressures. This is primarily due to secondary object impacts. Table 4 details the levels of impacts at various overpressure levels to buildings, equipment and persons.

An overpressure level of 0.3 psi would likely result in broken windows and some potential for serious injury. Complete structural damage and serious injury/fatality could occur for wooden buildings and unreinforced masonry as a result of exposure to an overpressure level of 1.0 psi. An overpressure level of 5.0 psi would result in structures being completely destroyed and an estimated 100 percent serious injury/fatality to building occupants.

Deflagration of the vapor cloud would produce impacts to persons located within the flammability limits of the vapor cloud. Persons located within the lower flammability limit would most likely suffer at least serious injuries. As there is some natural variability within the cloud, it is assumed that persons located within the area that would be encompassed by a level of

concern equal to one-half the lower flammability limit (a larger area than the lower flammability limit area) would suffer serious injuries.

Table 4 Overpressure Damage

Overpressure Level	Impact
0.04	Loud noise, sonic boom (143 dBA)
0.15	Glass breakage
0.30	Center for Chemical Process Safety projectile limit, 10% broken window glass, 95% no serious damage
1.0	Wood trailer roof and walls collapse Unreinforced masonry building partial collapse Estimated 10% injury rate
5.0	Wood trailer completely destroyed Unreinforced masonry building completely destroyed Utility poles snapped Estimated 100% injury rate
6.0	Reinforced building major damage/collapse Estimated 40% fatality rate
7.0	Loaded train wagons overturned
12.0	Reinforced building completely destroyed Estimated 100% fatality rate
15.0	Lung hemorrhage, lower range of direct human fatalities

Source: CCPS 1989

Table 5 details the criteria selected for the risk analysis for both fatalities and serious injuries. In this table, the zero percent fatality or serious injury level is the level at which fatalities or serious injuries could begin to occur.

E. Risk Analysis

The results of the failure rate and consequence analysis are finally combined to develop risk profile curves (plots of frequency versus the number of fatalities or serious injuries). These risk profile curves are commonly called risk profiles and represent "societal risk." This is the risk that a person could sustain serious injury or fatality. In calculating the risk profiles, a computer model is used that looks at the probability of the hazard occurring, the associated hazard zones, population distribution, meteorological conditions, and probabilities of ignition. The output of the model is the likelihood of an individual fatality or injury occurring. The risk analysis was only done for the mainline rail since the hazard zones at the SMR did not extend off the refinery property.

To develop the risk profile, many factors were considered. Each release scenario is evaluated for all wind directions, and for each combination of stability and wind speed. In any given direction

of travel, the chances of having the particular wind stability class, the cloud igniting on-site, and the cloud igniting offsite at every downwind location from the release site was evaluated.

Table 5 Fatality and Serious Injury Rates

Event	Fatality	Serious Injury	Reference
Vapor Cloud Fire	30% fatality within the lower flammability limit	100% injury within the lower flammability limit 50% injury within ½ lower flammability limit	Assumes 30% of the population is outdoors and would suffer 100% fatalities within the lower flammability limit. Assumes indoor population would not suffer more than serious injury due to subsequent fire and damage. Outdoor population percentage estimated.
Thermal Radiation Jet Fire or Pool Fire	100% fatality within flame jet area 11% fatalities at 10 kW/m^2	100% injury at 10 kW/m^2 10% injury at 5 kW/m^2	Based on Handbook of Chemical Hazards Analysis Procedures, exposure to 10 kW/m^2 produces second-degree burns in 14 seconds, 10% fatalities at 60 seconds based on Eisenberg Probit Equation (1975). Injury based on time to second-degree burns of less than 1 minute for 10 and 5 kW/m^2.
Boiling Liquid Expanding Vapor Explosion: Radiation Dosages	18% fatalities at 250 kJ/m^2	100% injury at 150 kJ/m^2 10% injury at 40 kJ/m^2	Based on total energy integration over boiling liquid expanding vapor explosion duration using the jet fire energy rate.
Explosion: Over Pressure	10% fatalities at 1 psi	5% injury at 0.3 psi	Based on Center for Chemical Process Safety Process Plant Buildings where occupants of a building experience 10% fatality at 1 psi for an unreinforced masonry or wood framed building. Injuries produced at 0.3 psi overpressure assumed to be 5% as per the probability of serious damage.
Toxic	1,000 ppm 10% fatality	100 ppm 10% injury	Estimated based on OSHA exposure limits and animal studies.

Notes: kW/m^2 = kilowatts per square meter; kJ/m^2 = kilojoules per square meter; psi = pounds per square inch; ppm = parts per million

The frequency of attaining the maximum downwind distances for flammable vapor dispersion will be reduced if the vapor cloud encounters ignition sources at the point of release or at any point along its travel path.

The approach used by the QRA model follows these basic steps:

1. Dividing the routes into segments based on the associated population densities and urban and rural characteristics;
2. Applying accident rates to each route segment;
3. Applying release probabilities to the accidents;
4. Developing the consequences of releases on the surrounding populations along each segment;

5. Applying accident-related trauma impacts for injuries and fatalities; and
6. Developing risk estimates.

Population Data

For the rail mainline QRA, the rail routes were divided into numerous segments based on population density using the categories listed in Table 6, and shown in Figures 2 and 3.

Table 6 Representative Default Population Densities

Designation	Density	Description
Remote	20 people/sq mile	Non-metropolitan area with scattered housing; farms
Rural	100 people/sq mile	Small village or town; recreation areas
Suburban	1,000 people/sq mile	Typical suburbs; mixed use areas
Urban	3,000 people/sq mile	Small city; densely populated suburbs; congested commercial areas
High	10,000+ people/sq mile	Very dense city area

Source: CCPS, 1995.

Ignition Probabilities

Flammable vapor clouds have the potential to ignite anywhere within their flammable limits. Hence, it is necessary to identify potential ignition sources that a cloud may encounter, and to quantify the likelihood of ignition if the cloud encompasses these sources. When determining ignition probabilities, there are two factors to take into account; source duration and source intensity. Source duration is the fraction of time that the source is present or in operation. Source intensity is the chance of the source actually causing ignition if contacted by a flammable cloud. For example, if a ground level flare is operating, it will almost always ignite a cloud, but it may only operate ten percent of the time. This would generate an overall chance of ignition by the ground level flare of 0.1 (or 10 percent).

In general, when trying to identify ignition sources, the search is primarily for open flames, hot surfaces and electrical sparks, and, to a lesser extent, friction sparks from both continuous and intermittent activities. Extensive listings of potential ignition sources and estimates of ignition probabilities may be found in the literature (CCPS 1989, UK 2004).

A release of a flammable material, for example, could experience instantaneous ignition leading to a fire. It could also disperse downwind, encounter an ignition source and burn or explode, or it could disperse safely.

Construction of Risk Profiles

Risk profiles display the frequency with which public safety impacts/consequences (e.g., fatalities or serious injuries) exceed a given magnitude. They can be used to show property damage (among others), but are generally used for public safety impacts. The risk profiles indicate accident size (based on numbers of persons affected) and display how the potential number of fatalities varies as a function of frequency. Risk profiles are generally plotted on logarithmic scales because they span multiple orders of magnitude.

Figure 2 UPRR Route and Population Densities (Roseville to SMR Routes)

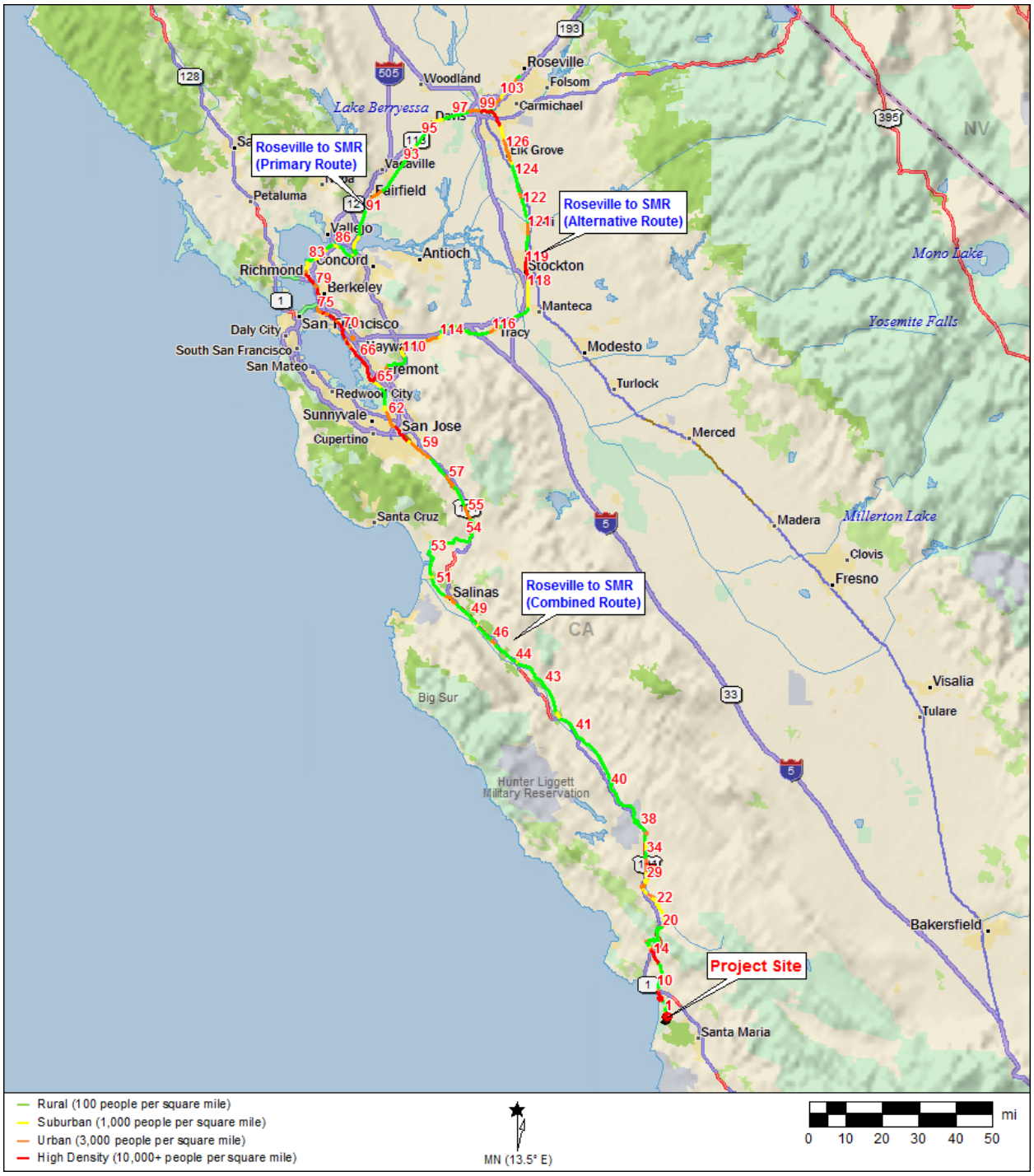
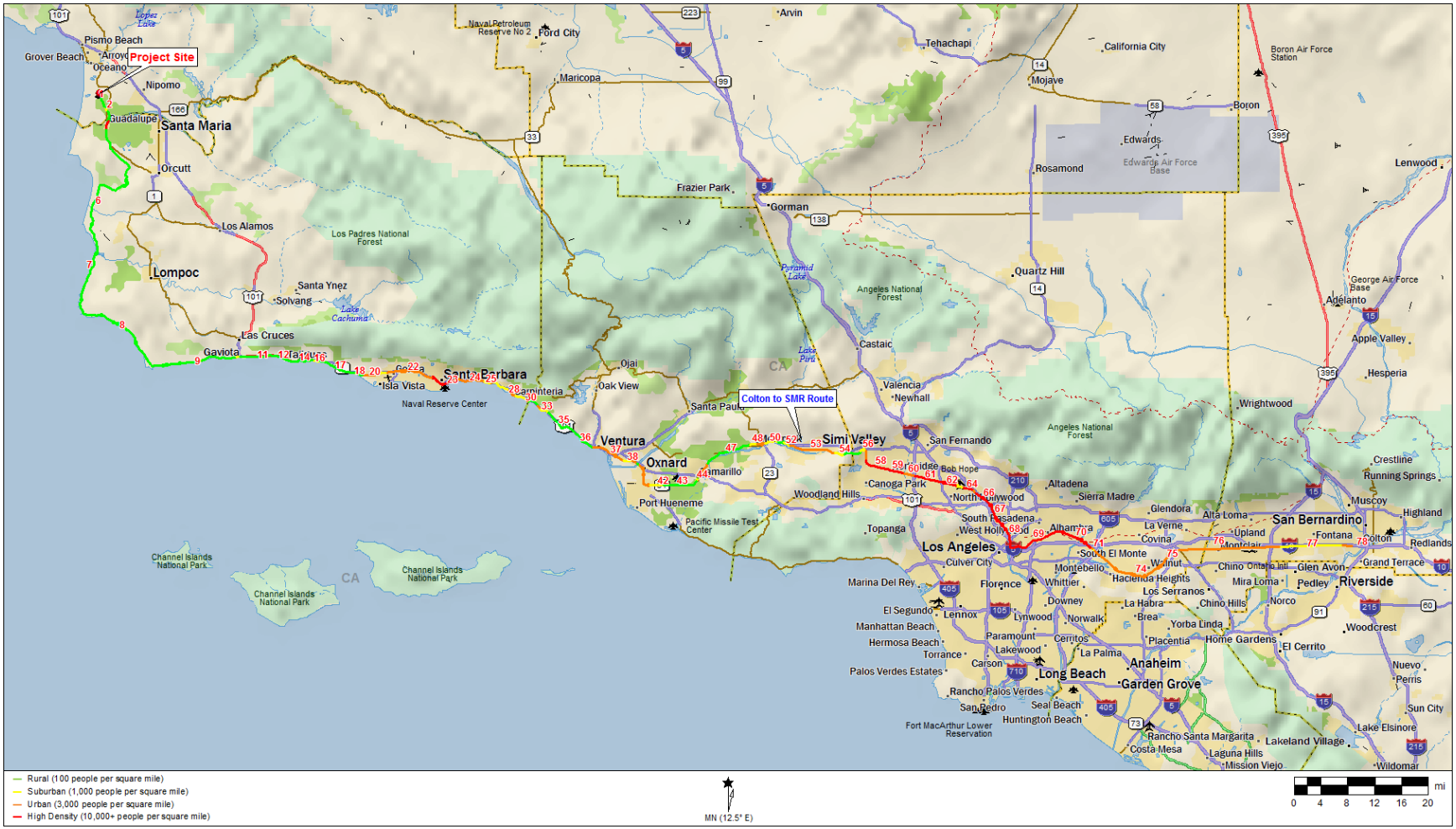


Figure 3 UPRR Route and Population Densities (Colton to SMR Route)



There are many sources of uncertainty that affect the risk profiles. These uncertainties include:

- Release frequency;
- Release size;
- Population impacts, including distribution and likelihood of fatality/serious injury;
- Behavior of the release (jet mixing versus passive dispersion);
- Accuracy of the hazard models; and
- Ignition sources and probabilities.

The release frequencies and sizes are the most important contributors to overall uncertainty. Changes in failure rates will directly influence the risk profile. A doubling of the event frequencies would double the probability of fatalities. Changes in the relative sizes of leaks and ruptures will influence the risk profile, but to a lesser extent. The assumptions concerning population distribution and ignition probability also influence the risk profiles.

F. References

References for this appendix are provided at the end of the Hazards and Hazardous Materials Section (Section 4.7.7).