APPENDIX D

HAZARD IMPACT CALCULATIONS

Consequence modeling was performed for the scenarios identified below. The purpose of the modeling was to estimate the offsite consequences of releases of flammable materials from units that are proposed for installation or modification as the result of the Chevron – El Segundo Refinery California Air Resources Board Phase 3 Clean Fuels Project.

The modeling was based on equations from the EPA's RMP Off-Site Consequence Analysis Guidance (May 24, 1996) document for estimating impact distances for explosions, fires, and BLEVEs. The EPA equations for these events were programmed into an EXCEL™ spreadsheet and used to determine the size of the impact zone. The equations are summarized below.

Vapor Cloud Explosions

For vapor cloud explosion, the total quantity of flammable substance is assumed to form a vapor cloud. The entire cloud is assumed to be within the flammability limits, and the cloud is assumed to explode. Ten percent of the flammable vapor in the cloud is assumed to participate in the explosion. The distance to the one pound per square inch (psi) overpressure level is determined using equation D-1.

$$X = 17\left(0.1\ W_f\ \frac{H_{Cf}}{H_{CTNT}}\right)^{1/3} \qquad \text{(D-1)}$$

Where:

X = distance to overpressure of 1 psi (meters)

W_f = weight of flammable substance (kg)

H_{Cf} = heat of combustion of flammable substance (joules/kg)

H_{CTNT} = heat of combustion of trinitrotoluene (4.68 E+06 joules/kg)

Pool Fires

The EPA equation is based on factors for estimating the distance to a heat radiation level that could cause second degree burns from a 40-second exposure. This heat radiation level was calculated to be 5,000 watts per square meter. The equation for estimating the distance from pool fires of flammable liquids with boiling points above ambient temperature is:

$$X = H_c \sqrt{\frac{0.0001\ A}{5000\ \Pi\ (H_v + C_p\ (T_B - T_A))}} \qquad \text{(D-2)}$$

Where:

X = distance to the 5 kilowatt per square meter endpoint (m)

HC = heat of combustion of the flammable liquid (joules/kg)

HV = heat of vaporization of the flammable liquid (joules/kg)

A = pool area (m2)

CP = liquid heat capacity (joules/kg-ºK)

TB = boiling temperature of the liquid (ºK)

TA = ambient temperature (ºK)

Boiling Liquid Expanding Vapor Explosion

The equations used by the EPA to estimate impact distances for BLEVEs are summarized below:

$$X = \sqrt{\frac{2.2\, t_a\, R\, H_c\, W_f^{0.67}}{4\Pi\left[\frac{3.42 \times 10^6}{t}\right]^{0.75}}}$$

(D-3)

Where:

X = distance to the 5 kilowatts per meter squared endpoint (m)

R = radiative fraction of the heat of combustion (assumed to be 0.4)

tA = atmospheric transmissivity (assumed to be 1)

HC = heat of combustion of the flammable liquid (joules/kg)

Wf = weight of flammable substance in the fireball (kg)

t = duration of the fireball in seconds (estimated from the following equations)

For W_f < 30,000 kg

$$t = 0.45\ W_f^{1/3} \quad \text{(D-4)}$$

For Wf > 30,000 kg

$$t = 2.6\ W_f^{1/6} \quad \text{(D-5)}$$

The following accident scenarios were considered in the analysis of offsite impacts:

- Case 1: Rupture of the pentane pipeline at the Refinery between the storage sphere and the loading rack. The pipeline is assumed to be ruptured due to a digging accident or earthquake. The pipeline releases pentane at the flow rate of the pipe for 10 minutes and forms a pool that spreads to a one centimeter depth until the pump is shut down. (The maximum flow rate of the pipeline is about 1,500 bbl per hour.) The released pool is assumed to ignite and burn after 10 minutes of spreading. Since this is a new pipeline, the incremental risk is estimated by comparing to a zero baseline.
- Case 2: A pentane pipeline to the cogeneration trains fails, releasing pentane that vaporizes, followed by an explosion. Pentane usage will be approximately 6,400 gallons per hour or 213 gallons for an assumed two-minute release before the pentane explodes. This scenario is compared to the rupture of a natural gas pipeline releasing a comparable amount of natural gas.
- Case 3: A catastrophic failure of the new pentane storage tank at the Refinery is assumed to release 30,000 bbl of pentane as a vapor cloud that explodes (U.S. EPA worst-case assumption). The catastrophic failure is assumed to be caused by a major external event such as an earthquake. The incremental risk of 30,000 bbl of pentane is compared to a zero baseline.
- Case 4: The contents of the pentane tank (30,000 bbl) are spilled into a dike that is 10 feet high and capable of containing the entire contents of the tank plus 20 percent. The liquid in the dike then catches fire. The storage tank failure is assumed to be caused by an external event or degradation of the equipment. The incremental risk is compared to a zero baseline.
- Case 5: A fire in the vicinity of the pentane tank causes the tank to fail catastrophically resulting in a "fireball" or BLEVE. Ten percent of the contents explode as a vapor cloud. The incremental risk is compared to a zero baseline.
- Case 6: A 30,000-gallon rail car of pentane ignites and burns. The pentane fire is compared to a zero baseline.
- Case 7: A 30,000-gallon rail car of pentane explodes. The pentane explosion is compared to a zero baseline.

- Case 8: The contents of an ethanol tank truck are spilled in a vehicle accident. The entire 8,800 gallons spread in an unconfined manner to a depth of one centimeter and ignite.
- Case 9: An ethanol truck is improperly connected/disconnected and releases 200 gallons of ethanol before the emergency shut-off can be activated. The spill spreads in an unconfined manner to a depth of one centimeter and ignites.
- Case 10: The contents of the ethanol tank (50,000 bbl) at the Montebello Terminal are spilled into a dike that is 1.8 feet high and 73,000 square feet in area. It is capable of containing the entire contents of the tank plus 17 percent. The liquid in the dike then catches fire. The storage tank failure is assumed to be caused by an external event or degradation of the equipment. The incremental risk is compared to a zero baseline.
- Case 11: The pentane pipeline at the Refinery ruptures between the storage sphere and the loading rack. The pipeline is assumed to be ruptured due to a digging accident or earthquake. The pipeline releases pentane at the flow rate of the pipe (1,500 bbl per hour for two minutes) when it reaches an ignition source and explodes. The incremental risk is estimated by comparing to a zero baseline.
- Case 12: The contents of the new gasoline tank (493,000 bbl) at the Refinery are spilled into a dike that is 10 feet high and capable of containing the entire contents of the tank plus 20 percent. The liquid in the dike then catches fire. The storage tank failure is assumed to be caused by an external event or degradation of the equipment. The incremental risk is compared to a zero baseline.
- Case 13: The contents of the converted gasoline tank (393,000 bbl) at the Refinery are spilled into a dike that is 10 feet high and capable of containing the entire contents of the tank plus 20 percent. The liquid in the dike then catches fire. The storage tank failure is assumed to be caused by an external event or degradation of the equipment. The incremental risk is compared with a similar release for MTBE (the former contents of the tank before conversion).
- Case 14: The contents of an ethanol tank truck are spilled during unloading. The entire 8,800 gallons are contained on the loading pad and ignite.
- Case 15: A catastrophic failure of the new Isomax Dependanizer at the Refinery is assumed to release 15,050 gallons of pentane as a vapor cloud that explodes. The catastrophic failure is assumed to be caused by a major external event such as an earthquake. The incremental risk of 15,050 gallons of pentane is compared to a zero baseline.
- Case 16: A catastrophic failure of the FCC Debutanizer at the Refinery is assumed to release 38,817 gallons of butane as a vapor cloud that explodes. The catastrophic failure is assumed to be caused by a major external event such as an earthquake. The incremental risk of 38,817 gallons of butane is compared with the contents of three smaller columns that were replaced (15,169 gallons).

- Case 17: A catastrophic failure of the FCC Depropanizer at the Refinery is assumed to release 23,689 gallons of propane as a vapor cloud that explodes. The catastrophic failure is assumed to be caused by a major external event such as an earthquake. The incremental risk of 23,689 gallons of propane is compared to the contents of three smaller columns that were replaced (12,103 gallons).
- Case 18: A catastrophic failure of the new FCC propane/propylene unit at the Refinery is assumed to release 19,306 gallons of propane as a vapor cloud that explodes. The catastrophic failure is assumed to be caused by a major external event such as an earthquake. The incremental risk of 19,306 gallons of propane is compared to the pre-project contents of 6,006 gallons.
- Case 19: A 30,000-gallon railcar of fuel ethanol ruptures, spills and ignites. The ethanol fire is compared to a zero baseline.

The results are summarized in Table D-1.

Table D-1
Distance (meters) to Endpoint from Center to Upset*

Case	Event	Explosion	Pool Fire	BLEVE
1[1]	Rupture Pentane Pipeline (10 min)	NA	395	NA
2	Rupture Pentane Pipeline (2 min)	137	NA	NA
3,4,**5**	Pentane Sphere Failure (30,000 bbl)	2,484	337	1,410
6,**7**	Pentane RR Car Accident (30,000 gallons)	715	669	NA
8	Ethanol Truck Accident	NA	137	NA
9	Bad Connect/Disconnect	NA	21	NA
10	Ethanol Tank Failure (50,000 bbl)	NA	196	NA
11	Rupture Pentane Pipeline (2 min)	295	NA	NA
12	Gasoline Tank Failure (493,000 bbl)	NA	928	NA
13	Gasoline Tank Failure (393,000 bbl)	NA	828	NA
13	MTBE Tank Failure (393,000 bbl)	NA	785	NA
14	Ethanol Contained on Pad (8,800 gal)	NA	21	NA
15	Isomax Depentanizer Fail (15,050 gal)	568	NA	NA
16	FCC Debutanizer (38,817 gal)	761	NA	NA
16	FCC Debutanizer (15,169 gal)	556	NA	NA
17	FCC Depropanizer (23,689 gal)	620	NA	NA
17	FCC Depropanizer (12,103 gal)	496	NA	NA
18	FCC Propane/Propylene Unit (19,306 gal)	579	NA	NA
18	FCC Propane/Propylene Unit (6,006 gal)	392	NA	NA
19	Ethanol RR Car Accident (30,000 gallons)	NA	250	NA

[1] Case numbers in **BOLD** have the potential for significant offsite impacts
* Endpoint – U.S. EPA RMP
Explosion endpoint – one psi
Fire/BLEVE source endpoint – 5kw/m^2 for 40 seconds or equivalent
NA = Not Applicable

Chemical Physical Parameters

Number	Chemical	Hc (joules/kg)	Hv (joules/kg)	Cp (joules/kg-K)	Tb (K)	Density (lb/gal)	Reference
1	Diesel	4.81E+07	275218	2183	447.0		1
2	Ethanol	2.97E+07	866265	2407	351.4	6.6	2
3	Gasoline	4.78E+07	300513	2198	398.7	5.89	1
4	Pentane	4.86E+07	356415	2283	309.0	5.26	1
5	MTBE	3.87E+07	320237	2098	327.0	6.18	3
6	n-Nonane	4.77E+07	287192	2190	423.5		1
7	Nonenes	4.71E+07	287285	2124	419.8		4
8	Butane	4.90E+07	384400			4.87	1
9	Hydrogen	1.30E+08	450189				5
10	Propylene	4.88E+07	436497				2
11	Propane	4.99E+07	424778	2484	231.0	4.233	1
12	Methane	5.54E+07	508713				1

References

1 Petroleum Refining, J. Gary and G Handwerk, Marcel Dekker, Inc, 1975

2 Perry's Chemical Engineering Handbook

3 Conversation with Dennis Feist, Equilon/Shell

4 ARCO Table 1C1.3

5 Standard Handbook for ME, Marks

Scenario Definitions

Scenario	Container	Event Type	Chemical	Barrels	Gallons	Pounds	Kg
1	Pipeline 1,500 bbl/hr (10-min flow)	Pool fire	Pentane	250	10,500	55,230	25,052
2	Pipeline 6,400 gal/hr (2-min flow)	Explosion	Pentane	5	213	1,122	509
3	30K BBL Sphere	Explosion	Pentane	30,000	1,260,000	6,627,600	3,006,279
4	30K BBL Sphere	Pool fire (Contained)	Pentane	30,000	1,260,000	6,627,600	3,006,279
5	30K BBL Sphere	BLEVE	Pentane	30,000	1,260,000	6,627,600	3,006,279
6	700 BBL Railcar	Pool fire	Pentane	714	30,000	157,800	71,578
7	700 BBL Railcar	Explosion	Pentane	714	30,000	157,800	71,578
8	Truck Accident	Pool fire	Ethanol	210	8,800	58,080	26,345
9	Truck Bad Connect	Pool fire	Ethanol	5	200	1,320	599
10	50K BBL Tank	Pool fire (Contained)	Ethanol	50,000	2,100,000	13,860,000	6,286,896
11	Pipeline 1,500 bbl/hr (2-min flow)	Explosion	Pentane	50	2,100	11,046	5,010
12	493K BBL Tank	Pool fire (Contained)	Gasoline	493,000	20,706,000	121,958,340	55,320,303
13a	393K BBL Tank	Pool fire (Contained)	Gasoline	393,000	16,506,000	97,220,340	44,099,146
13b	393K BBL Tank	Pool fire (Contained)	MTBE	393,000	16,506,000	102,007,080	46,270,411
14	8,800 Gal Tank on Pad	Pool fire (Contained)	Ethanol	210	8,800	58,080	26,345
15	Isomax Depentanizer	Explosion	Pentane	358	15,050	79,163	35,908
16a	FCC Debutanizer before	Explosion	Butane	361	15,169	73,873	33,509
16b	FCC Debutanizer after	Explosion	Butane	924	38,817	189,039	85,748
17a	FCC Depropanizer before	Explosion	Propane	288	12,103	51,232	23,239
17b	FCC Depropanizer after	Explosion	Propane	564	23,689	100,276	45,485
18a	FCC Propane/Propylene Unit before	Explosion	Propane	143	6,006	25,423	11,532
18b	FCC Propane/Propylene Unit after	Explosion	Propane	460	19,306	81,722	37,069
19	700 BBL Railcar	Pool fire	Ethanol	714	30,000	198,000	89,813

Confined Spill Surface Area. **Allowance for Precipitation** 20%

Scenario	Description	Tank Vol (BBL)	Containment Depth (ft)	Tank Vol (Gal)	Dike Volume (cu ft)	Containment Area (sq ft)	Area (sq m)
4	30K BBL Sphere - Pentane	30,000	6.5	1,260,000	202,139	31,098	2,889
10	50K BBL Tank - Ethanol	50,000	3.8	2,100,000	280,749	73,881	6,864
12	493K BBL Tank - Gasoline	493,000	8.3	20,706,000	2,768,182	333,516	30,985
13a	393K BBL Tank - Gasoline	393,000	8.3	16,506,000	2,206,684	265,866	24,700
13b	393K BBL Tank - MTBE	393,000	8.3	16,506,000	2,206,684	265,866	24,700
14	8,800 Gal Tank on Pad - Ethanol	210	1.4	8,800	1,176	840	78

Unconfined Spill Surface Area. Liquid spreads to a depth of 1 cm depth (0.0328 feet).

Scenario	Description	Spill Volume (BBL)	Spill Volume (Gal)	Spill Volume (cu ft)	Containment Area (sq ft)	Containment Depth (ft)	Area (sq m)
1	Pipeline 1,500 bbl/hr (10-min flow) - Pentane	250	10,500	1,404	42,786	0.0328	3,967
6	700 BBL Railcar - Pentane	714	30,000	4,011	122,246	0.0328	11,335
8	Truck Accident - Ethanol	210	8,800	1,176	35,859	0.0328	3,325
9	Truck Bad Connect - Ethanol	5	200	27	815	0.0328	76
19	700 BBL Railcar - Ethanol	714	30,000	4,011	122,246	0.0328	11,335

Off-Site Consequence Results

Pool Fire. Boiling point above ambient temperature. Distance is to energy flux of 5kW/m^2

Scenario	Description	Size (BBL)	Chemical	Hc (J/kg)	Hv (J/kg)	Cp (j/kgK)	Tb (K)	Ta (K
1	Pipeline 1,500 bbl/hr (10-min flow) - Pentane	250	Pentane	4.86E+07	3.56E+05	2.28E+03	3.09E+02	298
4	30K BBL Sphere - Pentane	30,000	Pentane	4.86E+07	3.56E+05	2.28E+03	3.09E+02	298
6	700 BBL Railcar - Pentane	714	Pentane	4.86E+07	3.56E+05	2.28E+03	3.09E+02	298
8	Truck Accident - Ethanol	210	Ethanol	2.97E+07	8.66E+05	2.41E+03	3.51E+02	298
9	Truck Bad Connect - Ethanol	5	Ethanol	2.97E+07	8.66E+05	2.41E+03	3.51E+02	298
10	50K BBL Tank - Ethanol	50,000	Ethanol	2.97E+07	8.66E+05	2.41E+03	3.51E+02	298
12	493K BBL Tank - Gasoline	493,000	Gasoline	4.78E+07	3.01E+05	2.20E+03	3.99E+02	298
13a	393K BBL Tank - Gasoline	393,000	Gasoline	4.78E+07	3.01E+05	2.20E+03	3.99E+02	298
13b	393K BBL Tank - MTBE	393,000	MTBE	3.87E+07	3.20E+05	2.10E+03	3.27E+02	298
14	8,800 Gal Tank on Pad - Ethanol	210	Ethanol	2.97E+07	8.66E+05	2.41E+03	3.51E+02	298
19	700 BBL Railcar - Ethanol	714	Ethanol	2.97E+07	8.66E+05	2.41E+03	3.51E+02	298

Based on EPA RMP Off-Site Consequence Analysis Guideline (5/24/96)

Blast. Distance to overpressure of 1 psi.

Scenario	Description	Size (BBL)	Chemical	Wt (kg)	Hc (joules/kg)	x (m)	x (m)
2	Pipeline 6,400 gal/hr (2-min flow) - Pentane	5	Pentane	5.09E+02	4.86E+07	137	140
3	30K BBL Sphere - Pentane	30,000	Pentane	3.01E+06	4.86E+07	2483	2,480
7	700 BBL Railcar - Pentane	714	Pentane	7.16E+04	4.86E+07	715	710
11	Pipeline 1,500 bbl/hr (2-min flow) - Pentane	50	Pentane	5.01E+03	4.86E+07	294	290
15	Isomax Depentanizer - Pentane	358	Pentane	3.59E+04	4.86E+07	568	570
16a	FCC Debutanizer before - Butane	361	Butane	3.35E+04	4.90E+07	556	560
16b	FCC Debutanizer after - Butane	924	Butane	8.57E+04	4.90E+07	761	760
Based on EPA RMP Off-Site Consequence Analysis Guideline (5/24/96) (Continued)							

17a	FCC Depropanizer before - Propane	288	Propane	2.32E+04	4.99E+07	495	500
17b	FCC Depropanizer after - Propane	564	Propane	4.55E+04	4.99E+07	620	620
18a	FCC Propane/Propylene Unit before - Propane	143	Propane	1.15E+04	4.99E+07	392	390
18b	FCC Propane/Propylene Unit after - Propane	460	Propane	3.71E+04	4.99E+07	579	580

BLEVE. Assumes 10% of total weight is evaporated and explodes. Distance is to energy flux of 5kW/m^2

Scenario	Description	Size (BBL)	Chemical	Wt (kg)	Hc (joules/kg)	Fire Ball Duration (s)	x (m)	x (m
5	30K BBL Sphere - Pentane	30,000	Pentane	3.01E+06	4.86E+07	21	1,409	

Based on EPA RMP Off-Site Consequence Analysis Guideline (5/24/96)