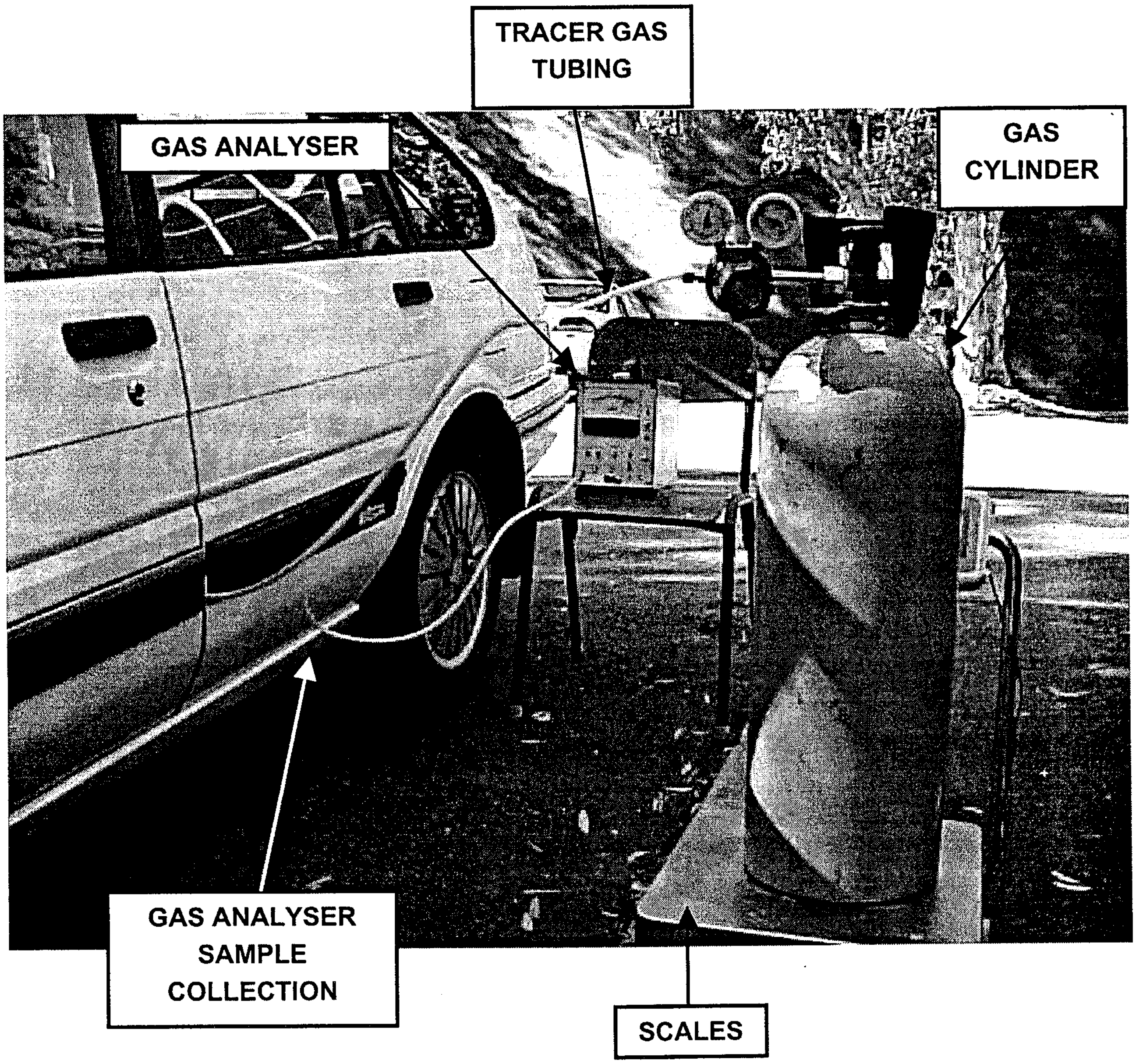


FIGURE AII.7
VIEW OF COROLLA WITH EXPERIMENTAL EQUIPMENT

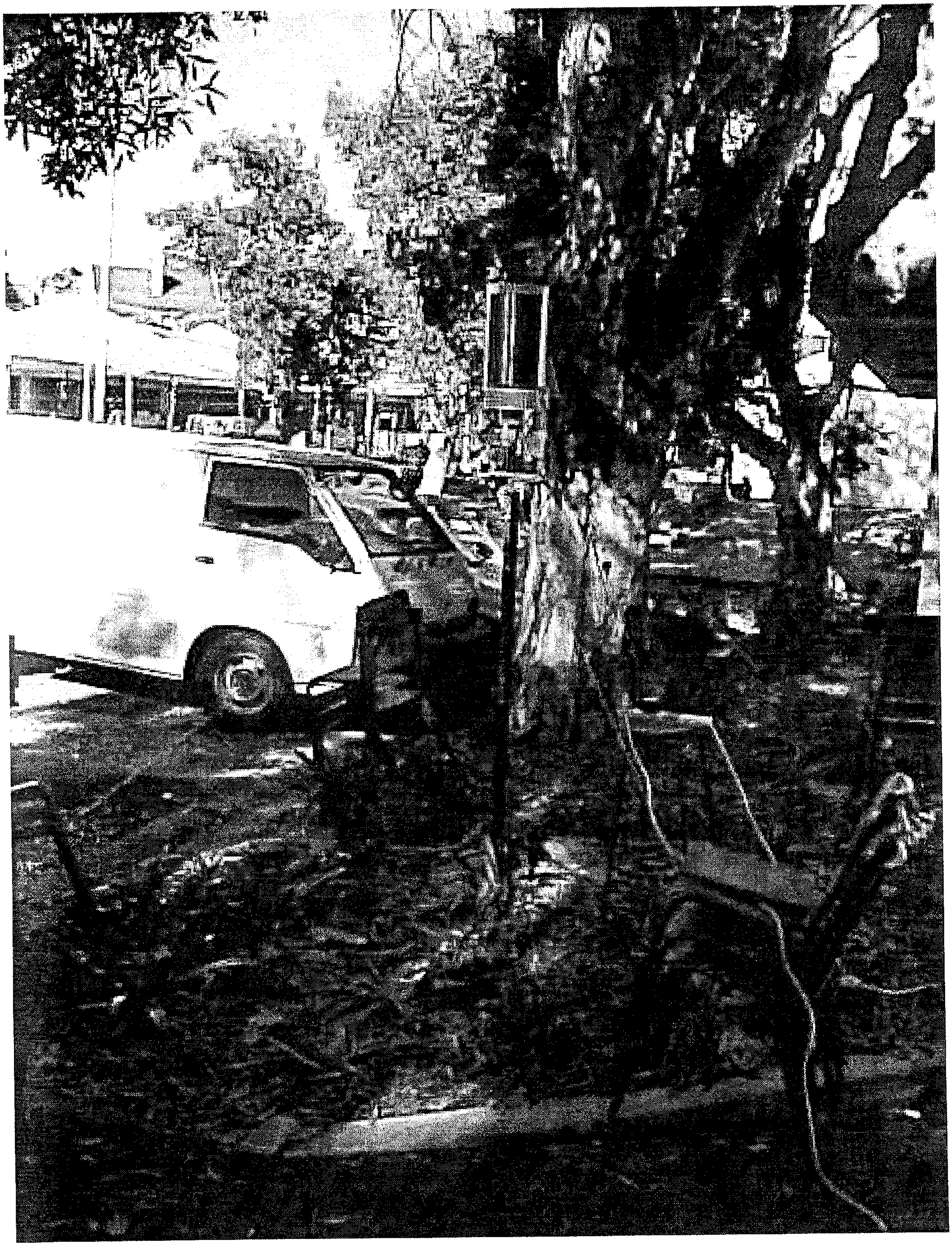


FIGURE AII.8
VIEW OF WEATHER STATION

APPENDIX III

RAW EXPERIMENTAL DATA

Experiment 1

Car Corolla
Location Inside

Time min	Concn ppm	Temp (inside room) deg C
0	570	16
0.5	570	
1	4000	
1.5	3000	
2	3000	
2.5	2600	
3	2600	
3.5	2500	
4	2950	
4.5	3500	
5	3600	
6	3600	16.4
7	3600	
8	3550	
9	3500	
15	3400	
20	3250	
25	3200	15.8
30	3100	
40	3000	
50	3000	
60	2950	15.8
70	2950	
80	2900	
90	2850	15.7
100	2800	
110	2800	
120	2800	
150	2700	15.5
180	2600	15.6
210	2550	
240	2450	15.2
Doors Opened:		
240.5	2450	
241	2400	
241.5	1700	
242	1400	
242.5	1100	
243	850	
243.5	700	
244	570	

Experiment 2

Car Laser
Location Inside

Time min	Concn ppm	Temp (inside room) deg C
0	470	15.4
0.5	470	
1	470	
2	470	
3	530	
4	700	
5	850	15.6
6	1300	
7	1650	
8	2150	
9	2000	
10	2300	15.2
15	2700	15.2
20	3200	15.2
25	3200	15
30	3100	14.8
40	2950	14.6
50	2900	14.6
60	2800	14.8
90	2750	14.7
120	2600	14.8
150	2500	14.8
180	2400	14.7
210	2300	14.6
240	2200	14.6
270	2150	15.4
300	2100	15.2
330	2000	14.8
360	1900	14.8
390	1850	14.6
Doors Opened:		
390.5	1850	
391	1500	
391.5	1000	
392	750	
392.5	650	

Experiment 3

Car Corolla
Location Outside

Time min	Concn ppm
0	500
0.5	600
1	4600
1.5	3700
2	2900
2.5	3000
3	3000
3.5	3200
4	3400
4.5	3600
5	3650
6	3750
7	3750
8	3700
9	3650
10	3600
15	3350
20	3200
25	3050
30	2950
40	2750
50	2550
60	2400
90	1970
120	1680
150	1550
Doors Opened:	
151	1550
151.5	1500
152	1500
152.5	1450
153	800
153.5	470

Experiment 4

Car Corolla
Location Outside

Time min	Concn ppm
0	450
0.5	450
1	3600
1.5	4200
2	4000
2.5	3150
3	2800
3.5	3400
4	3400
4.5	3350
5	3350
6	3600
7	3900
8	3900
9	3950
10	3900
15	3700
20	3600
25	3500
30	3400
40	3250
50	3100
60	3000
90	2700
120	2500
150	2250
Doors Opened:	
154	2200
154.5	2200
155	1300
155.5	1050
156	550
156.5	500

Experiment 5

Car Laser
Location Outside

Time min	Concn ppm
0	500
0.5	1800
1	4800
1.5	2400
2	3000
2.5	3400
3	3700
3.5	3700
4	3800
4.5	3800
5	3800
6	3750
7	3700
8	3650
9	3600
10	3500
15	3300
20	3000
25	2850
30	2700
40	2450
50	2250
60	2050
90	1580
120	1180
150	900

Experiment 6

Car Verada
Location Inside

Time min	Concn ppm	Temp (inside room) deg C
0	450	12.9
0.5	450	
1	3400	
2	3600	
3	3900	
4	3900	
5	4000	
6	4000	
7	4000	
8	4000	
9	3950	
10	3800	
15	3700	13.4
20	3600	
25	3550	13.5
30	3500	13.4
40	3400	13.5
50	3200	
60	3150	13.6
90	2950	13.6
120	2800	13.6
150	2650	13.9
180	2550	14.1
240	2400	14
270	2350	14.4
308	2300	14.3
342	2250	14.2
370	2200	14.3
400	2150	14.5
430	2120	14.7
440	2100	14.7
Doors Opened:		
440.5	2050	
441	2050	
441.5	1950	
442	1450	
442.5	1350	
443	1200	
443.5	1250	
444	850	
444.5	750	
445	700	

Experiment 7

Car Laser
Location Outside

Time min	Concn ppm
0	450
0.5	8400
2.5	5000
3	5000
3.5	4800
4	4650
4.5	4550
5	4400
6	4350
7	4200
8	4100
9	4000
10	3950
15	3750
20	3600
25	3500
30	3400
40	3250
50	3100
60	2900
90	2200
120	1760
150	1500
180	1280
Doors Opened:	
181	1260
181.5	1250
182	1050
182.5	800
183	580

Experiment 8

Car Commodore
Location Outside

Time min	Concn ppm
0	500
0.5	500
1	2800
1.5	3500
2	3200
2.5	3250
3	3600
3.5	2900
4	2900
4.5	2800
5	2750
6	2650
7	2700
8	2700
9	2700
10	2700
15	2650
20	2600
25	2580
30	2550
45	2500
55	2500
65	2400
90	2350
120	2300
130	2200
Doors Opened:	
131	2200
131.5	2100
132	2050
132.5	1800
133	750
133.5	600

Experiment 9

Car Laser
Location Outside

Time min	Concn ppm
0	500
0.5	500
1	4800
1.5	2300
2	1600
2.5	2000
3	2400
3.5	2600
4	3100
4.5	3100
5	3600
6	3600
7	3450
8	3400
9	3500
10	3500
16	3550
20	3500
25	3450
30	3350
40	3200
50	3150
60	3050
90	2900
120	2800
150	2700
Doors Opened:	
151	2700
151.5	1850
152	2100
152.5	1900
153	1700
153.5	1600
154	1000
154.5	800
155	700

Experiment 10

Car Verada
Location Outside

Time min	Concn ppm
0	450
1.5	3150
2	3650
2.5	4200
3	4150
3.5	3950
4	3900
4.5	3900
5	3900
6	3800
7	3750
8	3700
9	3650
10	3650
15	3500
20	3400
25	3350
30	3250
40	3100
50	3000
62	2850
90	2500
120	2300
152	2100
191	1900
232	1800
Doors Opened:	
234	1800
234.5	1150
235	600

Experiment 11

Car Laser
Location Outside

Time min	Concn ppm	Temp (in car) deg C
0	450	
0.5		
1		
1.5		
2		
2.5		
3		
3.5		
4	5000	
4.5	4950	
5	4850	19
6	4700	
7		
8		
9	4400	
10	4300	21
15	3950	22.5
21	3700	24
25	3550	24
30	3400	23.5
40	3250	22.5
50	2900	23
60	2700	22
92	2200	21
120	1700	23.5
152	1380	22
180	1100	21
210	850	23
Doors Opened:		
210.5	850	
211	800	
211.5	600	

Experiment 12

Car Commodore
Location Outside

Time min	Concn ppm	Temp (in car) deg C
0	420	20.5
0.5	420	
1	1400	
1.5	2600	
2	1900	
2.5	2100	
3	2300	
3.5	3200	
4	3400	
4.5	3550	
5	3700	20.5
6	3450	
7	3500	
8	3350	
9	3250	
10	3250	20.5
15	2800	
20	2750	20.5
25	2700	
30	2700	20.5
40	2600	20.5
50	2500	22
60	2450	22
90	2250	21
120	2100	20
150	2000	20
183	1850	20
201	1750	20
Doors Opened:		
202	1750	
202.5	1500	
203	500	

Experiment 13

Car Honda Civic
Location Inside

Time min	Concn ppm	Temp (inside room) deg C
0	450	15.3
1	600	
2	2200	
3	2600	
4	3600	
5	3600	15.7
6	3700	
7	3700	
8	3600	
9	3500	
10	3600	15.7
15	3400	15.6
22	3200	
25	3150	15.5
30	3200	15.6
40	3100	15.7
52	2950	15.5
60	2850	15.4
90	2700	15.5
123	2650	15.4
172	2550	15.4
212	2400	15.5
250	2300	15.6
280	2250	15.6
310	2200	15.7
340	2150	15.8
360	2050	15.5
Doors Opened:		
360	2050	
360.5	2050	
361	1900	
361.5	1550	
362	1650	
362.5	1550	
363	1000	
363.5	1200	
364	800	
364.5	600	

Experiment 14

Car Verada
Location Outside

Time min	Concn ppm
0	450
0.5	4500
1	5000
4	4650
4.5	4500
5	4400
6	4300
7	4300
8	4250
9	4150
10	4050
15	3850
21	3650
25	3500
31	3450
46	3200
50	3150
66	3000
90	2800
120	2600
150	2450
180	2300
210	2150
225	2100
Doors Opened:	
225	2100
225.5	1500
226	750
226.6	550

Experiment 15

Car Laser
Location Outside

Time min	Concn ppm	Temp (in car) deg C
0	400	22
1	2800	
1.5	2400	
2	3000	
2.5	3300	
3	4000	
3.5	3700	
4	3950	
4.5	3900	
5	3850	21.5
6	3800	
7	3750	
8	3700	
10	3700	21
15	3600	21
20	3500	20.5
25	3400	20.5
30	3200	20
40	2950	20
50	2700	19.5
60	2500	19
90	2200	18.5
120	1850	18
150	1550	17
180	1300	16
Doors Opened:		
180	1300	
180.5	1050	
181	650	

APPENDIX IV

WEATHER DATA

Weather Data for 16 June 1999

Time	Air Temp degC	Wind Speed km/h	Wind Dirn deg	Solar Radn W/m^2	Rel. Hum. %
10:30	12.5	0.2	138	49	47.3
10:40	12.7	0.1	54	87	46.7
10:50	12.9	0	132	55	46.4
11:00	13.1	0.1	180	60	46.1
11:10	13.2	0.3	174	65	45.7
11:20	13.4	0.1	210	157	45.5
11:30	13.7	0.2	90	300	44.7
11:40	14.2	0.2	138	701	43.6
11:50	15	0.3	150	707	41.5
12:00	15.7	0.2	198	712	39.8
12:10	16	0.3	114	711	38.1
12:20	16.3	0.1	114	706	37.4
12:30	16.6	0.2	30	699	36.8
12:40	16.6	0.2	150	559	36.6
12:50	16.1	0.2	162	59	37.5
13:00	15.5	0.3	120	51	38.4
13:10	15	0.2	168	43	39.7
13:20	14.8	0.4	132	33	41.1
13:30	14.6	0.2	258	29	41.5
13:40	14.6	0.3	186	27	41.9
13:50	14.6	0.1	90	30	42.2
14:00	14.5	0.1	102	11	42.5
14:10	14.5	0.2	156	6	42.4
14:20	14.5	0.1	150	6	42.7
14:30	14.4	0.1	240	9	43.1
14:40	14.4	0	258	7	43.4
14:50	14.3	0.2	168	9	43.2
15:00	14.2	0	132	8	43
15:10	14.1	0	300	12	43.9
15:20	14	0	90	10	43.9
15:30	13.9	0	342	6	44.2
15:40	13.7	0	300	4	44.9
15:50	13.6	0	108	3	45
16:00	13.4	0	102	0	45.2
16:10	13.3	0	204	5	45.8
16:20	13.1	0	162	14	46.7
16:30	12.9	0.1	132	6	47.6
16:40	12.7	0	126	0	48.3
16:50	12.4	0	90	0	49.3
17:00	12.2	0	222	0	49.7
17:10	12	0	138	0	49.9
17:20	11.8	0	78	0	50.3
avg	14.07	0.12	156.9	141.8	43.65
max	16.6	0.4	342	712	50.3
min	11.8	0	30	0	36.6

Weather Data for 17 June 1999

Time	Air Temp degC	Wind Speed km/h	Wind Dirn deg	Solar Radn W/m^2	Rel. Hum. %
8:30:00	11.5	0	306	99	49.2
8:40:00	11.3	0	144	271	47.1
8:50:00	11.6	0	162	313	47
9:00:00	11.7	0	156	352	46.4
9:10:00	12	0.1	66	359	45.7
9:20:00	12.1	0	132	139	46
9:30:00	12.2	0	168	114	45.9
9:40:00	12	0	114	158	45.8
9:50:00	11.7	0	96	343	46.4
10:00:00	11.9	0	84	181	46.9
10:10:00	12	0.1	132	50	46.2
10:20:00	11.9	0	120	38	46.7
10:30:00	11.8	0.2	144	45	46.7
10:40:00	12	0	144	63	47.1
10:50:00	12.2	0	180	54	47.1
11:00:00	12.4	0.1	120	65	46.6
11:10:00	12.5	0	72	54	46.5
11:20:00	12.7	0	144	169	46.2
11:30:00	13.1	0	54	324	46.1
11:40:00	14	0.1	156	698	44.9
11:50:00	15.1	0	168	701	42
12:00:00	15.9	0	90	704	39.9
12:10:00	16.4	0	96	702	38.6
12:20:00	16.8	0.1	306	698	37.6
12:30:00	17.3	0.1	96	689	37.3
12:40:00	17.1	0	204	513	37.1
12:50:00	16.7	0.2	330	60	38.6
13:00:00	16.4	0	294	50	39.9
13:10:00	16.2	0	24	41	40.8
13:20:00	16.1	0.1	312	36	41.2
13:30:00	16.1	0	126	24	41.6
13:40:00	16.1	0.3	96	25	41.8
13:50:00	16.1	0	294	20	41.8
14:00:00	16.1	0	114	34	42
14:10:00	16.2	0.1	60	33	42.1
14:20:00	16.2	0	222	5	42
14:30:00	16.2	0	72	4	42.1
14:40:00	16.1	0.1	102	9	42.3
14:50:00	16.1	0	168	4	42.3
15:00:00	15.9	0	252	11	42.3
15:10:00	15.8	0.1	6	6	42.8
15:20:00	15.8	0	126	6	42.8
15:30:00	15.7	0	318	4	43.8
15:40:00	15.6	0	36	3	44.3
15:50:00	15.4	0	108	4	44.9
16:00:00	15.3	0	36	6	45.3
16:10:00	15.1	0	96	7	45.7
16:20:00	15	0	48	9	46.1
16:30:00	14.8	0	78	3	45.3
16:40:00	14.6	0	90	0	45.9
16:50:00	14.3	0	90	0	47.2
17:00:00	14	0	90	0	48.8

Weather Data for 17 June 1999 (continued)

Time	Air Temp degC	Wind Speed km/h	Wind Dirn deg	Solar Radn W/m^2	Rel. Hum. %
17:10:00	13.6	0	90	0	50.4
17:20:00	13.3	0	90	0	51.9
17:30:00	12.9	0	90	0	53.3
17:40:00	12.6	0	90	0	54.8
avg	14.31	0.03	135.75	148.21	44.59
max	17.3	0.3	330	704	54.8
min	11.3	0	6	0	37.1

Weather Data for 18 June 1999

Time	Air Temp degC	Wind Speed km/h	Wind Dirn deg	Solar Radn W/m^2	Rel. Hum. %
8:20:00	12.6	0	96	68	55.1
8:30:00	13.3	0	6	224	53.5
8:40:00	14.2	0	60	259	52.5
8:50:00	14.8	0.2	72	294	51.1
9:00:00	15.2	0	36	331	50.2
9:10:00	16	0	48	347	48.7
9:20:00	16.6	0	108	168	47.1
9:30:00	16.7	0.1	60	160	46.5
9:40:00	16.6	0.1	114	178	46.7
9:50:00	16.4	0	0	118	47
10:00:00	15.9	0	60	114	48.2
10:10:00	15.8	0.1	288	89	49.5
10:20:00	15.8	0.1	30	55	49.3
10:30:00	15.6	0	48	51	50.3
10:40:00	15.5	0	6	55	51.8
10:50:00	15.6	0	60	66	51
11:00:00	15.7	0	66	70	49.4
11:10:00	15.9	0	54	94	48.3
11:20:00	16.6	0.2	96	202	47
11:30:00	17.1	0.1	30	286	44.6
11:40:00	17.8	0.4	120	675	42.5
11:50:00	18.6	0.3	168	672	40.8
12:00:00	19.2	0.5	168	668	39.5
12:10:00	19.8	0.5	174	669	38.2
12:20:00	20.1	0.6	174	668	37.2
12:30:00	20.2	1.3	78	659	36.7
12:40:00	20.1	1.2	174	511	36.7
12:50:00	19.8	1	354	61	36.8
13:00:00	19.5	0.3	36	54	36.6
13:10:00	19.1	0.2	282	47	37.2
13:20:00	19	0.5	222	35	37.3
13:30:00	18.8	0.4	0	27	36.6
13:40:00	18.7	0.6	198	24	36.9
13:50:00	18.6	0.5	294	26	37.1
14:00:00	18.5	0.4	276	26	37
14:10:00	18.5	0.1	342	19	37.2
14:20:00	18.5	0.4	348	24	36.8

Weather Data for 18 June 1999 (continued)

Time	Air Temp degC	Wind Speed km/h	Wind Dirn deg	Solar Radn W/m^2	Rel. Hum. %
14:30:00	18.5	0.1	36	10	37.4
14:40:00	18.5	0.4	318	10	37
14:50:00	18.4	0.1	306	6	36.6
15:00:00	18.4	0.4	354	12	37
15:10:00	18.3	0.2	300	3	37.4
15:20:00	18.1	0.1	354	6	38.1
15:30:00	18	0.1	342	6	38.7
15:40:00	17.8	0.3	66	4	39.1
15:50:00	17.8	0.3	312	12	39.3
16:00:00	17.8	0.5	258	15	39.1
16:10:00	17.6	0.4	354	19	38.8
16:20:00	17.4	0.3	0	1	39.3
16:30:00	17.2	0.1	258	0	39.7
16:40:00	16.9	0.1	336	0	40.6
16:50:00	16.6	0.1	36	0	41.8
17:00:00	16.3	0.1	318	0	42.8
avg	17.36	0.26	164.04	154.68	42.48
max	20.2	1.3	354	675	55.1
min	12.6	0	0	0	36.6

APPENDIX 11

IGNITION SOURCES AND PROBABILITIES

TABLE OF CONTENTS

A11.1. INTRODUCTION

A11.1.1 Purpose

This section plays an important part in the Safety Case submission. A fire or explosion inside a passenger vehicle may only occur if a flammable mixture is present in the required concentration range **and** an ignition source is available. The latter is the focus of this appendix.

Analysis of potential leak scenarios has been discussed in **Part III** of the main report and in **Appendix 7**.

A11.1.2 Objectives of this Appendix

The objectives of this Appendix were to:

- identify potential ignition sources present in a passenger vehicle;
- measure the electrical parameters (by way of voltage and current readings, inductance and stored energy) of identified sources;
- determine if the identified ignition source is of sufficient strength to cause an ignition of flammable hydrocarbon mixture with regards to AS 2380.7i "Intrinsic Safety" (Ref.1); and
- develop a rule set for ignition probabilities for input into the risk assessment.

A11.1.3 Scope of Appendix

The scope of this appendix covered electrical systems associated with a typical passenger vehicle. It is recognised that there may be some variations in electrical systems from one vehicle manufacturer to another. This appendix is intended to identify electrical systems that are common to all cars (e.g. central door locking, interior light).

For the testing, a range of components was selected from cars, which would be typical for private vehicle use, ranging from four-cylinder to eight-cylinder cars.

A11.2. DESCRIPTION OF CAR ELECTRICAL SYSTEMS

A11.2.1 Introduction

For the purposes of this assessment, electrical systems associated with a passenger vehicle may be divided into two areas:

- Engine Electrical System, and
- Chassis Electrical System (including passenger cabin).

A11.2.2 Engine Electrical System

The electrical systems include ignition, charging and starting components related to the car engine. Of interest in this study is the charging system (i.e. alternator) and starting system.

The starting system generally consists of battery, starter motor, starter solenoid and the electrical circuits connecting the components. Of interest here is the starter motor/ solenoid assembly. When the ignition key is turned to the "START" position, the starter solenoid is actuated through the starter control circuit. The starter solenoid then engages the starter motor. To crank the engine, it is the battery that supplies the electrical energy to the starter motor.

Typically, a reading of nine volts or more, with the starter motor turning at normal cranking speed is achieved.

The alternator and starting motor systems are all located in the engine bay.

A11.2.3 Chassis Electrical System

The electrical system in a typical passenger vehicle is a 12 volt, negative ground type from a lead/ acid type battery. This battery is charged by the alternator when the engine is running, supplies power for the lights and all electrical accessories (e.g. radio).

A typical electrical circuit consists of electrical components such as switches, relays, motors, fuses, fusible links or circuit breakers related to that component and the wiring and electrical connectors that link the component to both the battery and chassis.

Electrical problems usually arise from loose or corroded connections, a blown fuse, a melted fusible link or a bad relay. All components must be properly grounded.

A11.3. IDENTIFICATION OF POTENTIAL IGNITION SOURCES

A11.3.1 Identification

A review of passenger vehicle electrical systems was undertaken to identify areas where a potential ignition source existed. As given previously, the ignition source must be capable of generating sufficient energy to ignite a hydrocarbon mixture that is in the flammable concentration range. It is expected that the most likely source of potential ignition is arcing of electrical switches and relays on closing and opening. Another possible source is electrical motors fitted with carbon bushes which have the potential for spark generation. Ignition sources not associated with the normal operation of equipment in the vehicle (such as cigarettes and matches) can also result in ignition. However a report by Arthur D Little for the US Department of Energy (Ref.2) contains the results of a series of experiments conducted with ignition of non-inert refrigerants. It was found that only high energy ignition sources could cause ignition and not lit cigarettes or in-car cigarette lighters.

The potential for spark generation is dependent on the following factors:

- the size of current running through the component;
- the amount of inductance in the circuit. High inductance circuits (such as relay coils, motor windings, transformer windings) can generate high voltages at contacts when switches are operated, which can in turn lead to arcing;
- the degree of sealing of electrical contacts from the atmosphere; and
- the amount of wear and dirt on components which can reduce the voltage at which arcing can occur.

Arcing can also occur as a result of failures such as electrical shorting. The probability of ignition depends on the likelihood of a short occurring after a refrigerant leak has occurred and is still in the flammable range. The methodology undertaken was to assess the ignition potential from normal operations of electrical equipment.

A11.3.2 Car Cabin

In a modern car, a range of typical switches, relays and motors inside a passenger vehicle cabin are summarised in **Table A11.1**. These are typical of the range of components expected. **Figure A11.1** shows a typical layout for a power window system and **Figure A11.2** shows a layout for a power door lock system.

TABLE A11.1
ELECTRICAL COMPONENTS INSIDE A PASSENGER VEHICLE CABIN

Electrical System	**Components**
Combination on steering column	- wiper/ washer switch - headlight dimmer switch - light control switch - turn signal switch
Ignition assembly	- ignition switch
Cruise control assembly	- cruise control switch
Power window assembly	- power window motor - power window switch - master switch
Central door locking assembly	- door lock motor - door unlock detection switch - master switch - front passenger door lock manual switch
External rear view mirror assembly	- mirror adjustment switch
Radio assembly	- radio fuse
Others	- rear window defogger switch - interior light - stop light switch

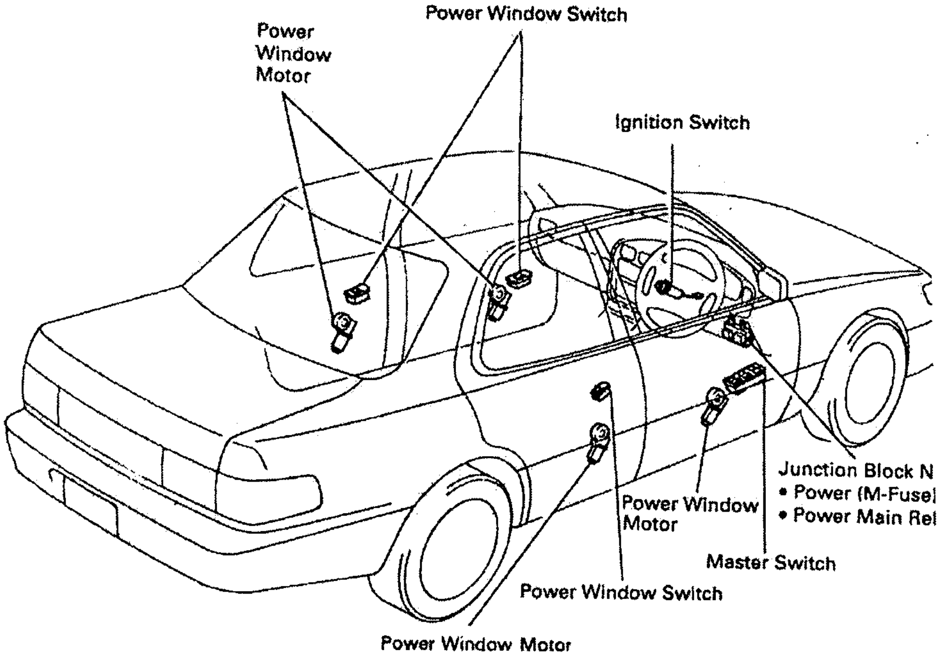


FIGURE A11.1
POWER WINDOW SYSTEM COMPONENT LAYOUT

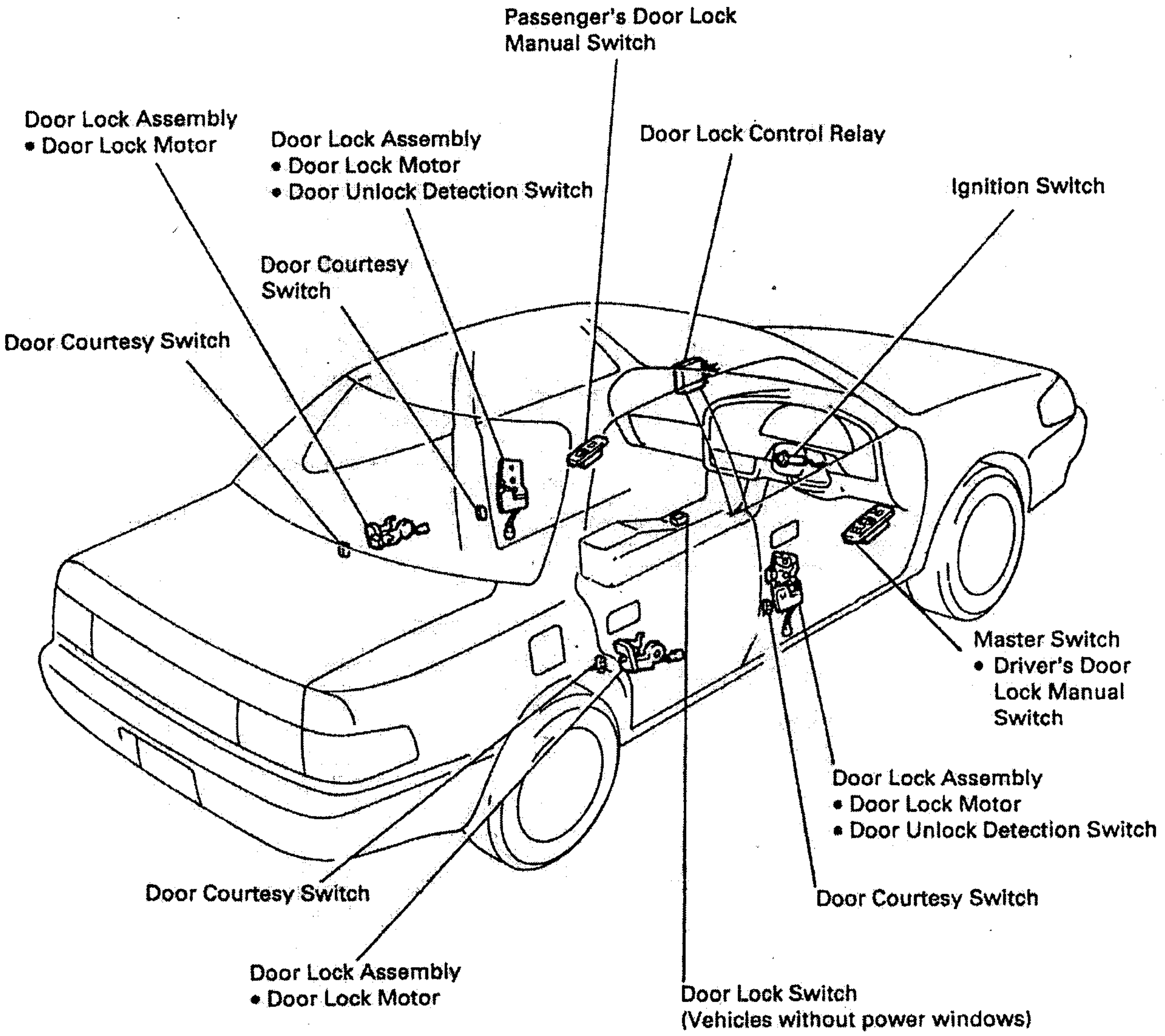


FIGURE A11.2
POWER DOOR LOCK SYSTEM COMPONENT LAYOUT

A11.3.3 Engine Bay

In a modern car, the location of typical switches, relays and motors inside the engine bay of a passenger vehicle is summarised in **Table A11.2**.

TABLE A11.2
ELECTRICAL COMPONENTS INSIDE PASSENGER VEHICLE ENGINE BAY

Electrical System	Components
Windshield wiper system	- windshield wiper motor
Horn system	- horn relay
Engine system	- ignition coil (primary) - ignition coil (secondary) - alternator/ generator - starter motor - starter motor solenoid
Others	- brake fluid level warning switch - neutral start switch - cruise control actuator - air-conditioning clutch - pressure switches - relays - fuses - headlights, etc.

A11.3.4 Others

Although not part of a passenger vehicle electrical system, other potential areas of concern are those with hot surfaces shown in **Table A11.3**.

TABLE A11.3
HOT SURFACES OF A PASSENGER VEHICLE

Location	Components
Passenger Vehicle Cabin	- none identified
Passenger Vehicle Engine Bay	- engine block (in operation) - exhaust manifold - radiator (upper section)

A11.4. EVALUATION OF POTENTIAL IGNITION SOURCES

A11.4.1 Voltage and Current Measurements

An initial assessment was made to determine voltage and current values from operation of electrical equipment. Based upon the reviews given in the earlier sections of this Appendix, a representative sub set of components from **Table A11.1** and **Table A11.2** was taken. This is shown in **Table A11.4**.

In order to measure the current and voltage associated with each component, a qualified autoelectrician was commissioned to undertake these readings. Testing was conducted on 5 May 1999 by Eastern Valley Automotive, MVRIC licence number 25148.

A11.4.1.1 Methodology

Rather than assess all potential electrical equipment which could be installed in vehicles, the approach taken was to determine the minimum ignition current from Appendix A of AS 2380.7 "Intrinsic Safety i" and compare this value with current values measured for a typical range of electrical equipment. In an initial set of tests, the testing was limited to obtaining the readings of voltage and current. As the refrigerant is predominantly propane, the curves for equipment classified to Group IIA in Appendix A of AS 2380.7 were used to determine the minimum ignition current.

It was assumed that circuits were either resistive (those that have an inductance less than 1 milliHenry)) or inductive (those that have an inductance greater than 1 milliHenry) . Figure A2 of AS 2380.7 gives the minimum ignition current for resistive circuits and Figure A5 for inductive circuits. Most cars currently operate with batteries of 12 Volts. For conservatism a battery voltage of 16 Volts was assumed, although the voltage could not reach this high in normal operation. This is the maximum voltage for a fully charged battery. The minimum ignition current is then about 4.5 amps for resistive circuits. To determine the minimum ignition current for inductive circuits, it was necessary to determine the inductance of the circuits considered. This was undertaken as described in **Section A11.4.2** below.

The methodology used for screening out a potential source was as follows:

For resistive circuits:

1. For the given maximum voltage (taken as 16 volts for a fully charged battery), from Figure A.1 provided in AS 2380.7i "Intrinsic Safety" (Ref.1), determine the minimum ignition current to ignite a mixture of propane and air (Group IIA material).

2. Measure the current across the selected resistive circuit. This was carried out by a licensed auto-electrician in a range of cars.

3. If the measured current in Step 2 is less than the minimum ignition current required as calculated in Step 1, then screen out the component as a potential ignition source.

For inductive circuits:

4. Measure the inductance of the selected component. This was carried out by Unisearch Limited, the consulting arm of the University of NSW (report prepared by Associate Professor T.R.Blackburn (Ref.3).

5. For the rated current of the component, obtain the inductance that would provide the minimum ignition energy for Group IIA material, from Figure A.5 of Ref.1. This is given for a 24V supply. Adjust this inductance value for a 16V supply, to give the same ignition energy, using the relationship $E=0.5\ LI^2$. This step assumes constant resistance and hence uses the relationship $I = V/R$.

6. If the measured current in Step 2 is less than the minimum ignition current required as calculated in Step 1, screen out the component as a potential ignition source.

7. If the inductance measured in Step 3 is less than that calculated in Step 5, then screen out the component as a potential ignition source.

A11.4.1.2 Results of Voltage/ Current Measurements

Table A11.4 details the measured voltage and current values associated with each component. The assessment of the components against the criteria of Ref.1 is discussed further after the inductance of circuits is determined in **Section A11.4.1**.

TABLE A11.4
MEASURED VALUES

Component	Measured Values	
	Voltage (V)	Current (A)
Passenger Vehicle Cabin		
Power window motor	12	3
Power windows switch	12	0.5
Ignition switch	12	0.5
Interior light	12	1
Central door lock motor	12	1.5
Fan motor	12	10
Passenger Vehicle Engine Bay		
Windscreen wiper	12	5
Starter motor	12	120
Ignition coil (primary)	12	3
Ignition coil (secondary)	12	3
Starter motor solenoid	12	4
Alternator	12	0

A11.4.2 Inductance Measurements

To determine typical values of inductance, Unisearch Ltd of the University of New South Wales were commissioned to undertake measurements of a range of typical electrical components. The following components were obtained from used spare parts dealers:

i Window winder motor:
Bosch: Germany, for a Commodore VB SL/E
Rated at 12 volts, 3 amps.

ii A/C Fan motor:
Harrison, GM: New York, for a Commodore VB SL/E
Rated at 12 volts, 10 amps (this is likely the full A/C rated current, not the fan only).

iii Central door lock motor:
by JIBECO, Japan: for Skyline, Series 1
Rated at 12 volts, 1.5 amps.

iv Windscreen wiper motor:
Lucas Australia: for Commodore VC.
Rated at 12 volts, 5 amps.

v Ignition coil:
Bosch Australia: for Telstar
Rated at 12 volts, 3 amps primary winding current.

vi Starter motor:
No obvious manufacturer identification on the unit.
Rating details supplied were: 12 volts, 4 amps solenoid and 120 amps cranking current.

In addition, the starter motors for the following vehicles were tested in situ:

- Toyota Corolla (1986);
- Mitsubishi Verada (1998); and
- Holden Commodore (1998).

The inductance values were measured with an AIM bridge used in series mode with 1 kHz frequency. The inductance measurement accuracy was checked with a number of standard inductors within the range of values measured.

The uncertainty of the measurements was estimated to be better than 4%.

The measured inductance values are given in **Table A11.5**. The corresponding energy stored in the inductance, based on the rated current is also given, using the equation $E = 0.5 L I^2$ (Joules).

TABLE A11.5
MEASUREMENT OF COMPONENT INDUCTANCE

Component	Rated Current (amps)	Measured inductance (milliHenry)	Stored Energy (Joule, based on rated current)	Resistive Circuit (Inductance <1mH)	Minimum Igniting Current (amps)	Evaluation
Cabin Equipment						
Window winder	3	0.450	0.002	Yes	4.5	Rated current less than minimum igniting current.
Fan motor	10	0.308	0.016	Yes	4.5	Rated current exceeds minimum igniting current.
Door lock motor	1.5	1.60	0.002	No	0.65	Rated current less than minimum igniting current.
Engine Bay Equipment						
Windscreen wiper motor	5	1.92	0.024	No	0.6	Rated current exceeds minimum igniting current. Unlikely to be operated at the same time as a significant leak.
Ignition coil: Primary	3	5.00	0.023	No	0.35	Rated current exceeds minimum igniting current.
Ignition coil: Secondary	-	38,800	< 0.023	No	Offscale, <20mA	Stored energy in coil secondary depends on primary stored energy. The energy transfer efficiency will be less than 100%.
Starter motor: Solenoid	4	0.5	0.004	Yes	4.5	Rated current exceeds minimum igniting current. Unlikely to be operated at the same time as a significant leak as occupants would detect leak.
Starter motor: Cranking motor	120	1.2	8.7	No	0.75	Rated current exceeds minimum igniting current. Unlikely to be operated at the same time as a significant leak.

Table A11.6 summarises the inductance values for the starter motors measured in situ for the sample cars. No details of the current ratings of these items were available, however it is expected that the current ratings will be similar and that the stored energy values will be similar.

TABLE A11.6
MEASUREMENT OF IN-SITU STARTER MOTOR INDUCTANCE (CRANKING MOTOR)

Component	Measured inductance (milliHenry)	Comments
Toyota Corolla	1.7	-
Mitsubishi Magna	0.94	-
Toyota Corolla	1.27	-

A11.4.3 Evaluation of Stored Energy in Inductive Components

A report for the US Bureau of Mines (Ref.4) gives the minimum spark ignition energy of propane in air as 0.26 mJ (2.6E4-5). Therefore, the components in **Table A11.5** will have a higher stored energy than the minimum spark energy required for ignition of a refrigerant leak. However, the potential for ignition will be reduced for the following reasons:

- Not all stored energy will be converted to spark energy as electrical equipment are designed to minimise the generation of sparks under normal operating conditions.
- The amount of intrinsic protection provided by equipment casings (i.e. central door lock sealed unit) is not taken into account.

A11.4.3.1 Evaluation Against AS2380.7

There are some components in the vehicle cabin, which according to the methodology of AS2380.7i (Ref.1) could potentially be an ignition source. The likelihood of these components resulting in ignition will depend on the level of intrinsic protection. It would be conservative to assume that there could potentially be some components used which would have little intrinsic protection as a range of components from different manufacturers could be used. Some protection from ignition would be provided by panelling as well, but the ignition potential is not readily assessable. Of particular concern is the ventilation fan motor, as it has a high current (about 10 amps) and would be normally in service when the air-conditioning is in service. However, if the fan is running a flammable mixture would not be generated in the vehicle cabin.

The central door locking mechanism has the stored energy that exceeded the minimum ignition energy for ER12. However, this circuit is essentially behind panelling and, even though not electrically sealed, i.e. is not directly exposed to the vapour-air mixture, unless the unit was damaged, or shorting occurred at the time of operation, releasing a high-energy ignition source. The unit is typically housed in a strong plastic casing.

There is also equipment in the engine bay which has the potential for ignition, but in this case a leak of refrigerant would have to occur in the engine bay and there would be protection from fires to passengers in the vehicle cabin.

A11.4.3.2 Ventilation Fan Speed Control Resistance

Heat produced from resistance has also been identified as another potential ignition source. The most likely source is the ventilation fan control unit that has a stepped series of resistors which are operated to control the speed of the fan motor. To determine the likelihood of ignition, a number of texts and manuals were referenced and figures on resistance values obtained.

One text (Ref. 5) gives figures of about 2Ω (ohms) for a typical car. The power lost due to resistance can be obtained by the formula $E = V^2/R$ where V is the voltage across the resistor and R the resistance. Assuming a conservative value of 16V across the resistor, this gives a power of 128 Watts. Given that the ignition temperature of propane is 466°C, the potential for ignition can be disregarded as the resistor will not reach this temperature.

A11.4.3.3 Conclusions

A preliminary assessment was made using AS 2380.7i (Ref.1) to determine the stored energy in resistive and inductive circuits of the electrical components in automobiles. It was found that some circuits would have sufficient stored energy to ignite a flammable mixture of hydrocarbon refrigerant according to AS 2380.7i (Ref.1). Of these, only the central door lock motor is likely to be operated when the vehicle is parked.

The stored energy does not mean automatic ignition, as there should be a fault in the electrical component to release a part of this energy towards ignition of a potential hydrocarbon refrigerant-air mixture.

The ignition probabilities used in the safety assessment is given in **Table AII.7**. Further details are given in **Appendix 12**.

TABLE AII.7
IGNITION VALUES USED IN STUDY

Ignition	Value Used in Study
Immediate ignition probability due to intrinsic failures (car moving)	0.01
Delayed ignition probability due to intrinsic failures (car moving)	0.01
Immediate ignition probability due to intrinsic failures (car stationary)	0.001
Delayed ignition probability due to intrinsic failures (car stationary)	0.001

A11.5. REFERENCES

1 Standards Australia (1987): AS 2380.7i – 1987, "Intrinsic Safety".

2 Arthur D Little (1995): "Risk Assessment of Flammable Refrigerants, Part 3: Car Air Conditioning", Cambridge.

3 T.R. Blackburn (1999): "Inductance Measurements on Automotive Electrical Components", Unisearch Limited, The University of New South Wales, Sydney.

4 J.M. Kuchta (1985): "Investigation of Fire and Explosion Accidents in the Chemical, Mining and Fuel-Related Industries – A Manual", US Department of the Interior, Bureau of Mines, Bulletin 680.

5 James E. Duffy: "Modern Automotive Mechanics", Goodheart-Willcox Company, South Holland, Illinois.

APPENDIX 12

FAILURE RATE DATA (DATA COLLECTION SURVEY)

TABLE OF CONTENTS

A12.1. INTRODUCTION

A12.1.1 General

This Appendix contains the rationale for the development of the rule sets for leak sizes used in the Safety Study as well as the associated frequency data. Granherne coordinated an extensive literature review with the following organisations including:

- UNSW Research and Professional Information Delivery (RAPID) Services.
- Newtek Pty Limited.
- Boral Energy.
- Boral Esanty.

A considerable amount of information is available in the literature on automobile air-conditioning systems. However, the focus of this literature has been under the broad headings of air-conditioning systems, refrigerant replacements to CFC, retrofitting, components associated with air-conditioning.

Little data was available in the public arena on parameters useful for a safety assessment. These parameters include risk assessments, quantification of leaks from air-conditioning systems as well as leak frequency data and failure modes of components. Other important parameters included car ventilation rates, vehicle volumes and air exchange rates.

There were very few reliable databases containing this information. Agencies such as the Federal Office of Road Safety and Standards Australia were contacted but no information was available. In addition, Granherne directly approached the car manufacturers and air-conditioning specialists such as General Motors Holden, Ford Australia and Air International. However due to confidentiality issues, information was not made available to Granherne.

Databases that did exist were related to numbers of registered vehicles and distribution of new vehicles in Australia and by state.

Therefore, it was necessary to obtain the required data for the Safety Report directly from the field in the form of surveys. This appendix outlines the survey results and their interpretation as well as the data analysis performed to obtain the required frequency values.

A12.1.2 Purpose

The purpose of this Appendix is to outline the methodology, results and derivation of leak frequency rule sets used in the Safety Study.

A12.1.3 Objectives

The objectives of this Appendix were to:

- provide results from the field surveys;
- provide discussion from interviewed accredited automotive mechanics on the results in relation to faulty equipment and their failure modes;
- undertake a parts count of a typical air-conditioning system;
- provide a rule set for leak sizes to be used in the Safety Study; and
- develop the frequency database to be used in the Safety Study.

Note:

1. A comprehensive failure modes and effects analysis (FMEA) study of a vehicle air-conditioning system has been included in **Appendix 2**.

A12.2. FIELD SURVEYS

A12.2.1 Introduction

Field surveys were carried out during January and June 1999 in Melbourne, Adelaide, Perth and Brisbane of motor vehicle repairers to collect data for frequency analysis in this report. The survey took the form of a questionnaire that was filled in during face-to-face interviews with accredited automotive mechanics in their workshop areas.

These cities were chosen for the following reasons:

- Both HCFC and HC products have been in use in South Australia, Western Australia and Victoria. Victoria has been using hydrocarbon refrigerants for a minimum of four years.
- Workshops in South Australia, Western Australia and Victoria were chosen as they had experience in both HCFC and HC products.
- Workshops in Queensland were chosen to gain experience of air-conditioning systems operating in high humidity conditions.

A total of 68 surveys were conducted. This was considered a reasonable sample population to derive statistically meaningful results. The survey distribution is given in **Table A12.1**.

TABLE A12.1
SURVEY DISTRIBUTION

State	No. of Surveys	Type of Refrigerant
Queensland (Brisbane)	12	HCFC
South Australia (Adelaide) and Western Australia (Perth)	19	HCFC/ HC
Victoria (Melbourne)	37	HCFC/ HC
TOTAL	**68**	

The survey's questions were developed to collect data from which leak frequencies could be calculated for the risk analysis section of this report. The leak size and source were particular objects of interest in the survey and detailed questions in this regard were asked. The survey sheet used is shown as **Figure A12.1**.

Melbourne

The survey was carried out in Melbourne in January 1999. Selected raw data is shown in **Table A12.2**. The results shown are those used in the subsequent calculations and data analysis for calculation of frequencies.

The MVAC repairers surveyed in Melbourne serviced vehicles with HFC or HC refrigerants.

A follow up survey was conducted in June 1999 with selected workshops to further refine the leak frequency of air-conditioning system components located in the vehicle cabin. These components were the thermal expansion valve (Tx) and evaporator.

Brisbane

Newtek Pty Ltd carried out the survey in Brisbane on Granherne's behalf during February 1999.

Twelve workshops were surveyed for data collection in this area. All the workshops serviced vehicles with HFC refrigerant only. The raw data is shown in **Table A12.3**.

Adelaide and Perth

The survey was carried out in Adelaide and Perth in April 1999 by Granherne. Nineteen workshops were surveyed for data collection.

The workshops serviced vehicles with HFC or HC refrigerants. The survey results are summarised in **Table A12.4**.

A follow up survey was conducted in June 1999 with selected workshops to further refine the leak frequency of air-conditioning system components located in the vehicle cabin. These components were the thermal expansion valve (Tx) and evaporator.

FIGURE A12.1
SURVEY QUESTIONNAIRE FORMAT

Date:	
Name of Company/ Repairer:	
Address:	
Name of Contact:	

1	How many cars are serviced here each day or per week?			
				/day or /week
2	How many days/weeks per year are you open? (ie: Mon-Sat, except Public Hols? etc)			
3	How many car air-conditioning systems are serviced per day or per week? (as for Qn 1)			
				/day or /week
4	How many of those car air-conditioning systems are recharged with refrigerant?			
				/day or /week
5	What type of refrigerant is used (%)?			
	HCFC	HC	CFC	Other
6	What types of leaks occur in the car air-conditioning system (%)?			
	Pinhole	Small	Rupture	Other
7	How many AC systems are damaged and in need of mechanical repair (%)?			

8	Where are they damaged (%)?						
	evaporator	condenser	compressor	TX valve	pipework	receiver drier	other

Other questions:

9	If there is damage to the AC system, what is the extent, the cause, the effects, the potential of leakage? etc.
10	How do you think pinhole/ small leaks occur?
11	Have you ever heard of explosions/ fires in cars due to air-conditioning refrigerant leaks?
12	Do new systems leak less than older designs?
13	Are systems designed for R134a? Are systems changed over to HC after repair or refilled with R134a?
14	Can you estimate an average leak rate on a yearly basis?

TABLE A12.2
MELBOURNE SURVEY RESULTS

No.	No. cars serviced / week	No. days open/ week	No. AC systems serviced / week	Leak Type (%)			Leak Source (%)								
				Pinhole	Small	Large	Evap	Cond	Comp	Tx	Pipework	Receiver / drier	O-rings	Seals	Other
1	66	6	66				15	15			15		40	15	
2	20	5	20												
3	36	6	36												
4	66	5.5	22					10	5	5		5	75		
5	44	5.5	44	90			10				30		30	30	
6	30	6	12		50		16	16		17	17	17		17	
7	100	6	100						20				80		
8	9	5.5	9				40				30				30
9	40	6	1	90				25	25	25		25			
10	25	5	3	90			30	30		10			30		
11	40	5.5	25		95	5		50	25		25				
12	37	5	12	9	90	1		50			50				
13	45	6	3.5	80	20			34	33			33			
14	45	6	35	45	45	10		30	30	20		10	10		
15	25	6	12		100		50	50							
16	25	5.5	24				25	25	25		25				
17	35	5.5	35	40				80			20				
18	55	6	3.5	90				30	30		40				
19	22	6	9	100			30	30	10	10	10	10			
20	75	5.5	50	80	20			20			80				
21	125	5	38	60	40										
22		5	25	50	50				45	10	45				
23	30	5	2	90	10		45				45				

TABLE A12.2
MELBOURNE SURVEY RESULTS

No.	No. cars serviced / week	No. days open/ week	No. AC systems serviced / week	Leak Type (%)			Leak Source (%)								
				Pinhole	Small	Large	Evap	Cond	Comp	Tx	Pipework	Receiver / drier	O-rings	Seals	Other
24	20	5	20	90			40		40			20			
25	83	5.5	83				20	20			30		30		
26	50	5	10												
27	50	5	8												
28	165	5.5	65				30	30					40		
29	6	5													
30	20	5	10	90				40		30	30				
31	45	5	15		100								100		
32		5	12				15	60				15		20	
33	12	5.5	12	50	50						50		50		
34	20	5	3				40				30		30		
35	20	5.5	20				25	25	25		25				
36	480	6	240	50	50		20	20	20			20	20		
37	55	6	30	50	25	25	33	33			34				

TABLE A12.3
BRISBANE SURVEY RESULTS

No.	No. cars serviced / week	No. days open/ week	No. AC systems serviced / week	Leak Type (%)			Leak Source (%)								
				Pinhole	Small	Large	Evap	Cond	Comp	Tx	Pipework	Receiver / drier	O-rings	Seals	Other
1	10	6	10	45	45	10		100							
2	40	5.5	40		80	20		80			10	10			
3	40	5	40	10	80	4		100							
4	22	5.5	18					100							
5	25	5.5	12	8	90	2									
6	23	5.5	23	20	80										
7	40	5.5	15	3	95	2									
8	60	5.5	60	2	92	3									
9	60	5.5	60	20	70	10		60	30		10				
10	42	5.5	42	25	60	2		100							
11	33	5.5	17	10	80	2									
12	50	5	15	2	95	2		90				10			

TABLE A12.4
ADELAIDE/ PERTH SURVEY RESULTS

No.	No. cars serviced / week	No. days open/ week	No. AC systems serviced / week	Leak Type (%)			Leak Source (%)								
				Pinhole	Small	Large	Evap	Cond	Comp	Tx	Pipework	Receiver / drier	O-rings	Seals	Other
1	25	7	25												
2	60	6	22	80	20			20	10				70		
3	55	5.5	11	90		10	30						70		
4	33	6	18	90	5	5	5	10	5				60	20	
5	100	5		80	15	5	10	20							70
6	20	5	3	85	10	5	10	20					70		
7	100	6	90	98	2		1	4					95		
8	60	5	5	99	1		5	5	5				85		
9	20	6	2	90	5	5		10	10				80		
10	60	6	12	90	10			15			15		70		
11	50	5	5	20	60	10	10	10	10	10			60		
12	60	6	18	90	9	1	2	5	5	5	10	10			
13	36	6	18	90	10			30	10				60		
14	25	5	15	85	10	5	10	30	20	10		30			65
15	24	6	24	75	15	10		20	10				70		
16	60	6	6	89	10	1		20					80		
17	60	6	18	90	10			30	20				50		
18	150	6	72	90	10			15	10		25		50		
19	108	6	60	90	8	2	5	5	5	5	10		70		

A12.2.2 Results

The raw data was then distributed to provide the following:

- Proportion of total vehicles serviced that have air-conditioning,
- Leak size distribution,
- Leak location distribution.

Statistical methods were also employed to demonstrate that the raw data sets were compatible and related to each other. The results are given in **Table A12.5** through to **Table A12.7** as well as shown in graphical form in **Figure A12.2** through to **Figure A12.4**.

TABLE A12.5
VEHICLES SERVICED BY SURVEYED WORKSHOPS

No.	Parameter	Value
1	Total number of vehicles repaired in surveyed workshops	3502 per week
2	Number of vehicles serviced with air-conditioning systems	1832 per week
3	Percentage of vehicles with air-conditioning systems	52.3

TABLE A12.6
LEAK SIZE DISTRIBUTION

Survey Location	Leak Type from Air-conditioning System		
	Pinhole	Large	Catastrophic
Melbourne	57%	39%	4%
Brisbane	13%	82%	5%
Adelaide	84%	12%	4%
Average	51%	44%	4%

TABLE A12.7
LEAK LOCATION DISTRIBUTION

Survey Location	Air-conditioning System								
	Evap.	Tx valve	‘O’ Ring	Compr. unit	Seals	Hoses	Cond.	Drier	Other
Melbourne	12.5	4.6	16.8	11.3	3.5	19	23.9	5.3	3.0
Brisbane	0	0	0	4.3	0	2.9	90.0	2.9	0
Adelaide	4.9	1.7	57.8	6.7	1.1	3.3	14.9	2.2	7.4
Average	5.8	2.1	24.9	7.4	1.5	8.3	42.9	3.5	3.5

FIGURE A12.2
LEAK SIZE DISTRIBUTION IN ENTIRE AIR-CONDITIONING SYSTEM (ENGINE BAY AND PASSENGER CABIN)

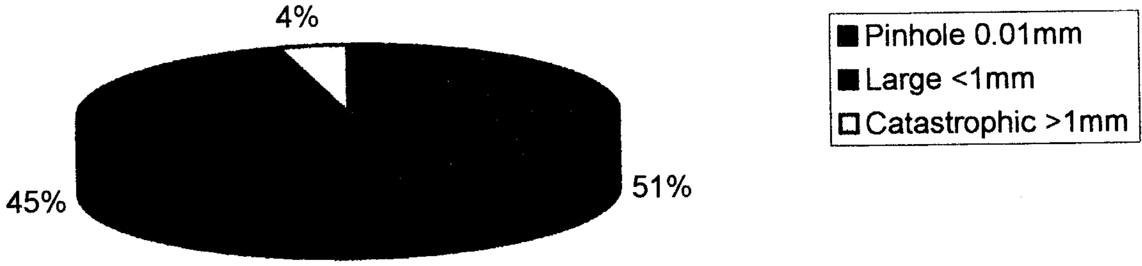


FIGURE A12.3
DISTRIBUTION OF LEAK LOCATIONS IN ENTIRE AIR-CONDITIONING SYSTEM

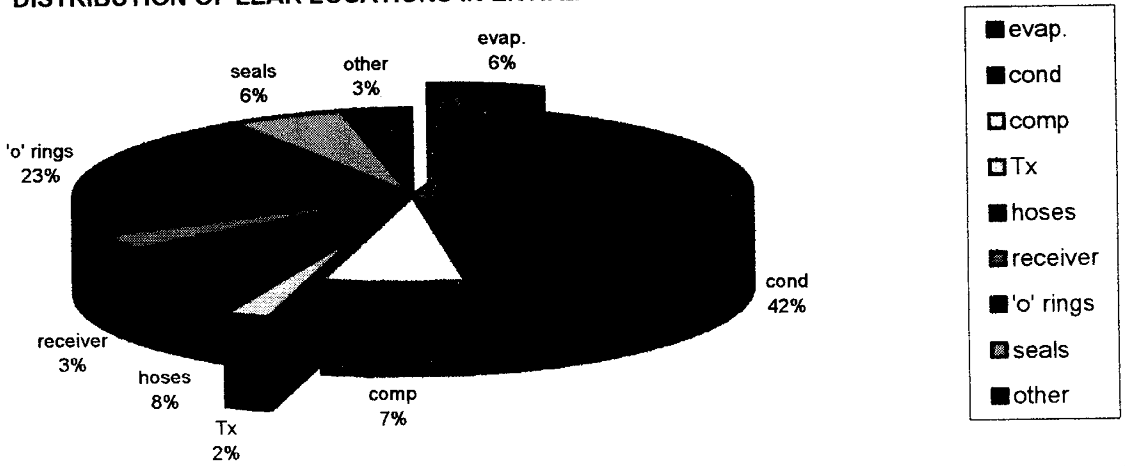
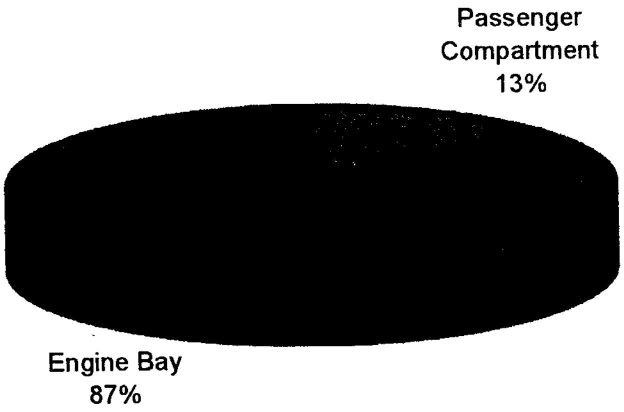


FIGURE A12.4
DISTRIBUTION OF LEAK SOURCES IN ENGINE BAY AND PASSENGER CABIN



A12.2.3 Discussion

The following comments are made with regards to the above results:

- All survey locations provided consistent values in terms of leak sizes.
- Survey results for Brisbane displayed a higher tendency for leaks arising from condensers followed by hoses and driers. All these components are located in the engine bay.
- Approximately 52% of all vehicles are fitted with air-conditioning systems. This value compares favourably with a statistic published by NSW Motor Vehicle Repair Industry Council of 50% (Ref.1).
- The majority of leaks fell between the leak classification of "pinhole" and "large".
- 44% of all leaks were defined as "pinhole". As given in **Section A12.3**, a pinhole leak was defined by the accredited automotive mechanics as a leak that occurs over "a period of 3-6 months".
- 52% of all leaks were defined as "large". As given in **Section A12.3**, a large leak typically occurs in the engine bay where air-conditioning system components are typically moving or exposed to vibration and corrosion. Failure modes are discussed in **Section A12.3**.
- Of the vehicles fitted with air-conditioning and assuming that the thermal expansion (Tx) valve is located inside the firewall, approximately 14%[1] have exhibited a leak inside the cabin. A detailed parts count is given in **Section A12.5**.

Section A12.6 details the leak frequencies developed for components inside a passenger vehicle cabin.

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[1] Conservatively assuming that the Tx valve is located inside the passenger cabin, approximately 2 'O' rings (**Section A12.5**) are present. This represents 25% of the overall number of 'O' rings. Thus the total percentage of leaks inside a cabin is equal to the sum of evaporator, Tx valve and its 'O' ring fittings. This value is estimated to be 14% (2%+6%+0.25(23%)).

A12.3. FAILURE MODES AND LEAK SIZES OF SYSTEM

A12.3.1 Introduction

The purpose of this section is to outline the failure modes of air-conditioning system components as gathered from the workshop surveys. In addition, comments regarding the typical leakage rate and leak size are given. The rule sets for leak size distribution are also provided. Finally comments are made regarding incidents involving ER12. This section is intended to supplement the FMEA study given in **Appendix 2**.

A12.3.2 Failure Modes of Components

This section summarises comments made by workshops regarding failure modes of motor vehicle air-conditioning systems. On average, each workshop had 10 years experience in automotive air-conditioning systems. This collectively represents more than 680 years of experience.

The survey focused more on causes of leaks in the air-conditioning components rather than issues relating to performance characteristics. A summary of the comments is presented in **Table A12.8**.

A12.3.3 Summary of Leak Size Rule Sets

Following from the workshop surveys and FMEA study, it was necessary to develop a rule set for leak sizes for the engine bay and passenger compartment. Based upon observations and discussions, the leak sizes for components inside the passenger cabin were found to be at least an order of magnitude lower than for the engine bay. This arises since:

- there are no moving air-conditioning components,
- components experience minimal vibration within the passenger cabin, and
- the evaporator is enclosed in a casing.

For the purposes of the Safety Study, the rule sets used in the analysis are given in **Table A12.9**.

TABLE A12.8
FAILURE MODES OF AIR-CONDITIONING COMPONENTS

No	Component	Typical Causes of Leak	Typical Leak Size	Detection of Leak	Comments
1	Evaporator (inside passenger cabin)	- corrosion	- pinhole and nearly undetectable (0.01mm and leak over period of weeks/ months) - some weeping (< 0.1mm – for an Australian manufactured vehicles) - workshops dismissed rupture scenarios	- dye testing - pressure testing - oil stain ("tell tale") - drain hole in evaporator housing unit (for large leaks)	- very difficult to detect - majority of leaks are so small can only go by "tell tale" oil stains - pressure still held for months (3 or more) - the evaporators of some popular Australian manufactured vehicles are particularly susceptible to leakage
2	Piping/ hoses (engine bay)	- abrasion and thinning against engine bay - heat stress from pipe touching hot surfaces - vibration (engine bay) - corrosion	- fine cracks - split pipework - blown hoses	- pressure testing	- blown hoses can occur frequently in the engine bay - cracks in piping depends on age (1 in 10 year leak)

TABLE A12.8
FAILURE MODES OF AIR-CONDITIONING COMPONENTS

No	Component	Typical Causes of Leak	Typical Leak Size	Detection of Leak	Comments
3	'O' rings (engine bay and passenger cabin)	- incorrect installation ('O' ring rolled not placed on properly) - incorrect installation ('O' ring squeezed too hard and becomes flat) - AC not used frequently with seals drying out	- fine cracks in 'O' ring - pinhole size (loss over days for Tx valve 'O' rings)	- by oil residue - by pressure testing	- 'O' ring leak quite susceptible for vehicles with Tx valve located in engine bay - 'O' rings in Japanese vehicles last for 5 years or more - hydrocarbon refrigerant is compatible with seals (cf R134a)
4	Tx Valve (engine bay and passenger cabin)	- defective unit from new (very rare)	- cracks in unit less than 1mm equivalent diameter - Tx valve units do not generally leak only fittings	- by oil residue - by pressure testing - by dye testing	- majority of workshops reported 9/10 times leaks from Tx valves are 'O' rings - rare as Tx valve bodies are made from brass
5	Condenser (engine bay)	- stone chips - acid from squashed insects	- start off as minor leaks	- visual oil stains - dye testing - pressure testing	- susceptible component of system
6	Compressor (engine bay)	- loss of oil and gas in system	- very small seal leaks (0.1mm and up)	- pressure testing - dye testing - oil stain	- hydrocarbon refrigerant is compatible with MVAC compressor units - susceptible component of system

TABLE A12.9
LEAK SIZE RULE SETS USED IN SAFETY STUDY

Location	**Leak Category**	**Equivalent Leak Size (mm)**
Engine Bay	Catastrophic	12 (vapour line) 8 (liquid line)
	Large	1
	Typical	0.1
Passenger Cabin	Catastrophic	1
	Large	0.1
	Typical	0.01

A12.4. INCIDENTS INVOLVING ER12

A12.4.1 Introduction

A prime objective of the workshop surveys and reviews was to determine if there had been any incidents in terms of release, ignition and fire from the use of the refrigerant, ER12.

Granherne found there have been no reported fire incidents in Australia or problems associated with the use of ER12 in automobiles.

A12.4.2 Incidents in the Workshops

As given in Question 11 of the survey form **Figure A12.1**, Granherne found that most workshops had not observed or heard of any fires or explosions resulting from the use of the refrigerant product.

The assessors did note that some workshops had "heard" from industry of service garages experiencing explosions and fires. However, upon further questioning, no reliable reference or source could be produced. These stories could only be classified as unsubstantiated.

Those workshops that did use hydrocarbon refrigerant were questioned on venting practices. Given that the workshops are typically large open garages with good venting, buildup of released refrigerant was not considered to be a major issue. Further the amount of gas released (up to 300 grams) was considered to be minor.

Some workshops reported experiencing a leak of refrigerant during charging which was directed across a running engine. However, no ignition occurred. One workshop reported igniting a release during charging and a small fire occurred over a short period of time. The flame was likened to the shape from a cigarette lighter and could be extinguished by blowing across it.

Use of ER12 in Vehicles

Granherne through Boral Esanty could not gather any evidence of vehicles experiencing a fire or explosion from the use of hydrocarbon refrigerant. This includes vehicles currently using the ER12 product.

During the course of the study, Granherne was only able to source one documented case where a vehicle using ER12 refrigerant had been involved in an accident. No fire or explosion resulted from this crash of which details are provided below.

Details of the crash were as follows:

- The vehicles involved in the collision were a Ford Panelvan and a late model Holden Vectra.
- The Holden Vectra was fitted with an air-conditioning system. The system was charged with approximately 250 - 270 grams of ER12 refrigerant.
- The accident occurred in Victoria (Grange Road, Toorak 11/5/99 8:16 am) where the panel van failed to give way at a stop sign.
- The Holden Vectra was involved in a front on collision at approximately 40-50 km/hr.
- The impact was described as heavy and caused substantial damage to both vehicles.
- In particular, the Holden Vectra suffered the following damage: - radiator, bumper bar, R/H headlight, R/H guard, bonnet, and a number of other parts including the AC condenser, AC Receiver Drier, AC and Engine fans, AC hoses and pipework.
- The condenser was ruptured and a total loss of refrigerant occurred. The driver reported the refrigerant appeared as a white cloud that very quickly dissipated. There was no ignition, and no explosion nor fire.

Photographs of the damaged Holden Vectra are given in **Figure A12.5** and **Figure A12.6**.

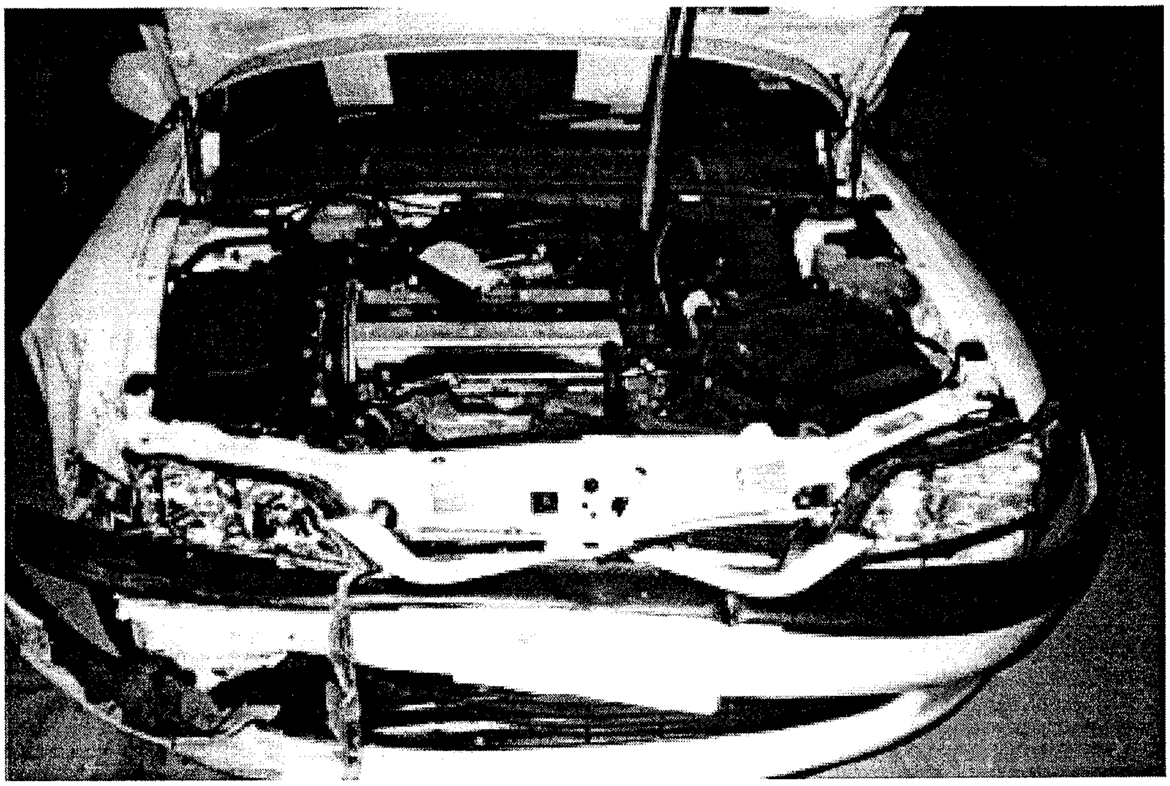


FIGURE A12.5
PHOTOGRAPH OF DAMAGED VEHICLE – 1

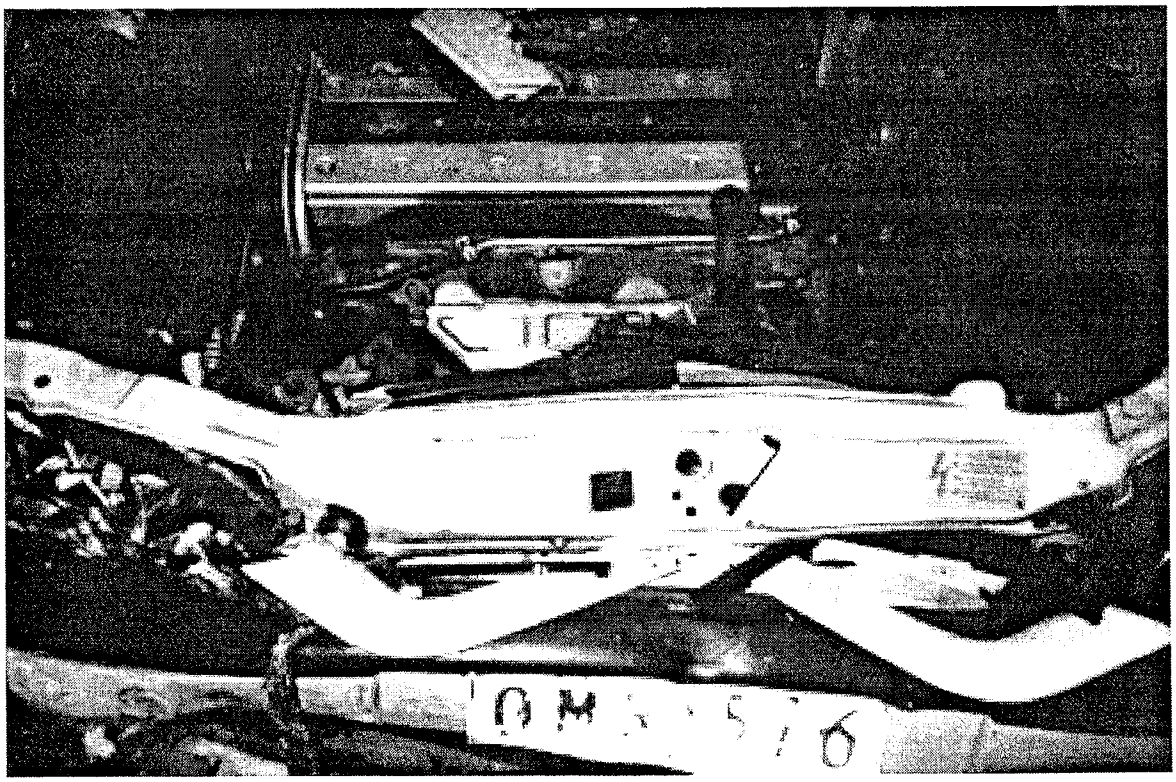


FIGURE A12.6
PHOTOGRAPH OF DAMAGED VEHICLE – 2

A12.5. PARTS COUNT OF AIR-CONDITIONING SYSTEM

A12.5.1 Introduction

The purpose of this section is to undertake a parts count of a typical vehicle air-conditioning system. This data is then used in determining the leak frequency from components located inside the passenger cabin.

Emphasis has been placed on the passenger cabin since incidents involving a leak of refrigerant in the engine bay have been shown not to affect occupant(s) of the passenger cabin.

A12.5.2 Parts Count

A drawing of the basic components of the air-conditioning system is given in **Figure A12.7**. A schematic of this air-conditioning system is given in **Figure A12.8**.

A summary of the parts count of fittings is shown in **Table A12.10** and **Table A12.11**. A reference to each component listed in the table is provided in **Figure A12.8**.

TABLE A12.10
PARTS COUNT OF FITTINGS IN A TYPICAL AIR-CONDITIONING SYSTEM

Air-conditioning System		Fitting Type	Number of Fittings	Ref. in Fig. A12.8
From	To			
Compressor	-	Seal on suction and discharge lines	2	A, B
Compressor	Condenser	'O' ring seal and screwed fitting	2	C, D
Condenser	-	None – seamless with no welded elbows	n/a	
Condenser	Receiver/ Drier	'O' ring seal and screwed fitting	1	E
Receiver/ Drier	Expansion valve	'O' ring seal and screwed fitting	1	F
Expansion valve	-	'O' ring seal and screwed fitting (or flared joint) upstream and downstream	2	G, H
Expansion valve	Evaporator	None – seamless with no welded elbows	n/a	
Evaporator	Compressor	'O' ring seal and screwed fitting	2	I, J

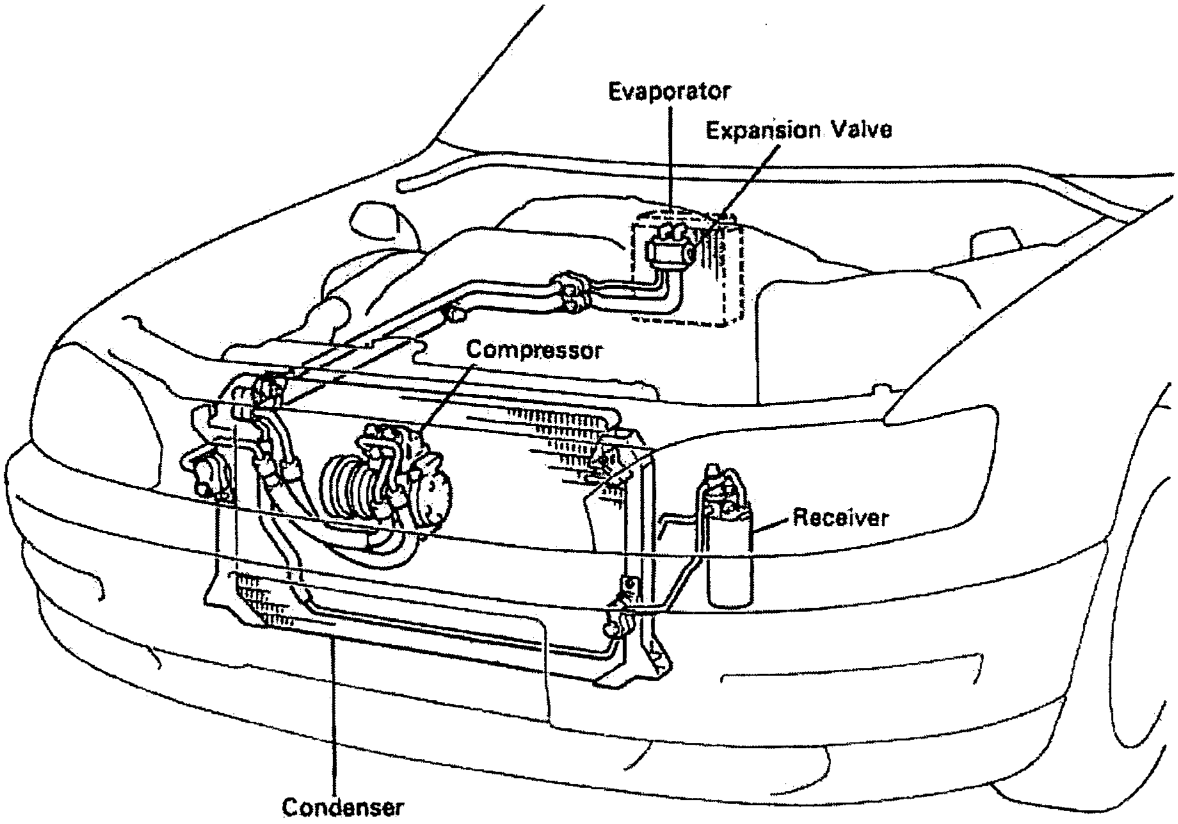
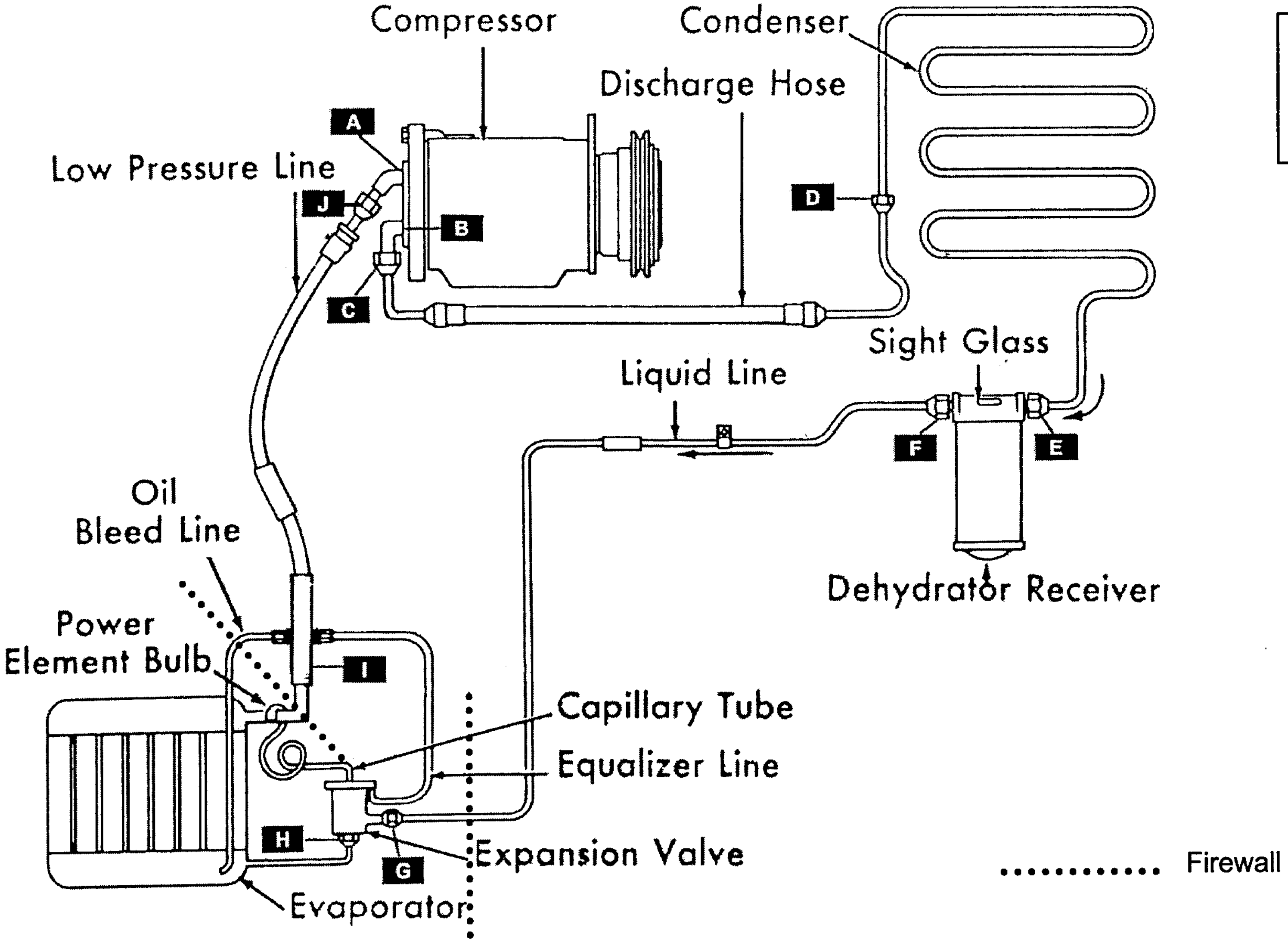


FIGURE A12.7
DRAWING OF TYPICAL VEHICLE REFRIGERATION SYSTEM

FIGURE A12.8
SCHEMATIC OF TYPICAL VEHICLE REFRIGERATION SYSTEM



Using **Table A12.10**, the distribution of the fittings within the vehicle may be done as shown in **Table A12.11**.

As shown in the previous drawings, the location of the various components of the air-conditioning system may be conveniently divided between the engine bay and passenger cabin. These two areas are separated by the firewall.

In discussion with workshops, it was found that Tx valves might be present in either the engine bay or passenger cabin. In general, General Motors Holden and Ford vehicles have their Tx valves in the engine bay whilst most popular Japanese makes have the valves positioned in the passenger compartment.

Conservatively assuming that the thermal expansion valve is located inside the passenger cabin, the number of fittings (and hence potential leak sources) is two or 25% of the total 'O' ring fittings.

TABLE A12.11
DISTRIBUTION OF 'O' RING FITTINGS

Location	**Number of 'O' Ring Fittings**	**% of Total**
Engine Bay	6 (locations C, D, E, F, I, J on **Figure A12.8**)	75
Cabin	2 (locations G, H)	25
Total	8	100

A12.6. FREQUENCY USED IN SAFETY STUDY

A12.6.1 Base Frequencies

The base frequency values for the Safety Study were determined from the survey data obtained from the workshops (**Section A12.2**). Only evaporator and Tx valve base failure frequencies were calculated as they are the only two components that can fail and cause a leak into the passenger compartment of a car. The base frequencies are shown in **Table A12.12**.

TABLE A12.12
BASE FREQUENCY VALUES

Component	Base Frequency Value	Justification
Evaporator	0.00191 evaporator failures /car-year	A range of evaporator leak frequencies per year was obtained from the survey data (0 to 750/year). These values were then used to obtain the evaporator failures/ car-year using the number of cars with air-conditioning repaired by each workshop to do the calculation. The base frequency is an average of these results.
Tx valve fittings	0.043 Tx valve failures /car-year	Similarly, a range of Tx valve leak frequencies per year was obtained from survey data (0.2 to 12/year) and these were used to calculate the Tx valve failures /car-year. The base frequency is an average of these results.

A leak frequency for each leak category (typical, large, catastrophic) was required for use in the risk calculations. The values selected are shown in **Table A12.13**. These values were calculated by distributing the base frequencies given in **Table A12.12** as follows:

• Typical (0.01mm)	90% base frequency
• Large (0.1mm)	9% base frequency
• Catastrophic (1mm)	1% base frequency

Over a total of 46,950 car years there were no 1mm evaporator failures. Using a binomial distribution, the failure frequency for a 1mm leak can be predicted with a 50% confidence limit as:

$$= 1 - (1 - 0.5)^{1/46950}$$
$$= 1.5\mathrm{E} - 05 / \mathrm{car} - \mathrm{year}$$

This value is in close agreement with the value for this category given in **Table A12.13** (1.91E-05/ car-year, for a 1mm evaporator failure).

TABLE A12.13
LEAK FREQUENCY DISTRIBUTION

Component	Leak Category	Leak Size (mm)	Leak Frequency (/ car-year)
Intrinsic			
Evaporator	Typical	0.01	1.72E-03
	Large	0.1	1.72E-04
	Catastrophic	1	1.91E-05
Tx valve	Typical	0.01	3.87E-02
	Large	0.1	3.87E-03
	Catastrophic	1	4.3E-04
Collision			
AC system	Catastrophic	1	1.78E-03 [1]

Note: 1. Ref. 2

A12.6.2 Probabilities Used in Assessment

The probabilities used in the assessment for calculation of the leak frequency and frequency of fire/ explosion due to ignition of the leak are given in **Table A12.14**.

TABLE A12.14
PROBABILITIES USED IN ASSESSMENT

Probability Description	Value	Sensitivity Range	Reference/ Justification
Tx valve inside passenger cabin	0.6	-	Fords and Holdens have Tx valve outside cabin, from **Table A12.15** these make up approximately 40% of Australian new cars sold in 1998, therefore approximately 60% of cars have Tx valve inside passenger cabin.
Overcharged system with refrigerant	0.09	-	Ref.3 gives this value for "fairly simple task performed rapidly or given scant attention".
Moving car	1.8/24 = 0.075	6/24 = 0.25	1.8 hours per person per day are spent in a car on average (Ref.4). Ref.5 gives average mileage per week for cab drivers as 1300 to 3200 km/week; for casual drivers 80-400 km/week. These mileages were averaged to give the sensitivity range shown.
Stationary car	0.925	0.75	Moving car probabilities were subtracted from one to give stationary car probabilities.
Parked inside	0.5	0.7	Estimate
Small car	0.5	-	VFACTS database (Ref. 6)
Medium car	0.1	-	VFACTS database (Ref. 6)
Fresh air vents closed	0.5	-	Estimate
AC on	0.4	0.6	Estimate. 0.25 value from Coldic 1997.
AC off	0.6	0.4	Estimate
Leak in engine bay due to collision	0.99	-	ADL 1995, Ref. 2
Leak in cabin due to collision	0.01	-	ADL 1995, Ref. 2
Ignition			
Immediate ignition probability due to intrinsic failures (car moving)	0.01	-	ADL 1995, Ref. 2
Delayed ignition probability due to intrinsic failures (car moving)	0.01	-	ADL 1995, Ref. 2
Immediate ignition probability due to intrinsic failures (car stationary)	0.001	-	ADL 1995, Ref. 2
Delayed ignition probability due to intrinsic failures (car stationary)	0.001	-	ADL 1995, Ref. 2
Immediate ignition probability due to collision	0.03	-	ADL 1995, Ref. 2
Delayed ignition probability due to collision	0.01	-	ADL 1995, Ref. 2
Ignition probability in the cabin	0.05	-	ADL 1995, Ref. 2
Evaporator damage resulting from collision	0.05	-	ADL 1991, Ref. 7

A12.6.3 Cars Registered in Australia

The numbers of cars sold new in Australia in 1998 was used to determine the proportion of the most popular makes: Ford, Holden, Mitsubishi and Toyota on the road. It was assumed that the new cars sold in 1998 are representative of all cars on the road. The values are shown in **Table A12.15**.

TABLE A12.15
CARS SOLD NEW IN 1998 IN AUSTRALIA

Car Type	% New Sold in Australia in 1998[1]
Ford	18
Holden	20.5
Mitsubishi	10.9
Toyota	15.3
Other	35.2

Note: 1. VFACTS Database, Ref.6.

It can be seen from **Table A12.15** that the proportion of Ford and Holden cars on the road in Australia can be estimated as approximately 40% of all cars. As Fords and Holdens have their Tx valves on the outside of the passenger cabin, while the majority of other makes have the Tx valve inside the passenger cabin, it was assumed for the purposes of this assessment that 40% of all cars have the Tx valve in the engine bay.

Data for the total number of registered cars in Australia was obtained from the Australian Bureau of Statistics. It was estimated that 50% of Australian cars have air-conditioning installed (Ref.1). This data is presented in **Table A12.16**.

TABLE A12.16
TOTAL CARS REGISTERED IN AUSTRALIA

Year	Passenger Vehicles	Campervans	Light Commercial Vehicles	Total	Total with AC
1995	8 628 806	31 835	1 527 212	10 187 853	5 093 927
1996	8 989 136	32 339	1 601 641	10 623 116	5 311 558
1997	9 206 236	33 291	1 632 219	10 871 746	5 435 873
1999[1]	-	-	-	11 600 000	5 800 000

Note: 1. Extrapolation of given data used to estimate the 1999 values.

Serious injury/ fatal crash data was obtained from the Federal Office of Road Safety and is shown in **Table A12.17**.

TABLE A12.17
FATAL/ SERIOUS INJURY CRASH DATA

Year	Number of Fatal/ Serious Injury Crashes	% Total Cars on Road
1992	18 550	0.2
1993	18 901	0.2
1994	19 270	0.2
1995	19 622	0.2
1996	19 280	0.2

A12.6.4 INITIATING FREQUENCIES FOR EVENT TREES

The frequency data given in **Table A12.13** and **Table A12.14** was used in the calculation of the final risk values for the Safety Assessment using event trees. The details of these event tree calculations are given in **Appendix 16**. **Table A12.18** shows the initiating frequencies used for each event.

A sample calculation is given for a small car, 1mm leak (Events 6,8,12):

Initiating Frequency = [(freq. evap. leak 1mm) + (freq. Tx leak 1mm) * (prob. Tx inside cabin) * (prob. Ford)] * (prob. small car)

= (1.91E-05 + 4.3E-04 * 0.6 * 0.1) * 0.5

= 2.25E-05 pa

TABLE A12.18
INITIATING EVENT FREQUENCIES FOR RISK ASSESSMENT

Event Numbers	Event Description	Initiating Frequency / car-year	Method
6, 8, 12	Small car, 1mm leak	2.25E-05	Sum of evaporator and Tx (adjusted to account only for Tx inside the vehicle) leak frequencies for 1mm leak, multiplied by small car percentage
8	Medium/ large car, 1mm leak	2.25E-05	Sum of evaporator and Tx (adjusted to account only for Tx inside the vehicle) leak frequencies for 1mm leak, multiplied by medium and large car percentage
12	Small car, 0.1mm leak	2.02E-04	Sum of evaporator and Tx (adjusted to account only for Tx inside the vehicle) leak frequencies for 0.1mm leak, multiplied by small car percentage
18	Medium car, 1mm leak	4.49E-06	Sum of evaporator and Tx (adjusted to account only for Tx inside the vehicle) leak frequencies for 1mm leak, multiplied by medium car percentage
19	Small car, 1mm leak	2.25E-05	Sum of evaporator and Tx (adjusted to account only for Tx inside the vehicle) leak frequencies for 1mm leak, multiplied by small car percentage
20	Collision	8.90E-05	Leak frequency from AC due to collision multiplied by probability of evaporator damage due to collision

A12.7. REFERENCES

1 NSW Motor Vehicle Repair Industry Association (1996): "Briefing Paper: Alternatives to CFC as Refrigerants in Motor Vehicle Air-Conditioners – Hydrocarbons compared to R134a", Sydney, January.

2 Arthur D. Little (1995): "Risk Assessment of Flammable Refrigerants, Part 3: Car Air-conditioning".

3 Williams, J.C., "A data based method for assessing and reducing Human Error", Proceedings of IEEE 4th Conference on Human Factors in Power Plants, Monterey, California, 1988.

4 Crowe, A. (1999): "Measurement of Air Exchange Rate of Stationary Vehicles and Estimation of In-Vehicle Exposure", Thesis, University of Adelaide.

5 "Retrofitting fleet A/Cs with HFC-134a refrigerant", *Automotive Engineering*, March 1994, pp. 49-51.

6 VFACTS Database(1998): "New Passenger Vehicle Sales by Size, Australia", December.

7 Arthur D. Little (1991): "Non-Inert Refrigerant Study for Automotive Applications – Final Report", Prepared for the US Department of Energy, Office of Transportation Technology, November.

APPENDIX 13

FAILURE RATE DATA (OTHERS)

TABLE OF CONTENTS

A13.1. INTRODUCTION

A13.1.1 General

As outlined in **Appendix 12**, an extensive literature review was conducted in the public arena on air-conditioning systems. Despite the many publications on the subject matter, limited data was available regarding risk assessments and in particular, estimation of leak frequencies.

Very little data was available in the public arena on parameters useful for a Safety Assessment. These parameters include risk assessments, quantification of leaks from air-conditioning systems as well as leak frequency data and failure modes of components. Other important parameters included car ventilation rates, vehicle volumes and air exchange rates.

A13.1.2 Purpose

The purpose of this appendix is to summarise any previous published frequency data relevant for this study.

A13.1.3 Data Sources

Granherne was able to source three published reports related to risk assessment studies and frequency analysis of automobile air-conditioning systems. These data sources are summarised in this appendix:

1. Arthur D. Little Ltd (1995): "Risk Assessment of Flammable Refrigerants" (Ref.1).
2. Arthur D. Little Ltd (1991): "Non-Inert Refrigerant Study for Automotive Applications – Final Report" (Ref.2).
3. Denis Clodic (1997): "Zero Leaks – Limiting Emissions of Refrigerants" (Ref.3).

Each of these reports is addressed separately to give the information contained within it. The data is then summarised for comparison with the data generated by Granherne through the survey work conducted and shown in **Appendix 12**.

Arthur D. Little (ADL) Limited is a US based consulting firm specialising in areas of technical safety and risk management. ADL has conducted two studies on hydrocarbon refrigerant prepared for Calor Gas Limited (1995) and the US Department of Energy (1991). The former study was an independent risk assessment study of Calor Gas hydrocarbon refrigerant products in the application of refrigerated road transport vehicles and automobile air-conditioning systems. The product marketed by Calor Gas is of similar composition to ER12 refrigerant.

The latter study for the US Department of Energy focused on a comparative study between refrigerants in terms of performance. The report also contained a risk assessment of vehicle collisions and experimental data.

Denis Clodic is deputy director of the Centre for Energy Studies of Ecole des Mines de Paris. He is a member of ASHRAE and a member of the United Nations Environment Programme (UNEP) Technical Option Committee (TOC) on Refrigeration under the Technical and Economics Assessment Panel (TEAP) of the Montreal Protocol.

Under ASHRAE, the document focussed on estimating the typical leak rate and frequency from various uses of refrigerants from industrial to vehicle air-conditioning systems. For the vehicle assessment, the author has investigated potential leak sources from the various air-conditioning components.

A13.2. LEAK FREQUENCY DATA

A13.2.1 Arthur D. Little, 1995

A review of the Calor Gas Risk Assessment study revealed the following ADL findings:

Consequence Analysis

- Most leaks that occur from a motor vehicle air-conditioning system are in the engine bay.
- Engine compartment leaks if ignited will have negligible effects in terms of consequences such as explosion.
- Unlikely that leaks in the engine bay will be ignited by hot surfaces (i.e. engine running).
- ADL laboratory tests showed that a vehicle lighter and lit cigarette had insufficient energy to ignite a hydrocarbon mixture.
- Consequence analysis conducted by ADL was recognised as being **conservative** and concentrated on catastrophic releases. The study did not provide a failure modes and effects analysis. It also very conservatively assumed that all leaks were continuous whilst in reality, depressuring occurs thus lowering the leak rate.
- Nevertheless, the explosion assessment for ignited catastrophic releases demonstrated that passengers in the cabin would be exposed to very small overpressures that would decay almost to zero. The bulkhead and dashboard would absorb much of the energy. This injury potential to personnel was minimal.
- Flashfires in the cabin from ignited catastrophic releases would cause very minor burns to the driver and passenger.

Frequency and Risk Analysis

- The total frequency of fires/ explosions that can cause harm to people from ignited CARE refrigerant was estimated to be 3.05E-07 per car per year.
- It was concluded that the use of hydrocarbon refrigerant would have negligible or very small increase in public risk.

- Based upon UK statistics, the probability of leak due to collision was calculated as 1.78E-03 per year of air-conditioning equipped car. ADL has estimated that 99% of leaks resulting from a collision will occur in the engine bay and 1% in the passenger cabin.
- The frequency of a leak rate for a passenger vehicle was estimated from refrigerated road transport systems to be 8.4E-03 per car per year. ADL has estimated that 98% of intrinsic leaks will occur in the engine bay and 2% in the passenger cabin.
- The ignition probabilities for a vehicle involved in a collision with hydrocarbon refrigerant was taken to be 3% for immediate ignition and 1% for delayed ignition.
- The ignition probabilities from a leak of hydrocarbon refrigerant due to intrinsic failure was taken to be 1% for immediate ignition and 1% for delayed ignition.

A13.2.2 Arthur D. Little, 1991

A review of the US Department of Energy study revealed the following ADL findings:

Consequence Analysis

- Most leaks that occur from a motor vehicle air-conditioning system are in the engine bay.
- Jet mixing and dispersion will limit the formation of a flammable mixture in the engine bay and hence ignition potential is very low. Thus any generated explosion overpressure is very low (<< 1psi) due to the open venting at the bottom of the engine compartment.
- Potential ignition sources in the engine bay would be broken battery cables.
- Only 1.5% of crashes result in deformations greater than 6 inches in the vicinity of the A-pillar and instrument panels and the evaporator is typically located at least 12 inches inboard of the passenger side door.
- Considerable deformation and dislocation of the evaporator can occur without causing refrigerant leaks. ADL assigned a probability of 5% for leakage for accidents. Thus full rupture of an evaporator in the event of a crash is considered by ADL to be very low. Laboratory tests demonstrated that the evaporator requires significant force on a typical impaling punch before any leakage occurs.

- Any explosion in the passenger compartment is unlikely to cause injury to passengers as relief would be provided by the windows blowing out.

Frequency and Risk Analysis

- The total frequency of fires that can cause harm to people from ignited hydrocarbon refrigerant was estimated to be 3.50E-07 per car per year and is very low. This assessment was based upon conservative assumptions.

- No credible ignition sources are known for the passenger compartment, and assigned a 5% probability although this value is thought to be very high.

- The frequency of a fire in the engine bay resulting from an ignition of hydrocarbon refrigerant is of the order of 14 to 50E-06 per car per year.

- No databases were available in the United States relating specifically to fires from vehicle accidents.

A13.2.3 Denis Clodic, 1997

By comparison with the ADL risk assessment studies, the ASHRAE publication focussed on estimating the likely emission rates from an air-conditioning system. These were the result of intrinsic failures of the system. Some research was also done in crash or collision situations.

Failure Modes

- Air-conditioning systems do not experience major leaks.

- Losses from an air-conditioning system are due to fugitive emissions (mostly due to hose permeation).

- Hoses in the engine bay in the AC system are made of rubber or plastic, are porous and introduce an intrinsic level of leakage due to permeability.

- Full loss of charge principally occurs from traffic accidents.

Leakage Rates

- The US EPA conducted leak tests of air-conditioning systems using R12 and found the following:

    - average emission rate of refrigerant from the system due to pipe leaks was 0.36 kg/year per vehicle, half of which was fugitive emissions that were not located by leak detectors with a 1g/year sensitivity, and

  - significantly higher level of fugitive emissions can be expected from a system that is operating and one that is not operating.

  This confirms that the intrinsic leak rate is very small (and can be equated to leak category of "pinhole", as used in the present Safety Study).

- Losses from hoses when the air-conditioning system is off and running have been estimated to be a total of 0.88 kg/year.

Frequency and Risk Analysis

- In service company statistics, condenser tubing ruptures due to accidents represent about 10% to 15% of causes of all AC system services. Other ruptures can occur, especially at the crimp on metal fittings of rubber hoses. This confirms ADL findings that a high percentage of air-conditioning system leaks occur in the engine bay following an accident.
- In the United States, the average running time of an automobile air-conditioning system is estimated to be 120 to 200 hours for an average annual travel distance of 24,000 kilometres with an average driving time of 800 hours.

A13.2.4 Summary

Table A13.1 summarises the leak frequencies used in previous studies.

TABLE A13.1
SUMMARY OF DATA USED IN PREVIOUS STUDIES

Parameter	Description	Value	Reference
Frequencies	Intrinsic leak from air-conditioning system (all components)	8.40E-03 per car per year	ADL 1995
	Leak from air-conditioning system due to collision	1.78E-03 per car per year	ADL 1995
	Fire frequency resulting from ignition of intrinsic leak causing injury	3.05E-07 per car per year	ADL 1995
	Fire frequency resulting from ignition of leak due to collision causing injury	3.50E-07 per car per year	ADL 1991
	Fire frequency resulting from ignition of leak	14-50E-06 per car per year	ADL 1991
Leak Probabilities	Probability of leak in engine bay due to intrinsic leak	0.98	ADL 1995
	Probability of leak in cabin due to intrinsic leak	0.02	ADL 1995
	Probability of leak in engine bay due to collision	0.99	ADL 1995
	Probability of leak in cabin due to collision	0.01	ADL 1995
Ignition Probabilities	Immediate ignition probability due to intrinsic failures	0.01	ADL 1995
	Delayed ignition probability due to intrinsic failures	0.01	ADL 1995
	Immediate ignition probability due to collision	0.03	ADL 1995
	Delayed ignition probability due to collision	0.01	ADL 1995
	Ignition probability in the cabin	0.05	ADL 1991
Others	Probability of evaporator damage resulting from collision	0.05	ADL 1991
	Probability of condenser rupture due to collision	0.15	Clodic 1997
	Probability that air-conditioning system is operating during the year (US figures)	0.25	Clodic 1997

A13.3. REFERENCES

1 Arthur D. Little (1991), "Non-Inert Refrigerant Study for Automotive Applications, Final Report".

2 Arthur D. Little (1995), "Risk Assessment of Flammable Refrigerants, Part 3: Car Air-conditioning".

3 Clodic, D. (1997), "Zero Leaks, Limiting Emissions of Refrigerants".

APPENDIX 14

CORRESPONDENCE AND CONSULTATIONS

TABLE OF CONTENTS

A14.1. INTRODUCTION

A14.1.1 Purpose

The purpose of this Appendix is to outline concerns and issues raised by commercial organisations, motorists associations and government departments regarding the use of ER12 hydrocarbon refrigerant.

A14.1.2 Scope

Concerns and issues were gathered from interviews held with the following organisations located in Victoria, South Australia and Western Australia where hydrocarbon refrigerant is used in passenger vehicles:

Distributors

- Bursons (Marketing Manager, distributors of ER12 in Melbourne).
- Motor Traders (Marketing Manager, distributors of ER12 in Adelaide).

Motorists Associations

- SA Royal Automobile Association (Adelaide Head Office).
- The Royal Automobile Club of WA (Perth Head Office).

Government Departments

- Department of Mines and Energy Queensland (Chief Gas Examiner, Brisbane).
- WA Department of Energy (Chief Gas Examiner, Perth).
- TransAdelaide (St. Agnes Depot).

A14.1.3 General

In order to identify issues and concerns regarding the use of ER12 hydrocarbon refrigerant in vehicles, Granherne undertook the following:

- Failure Modes and Effects Analysis (FMEA, **Appendix 2**);
- Hazard Identification (HAZID, **Appendix 3**);
- Workshop Surveys (**Appendix 12**); and
- Consultations.

This Appendix presents findings from consultations with:

- distributors of ER12 product;

- motorists associations; and
- government bodies and departments.

For the purposes of the study, consultations were limited to organisations located in Victoria, South Australia and Western Australia. This was done as hydrocarbon refrigerant products including ER12 are used in these states.

A14.2. CONSULTATIONS

A14.2.1 Introduction

The following tables summarise the issues regarding hydrocarbon refrigerant which were discussed with distributors, motorists associations and government departments. Both distributors interviewed initially had concerns regarding flammability issues with the product. However, upon internal reviews and discussions with Boral Energy, they were satisfied that the product did not pose a risk to workshops or end-users (i.e. motorists).

This was also the view held by a South Australian public transport section who undertook an internal safety and health risk assessment. They concluded that the risk of using ER12 product in their bus fleet was minimal and acceptable.

Motorists associations were non-committal towards the use of hydrocarbon refrigerant. Both organisations believed that the ER12 product would be accepted if the risk to the driver was proven to be acceptable.

A14.2.1.1 Distributors

A summary of the main comments from the distributors is shown in **Table A14.1**.

A14.2.1.2 Motorists Associations

A summary of the main comments from the distributors is shown in **Table A14.2**.

A14.2.1.3 Government

A summary of the main comments from government bodies and departments is shown in **Table A14.3**.

TABLE A14.1
COMMENTS FROM DISTRIBUTORS

Distributor	Issue/ Concern	Comments
Bursons (Melbourne, Victoria)	ER12 Gas Bottles	- Product has been sold since October 1995 - No leaking cylinders - No damaged cylinders - Of the 8,000 units sold only one faulty unit (internal valve passing– not a safety issue)
	Packaging/ Labelling	- Packaging and labelling of product was done in consultation with the Victorian Dangerous Goods inspector
	Fire Events	- Unaware of fire incidents involving ER12 - False rumours of fires and explosions in workshops. When investigated by Bursons revealed no evidence
Motor Traders (Adelaide, South Australia)	ER12 Gas Bottles	- Product has been sold since October 1998 - No leaking cylinders - No damaged cylinders - Of the 400 units sold only one faulty unit (internal dip tube – not a safety issue)
	Fire Events	- No reported incidents from workshops using the product
	Packaging	- Could be enhanced by placing “charge charts” into box prior to sealing
	Public Risk	- Group Manager believed that product has an acceptable risk to the public due to minor quantity used - Risk is comparable to that of vehicle containing 60 litres of LPG or petrol - Product is more environmentally friendly than current refrigerants

TABLE A14.2
COMMENTS FROM MOTORISTS ASSOCIATIONS

Distributor	Issue/ Concern	Comments
Royal Automobile Association of SA, Inc. (RAA)	Public Risk	- RAA has no formal commitment to the use of hydrocarbon refrigerant - Safety Report needs to determine risk involved with the flammability of the product - Safety Report needs to determine if risk from product to the public (i.e. motorist) is acceptable
	Fire Events	- RAA had not heard of any proven fire incidents involving product
	Others	- RAA views that product will currently fill the lower end of the market - Safety Case should highlight performance characteristics of the product
The Royal Automobile Club of WA Inc. (RAC)	Workshop Risk	- Safety Report should investigate the handling of a hydrocarbon product at workshop level - Safety Report should comment on the level of training provided to workshops on product handling and use
	Public Risk	- Safety Report should investigate the situation of a vehicle parked overnight
	Others	- Safety Case should provide a statement whether the refrigerant can be used in existing vehicle air-conditioning systems - Recognised that the product is more environmentally friendly than current refrigerants - Safety Case needs to explain mixing of refrigerant in cabin following a leak

TABLE A14.3
COMMENTS FROM STATE GOVERNMENT DEPARTMENTS

Distributor	**Issue/ Concern**	**Comments**
Western Australian Department of Energy	Public Risk	- Safety Report needs to determine the risk to the public and acknowledge whether it is safe for use or not - Safety Report needs to determine if risk from product to the public (ie motorist) is acceptable
	Fire Events	- Department had not heard of any proven fire incidents involving product - Safety Report needs to investigate potential ignition sources - Safety Report needs to discuss how refrigerant leak is dissipated
	Others	- Department has issued a position paper on the use of hydrocarbon refrigerants - Motor Traders Association in WA is in agreement with Departments position
TransAdelaide (St. Agnes Depot)	Public Risk	- An internal risk management study was undertaken on product use - Risk was found to be acceptable to driver and public
	Others	- At least 100 buses use the product for driver comfort - Maintenance downtime has decreased significantly (greater than 80%) from use of product
Department of Mines and Energy (DME) Queensland		- The concerns raised by the QLD DME have been addressed throughout the Safety Study (see **Section 1.4** of the main report)

APPENDIX 15

APPROVAL REQUIREMENTS FOR QUEENSLAND

The approval requirement in Queensland for use of hydrocarbon refrigerants in automobile air-conditioners consists of obtaining an approval under Section 4(c) of Regulation 108A, Queensland Gas Regulation Act 1989. The approval authority is the Chief Gas Examiner.

Section 4(c):

> *As an alternative to 4(a) and 4(b) above, approval may be sought from the Chief Gas Examiner for a particular installation or class of installation.*
>
> *Applications for such approval must be supported by a full and comprehensive safety report.*
>
> *The report must include an assessment of hazard and risk in all phases of the life cycle of the refrigeration or air-conditioning system including installation, maintenance, use, decommissioning, disposal and obsolescence. The assessment of hazard and risk must include at least the following-*
>
> - *an assessment of the effect on the safety and reliability of the refrigeration or air-conditioning system and its components that a change of refrigerant may have;*
> - *identification of all hazards associated with each life cycle phase listed above. Appropriate hazard identification models such as Hazard and Operability Study (HAZOP), Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis and Event Tree Analysis must be used;*
> - *an analysis of such hazards in terms of their consequences and their likelihood of occurrence;*
> - *assessment of the vulnerability of people who could be affected by an incident involving the refrigeration or air-conditioning system;*
> - *consideration of the controls and other factors that could be implemented to mitigate the hazard and risk to all phases of the life cycle. The decision to accept or reject any control measure should be justified;*
> - *assessment and qualification of risk for each life cycle phase. The risk must be presented as a comparison with the original design. Where a finite population is known, an estimate of the likely number of injuries and fatalities per year should be presented. The assessment should consider qualitative as well as quantitative outputs of the analysis. In particular this must include environmental risk, avoidable risk and societal risk.*

All information and data sources must be referenced, the results of testing presented and all assumptions clearly stated.

The installation of flammable hydrocarbon gas in a refrigeration or air-conditioning system must comply with Technical Standard 2 above and one other Technical Standard listed above.

TRAINING FOR WORKERS IN THE USE OF THE GASES IN REFRIGERATION OR AIR-CONDITIONING

From 31 December 1995, all persons involved in the commissioning, installation, service, repair, maintenance or de-commissioning of refrigeration or air-conditioning systems using flammable hydrocarbon gases must be licensed under the Gas Act. Training courses will be introduced which will provide the safety training necessary to work with these gases. Persons currently working with these gases may apply for a licence at any time and will be assessed in terms of their knowledge and experience.

SAFE OPERATION OF REFRIGERATION OR AIR-CONDITIONING WORKSHOPS IN WHICH THE GASES ARE USED

From 31 December 1995, all workshops at which the commissioning, installation, service, repair, maintenance or de-commissioning of air-conditioning or refrigeration systems using flammable hydrocarbon gases will be carried out must conform to Australian Standard AS 2746-1985 "Australian Gas Vehicles Workshops Code", Clauses 2.3(b), (c), (d) and Clause 2.4, and must be equipped with an electronic gas leak detector.

Areas where flammable hydrocarbon gases are stored or used are classified as hazardous areas in accordance with Australian Standard AS 2430 Part 1 –1997 and Part 3-1991 "Classification of Hazardous Areas" and must conform to the requirements of Australian Standards dealing with installations in hazardous areas. They must also conform to Australian Standard AS 1596-1989 "Storage and Handling of LP Gas".

SIGNS, SAFETY NOTICES AND CERTIFICATON THAT MUST BE DISPLAYED OR PROVIDED

From the date of commencement of the Approval, where flammable hydrocarbon gas is used in a refrigeration or air-conditioning system, a clearly marked data plate must be fitted indicating that the refrigeration or air-conditioning system contains flammable gas. The data plate shall be affixed to the installation in such a position that it will be easily observed by any person carrying out work on the system or any associated equipment.

In workshops, where work is being carried out with flammable hydrocarbon gases, "No Smoking" signs as described in AS 1319-1994 must be displayed.

Licensed persons supplying flammable hydrocarbon gas to an installation shall provide to the owner of that installation a certificate stating the work has been carried out in accordance with the requirements of the Gas Act and the Regulations. This certificate is required to contain –

- *the name and address of the owner of the installation;*
- *the type of installation;*
- *the quantity of flammable hydrocarbon gas used;*
- *the certificate stated above;*
- *the name, licence number and signature of the licensed person.*

A copy of the certificate is to be retained by the licensed person and be made available to a gas examiner on request.

A table listing the DME requirements has been provided in the main report (**Table 1.2**) with the appropriate cross-references.

APPENDIX 16

RISK ASSESSMENT

TABLE OF CONTENTS

A16.1. INTRODUCTION

This Appendix details the methodology, calculations and results of the risk assessment part of the Safety Study. The risk assessment was performed using event trees which are shown in the following sections. The frequencies and probabilities used in the calculations were taken from the data presented in **Appendix 12** and **Appendix 13**.

The incident scenarios that were analysed were those carried forward from the consequence analysis as listed in **Appendix 7**. Incidents were chosen for further analysis based on whether they had the potential to cause a concentration of ER12 in the passenger cabin greater than 50% LFL.

A16.2. METHODOLOGY

A16.2.1 Incident Scenarios Carried Forward for Risk Assessment

The incidents carried forward for risk analysis are shown in **Table A16.1**. No engine bay releases were carried forward because they were shown not to affect the passenger cabin (**Appendix 8**).

TABLE A16.1
PASSENGER CABIN INCIDENTS CARRIED FORWARD FOR ANALYSIS

ID No.	No.	Vehicle Status	Car Type	Vent Status	AC Status	Hole Size (mm)	Concn > 50% LFL
N-1	6	Moving	Small	Closed	On	1	Yes
N-7	8	Moving	All	Closed	Off	1	Yes
N-4	12	Stationary (inside)	Small	Closed	Off	0.1, 1	Yes
N-8	18	Overcharged	Medium	Closed	Off	1	Yes
N-8	19	Overcharged	Small	Closed	On/ Off	1	Yes
N-3	20	Collision	All	-	-	-	Yes

Note: ID No. refers to the numbering of incidents in **Appendix 3**.

Each of these incidents was analysed separately to give the various outcome frequencies. The outcomes used in this study following a release of ER12 refrigerant were:

- Diffuse fire (due to immediate ignition of ER12 refrigerant).
- Flashfire/ explosion (due to delayed ignition of ER12 refrigerant).
- No effect to passenger (due to safe dispersion of ER12 refrigerant).

The individual event frequencies could then be summed for each car type (small, medium, large) and for each incident outcome (diffuse fire, flashfire/ explosion, no effect).

A16.2.2 Event Tree Analysis

Event Tree Analysis (ETA) is applied when an incident scenario can result in a variety of consequences. For this Safety Study, ETA identifies and evaluates potential accident outcomes that might result following a leak of ER12 refrigerant, normally called an initiating event. ETA is an inducting reasoning technique which is used to study the ultimate frequency and consequences of events, working from cause to effect. Event trees are logic diagrams showing the alternative ways in which a system can fail after a given initial event.

An ETA is a development of an incident from the initiating event through to the consequences resulting from the circumstances or state of the vehicle at the time of the event.

The probabilities of stated conditions were obtained from survey data and past risk assessment studies.

A16.2.2.1 Base Case and Sensitivity Analyses

The following case studies were investigated in the Safety Study as given in **Table 16.2**.

TABLE 16.2
CASE STUDIES INVESTIGATED IN SAFETY STUDY

Case Study	Description	Variable	Justification
Base	Risk values calculated based upon values given in **Appendix 12** and **Appendix 13**	-	-
Sensitivity 1	Stationary (Incident 12)	The probability of a car being parked in the open was changed from 0.5 to 0.7	It was postulated that in Queensland, or in sub-tropical conditions, cars are parked more commonly in carports or in the open rather than garages. Carports are classed for the purposes of air exchange rates as being in the open air
Sensitivity 2	Moving (Incident 6, 8)	The probability that a car would be moving was changed from 0.075 to 0.25	6 hours per day was seen as a reasonable average upper bound for the number of hours per day a car is moving due to occupations such as Taxi driving where a person is in a moving car for their working day
Sensitivity 3	Moving (Incident 6, 8)	The probability that the AC is on was changed from 0.4 to 0.6	In QLD, it was postulated that the air-conditioning system in a car may be on for up to 60% of the year due to the higher temperatures experienced there
Sensitivity 4	Stationary (Incident 6, 8, 12)	The probability of ignition was changed from 0.001 to 0.01	Although the number of ignition sources present in a stationary vehicle (engine off) is considerably less than when the vehicle is in operation, assumed ignition probability is the same for all modes

A16.3. CALCULATIONS AND RESULTS

A16.3.1 Introduction

Each event tree for the Base Case is presented in this section to show the calculation of all incident frequencies. The base frequencies and probabilities used in the event trees were taken from **Table A12.13** and **Table A12.14**, in **Appendix 12**.

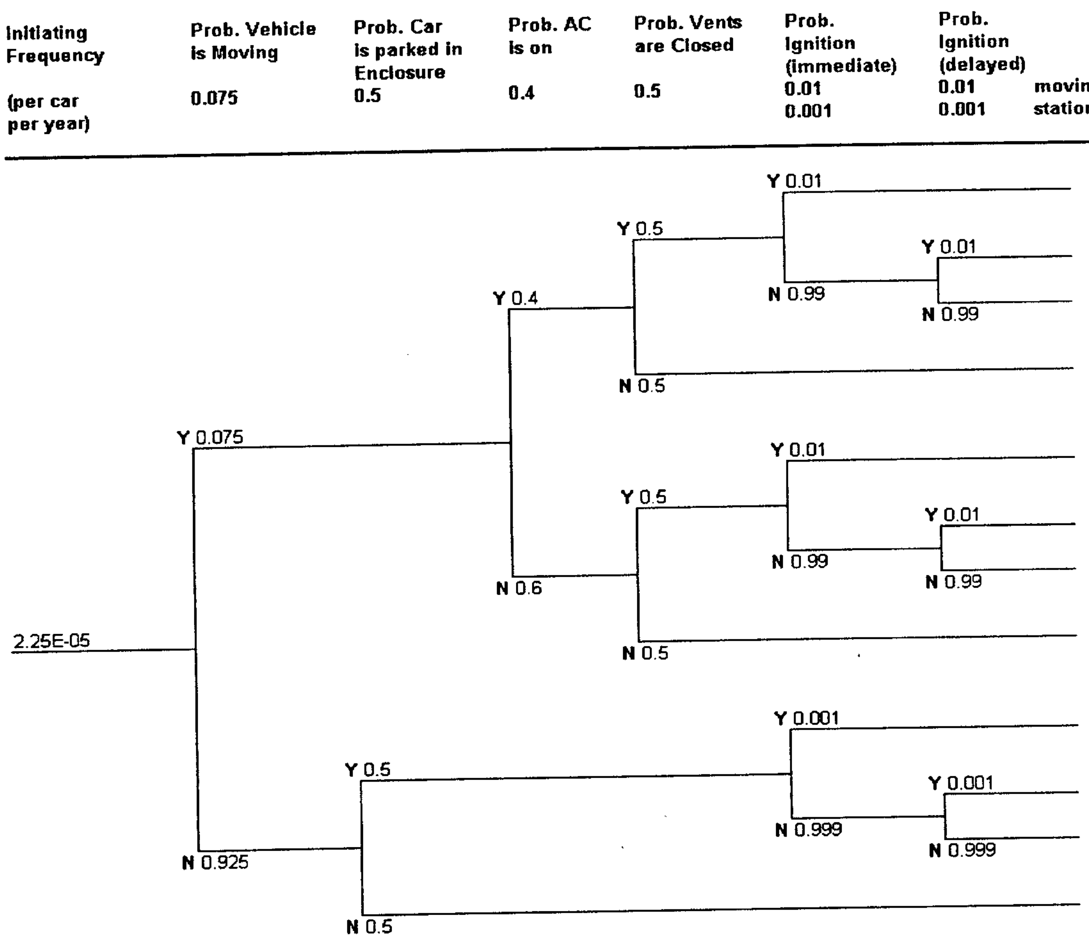
Two sensitivity cases were also undertaken to allow for some variation in incident probabilities. The changes made to the Base Case figures are given and the results of the event trees shown.

A16.3.2 Base Case Event Trees

The results of the Base Case Event Trees are shown in **Table A16.3**.

TABLE A16.3
BASE CASE RESULTS

Event No.	Event Description	Outcome (/ car-year)								
		Diffuse Fire			Flashfire/ Explosion			No Effect/ Safe Dispersion		
		S	M	L	S	M	L	S	M	L
6	Small car, moving, vents closed, AC on, 1mm leak	3.4E-09	-	-	3.3E-09	-	-	6.7E-07	-	-
8	All cars, moving, vents closed, AC off, 1mm leak	5.1E-09	2.3E-08	9.0E-08	5.0E-09	2.2E-08	9.0E-08	1.0E-06	4.5E-06	1.8E-05
12	Small car, stationary, inside, 0.1 and 1mm leak	1.1E-07	-	-	1.1E-07	-	-	2.2E-04	-	-
18	Medium car, overcharged, AC off, 1mm leak	-	1.2E-09	-	-		-	-	4.0E-07	-
19	Small car, overcharged, AC off, 1mm leak	6.1E-09	-	-	6.0E-09	-	-	1.6E-06	-	-
Sub-Total		1.3E-07	2.4E-08	9.0E-08	1.3E-07	2.2E-08	9.0E-08	2.3E-04	4.9E-06	1.8E-05
20	Collision	2.7E-08			4.3E-09			8.9E-05		
Total		2.7E-07			2.4E-07			3.4E-04		

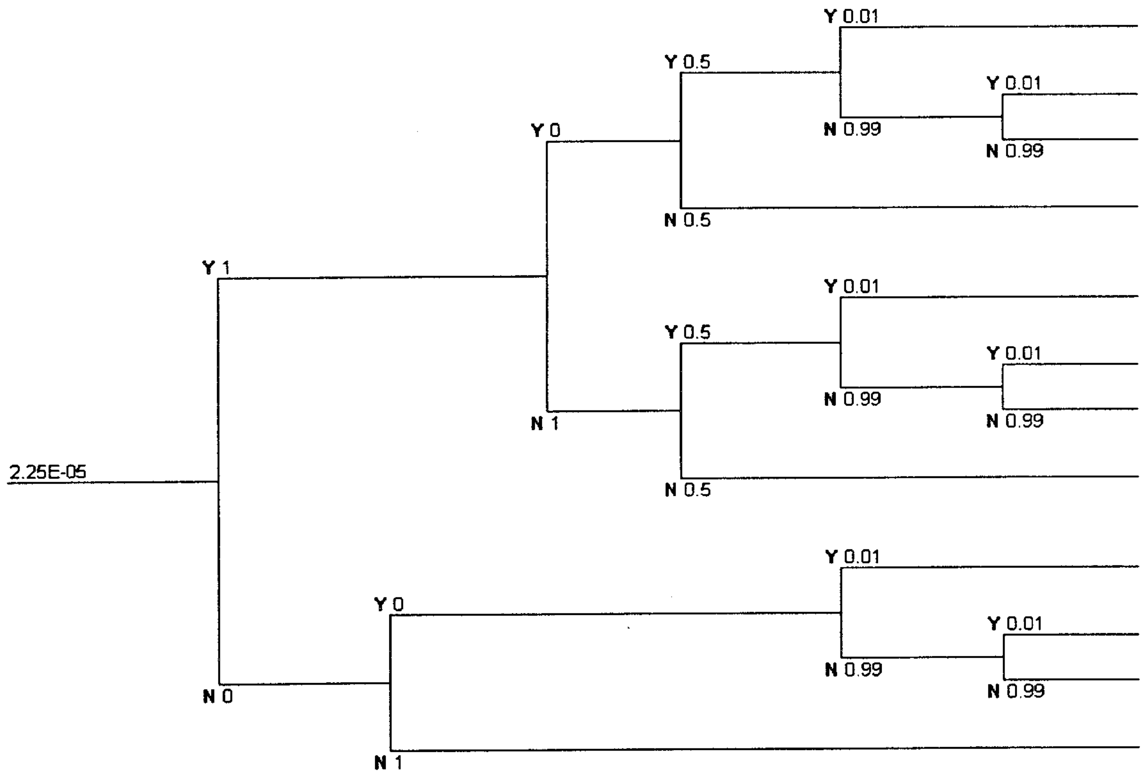


Outcome		Event 6	Event 12	Event 8
diffuse fire at source	3.37E-09	3.37E-09		
flashfire/ explosion in cabin	3.33E-09	3.33E-09		
no injury to persons in cabin	3.30E-07	3.30E-07		
no injury to persons in cabin	3.37E-07	3.37E-07		
diffuse fire at source	5.05E-09			5.05E-09
flashfire/ explosion in cabin	5.00E-09			5.00E-09
no injury to persons in cabin	4.95E-07			4.95E-07
no injury to persons in cabin	5.05E-07			5.05E-07
diffuse fire at source	1.04E-08		1.04E-08	
flashfire/ explosion in cabin	1.04E-08		1.04E-08	
no injury to persons in cabin	1.04E-05		1.04E-05	
no injury to persons in cabin	1.04E-05		1.04E-05	
Summary- Total	2.25E-05	6.74E-07	2.08E-05	1.01E-06
diffuse fire at source	1.88E-08	3.37E-09	1.04E-08	5.05E-09
flashfire/ explosion in cabin	1.87E-08	3.33E-09	1.04E-08	5.00E-09
no injury to persons in cabin	2.24E-05	6.67E-07	2.07E-05	1.00E-06

FIGURE A16.1

EVENT TREE FOR INCIDENTS 6,8, 12: SMALL CAR, 1mm LEAK

Initiating Frequency (per car per year)	Prob. Vehicle is Moving	Prob. Car is parked in Enclosure	Prob. AC is on	Prob. Vents are Closed	Prob. Ignition (immediate)	Prob. Ignition (delayed)
	1	0	0	0.5	0.01	0.01

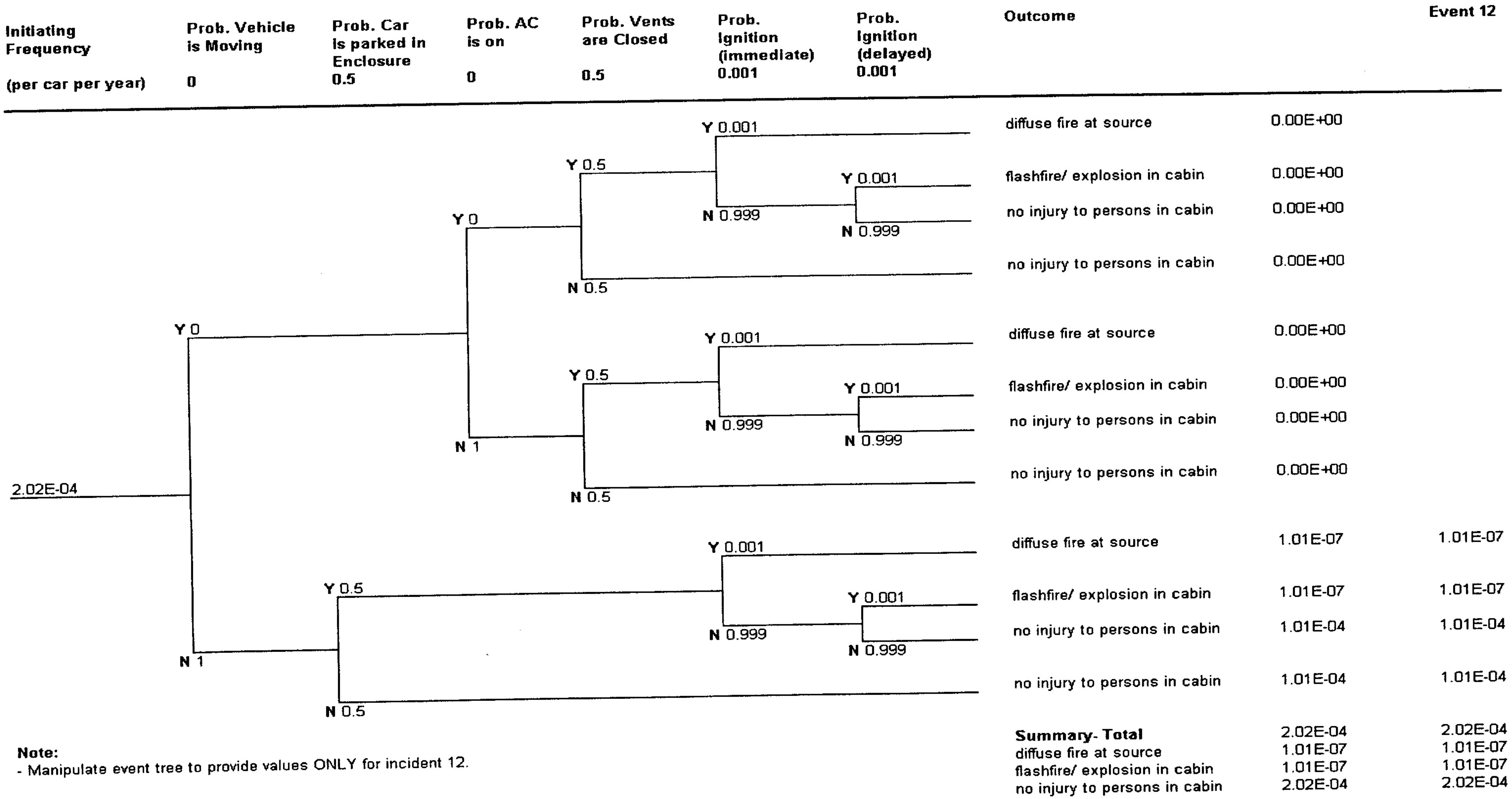


Outcome		Event 8 (M&L)	Event 8 (medium)	Event 8 (large)
diffuse fire at source	0.00E+00			
flashfire/ explosion in cabin	0.00E+00			
no injury to persons in cabin	0.00E+00			
no injury to persons in cabin	0.00E+00			
diffuse fire at source	1.12E-07	1.12E-07	2.25E-08	8.98E-08
flashfire/ explosion in cabin	1.11E-07	1.11E-07	2.22E-08	8.89E-08
no injury to persons in cabin	1.10E-05	1.10E-05	2.20E-06	8.80E-06
no injury to persons in cabin	1.12E-05	1.12E-05	2.25E-06	8.98E-06
diffuse fire at source	0.00E+00			
flashfire/ explosion in cabin	0.00E+00			
no injury to persons in cabin	0.00E+00			
no injury to persons in cabin	0.00E+00			
Summary- Total	2.25E-05	2.25E-05	4.49E-06	1.80E-05
diffuse fire at source	1.12E-07	1.12E-07	2.25E-08	8.98E-08
flashfire/ explosion in cabin	1.11E-07	1.11E-07	2.22E-08	8.89E-08
no injury to persons in cabin	2.22E-05	2.22E-05	4.45E-06	1.78E-05

Note:
- Manipulating event tree to provide value ONLY for Event 8
- As split between cars is 50% small, 10% medium and 40% large, had to adjust when only medium and large vehicles present.

FIGURE A16.2

EVENT TREE FOR INCIDENT 8: MEDIUM AND LARGE CARS, 1mm LEAK

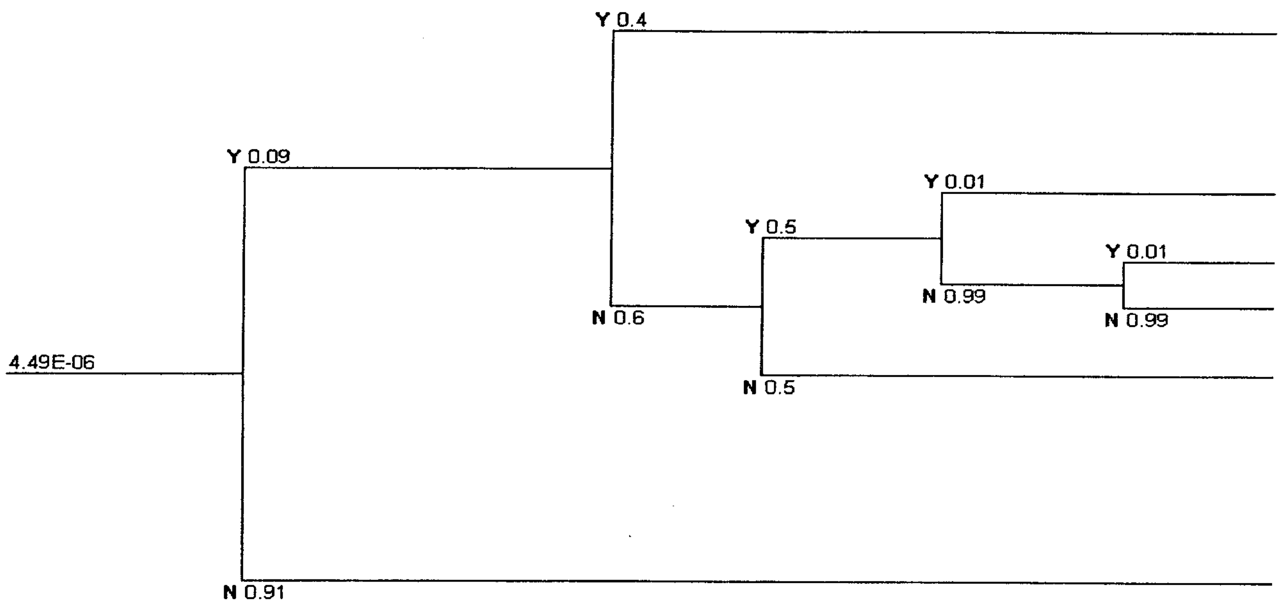


Note:
- Manipulate event tree to provide values ONLY for incident 12.

FIGURE A16.3

EVENT TREE FOR INCIDENT 12: SMALL CAR, 0.1mm LEAK

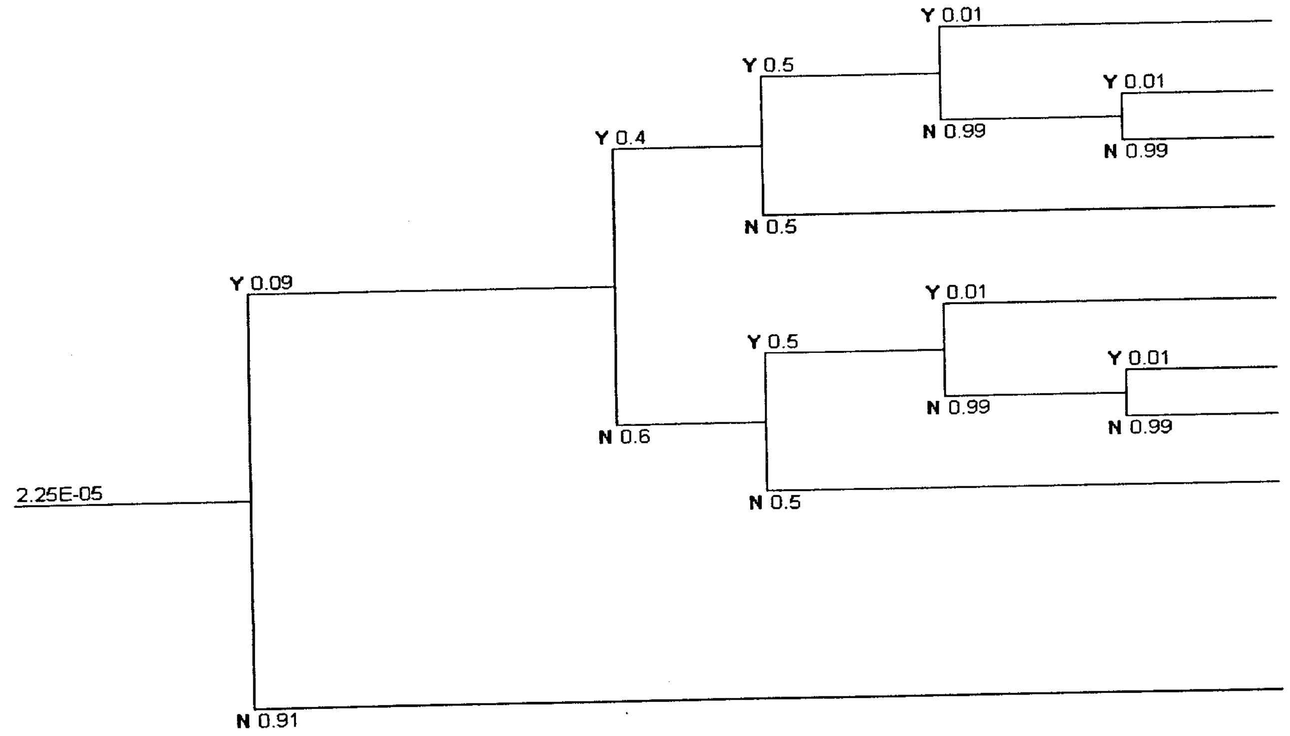
Initiating Frequency (per car per year)	Prob. Vehicle Overcharged	Prob. AC is on	Prob. Vents are Closed	Prob. Ignition (immediate)	Prob. Ignition (delayed)
	0.09	0.4	0.5	0.01	0.01



Outcome		Event 18
no injury to persons in cabin	1.62E-07	1.62E-07
diffuse fire at source	1.21E-09	1.21E-09
flashfire/ explosion in cabin	1.20E-09	1.20E-09
no injury to persons in cabin	1.19E-07	1.19E-07
no injury to persons in cabin	1.21E-07	1.21E-07
Car is not overcharged and falls under previous event tree developed for Event 8 (medium car - 1mm leak)	4.09E-06	4.09E-06
Summary- Total	4.49E-06	4.49E-06
diffuse fire at source	1.21E-09	1.21E-09
flashfire/ explosion in cabin	1.20E-09	1.20E-09
no injury to persons in cabin	4.02E-07	4.02E-07
To event tree 8	4.09E-06	4.09E-06

FIGURE A16.4
EVENT TREE FOR INCIDENT 18: OVERCHARGING, MEDIUM CAR

Initiating Frequency (per car per year)	Prob. Vehicle Overcharged	Prob. AC is on	Prob. Vents are Closed	Prob. Ignition (immediate)	Prob. Ignition (delayed)
	0.09	0.4	0.5	0.01	0.01



Outcome		Event 19
diffuse fire at source	4.04E-09	4.04E-09
flashfire/ explosion in cabin	4.00E-09	4.00E-09
no injury to persons in cabin	3.96E-07	3.96E-07
no injury to persons in cabin	4.04E-07	4.04E-07
diffuse fire at source	6.06E-09	6.06E-09
flashfire/ explosion in cabin	6.00E-09	6.00E-09
no injury to persons in cabin	5.94E-07	5.94E-07
no injury to persons in cabin	6.06E-07	6.06E-07
Car is not overcharged and falls under previous event tree developed for Event 6,8,12 (small car - 1mm leak)	2.04E-05	2.04E-05
Summary- Total	2.25E-05	2.25E-05
diffuse fire at source	6.06E-09	6.06E-09
flashfire/ explosion in cabin	6.00E-09	6.00E-09
no injury to persons in cabin	1.60E-06	1.60E-06
To event trees	2.04E-05	2.04E-05

FIGURE A16.5
EVENT TREE FOR INCIDENT 19: OVERCHARGING, SMALL CAR

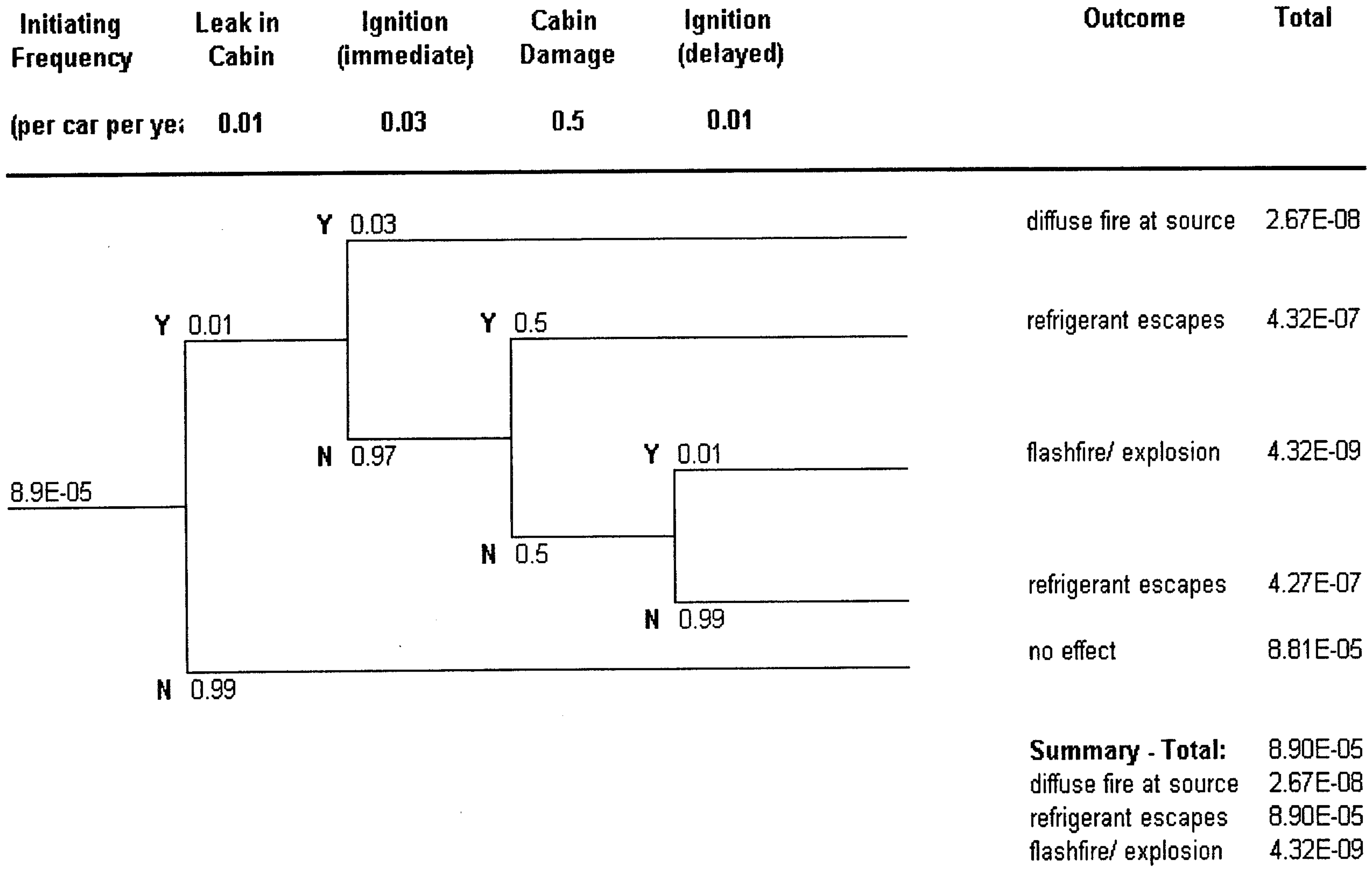


FIGURE A16.6
EVENT TREE FOR INCIDENTS 20: COLLISION

A16.3.3 Sensitivity Case 1

As given in **Table A16.2**, Sensitivity Case 1 involved changing the probability of a stationary vehicle being parked outside or inside. This change affected only the results for Incident 12, as it was the only incident carried forward to this part of the analysis where the car is stationary. The resulting event frequencies are shown in **Table A16.4**.

TABLE A16.4
SENSITIVITY CASE 1 RESULTS

Event No.	**Event Description**	**Outcome (/ car-year)**								
		Diffuse Fire			**Flashfire/ Explosion**			**No Effect/ Safe Dispersion**		
		S	**M**	**L**	**S**	**M**	**L**	**S**	**M**	**L**
6	Small car, moving, vents closed, AC on, 1mm leak	3.4E-09	-	-	3.3E-09	-	-	6.7E-07	-	-
8	All cars, moving, vents closed, AC off, 1mm leak	5.1E-09	2.3E-08	9.0E-08	5.0E-09	2.2E-08	9.0E-08	1.0E-06	4.5E-06	1.8E-05
12	Small car, stationary, inside, 0.1 and 1mm leak	6.7E-08	-	-	6.7E-08	-	-	2.2E-04	-	-
18	Medium car, overcharged, AC off, 1mm leak	-	1.2E-09	-	-	1.2E-09	-	-	4.0E-07	-
19	Small car, overcharged, AC off, 1mm leak	6.1E-09	-	-	6.0E-09	-	-	1.6E-06	-	-
Sub-Total		8.1E-08	2.4E-08	9.0E-08	8.1E-08	2.3E-08	9.0E-08	2.3E-04	4.8E-06	1.8E-05
20	Collision	2.7E-08			4.3E-09			8.9E-05		
Total		2.2E-07			2.0E-07			3.4E-04		

A16.3.4 Sensitivity Case 2

The probability of whether the car would be moving or stationary was changed for this sensitivity case. This change affected Incidents 6, 8 and 12 only. The resulting event frequencies are shown in **Table A16.5**.

TABLE A16.5
SENSITIVITY CASE 2 RESULTS

Event No.	Event Description	Outcome (/car-year)								
		Diffuse Fire			Flashfire/ Explosion			No Effect/ Safe Dispersion		
		S	M	L	S	M	L	S	M	L
6	Small car, moving, vents closed, AC on, 1mm leak	1.1E-08	-	-	1.1E-08	-	-	2.2E-06	-	-
8	All cars, moving, vents closed, AC off, 1mm leak	1.7E-08	2.3E-08	9.0E-08	1.7E-08	2.2E-08	9.0E-08	3.3E-06	4.5E-06	1.8E-05
12	Small car, stationary, inside, 0.1 and 1mm leak	1.1E-07	-	-	1.1E-07	-	-	2.2E-04	-	-
18	Medium car, overcharged, AC off, 1mm leak	-	1.2E-09	-	-	1.2E-09	-	-	4.0E-07	-
19	Small car, overcharged, AC off, 1mm leak	6.1E-09	-	-	6.0E-09	-	-	1.6E-06	-	-
Sub-Total		1.4E-07	2.4E-08	9.0E-08	1.4E-07	2.3E-08	9.0E-08	2.3E-04	4.9E-06	1.8E-05
20	Collision	2.7E-08			4.3E-09			8.9E-05		
Total		2.8E-07			2.6E-07			3.4E-04		

A16.3.5 Sensitivity Case 3

The probability that the air-conditioning system would be on was varied for this sensitivity case. The resulting outcomes are presented in **Table A16.7**. Changes occurred for Incidents 6, 8, 18 and 19.

TABLE A16.7
SENSITIVITY CASE 3 RESULTS

Event No.	Event Description	Outcome (/car-year)								
		Diffuse Fire			Flashfire/ Explosion			No Effect/ Safe Dispersion		
		S	M	L	S	M	L	S	M	L
6	Small car, moving, vents closed, AC on, 1mm leak	5.1E-09	-	-	5.0E-09	-	-	1.0E-06	-	-
8	All cars, moving, vents closed, AC off, 1mm leak	3.4E-09	2.3E-08	9.0E-08	3.3E-09	2.2E-08	9.0E-08	6.7E-07	4.5E-06	1.8E-05
12	Small car, stationary, inside, 0.1 and 1mm leak	1.1E-07	-	-	1.1E-07	-	-	2.2E-04	-	-
18	Medium car, overcharged, AC off, 1mm leak	-	8.1E-10	-	-	8.0E-10	-	-	4.0E-07	-
19	Small car, overcharged, AC off, 1mm leak	4.0E-09	-	-	4.0E –09	-	-	1.4E-06	-	-
Sub-Total		1.2E-07	2.3E-08	9.0E-08	1.2E-07	2.3E-08	9.0E-08	2.3E-04	4.9E-06	1.8E-05
20	Collision	2.7E-08			4.3E-09			8.9E-05		
Total		2.6E-07			2.4E-07			3.4E-04		

A16.3.6 Sensitivity Case 4

As given in **Table A16.2**, Sensitivity Case 4 involved changing the probability of ignition for a stationary vehicle to that equal to the ignitoon prbaility when a vehicle is in operation (all electrical systems active). The resulting outcomes are presented in **Table A16.8**. Changes occurred for Events 6,8,18.

TABLE A16.8
SENSITIVITY CASE 4 RESULTS

Event No.	Event Description	Outcome (/ car-year)								
		Diffuse Fire			Flashfire/ Explosion			No Effect/ Safe Dispersion		
		S	M	L	S	M	L	S	M	L
6	Small car, moving, vents closed, AC on, 1mm leak	3.4E-09	-	-	3.3E-09	-	-	6.7E-07	-	-
8	All cars, moving, vents closed, AC off, 1mm leak	5.1E-09	2.3E-08	9.0E-08	5.0E-09	2.2E-08	9.0E-08	1.0E-06	4.5E-06	1.8E-05
12	Small car, stationary, inside, 0.1 and 1mm leak	1.1E-06	-	-	1.10E-6	-	-	2.2E-04	-	-
18	Medium car, overcharged, AC off, 1mm leak	-	1.2E-09	-	-	1.2E-09	-	-	4.0E-07	-
19	Small car, overcharged, AC off, 1mm leak	6.1E-09	-	-	6.0E-09	-	-	1.6E-06	-	-
Sub-Total		1.1E-06	2.4E-08	9.0E-08	1.1E-06	2.3E-08	9.0E-08	2.3E-04	4.8E-06	1.8E-05
20	Collision	2.7E-08			4.3E-09			8.9E-05		
Total		1.2E-06			1.2E-06			3.4E-04		

A16.3.7 Summary of Results

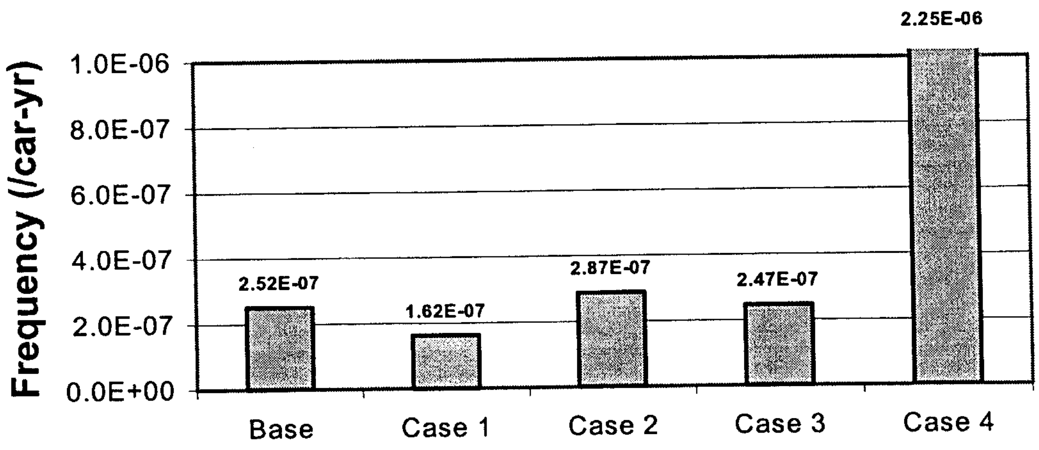
A16.3.7.1 Non-Collision Events

A summary of the results for non-collision events is given in **Table A16.9**. **Figure A16.7** shows the results for small cars in graphical form.

TABLE A16.9
SUMMARY OF NON-COLLISION RESULTS CAUSING INJURY

Case	Car Type	Value (/ car-year)	% Contribution	
			Flashfire/ Explosion	Diffuse Fire
Base	Small	2.5E-07	50	50
	Medium	4.7E-08	50	50
	Large	1.8E-07	50	50
Sensitivity Case 1	Small	1.6E-07	50	50
	Medium	4.7E-08	50	50
	Large	1.8E-07	50	50
Sensitivity Case 2	Small	2.9E-07	50	50
	Medium	4.7E-08	50	50
	Large	1.8E-07	50	50
Sensitivity Case 3	Small	2.5E-07	50	50
	Medium	4.6E-08	50	50
	Large	1.8E-07	50	50
Sensitivity Case 3	Small	2.25E-06	50	50
	Medium	4.7E-08	50	50
	Large	1.8E-07	50	50

FIGURE A16.7
SMALL CAR - NON-COLLISION EVENTS



It can be observed from the values in **Table A16.8** and **Figure A16.7** that the small car events are most affected by the sensitivity analysis. The range of values for a small car is 1.6E-07 to 2.9E-07 /car-yr with the base case of 2.5E-07 /car-yr.

A16.3.7.2 Collision Events

Table A16.10 shows the frequency of collision events calculated for each case.

TABLE A16.10
SUMMARY OF COLLISION RESULTS CAUSING INJURY

Case	Value (/ car-year)	% Contribution	
		Diffuse Fire	Flashfire/ Explosion
Base	3.1E-08	86	14
Sensitivity Case 1	3.1E-08	86	14
Sensitivity Case 2	3.1E-08	86	14
Sensitivity Case 3	3.1E-08	86	14
Sensitivity Case 4	3.1E-08	86	14

APPENDIX 17

COMPANY BACKGROUND AND PERSONNEL INVOLVED IN STUDY

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A17.1. COMPANY BACKGROUND

Granherne Pty Ltd is a wholly owned subsidiary of the Halliburton Company, an international engineering company offering a range of professional services to the world's oil and gas production, processing, refining, chemical process industries and mining and minerals processing industries. Granherne has successfully developed a world-wide consultancy capability in the specialist areas of front end engineering, process engineering, safety technology, reliability engineering, risk management and environmental protection.

Granherne Management and Employees have a commitment to quality and an effective Quality Management System has been established to satisfy this pledge. The company has achieved accreditation to ISO 9001 as approved by Lloyds Register Quality Assurance Limited.

Granherne employs over 600 people world-wide, in our offices in the UK, USA, Middle East, South East Asia and Australia. In Australia, Granherne employs around 70 professional engineers and scientists, of whom approximately 50 work in field development engineering and 20 are specialists in the fields of safety, risk, environment and reliability engineering. This resource is divided between our Perth, Sydney and Melbourne offices.

A17.2. PROJECT MANAGEMENT

A17.2.1 Project Team

The following Granherne personnel were involved in the study:

Dr Raghu Raman	Head Consultant (Project Manager)
Mr Ray Wells	Head Consultant (Technical Checker)
Mr Steve Sylvester	Senior Consultant
Mr Stuart Chia	Principal Safety/ Environmental Engineer (Team Leader)
Mr John Bertram	Senior Safety Engineer
Mr John Brini	Senior Safety Engineer (Quality Assurance reviewer)
Ms Belinda Gourlay	Safety Engineer

All the above personnel are either members of professional institutions or qualified to be members of the Institution of Engineers, Australia.

A17.2.2 Brief Summary of Experience

A brief summary of experience for each consultant is given below.

Dr Raghu Raman

Dr Raman is a Head Consultant, based in Granherne's Sydney office, and has over 30 years engineering experience and over 14 years experience in risk and safety studies. He is one of Australia's recognised leaders in risk and safety engineering and has led and conducted over 500 safety studies for industry and government. Dr. Raman has extensive experience in the assessment of risks and the development of Safety Management Systems (SMS) using the Safety Case approach. He has performed Safety Case assessments and risk assessment studies for a number of offshore oil and gas platforms.

Dr Raman has a PhD in chemical engineering and is a Fellow of the Institution of Chemical Engineers.

In this study, Dr. Raman was the Project Manager.

Ray Wells

Currently Head Consultant within the Granherne Melbourne office, Ray has 23 years' post-graduate experience, of which 19 years have been in safety risk and reliability engineering, safety and reliability analysis, and safety management. He holds a degree in physics and is a Registered Safety Professional with the Institution of Chemical Engineers.

Mr. Wells' role in the Safety Study was to undertake the technical audit of the Safety Study calculations.

Steven Sylvester

Mr. Sylvester is a Senior Consultant at Granherne and has over 25 years of wide ranging experience, covering marine engineering, heavy engineering production and maintenance, and chemical process industry. Over 11 years specifically related to risk and reliability engineering and technical safety in the chemical, mineral processing, mining and oil and gas industries. He holds a bachelor's degree in Mechanical Engineering.

Mr. Sylvester was previously Risk Engineering Technical Manager, BHP Engineering Pty Ltd, responsible for managing and conducting risk engineering projects both in-house and for external clients. Studies conducted cover a wide range of industries: chemical process, oil and gas, mineral processing, mining (open cut and underground, both coal and metalliferous), and manufacturing. The projects include hazard identification, quantitative risk analysis (QRA), hazard and operability studies (HAZOPs), technical safety audits, reliability and maintenance planning, and HAZOP training courses. In this Safety Study, Mr. Sylvester was the FMEA leader and provided mechanical engineering support.

Stuart Chia

Mr. Chia is a chemical and environmental engineer with over 7 years' experience in the process safety and environmental field. Studies have been conducted for clients in the offshore and downstream oil and gas, chemical process industries, mineral processing, waste management, hazardous materials transportation and storage terminals. Mr Chia holds a bachelor's degree in Chemistry and Chemical Engineering, and a Masters degree in Environmental Engineering. He is a graduate member of the Institution of Engineers Australia, and the Institution of Chemical Engineers.

Experience in process safety engineering has included studies involving Hazard Identification, Hazard Analysis (HAZAN), Scenario Based Hazard Identification, Quantitative Risk Analysis (QRA), Emergency Response Plans, Fire Safety Studies, Hazard Audits and offshore Safety Case (SC) preparation.

Mr. Chia has been involved in major studies for oil and gas clients such as Shell International, Caltex Australia and Boral Energy. In this study, he was the team leader of the Safety Study and was involved extensively in the experimental trials, workshop surveys, coordination with research and government organisations and consequence assessment as well as the risk assessment.

John Bertram

Mr. John Bertram has over 18 years of experience in the fields of power plant engineering, risk and reliability engineering. Has a wide background in consulting, maintenance management and maintenance planning. Experienced in the supervision of engineering maintenance teams, hazard analysis of industrial facilities; system analysis and reliability assessment. Over 8 years experience in the field of risk and reliability engineering. He holds a bachelor's degree in Electrical Engineering.

Currently Senior Safety Engineer, Granherne Pty Ltd, located in the Sydney Office, Australia, and responsible for providing safety and risk engineering consulting services. Mr. Bertram was involved in the assessment of automobile electrical systems.

John Brini

Mr. John Brini has over 12 years of experience in Over 6 years experience in production and process safety consulting. Mr. Brini has been involved with commissioning and monitoring performance of production, conceptual process design and reviewing process design for on-shore and off-shore oil and gas facilities. One year experience in design of processing facilities in the energy industry. Mr Brini is a graduate in chemical engineering and is a graduate member of the Institution of Chemical Engineers.

In this study, Mr. Brini was the lead quality assurance reviewer of all documents produced in the Safety Report.

Belinda Gourlay

Miss Belinda Gourlay is a graduate chemical engineer, and is currently a Safety Engineer at Granherne. In the last eighteen months has been a team member on a number of safety studies, including the Formal Safety Assessment of the BHP Hot Briquetted Iron facility, LPG dispersion studies for Shell Lara Terminal, and hazard analysis of two agricultural chemicals formulation plants.

She was also a team member involved in Building Respiration Tracer Gas Studies for the WA Water Corporation.

In this study, Miss Gourlay has been a team member, performing experimental work, consequence analysis modelling and risk assessment.