BAKERRISK

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September 19, 2008

Jean Hardy, ing. MBA
Agence métropolitaine de transport (AMT)
500 Place d'Armes, 25e etage
Montreal, Quebec Canada H2Y 2W2

Re: **Explosion Risk for Suburban Rail Line Siting – Final Report**
BakerRisk Project No. 01-1638-001-06

Dear Mr. Hardy:

Enclosed is the final report prepared by Baker Engineering and Risk Consultants, Inc. (BakerRisk) for the explosion risks to the proposed suburban rail line extension in suburban Montreal.

If you should require additional information or would like to discuss any aspect of our report, please contact me at (210) 824-5960 or email at RBennett@BakerRisk.com.

Sincerely,

Raymond H. Bennett, P.E., Ph.D.
Manager, Protective Structures Section

Approval:

Adrian J. Pierorazio, P.Eng.
Canadian Operations Manager

cc: Adrian Pierorazio, BakerRisk

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POTENTIAL EXPLOSION RISK STUDY FOR SUBURBAN RAIL LINE EXTENSION

Final Report
September 19, 2008

Prepared for:
Agence Metropolitaine de Transport

Prepared by:
Raymond H. Bennett, P.E., Ph.D.
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Benjamin Daudonnet, Ph.D.

BakerRisk Project No.
01-1638-001-06

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BakerRisk regards the work that it has done as being advisory in nature. The responsibility for use and implementation of the conclusions and recommendations contained herein rests entirely with the client.

EXECUTIVE SUMMARY

Baker Engineering and Risk Consultants, Inc. (BakerRisk) was contracted by the Agence Metropolitaine de Transport (AMT) to assess the potential risks to passengers from an accidental explosion within the storage area of the munitions plant operated by General Dynamis (formely SNC TEC). AMT is proposing to extend suburban rail service and the proposed alignment would impinge on the Quantity-Distance Separation Requirements established by the Explosives Branch of Natural Resources Canada. The required separation distance is referred to as D5 and is $14.8 \times Q^{1/3}$, where Q is the quantity of explosives in kg. The minimum D5 distance is specified as 180 m regardless of the quantity of explosives stored. For the quantities of explosives stored at General Dynamics (GD), the D5[1] distances are between 250 m and 670 m depending on the individual potential explosion source.

The assessment by BakerRisk identified the potential consequences of an accidental explosion within the storage area as well as the expected frequency of such an event. The frequency of an accident in the storage area is estimated to be on the order of 1×10^{-4} events per magazine per year. The potential consequences of an accidental explosion, should it occur, include light damage to the shell of the rail cars but with almost no potential for a fatality to the passengers or crew of the rail cars. The combination of consequence and frequency is low enough that the mitigation is not required par the American Public Transportation Association guidelines.

A comparison to Canadian passenger train accident statistics and to Quebec road accident statistics shows that the risk to train passengers due an accidental explosion at the GD site is 3900 to 30,000 times lower than for train or car travel in general for the same distance.

An individual risk calculation shows that the most exposed individuals (i.e., train personnel) would be exposed to an individual risk level of 3.3×10^{-8} fatalities/year. This level is well below the 10^{-6} fatalities/year threshold that is used for "off site" risk at some industrial sites.

The result of these calculations show that for the proposed routing, the risk due to an accidental explosion at GD is not a significant factor in the overall risk to passengers and personnel on the proposed train line.

The risks are low enough not to require mitigation. However, an earthen berm will be built along the rail line using material obtained during grading and construction of the line and will prevent projected debris from hitting the train. Il will also block the view of the GD facility from the train. To block the line-of-sight, the berm will only need to be slightly taller than the top of the car windows (4m). The berm could be sloped on both the track and GD sides to ensure stability of the mound. An example design is shown in the figure below.

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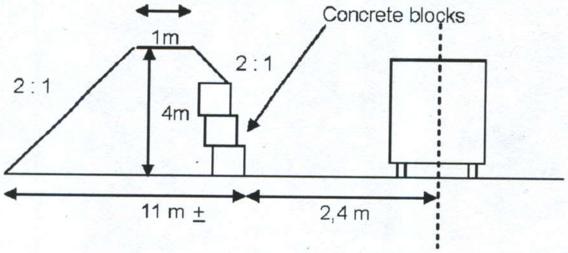
[1] The D5 distance is the separation distance required to most roads and highways.



Example Design Layout of Berm and Railcar

AMT intends to construct such a berm and put in place a series of other measures to further increase the safety of the passengers. These take the form of minimizing the exposure time and reducing the chances that the AMT train will have to slow or stop within the D7[2] range of GD's facility. The measures include:

- Designing the line to operate at 45 mph on the section of track inside the D7 zone.
- The use of new bi-mode locomotives for the Train de l'Est that will have two diesel prime movers, running simultaneously. These locomotives can operate with just one prime mover, and as a result, a shutdown that would require the simultaneous failure of both engines is therefore extremely unlikely.
- The emergency response plan will specify that passengers should not be evacuated while within the D7 area. Instead, an idle locomotive will be used to push the train to the next station.
- The locomotive fuel tanks will be compartmented (into at least 4 compartments) and the bottom of the tanks will be at least 15 inches from the top of the tracks compared to the usual 12 inches to reduce the risk of a fuel leak in the Mont-Royal tunnel. This would also reduce the likelihood of a fire in the event that the locomotive encountered debris as a result of an event at GD.
- A cow catcher or similar system will be used in front of the locomotive to reduce the chances of debris hitting and derailing the train.
- A new grade separation is proposed at the proposed Pierre Le Gardeur crossing so that there will not be a road-railway conflict that would cause the train to stop within the D7 area. A new separate track will be built between Repentigny and Charlemagne for the AMT train; this means the AMT train will not have to stop to wait for a CN freight train and would thereby limit the possibility of the train being stopped in the D7 stand-off area from the GD facility.
- The rail cars are robust structures (similar to blast resistant modules on land), and calculations and comparisons to test data indicate that they would suffer cosmetic damage in the postulated event.

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[2] The D7 distance is the separation distance required to very busy roads and to building where people may assemble

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1.0 INTRODUCTION

AMT is proposing to extend suburban rail service and the proposed alignment would impinge on the Quantity–Distance Separation Requirements established by the Explosives Branch of Natural Resources Canada. The required separation distance is referred to as "D5" and is 14.8 x $Q^{1/3}$, where Q is the quantity of explosives in kg. The minimum D5 distance is specified as 180 m regardless of the quantity of explosives stored. For the quantities of explosives stored at General Dynamics, the D5 distances are between 250 m and 670 m depending on the individual potential explosion source.

Baker Engineering and Risk Consultants, Inc. (BakerRisk) was contracted by the Agence Metropolitaine de Transport (AMT) to assess the potential risks to passengers from an accidental explosion within the storage area of the munitions plant operated by General Dynamics (formerly SNC TEC).

The assessment was to include the risk of train derailment due to overpressure and the risk of debris impacting the train.

A discussion of the Potential Explosive Sources (PES) is provided in Section 2.0 and the response of the passenger cars is defined in Section 3.0. The risk calculations are discussed in Section 4.0 and Conclusions and Recommendations are presented in Section 5.0.

2.0 POTENTIAL EXPLOSION SOURCES

There are fifteen Potential Explosion Sites (PESs) on the General Dynamics site:

- Magazine 406
- Magazine 406A
- Magazine 410
- Magazine 411
- Magazine 412
- Magazine 412A
- Magazine 412B
- Magazine 415
- Magazine 416
- Magazine 417
- Magazine 417A
- Magazine 417B
- Magazine 412A1
- Magazine 412B1
- Shipping Marshalling Area (SMA)

Fourteen of the PESs are above-ground magazines. The 15th PES is the marshalling area (SMA), which includes cargo vans parked within a bermed area. All of the PESs are surrounded by barricades that are constructed in accordance with NRcan's *Quantity Distance Principles*.

2.1 General Magazines Description

The magazines are constructed with twelve (12) inch thick brick walls with concrete floors and either wood or concrete roofs. Sand-filled wooden barricades protect the surrounding area from direct hit debris projection. Explosives are staged in the marshalling area for short periods of time while awaiting loading/unloading.

Magazines 412A1 and 412B1 are proposed and not yet constructed. The quantities of explosives in the SMA reflect the quantity that will be present after the SMA is divided into two sections. The required separation distance between the rail line and each PES is based on the D5 distance, which is equal to the cube root of the explosive weight in kg multiplied by 14.8. The actual separation distance was scaled from a drawing prepared by General Dynamics. The distances shown in Table 1 are the shortest distance from the edge of a magazine to the centerline of the proposed rail alignment. The accuracy of the measured distances is on the order of 10 meters. The current proposed rail location will impinge on the D5 separation distance for 5 of the 15 PESs.

Table 1. PES Maximum Quantities and Required Separation Distances

(Highlighted entries do not meet the required separation distance)

PES	Required Separation Distance for "D5" (m)	Actual Separation Distance (m)
406	526	820
406A	570	700
410	620	860
411	663	730
412	632	600
412A	538	480
412B	443	360
415	610	950
416	600	830
417	600	730
417A	570	620
417B	253	510
412A1	538	430
412B1	443	300
SMA	484	500

Note: Refer to GD-OTS licenses issued by NRCAN

3.0 RAIL CAR CONSTRUCTION, RESPONSE, AND POTENTIAL FOR OCCUPANT INJURIES

3.1 Rail Car Construction

The commuter cars are to be constructed in accordance with the requirements of the 49 CFR Part 238 – Passenger Equipment Safety Standards, and the American Public Transportation Association (APTA) Standard for the Design and Construction of Passenger Rolling Stock.

The floor plan and elevation of a typical passenger car that will operate on the line is shown in Figure 1. The key components of the car that will affect its response to the potential blast loading are the window glazing, and wall and roof construction. The cars are designed to withstand substantial collision forces and overturning. The window and door glazing is designed to be bulletproof and resist the impacts of 24 lb concrete masonry units.

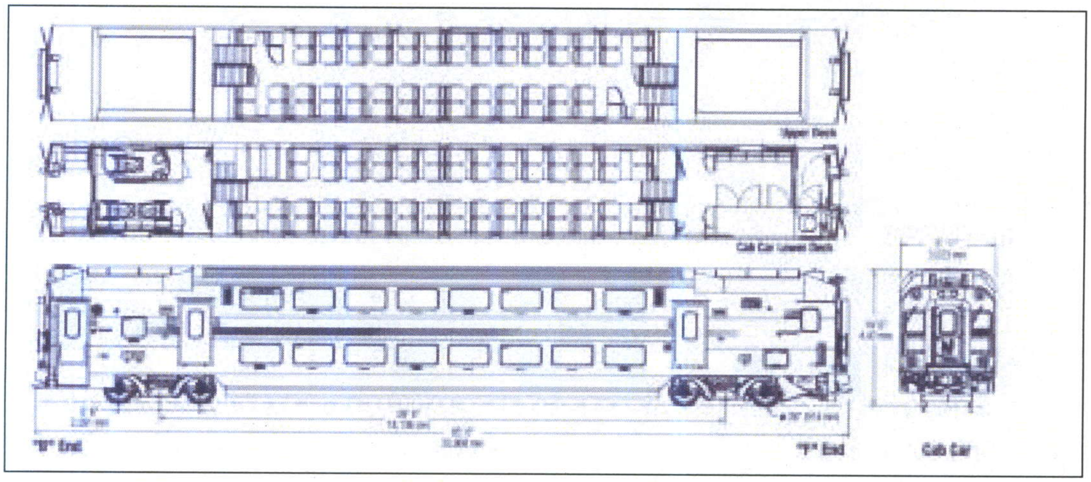

Figure 1. Typical Commuter Rail Car

The windows on the sides of the car are nominally 1.2 × 0.6 m (4 ft. × 2 ft.). The glazing is 12 mm (0.47 in.) thick polycarbonate. The side posts will be placed between windows and are assumed to be 1.5 m (5 ft.) on center. The exterior skin is modeled as 0.125-inch mild steel (fy =227 MPa or 33,000 psi) flat plate. This is the specified minimum. While corrugated and/or stainless steel sides are used, their capacity must equal the minimum as defined in the documents cited above. The minimum section modulus for side posts is specified as 0.30 in^3/foot of distance between posts, or 1.5 in^3/ for the 5-foot spacing. The calculations in Section 3.2 assume a HSS 3x2x1/4. This has a section modulus of 1.47 in^3.

Since the roof loads are significantly lower than the side loads, and the roof construction is as robust as the sides, only the response of the side walls was evaluated in this study.

3.2 Rail Car Response

3.2.1 Window Response

The properties of the windows were calculated using the WINLAC computer code. The window glazing has an ultimate blast capacity of 100 kPa (14.6 psi) and is not expected to break, even under the most severe loadings. For the glazing to develop its full capacity, an edge bite of 25 mm (1 in.) is required. Only a ½-inch bite is required to develop the capacity required to resist the applied loads. The fragment penetration of the window by the design weapon fragment from a M107 round at the closest standoff (300m) shows the fragment will not penetrate the window.

3.2.2 Car Body Flexural Response

The sides of the cars were modeled using single–degree-of-freedom models for the side wall panels and the side posts. The panel model included the effects of tension membrane forces. The side panels of the car will be damaged by the potential explosions. The metal side panels may suffer permanent displacements on the order of 50 mm (2 in.) under the worst-case loading.

The side posts were modeled as beams that are continuous over the mid-height floor framing. The posts are expected to undergo only minor permanent deformations on the order of 10 mm (0.4 in.). These deformations are not expected to result in a significant risk to the occupants of the cars.

The above are conservative estimates in that they do not allow for the global response of the car. This is discussed in Sections 3.2.3 and 3.2.4.

3.2.3 Rigid Body Response

The potential for car overturning was checked using a simple rigid body model. The center of gravity of the car was assumed to be at the center of the car in an end-on-view. The overturning impulse was calculated as the impulse delivered to the side of the car, and the point of rotation was taken as the rail to wheel interface on the side away from the explosion. The only restoring force considered was the weight of the car. The extent of rotation of the car about the rail-to-wheel interface can then be calculated from:

$$I_\alpha^2/2Mr^2 = T\alpha$$

Where:
I_α = Rotational impulse
M = Mass of Car
r = distance from center of mass to point of rotation
T = Restoring torque (Car Weight x distance from car c.g. to point of rotation)
α = angle of rotation (radians)

Under the worst-case loading, the peak rotation was found to be on the order of .03 radians, and the center of gravity will rotate approximately 8.9 cm (3.5 in.). This displacement assumes that the net overturning energy applied by the blast loads to the front, back, and rear sides of the car is resisted by the weight of the car. The flexibility of the suspension of the car was not assessed. The trucks (wheel sets) are attached to the car and are able to resist a static load of 250,000 lbs. This is equivalent to a static pressure on the side of the car of approximately 4 psi. Hence, the trucks are expected to remain attached.

3.2.4 Comparison to Test Data

The United States Government has published data on the response of railroad equipment exposed to the airblast effects resulting from nuclear weapon detonations. The testing was conducted in the 1950's and the weapons had a yield of approximately 1 kiloton of TNT. Several aircraft were also tested and are of interest because of the damage to lightly skinned metal structures. The aircraft were B-17s, oriented both end-on and side-on to the blast waves. The results of these tests are summarized in Table 2 and Table 3.

Table 2. Results of Nuclear Weapon Tests on Railway Equipment

Railway Equipment Tested	Loading (incident pressure reported in psi)	Estimated Range (ft/m)	Results
Empty Wooden Boxcar – Approximately 40 feet long with a weight of 40,000 lbs. Lighter per foot than commuter cars.	2 psi – incident 4.2 psi – reflected Estimated incident impulse based on 1kt nuclear explosion is 330 psi-ms.	2670 feet 814 m	Minor damage. Track did not suffer damage.
Loaded wooden boxcar – Approximately 40-feet long with a weight of 100,000 lbs. Heavier per foot than commuter cars.	4 psi- incident 8.8 psi- reflected Estimated incident impulse based on 1kt nuclear explosion is 500 psi-ms.	1650 feet 503 m	Structural damage to the car. Car remained on the tracks. Track did not suffer damage. See Figure 2
Empty Wooden Boxcar – Approximately 40 feet long with a weight of 40,000 lbs. Lighter per foot than commuter cars.	6 psi – incident 13.9 psi – reflected Estimated incident impulse based on 1kt nuclear explosion is 650 psi-ms.	1390 feet 424 m	Car body blown off of tracks. Car body pulled trucks (bogies) off of the tracks. Track did not suffer damage.
Loaded wooden boxcar – Approximately 40-feet long with a weight of 100,000 lbs. Heavier per foot than commuter cars.	6 psi – incident 13.9 psi – reflected	1390 feet 424 m	Car body badly damaged including roof blown off. Car could still be moved after test. Track did not suffer damage. See Figure 3
Loaded wooden boxcar – Approximately 40-feet long with a weight of 100,000 lbs. Heavier per foot than commuter cars.	7.5 psi – incident 18 psi – reflected Estimated incident impulse based on 1kt nuclear explosion is 740 psi-ms.	1140 feet 350 m	Car overturned. Track damage not stated.

Railway Equipment Tested	Loading (incident pressure reported in psi)	Estimated Range (ft/m)	Results
Loaded wooden boxcar – Approximately 40-feet long with a weight of 100,000 lbs. Heavier per foot than commuter cars.	9 psi – incident 22.4psi – reflected Estimated incident impulse based on 1kt nuclear explosion is 790 psi-ms.	1030 feet 314 m	Car overturned and demolished. Track damage not stated.
Diesel Locomotive – weight 46 tons. Body construction would be similar to commuter cars.	6 psi – incident 13.9 psi – reflected	1390 feet 424 m	Engine continued to run through the test (idle). Window broken and damage to metal panels. Track did not suffer damage.

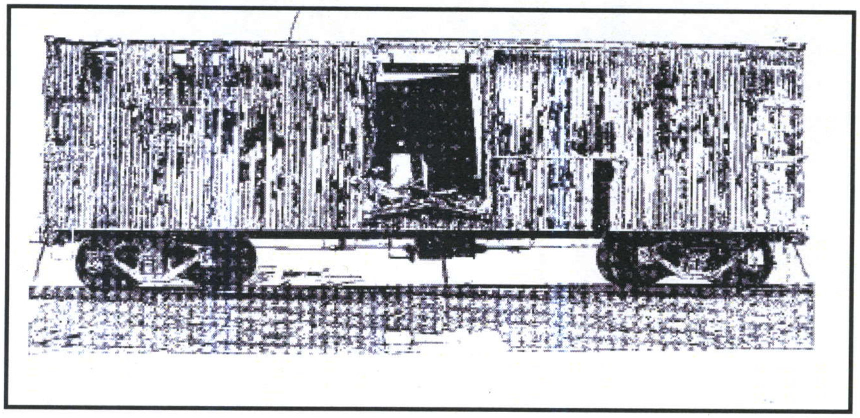

Figure 2. Loaded Wooden Boxcar after a Nuclear Explosion (4 psi overpressure)

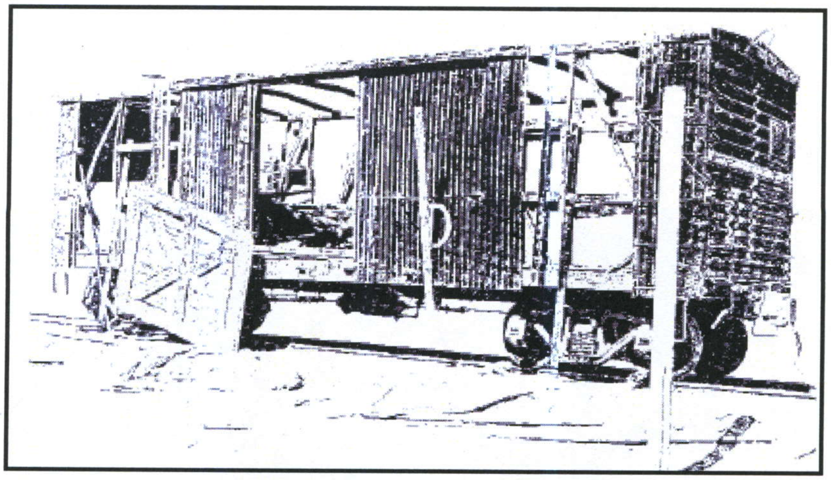

Figure 3. Loaded Wooden Boxcar after a Nuclear Explosion (6psi peak overpressure)

Table 3. Results of Nuclear Weapon Tests on Aircraft

Aircraft Tested	Loading (incident pressure reported in psi)	Estimated Range (ft/m)	Results
B-17 Side-on	3.6 psi- incident 11.9 psi- reflected Estimated incident impulse based on 1kt nuclear explosion is 480 psi-ms.	1170 feet 357 m	Fuselage buckled in bending behind the wings. Aluminum skin panels remained intact. See Figure 4.
B-17 End-on	2.4 psi- incident Estimated incident impulse based on 1kt nuclear explosion is 370 psi-ms.	2340 feet 713 m	Fuselage OK. Some skin buckling. See Figure 5.

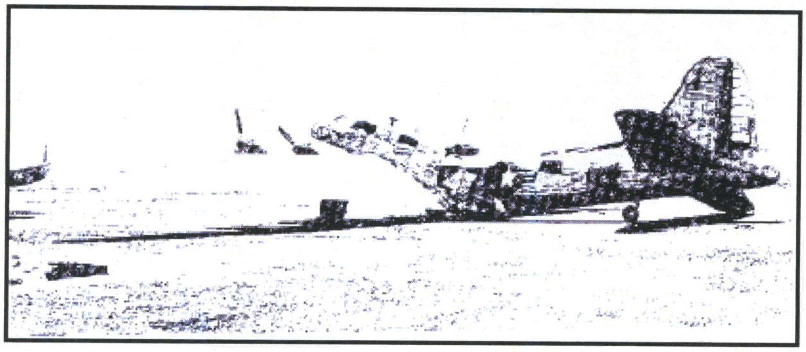

Figure 4. Aircraft after Side Exposed to a Nuclear Explosion (3.6 psi overpressure)

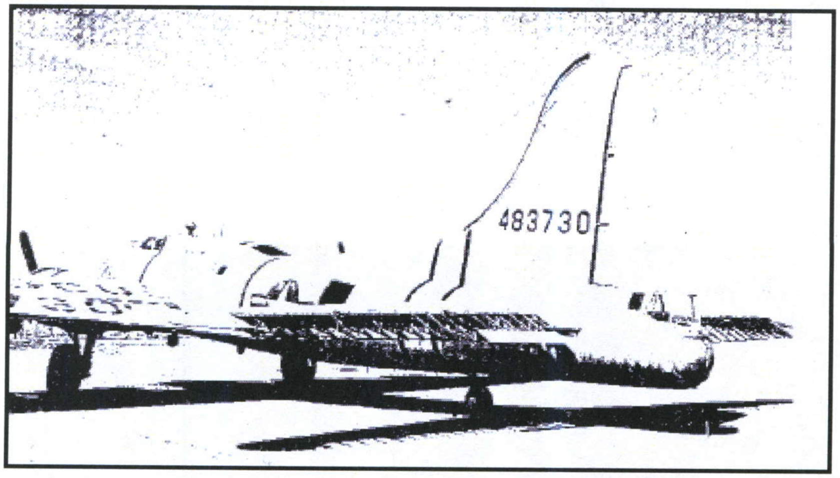

Figure 5. Aircraft after Tail Exposed to a Nuclear Explosion (2.4 psi peak overpressure)

The nuclear weapon tests on the locomotive and the aircraft (especially the B-17 in Figure 5 that was exposed to greater pressures than predicted for the rail cars) indicate that little damage would be expected to the shell and structural frame of the rail cars. The tests on the box cars indicate that the cars would not be expected to roll over.

3.3 Potential for Occupant Injury

The deformations of the car are not expected to result in the potential for any serious injury to the railcar occupants. However, the accelerations and deformations may cause some internal equipment to become detached and strike occupants. Typical vulnerability numbers for individuals in these circumstances are on the order of 0.01% or less. The vulnerability of occupants in various buildings as a function of building type is shown in Figure 6. The damage to the railcar was determined to be cosmetic and would be considered approximately equal to Building Damage Level 1. Hence the occupant vulnerability is expected to be very low, even for substantially greater levels of damage.

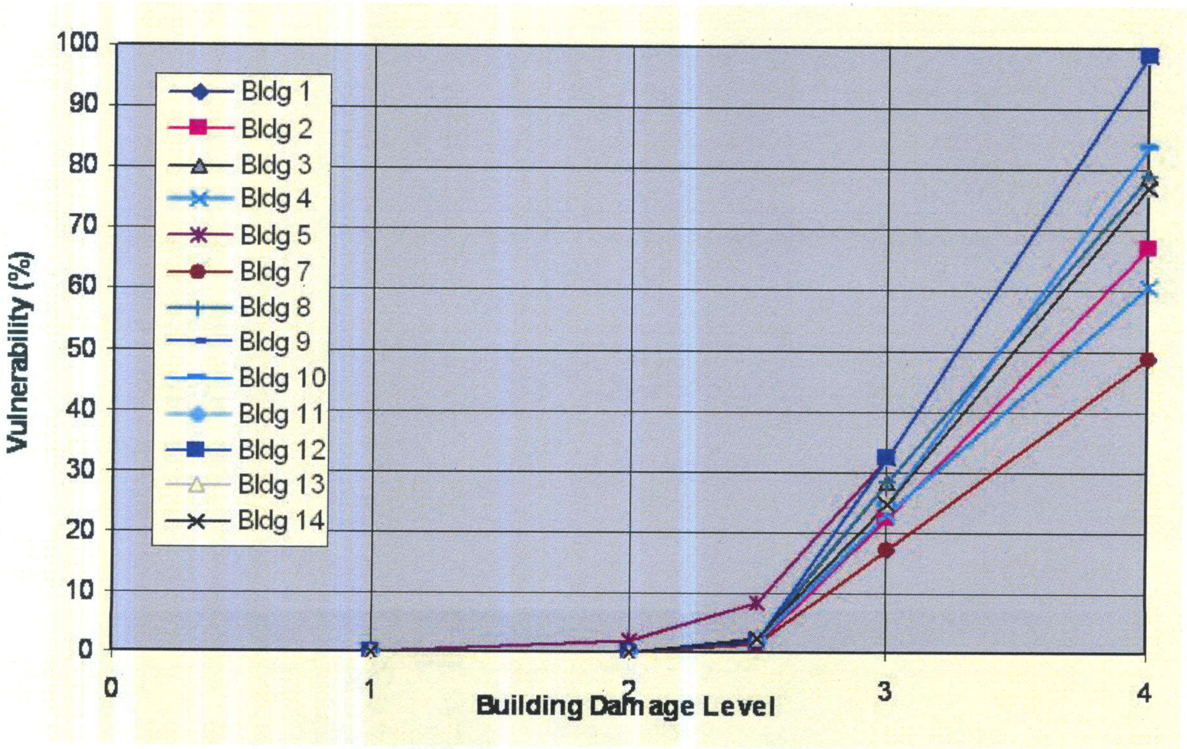

Figure 6. Occupant Vulnerability as a Function of Building Damage Level

4.0 RISK EVALUATION

The previous sections have considered just the consequences of an accidental explosion at GD, independent of the likelihood of an accidental explosion. This section will extend the analysis to consider the risk to passengers as a result of such an event. Risk is defined as the product of three factors:

- The frequency of the event (f): the more often the event happens, the higher the risk that someone can be affected,
- The exposure (exp): the more time someone spends in a place where they are likely to affected by the event, the higher the risk for this,
- The vulnerability of the event (vuln): this is a measure of the probability of an adverse outcome for a person given that they are exposed to the threat.

The risk calculated here represents the probability of a fatality on the proposed commuter train route as a result of an accidental explosion at the GD Facility. As such, the frequency is the frequency of an accidental explosion, the exposure is the likelihood of person being in an exposed location on the train (i.e., train within range of the hazard and a person being in a location on the train that would result in them being exposed to the hazard), and the vulnerability is the probability of a train occupant being fatally injured if exposed to the hazard. The resulting risk measure is expressed both as fatalities/year and years per fatality. It must be stressed that these are probabilistic measures and should not be interpreted to mean that no more than one fatality could occur, nor that a particular period of time will pass between fatal accidents.

To assess the acceptability of the risk measure, comparisons are provided between the calculated risk and industry standards and transportation accident statistics.

4.1 Risk Due to an Accidental Explosion at the GD Facility

In this case, there are three main types of risk:

- Risk due to airblast (i.e., derailing, overturning, structural, or non-structural damage)
- Risk due to debris (i.e., pieces of the magazine structure impacting the train)
- Risk due to fragments (i.e., pieces of ammunition as a result of accidental explosion)

The first two risks are discussed in the sections below. The last, risk due to fragments, is neglected since it was shown in section 3.2.1 that these primary fragments would be unable to penetrate the rail cars at the distances involved.

4.1.1 Risk Due to Airblast

The risk from an accidental explosion may be expressed in four ways as shown in Figure 7. This report modifies the calculation for the "maximum expected fatalities per PES year" in that it sums the risks from all the PES sources that have a potential impact on the rail line. Thus, the risk is expressed as the "maximum expected fatalities per year."

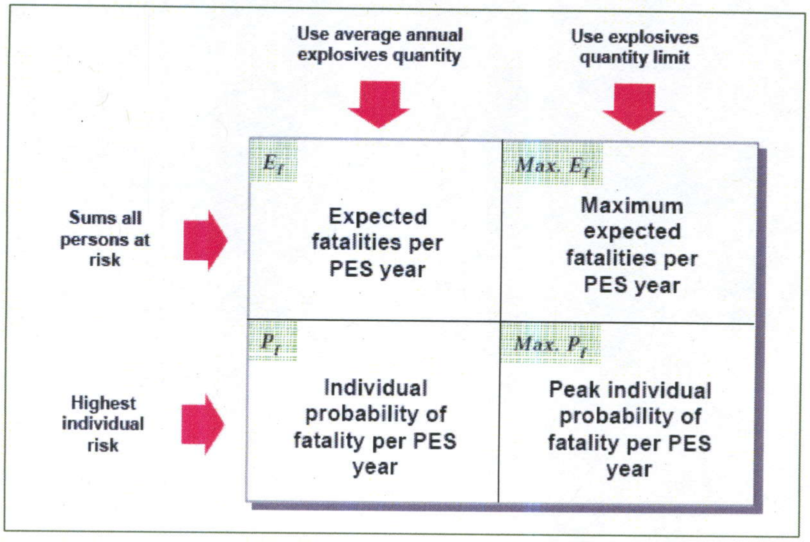

Figure 7. Types of Risk as Defined by the U.S. DDESB

The risk of a fatality for an individual is calculated as:

$$Pi/f = P_{ev} * P_{ex} \times P_f$$

Where:
Pi/f = Probability of individual fatality
P_{ev} = Probability of event
P_{ex} = Probability the individual is exposed to the event
P_f = Probability of a fatality given exposure to the event.

The maximum expected "fatalities per year" is the sum of the individual risks for all persons exposed. This is a simplification in that the risk and exposure calculations are all based on each individual being at the closest point on the rail line to each PES.

The derivation of each of the probabilities on the right hand side of the equation is discussed in the paragraphs below.

The probability of an accidental explosion occurring at a Potential Explosion Source (PES) has been developed by the DDESB and is shown in Table 4 below. The probability of an accidental explosion is dependent on the type of explosive handled (as designated by the Roman numerals) and the type of operation. The groups and scaling factors are defined in Figure 8. The munitions are Element Type I, II, and III (Compatibility Groups D and E). The probability of an event occurring in the above-ground magazines is between 1E-4 and 3E-5 depending on whether a magazine is considered as temporary or deep storage. The probability of an explosion in the SMA is 3E-4 if the SMA is considered to be in transit storage.

Table 4. Probability of an Accidental Explosion Per PES Year

PES used primarily for:	Allowable Scaling Factors	1E-6	3E-6	1E-5	3E-5	1E-4	3E-4	1E-3	3E-3	1E-2	3E-2	1E-1	3E-1
Burning Ground / Demilitarization / Demolition / Disposal	A1, A2, A8, B1, B2							III	II		I		
Assembly / Disassembly / LAP / Maintenance / Renovation	A1, A4, A5, A8, B1, B2					III	II		I				
Lab / Test / Training	A1, A3, A4, A5, B1, B2, B3, B4					III	II		I				
Manufacturing	A4, A5								All				
Inspection / Painting / Packing	A1, A2, B1, B2				III	II		I					
Loading / Unloading	A1, A2, B1, B2, B3, B4				III	II		I					
In-Transit Storage (hrs - few days)					III	II	I						
Temporary Storage (1 day - 1 month)				III	II	I							
Deep Storage (1 month - year)	A1, A2		III		I, II								

Elements	Compatibility Group
I	L, A, B, G, H, J, F
II	C
III	D, E

Scaling Factors:

A. Increase P_e by a factor of 10 (two columns to the right) for:
   1. Outside Continental United States (OCONUS) operations in support of wartime actions
   2. Operations involving dangerously unserviceable items awaiting destruction
   3. Initial tests of new systems
   4. Operations occurring in hazardous environments with gases, fibers, etc.
   5. Required remote operations
   6. Temporary Duty (TDY) activities during exercises/contingencies/alerts
   7. Integrated Combat Turn (ICT) operations
   8. Operations involving exposed explosives

B. Increase P_e by a factor of 3 (one column to the right) for:
   1. Outdoor storage/operations normally done indoors
   2. Home station activities during exercises/contingencies/alert
   3. Flightline holding areas
   4. TDY operations during peacetime

Figure 8. Terms Used in Table 4

The HSE reviewed historical data and determined that the risk of an accidental explosion at a storage site was 1E-4 per PES year. This data includes all storage facilities including those accessed on a regular basis. Other countries have adopted a similar number. The combined frequency from all sources is based on the assumption that ½ the magazines are used for storage of less than a month, and ½ are used for storage that exceeds one month. The SMA is assigned a frequency of $3x10^{-4}$. The combined probability is thus:

$$1.2x10^{-3} \ (3x10^{-4} + 7 \ x \ 1x10^{-4} + 7 \ x \ 3x10^{-5}).$$

The probability that any passenger (not a singular individual) will be exposed to the risk is the percentage of time a train will be present on the short stretch of track that is close to the explosives storage area. Based on the planned train schedule, the length of the planned route that would be exposed to the threat, and the average train speed though this section (40 mph), the train will be exposed to the threat of an accidental explosion at the GD facility for 34 minutes a day, 5 days a week. This represents approximately 2.8 hours per 168-hr week for an overall exposure probability of 0.017.

The probability of a fatality given an individual is exposed to the explosion hazard while in a rail car is estimated in Section 3.3. Since no damage mechanism was identified that could result in a fatality, an estimate of 0.0001 was used (conservative estimate based on damage level of 1 for a pre-engineered metal building). This is discussed more thoroughly in Section 3.3.

The predicted ridership data was provided by AMT. This data shows that the train is expected to have an average of 256 passengers on this section of track.

The estimated annual risk of a fatality due to airblast is thus:

$$5x10^{-7} \ (1.2x10^{-3} \ x \ 0.017 \ x \ 0.0001 \ x \ 256) \text{ or one fatality per 2,000,000 years.}$$

4.1.2 Risk Due To Debris

The probability of a piece of debris larger than 0.45 kg striking the window area of a rail car is between 0.3 and 0.4. This value is computed by summing the expected number of hits of all the debris sizes greater than 0.45 kg. The glazing is designed and tested to provide protection from either small (.22-caliber bullets) or large (standard 24-lb masonry units) objects with a kinetic energy of 100 ft-lbs, directed normally to the window. Since debris at these extreme ranges will be falling on trajectories of between 45-degrees and vertical the 0.45 kg cut-off for minimum debris size is reasonable. The probability of debris striking a window is thus $8 \ x \ 10^{-6}$ ($1.2x10^{-3}$ x 0.017 x 0.4) or one fragment per 125,000 years. At these high angles of incidence, the debris would be expected to affect just one seat if it were to penetrate the rail car. Based on ridership data, the train is expected to have an average occupancy of 256 passengers and these would be sitting in a train with 1420 seats. As a result, the probability of a person being in the seat affected is 18% (256/1420). If it is further assumed that the probability of fatality if struck by a piece of debris is 50% (conservative estimate based on the premise that all strikes to the upper body would be fatal), the overall probability of fatality given a fragment penetration is 9%. The overall probability of fatality due to debris is, therefore, 7.4×10^{-7} ($1.2 \times 10^{-3} \times 0.017 \times 0.4 \times 0.18 \times 0.5$) or one fatality per 1,400,000 years.

4.2 Comparison to Transportation Risk Guidelines

The American Public Transportation Association (APTA) provides risk assessment guidelines for the fire risks associated with existing equipment. While not directly applicable to the explosion risks associated with a new rail location, the document does place a discussion of explosives risks in the proper context.

The APTA approach defines risk in terms of frequency and consequences. Risks are placed in four categories:

1. Unacceptable: Poses immediate threat to personal safety. Correct or control immediately.
2. Acceptable short-term: May pose threat to personal safety. Formulate corrective action plans and implement on a priority basis.
3. Acceptable with management review: Deemed acceptable or unavoidable risk after review by person(s) with appropriate authority. Formal documentation of acceptance and sign-off necessary with documentation of risk analysis process. Nevertheless, correct the risk scenario if feasible.
4. Acceptable: Not deemed to be a risk.

4.2.1 APTA Consequence Levels

The definitions of the consequence levels established by the APTA are:

1. Catastrophic – Fire involving loss of life or serious injury
2. Serious – Fire that may cause lost time injuries or hospitalization
3. Significant – Evacuation of vehicle but no injuries
4. Negligible – No injuries or evacuation required

4.2.2 APTA Frequency Definitions

The frequency definitions established by the APTA are:

1. Frequent – More than two occurrences per year or one occurrence per 6×10^6 vehicle miles
2. Probable: More than one occurrence per 3 years or 3.6×10^7 vehicle miles, but less than two occurrences/year or per 6×10^6 vehicle miles.

3. Occasional: More than one occurrence per 15 years or $2\text{x}10^8$ vehicle miles, but less than one occurrence per 3 years or $3\text{x}10^7$ vehicle miles.
4. Remote: More than one occurrence per 75 years or 10^9 vehicle miles, but less than one occurrence per 15 years or $2\text{x}10^8$ vehicle miles
5. Improbable: Less than one occurrence per 75 years or 10^9 vehicle miles.

The Risk Index Matrix used to establish the specific risk category as a function of the consequence severity and frequency is shown in Table 5.

Table 5. Risk Index Matrix

APTA Frequency	Consequence Severity			
	Catastrophic 1	**Serious 2**	**Significant 3**	**Negligible 4**
Frequent (1)	1	1	1	3
Probable (2)	1	1	2	3
Occasional (3)	1	2	2	4
Remote (4)	2	2	3	4
Improbable (5)	3	3	3	4

Given that the damage to the rail cars is not expected to result in serious injuries, the consequences of a potential explosion would be considered "Significant" under the APTA definitions described above, and potentially serious if an individual were seriously injured. The frequency estimate of an explosion occurring while the train is in the area $2.0 \text{ x } 10^{-5}$ ($1.2\text{x}10^{-3}$ x 0.017) is 3 orders of magnitude less than the upper range of improbable. The overall risk ranking is therefore considered as a 3 (acceptable with management review), and given the extremely low probability of occurrence, may be considered a 4 (acceptable).

4.3 Individual Risk

To this point, the discussion has been focused on the rate of fatalities expected for the train as a whole. Another measure that is used in risk assessment is individual risk. Individual risk is the risk that a single individual would be exposed to if they were present at the potential location "full time." In this particular case, there are three ways to define what is considered to be "full time"—24 hrs/day, 40 hrs/week, or the time that the train is present. For residential environments, 24 hrs/day is sometimes used to represent the risk to residents since some fraction will indeed be home 24 hrs/day at least some of the time. For work environments, the 40 hr/week value is often used to represent the risk to a typical worker. In the case of the train, a 'typical' commuter will take two trips per day, one outbound, and one return, and will only be exposed to the risk from the GD facility while within range of it. In this case, the total exposure time per commuter would be approximately 21 minutes/week. The bounding case would be for the AMT employees who may be conservatively considered to be on every train that passes through this area, every day of the week. This results in an exposure of 2.8 hours/week. It is this latter exposure time that will be used for the basis of the individual risk calculations in this study.

The total risk to the most exposed individual would be from three types of risk:

- Airblast Risk:	$2.0\text{x}10^{-9}$ ($1.2\text{x}10^{-3}$ x 0.017 x 0.0001 x 1)
- Debris Risk:	$2.9\text{x}10^{-8}$ ($1.2\text{x}10^{-3}$ x 0.017 x 0.4 x 1/142 x 0.5)
- Unexploded Ordinance Risk:	$2.4\text{x}10^{-9}$ ($1.2\text{x}10^{-3}$ x 0.017 x 0.017 x 1/142)

The sum of the individual risk from these three sources is $3.3\text{x}10^{-8}$ fatalities/year.

4.4 Comparison to Other Transportation Risks

To put the risks presented here into perspective, the fatality rate can be compared to industry-wide data for transportation risks. In general, these are expressed as a number of fatalities per passenger-km to provide a meaningful comparison between alternative means of transport. For the portion of the proposed train line that would be exposed to the threat of an accidental explosion at the GD facility, the following information may be used to calculate the expected number of passenger-km affected:

- Exposed portion of track:	~2.0 km
- Number of trains per week	80 (16 trains per day, 5 days per week)
- Average number of passengers per train:	256

As a result, this portion of track represents 2.1×10^6 passenger-km per year of transportation.

4.4.1 Canadian Passenger Train Fatality Statistics

The following statistics for the train can be used:

- According to the TSB[3] (Transportation Safety Board of Canada), there were 2 fatalities and 7 serious injuries (among passengers and employees) in 2005 (the most recent data) for rail transport in Canada,
- Transport Canada[4] reports that the number of passenger-miles in Canada was 1.478×10^9 passenger-km in 2005 (most recent data)

From this data, the number of fatalities per passenger-km per year is 1.4×10^{-9} (number of

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[3] Transportation Safety Board of Canada, bst-tsb.gc.ca/en/stats/rail/2005/statssummaryrail05_sec2.asp

[4] Transport Canada Web Site, www.tc.gc.ca, Transport Canada (ACACB) and Statistics Canada, rail carrier Annual Reports

injuries: 4.7×10^{-9}). For the same passenger-km use rate as the section of track considered in this report, the expected fatality rate would be 2.9×10^{-3} /year ($2.1 \times 10^{6} \times 1.4 \times 10^{-9}$) or 1/344 years. Using a similar method, the annual risk of serious injuries, would be 1.0×10^{-2}/year or 1/100 years.

4.4.2 Road Fatality Statistics

If the train does not go through this area, an alternative would be for commuters to drive. Assuming that the drivers will commute a similar distance, it is relevant to compare the risk of the exposed section of rail to a comparable section of road. The Canadian Motor vehicle Traffic Collision statistics for 2005[5] reveal that the rate of road fatalities in Quebec was 17 fatalities per billion vehicle-miles. The number of serious injuries for the same period (~8% of total injuries) was approximately 112 per billion vehicle-miles. For the same number of vehicle-miles as the exposed portion of the proposed train route, the fatality rate would be 2.2×10^{-2}/ year (1/45 years) and the annual risk of serious injury would be 1.4×10^{-1}/year (~1/7 years).

4.4.3 Transportation Statistics Summary

A comparison between the transportation statistics are summarized in Table 6:

- In the case of the train, the fatality rate due to accidental explosions at the GD site is one per 1,400,000 years
- For the passenger trains in general, the fatality rate for the same number of passenger-km would be one per 345 years and one serious injury every 100 years
- For road travel, the fatality rate would be one fatality per 45 years and one serious injury every 7 years.

Table 6. Comparison of Train/Car Risk Statistics

Event	Train (explosion)	Train (Other Hazards)	Car (Quebec)
Years per fatality	1,400,000	345	45
Years per serious injury	Not Assessed	100	7

This comparison shows that a train passenger is 3900 times more likely to be killed as a result of typical train operations and accidents on the same stretch of track than as a result of an accidental explosion at the GD facility. This means that routing the train as proposed increases the risk to occupants by less than 0.03% over routing it somewhere else, assuming that the distance of the route would be unchanged if an alternate route was used. It also indicates that,

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[5] Transport Canada Web Site, www.tc.gc.ca/roadsafety/tp/tp3322/2005/page5.htm

for the same distance of travel, road transport presents a risk that is 30,000 times higher than that presented by travel near the GD facility.

4.5 Recommendations

The rail car construction discussed in Section 3.0 may be considered adequate to mitigate the risk to the passengers from an explosion in the storage area. The risk of a fatality due to airblast is approximately $5x10^{-7}$ and the risk of a fatality due to debris strike is conservatively estimated as $7.4x10^{-7}$. These risks are 3900 – 30,000 times lower than the risk to passengers in trains or cars for the same distance traveled.

The individual risk for the most exposed individual (i.e., train personnel) is $3.3x10^{-8}$ fatalities/year. This is well below the 10^{-6} fatality/year individual risk criterion that is applied in some industrial 'off site' risk analyses.

From these comparisons, it is concluded that the proposed train route does not appreciably increase the risk to passengers relative to other hazards (i.e., normal transportation and industrial risks). It is recommended that AMT focus their risk-reduction efforts on reducing the risk due to normal train operations rather than on an accident at GD.

5.0 SUMMARY AND CONCLUSIONS

The risks associated with the location of the rail line extension are small and significantly lower than the risk criteria established by the APTA, the risk to passenger train occupants in general, and the risk to passengers on the road.

The rail cars are robust structures (equivalent to blast resistant modules on land), and calculations and comparisons to test data indicate that they would only suffer cosmetic damage in the postulated event. The highest risk to passengers from the GD facility is expected to result from a piece of large debris striking a window.

The risks are low enough not to require mitigation. However, if desired, an earthen berm could be built along the rail line using material obtained during grading and construction of the line. Based on the results of this risk analysis, the berm would not need to be designed to resist the blast and debris loads, though it would be at least partly effective for that purpose, but would be built primarily to block the view of the GD facility from the train. To block the line-of-sight, the berm would only need to be slightly taller than the top of the car windows (4m). The berm could be sloped on both the track and GD sides to ensure stability of the mound. An example design is shown in Figure 9.

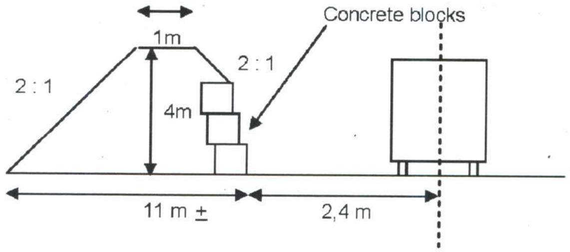

Figure 9. Example Design Layout of Berm and Railcar

AMT intends to construct such a berm and to put in place a series of other measures to further increase the safety of the passengers. These take the form of minimizing the exposure time and reducing the chances that the AMT train will have to slow or stop within the D7 range of GD's facility. The measures include:

- Designing the line to operate at 45 mph on the section of track inside the D7 zone.
- The use of new bi-mode locomotives for the Train de l'Est that will have 2 diesel prime movers, running simultaneously. These locomotives can operate with just one prime mover and, as a result, a shutdown that would require the simultaneous failure of both engines is therefore extremely unlikely.
- The emergency response plan will specify that passengers should not be evacuated while

within the D7 area. Instead, an idle locomotive will be used to push the train to the next station.

- The locomotive fuel tanks will be compartmented (into at least 4 compartments) and the bottom of the tanks will be at least 15 inches from the top of the tracks compared to the usual 12 inches to reduce the risk of a fuel leak in the Mont-Royal tunnel. This would also reduce the likelihood of a fire in the event that the locomotive encountered debris as a result of an event at GD.
- A cow catcher or similar system should be used in front of the locomotive to reduce the chances of debris hitting and derailing the train.
- A new grade separation is proposed at the proposed Pierre Le Gardeur crossing so that there will not be a road-railway conflict that would cause the train to stop within the D7 area. A new separate track will be built between Repentigny and Charlemagne for the AMT train; this means the AMT train will not have to stop to wait for a CN freight train and would thereby limit the possibility of the train being stopped in the D7 stand-off area from the GD facility.