**CRASH DATA RESEARCH CENTER**

Calspan Corporation
Buffalo, NY 14225

# CALSPAN ON-SITE HYBRID VEHICLE CRASH INVESTIGATION
# SCI CASE NO.:CA09012

## VEHICLE: 2005 TOYOTA PRIUS HATCHBACK

## LOCATION: NORTH CAROLINA

## CRASH DATE: JANUARY 2009

Contract No. DTNH22-07-C-00043

Prepared for:

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National Highway Traffic Safety Administration
Washington, D.C. 20590

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The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points are coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics in order to determine the pre-crash, crash, and post-crash movements of involved vehicles and occupants.

Because each crash is a unique sequence of events, generalized conclusions cannot be made concerning the crashworthiness performance of the involved vehicle(s) or their safety systems.

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| *16. Abstract*<br>This on-site investigation focused on the crashworthiness of the hybrid battery system in a 2005 Toyota Prius Hybrid. The Prius was involved in a front-to-side impact configuration with a transit bus. The Prius was equipped with a high-voltage nickel-metal hydride battery pack using potassium hydroxide electrolyte. This battery pack had a total output rating of 200 volts and was used for low speed vehicle acceleration/motion and to assist the 1.5 liter (92 ci) gasoline engine in higher speed travel. This battery pack was located in the rear center area of the vehicle under the floor in the cargo area. This vehicle was equipped with a regenerative braking system to charge the hybrid battery. A standard 12-volt battery was located in the right rear of the vehicle that provided power to the gasoline engine, accessories and the air bag systems. The Prius was equipped with a Certified Advanced-208 Compliant frontal air bag system for the driver and front right passenger positions. A CAC vehicle is certified by the manufacturer to be compliant to the Advanced Air Bag Portion of Federal Motor Vehicle Safety Standard No 208. The CAC frontal air bag system did not deploy The Prius was also equipped side impact air bags located in the front seat backs which did not deploy, and Inflatable Curtain (IC) air bags located in the right and left roof side rails. The right IC air bag deployed in this side impact crash. The 52-year old male driver of the Prius was not injured. There was no damage to the Prius' hybrid battery. The Prius was towed while the bus was driven from the scene of the crash. | | | |
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## BACKGROUND

This on-site investigation focused on the crashworthiness of the hybrid battery system in a 2005 Toyota Prius Hybrid. The Prius was involved in a front-to-side impact configuration with a transit bus. **Figure 1** is an image of the Prius involved in this case. The Prius was equipped with a high-voltage nickel-metal hydride battery pack using potassium hydroxide electrolyte. This battery pack had a total output rating of 200 volts and was used for low speed vehicle acceleration/motion and to assist the 1.5 liter (92 ci) gasoline engine in higher speed travel.

**Figure 1. The 2005 Toyota Prius case vehicle**

This battery pack was located in the rear center area of the vehicle under the floor in the cargo area. This vehicle was equipped with a regenerative braking system to charge the hybrid battery. A standard 12-volt battery was located in the right rear of the vehicle that provided power to the gasoline engine, accessories and the air bag systems. The Prius was equipped with a Certified Advanced-208 Compliant frontal air bag system for the driver and front right passenger positions. A CAC vehicle is certified by the manufacturer to be compliant to the Advanced Air Bag Portion of Federal Motor Vehicle Safety Standard No 208. The CAC frontal air bag system did not deploy The Prius was also equipped side impact air bags located in the front seat backs which did not deploy, and Inflatable Curtain (IC) air bags located in the right and left roof side rails. The right IC air bag deployed in this side impact crash. The 52-year old male driver of the Prius was not injured. There was no damage to the Prius' hybrid battery. The Prius was towed while the bus was driven from the scene of the crash.

The vehicle was identified through a visit to a regional salvage facility on Monday, March 2, 2009 and forwarded to SCI 1 for review on the same day. Based on the severity and location of the damage to the Prius, the case was assigned for on-site investigation on Tuesday, March 3, 2009. The investigation was initiated on March 4, 2009. This investigation involved the inspection and documentation of the Prius, the transit bus, the crash site, and interviews with driver of the Prius, the bus company manager, and the tow operator.

## SUMMARY

### *Crash Site*

The crash occurred on a residential two-lane roadway during daylight hours. At the time of the crash, the environmental conditions were snow with cloud cover. The asphalt road surface was snow covered with two furrows formed in the snow from previous traffic. The roadway extended in an east/west direction. In the eastbound direction of travel, the roadway was straight and level and transitioned to a shallow curve to the left with a positive grade of 6.5 percent. In the westbound direction of travel, the roadway was straight with a downhill grade of -3.3 percent that transitioned to a right curve with a downhill grade of -6.5 percent. The travel lanes were bordered by barrier curbs that were 16 cm (6.3") in height. Parallel parking was permitted at both curb lines. The north roadside was surfaced with grass and was level. The posted speed limit was 56 km/h (35 mph). The crash schematic is included as **Figure 12** of this report.

### *Vehicle Data*

#### *2005 Toyota Prius*

The 2005 Toyota Prius was a four-door hatchback that was manufactured in February, 2005 and identified by Vehicle Identification Number (VIN) JTDKB20U853 (production number deleted). The vehicle was purchased in 2006 as a used vehicle by the current owner/driver. The odometer reading at the time of the crash was 89,290 km (55,482 miles). The driver used the vehicle primarily for transportation to and from work and recreational activities.

The front-wheel drive Prius was equipped with a 1.5 liter (92 ci) transverse mounted four-cylinder gasoline engine linked to an electric hybrid motor and a continuously variable transmission (CVT). There was a console-mounted shift lever selecting forward, neutral, reverse or engine braking to charge the hybrid battery pack. The hybrid electric motor was powered by a 200 volt nickel-metal hydride battery pack using potassium hydroxide electrolyte. The battery was located in the interior of the vehicle, at the center rear above the rear axle. The hybrid battery was concealed by an aluminum cover and a carpeted panel that forms the forward part of the cargo area floor. The service brakes were front wheel disc and rear wheel drum with four-wheel antilock. All four windows were closed at the time of the crash. The vehicle manufacturer recommended tire size was 185/65R15 at 241 kPa (35 PSI) of cold tire pressure in the front tires and 228 kPa (33 PSI) of cold tire pressure in the rear tires. The tires were mounted on OEM alloy wheels. The Prius was equipped with an indirect Tire Pressure Monitoring System (TPMS). The driver reported in the interview that the TPMS warning light was not on prior to the crash. The right front, right rear and left front tires were all the recommended size, the left rear tire was size 195/60R15. The specific tire data at the time of the SCI inspection was as follows:

| Position | Measured Tire Pressure | Measured Tread Depth | Damage |
|---|---|---|---|
| Left Front | 172 kPa (25 PSI) | 4 mm (5/32") | None |
| Left Rear | Tire Flat | 2 mm (3/32") | None |
| Right Rear | Tire Flat | 1 mm (1/32") | Outside sidewall cut |

| Position | Measured Tire Pressure | Measured Tread Depth | Damage |
|---|---|---|---|
| Right Front | 193 kPa (28 PSI) | 4 mm (5/32”) | None |

The interior of the Toyota Prius Hybrid was configured as a cloth surfaced five-passenger hatchback with front bucket seats separated by a center console and a rear bench seat with 60/40 split forward folding seat backs. The front seats had adjustable head restraints, both of which were found in the full-down position. The front left seat back was adjusted to a measured angle of seven degrees aft of vertical and the front right seat back recline measured nine degrees.

***1996 RTS Transit Bus***

The 1996 RTS Transit Bus was manufactured in October, 1996 by Novabus, Inc. and was identified by the VIN 4RKMDTGA6TR (production sequence deleted). The bus was configured as a 36-seat local transit bus with two doors on the right side. The Gross Vehicle Weight Rating (GVWR) was 17,917 kg (39,500 lb) when mounted with 12.50 – 22.50 H tires on 8.25 x 22.50 rims.

***Crash Sequence***

***Pre-Crash***

Prior to the crash, the 2005 Toyota Prius was eastbound on the roadway. The driver was traveling to work and was concerned with being late due to slow driving conditions in the snow. The driver was traveling on a straight, flat section of roadway at approximately 40 km/h (25 mph). The 1996 transit bus was traveling at approximately 40 km/h (25 mph). As the driver of the Prius ascended the hill and entered the slight curve to the left, he increased throttle **(Figure 2)**. The Prius broke traction on the snow covered road and rotated approximately 95 degrees counterclockwise (CCW), crossing the center line into the path of the transit bus. The driver of the Prius applied the brakes and braced with both hands against the steering wheel when he realized the crash was imminent. The safety manager of the company operating the bus stated that the bus driver applied the brakes but did not steer left or right prior to the impact. Due to the snow on the roadway, there were no skid marks present during the scene inspection to mark the trajectory of either vehicle.

**Figure 2: Prius’ pre-crash trajectory**

***Crash***

The front plane, left aspect, of the transit bus impacted the right plane of the Prius within the westbound lane. The resultant directions of force were 3 o’clock for the Prius and 12 o’clock for the bus. The Transit bus was outside the scope of a WINSMASH analysis. The delta V of the Prius based on the Barrier Algorithm of the WINSMASH model was 34 km/h (21.1 mph). The longitudinal and lateral components of the delta V were 5.9 km/h (3.7 mph) and -33.5 km/h (-20.8 mph), respectively. The WINSMASH results were

considered borderline. As a result of the crash, the right IC air bag deployed during this event.

The momentum of the transit bus, in combination with the impact located aft of the Prius' center of gravity, redirected the Toyota from a counterclockwise (CCW) rotation to clockwise (CW). The vehicles subsequently engaged in a side-slap configuration involving the forward aspect of the right plane of the Prius against the right plane, forward aspect, of the transit bus. The resultant directions of force were 3 o'clock for both vehicles. The Barrier Algorithm of the WINSMASH model computed a delta V of 7 km/h (4.4 mph). The longitudinal and lateral components were 0 km/h and -7 km/h (-4.4 mph), respectively.

The Prius rotated approximately 90 degrees CW between the two impacts and was displaced rearward as it traveled down the grade on the snow covered surfaces. The Prius traveled approximately 28 m (91.9 feet) rearward down the negative 6.5 percent grade from the side-slap to final rest, traveling over the 16 cm (6.3 in) barrier curb and onto a grass lot to final rest. The transit bus stopped in the travel lanes near the location of the secondary event.

***Post-Crash***

The police and tow personnel responded to the crash site. The driver of the Prius exited the vehicle under his own power through the left front door. The driver was not injured. The driver of the bus was not injured. The investigating officer noted on his report that several passengers of the transit bus left the scene without providing information to the police. The driver of the Prius stated in the interview that he did not see any leakage under his vehicle and did not take any further safety precautions with his hybrid vehicle. The tow operator was contacted and stated that his company does have warnings and precautions listed for dealing with hybrid vehicles posted on an employee bulletin board. Prior to this call, he was busy and had another call pending due to the snow; therefore he decided that the damage to the Prius "didn't look bad enough," so he did not take any additional precautions beyond that of a normal tow. The Prius was loaded onto a rollback-type tow truck and transported to the tow company's storage lot where it remained until it was transferred to a regional salvage facility.

***Exterior Damage***

***2005 Toyota Prius***

The right side of the Toyota Prius was damaged in this multiple event crash. The initial impact involved moderate severity damage to the right rear side area of the Prius **(Figure 3)**. The direct contact damage began on the right front door 130 cm (51.2 in) aft of the right front axle and extended 173 cm (68.1 in) rearward to the right rear taillight area. Lateral crush was present to the right doors, C-pillar, and quarter panel. The right front and right rear door hinges were intact

**Figure 3: Initial impact damage to the right rear side area of the Prius.**

and remained attached to the A- and B-pillars, respectively. Both right side door latches remained engaged as both right side doors remained closed during the crash. The right rear tire and wheel were engaged by the bus that resulted in separation of the suspension components. The combined direct and induced damage (Field L) began 88 cm (34.6 in) rear of the right front axle and extended 256 cm (100.8 in) rearward. The residual crush profile was measured at the mid door elevation and was as follows: C1 = 2 cm (0.8 in), C2 = 21 cm (8.3 in), C3 = 31 cm (12.2 in), C4 = 20 cm (7.9 in) C5 = 6 cm (2.4 in), C6 = 0 cm. The maximum crush was located aft of the C-pillar, 252 cm (99.2 in) rearward of the right front axle and measured 33 cm (13 in). The elevation of the maximum crush was 59 cm (23.2 in), consistent with the measured front bumper height of the bus, which extended 50 cm (20.1 in) to 89 cm (35 in) above ground level. The Door Sill Differential (DSD) was 23 cm (9.1 in). The right roof side rail deformed laterally and buckled the roof upward along the backlight header. The Collision Deformation Classification (CDC) of this impact was 03-RZAW-3.

The secondary sideslap damage involved the right front door and fender of the Prius in the area of the right A-pillar. The direct damage began on the right front door 70 cm (27.6 in) rear of the right front axle and extended forward 92 cm (36.2 in) onto the right front fender **(Figure 4)**. The Field L for this damage began 76 cm (29.9 in) rear of the right front axle and extended forward 106 cm (41.7 in). The residual crush profile measured at the mid door elevation was as follows: C1 = 0 cm, C2 = 2 cm (0.8 in), C3 = 6 cm (2.4 in), C4 = 4 cm (1.6 in), C5 = 3 cm (1.2 in), C6 = 0 cm. The maximum crush was located at C3, located 33 cm (13 in) rearward of the right front axle. The CDC for this impact was 03-RYEW-1.

**Figure 4: Side-slap damage to the Prius**

***1996 RTS Transit Bus***

The front left and right front side areas of the transit bus were damaged in this crash. The bus was driven from the scene and was fully repaired and returned to service prior to the assignment of this case. Images of the initial impact damage to the front left area were obtained from the company that operates the transit bus. The damage involved the front bumper fascia, the front cowl in the area of the left headlamp assembly, and to the bicycle rack on the front of the bus **(Figure 5)**. No images of the secondary side-slap damage to the right front side area were available. The representative of the company


**Figure 5: Initial impact damage to front left area of bus (Image provided by the bus company).**

stated the right side damage was limited to minor scratches only, and was repaired prior to case assignment. The bus is outside the scope of CDC and Truck Deformation Classification (TDC).

The repaired bus involved in this crash was made available for inspection. The front bumper of the bus measured 50-89 cm (20.1-35 in) above the ground. The bus was equipped with several cameras covering aspects inside and outside of the bus, including a front aspect that showed the crash sequence. A copy of this video was made available to the SCI investigator by the company that operates the bus.

### *Interior Damage*

#### *2005 Toyota Prius*

The Toyota Prius sustained moderate right side intrusion in the front right and rear right seat positions as a result of the initial impact. The right B-pillar was displaced laterally into the outboard aspect of the front right seat back. This engagement did not compress the seat back. The right rear door and C-pillar intruded laterally and compressed the rear seat backs. The right roof side rail in the second row intruded laterally. The rear right and center seat backs intruded laterally 12 cm (4.7 in), causing them to move forward over the left rear seat back, causing a 15 cm (5.9 in) longitudinal intrusion of the right and center rear seat backs. The damage to the rear seats made it impossible to fold down the rear seats to access the front of the panels covering the hybrid battery and remove the panels to photograph the battery. The side panel aft of the right C-pillar intruded laterally and compressed the floor of the trunk/cargo area at the location of the hybrid battery and is depicted in **Figure 6**. The rear seat damage is depicted in **Figure 7.**

**Figure 6: Cargo area intrusion.**

**Figure 7: Rear seat lateral and longitudinal intrusion**

The intrusion to the Prius is listed on the following table:

| Position | Component | Direction | Magnitude |
|---|---|---|---|
| Row 1 right | RF door RLQ | Lateral | 9 cm (3.5 in) |
| Row 1 right | Right B-pillar | Lateral | 10 cm (3.9 in) |
| Row 1 right | Door sill | Lateral | 6 cm (2.4 in) |
| Row 2 right | RR door RUQ | Lateral | 17 cm (6.7 in) |
| Row 2 right | Right C-pillar | Lateral | 18 cm (7.1 in) |

| Position | Component | Direction | Magnitude |
|---|---|---|---|
| Row 2 right | Door sill | Lateral | 14 cm (5.5 in) |
| Cargo area | Side panel rear of C-pillar | Lateral | 15 cm (5.9 in) |
| Row 2 left | Second seat back (center) | Lateral | 12 cm (4.7 in) |
| Row 2 right | RR door RLQ | Lateral | 18 cm (7.1 in) |
| Row 2 right | Roof side rail | Lateral | 6 cm (2.4 in) |

### *Manual Restraint Systems*
### *2005 Toyota Prius*

The manual restraint systems in the Toyota Prius consisted of three-point lap and shoulder belts in all five seat positions. The driver's restraint consisted of continuous loop webbing, an Emergency Locking Retractor (ELR), a sliding latch plate and a height adjustable D-ring. The driver's belt system yielded two points of loading; stretching was evident 105-146 cm (41.2-57.5 in) above the floor anchor and a frictional abrasion from passing through the latchplate was located 91 cm (35.8 in) above the floor anchor. The driver's D-ring was in the full-up position and this safety belt was equipped with a retractor pretensioner that did not actuate. The length of the driver's safety belt webbing when fully extended was 218 cm (85.8 in).

The front right and second row safety belt systems utilized switchable ELR/Automatic Locking Retractors (ALR). In addition, the front right belt system contained a retractor mounted pretensioner that did not actuate. The front right height-adjustable D ring was in the full-up position. The center rear belt system was integrated into the center rear seat back. These positions were unoccupied at the time of the crash.

### *Frontal Air Bag System*
### *2005 Toyota Prius*

The Prius was equipped with a Certified Advanced 208-Complaint (CAC) frontal air bag system for the driver and front right passenger positions. A CAC vehicle is certified by the manufacturer to be compliant to the Advanced Air Bag Portion of Federal Motor Vehicle Safety Standard No 208. The CAC system consisted of dual stage driver and passenger air bags, a front right occupant weight sensor, front seat track positioning sensors and front retractor pretensioners. The CAC frontal air bag system did not deploy in this side impact crash.

### *Side Impact Air Bag System*
### *2005 Toyota Prius*

The Prius was equipped with driver and front right passenger side impact air bags mounted in the upper aspect of the outboard side of the seat backs. IC air bags were mounted in the roof side rails and provided coverage to the four outboard seat positions. The seat back mounted side impact air bags did not deploy in this crash; however, the right IC air bag deployed during the initial impact event.

**Figure 8: Right side inflatable curtain**

The IC deployed from the right roof side rail. The air bag membrane measured 157 cm (61.8 in) in length. At the front seating position, the membrane measured 44 cm (17.3 in) in height **(Figure 8)** and at the rear seating position; the membrane measured 46 cm (18.1 in) in height.

The curtain air bag was tethered at the A-pillar by a sail panel that measured 23 cm (9.1 in) and 17 cm (6.7 in) in height at the rear and front, respectively, and 21 cm (8.3 in) and 23 cm (9.1 in) in width at the top and bottom, respectively. This sail panel provided for longitudinal coverage over the entire right front glazing at the A-pillar area with the exception of 5 cm (2") at the front of the opening. Vertically, the IC air bag extended below the beltline at each outboard position. The air bags provided head protection from the roof to the belt line and from the A-pillar to the C-pillar of the vehicle. The right IC was free from occupant contact evidence and damage. There was a 14 cm (5.5 in) tear in the headliner at the rear attachment of the passenger assist handle. Both front seats were covered with aftermarket floral print seat covers that concealed the side impact air bag modules.

### *Hybrid Vehicle Battery System*
### *2005 Toyota Prius*

The 2005 Toyota Prius is equipped with a hybrid battery system used to drive an electric motor that assists the gasoline engine. This system improves fuel efficiency while the gasoline engine is in use, or to provide power for vehicle movement at lower speeds without use of the gasoline engine. The battery back is a Panasonic Metal Case Prismatic Module consisting of 168 cells in 28 modules. It has a nominal voltage of 201.6 V with a capacity of 6.5 Ah using nickel-metal hydride and a potassium hydroxide electrolyte. The battery compartment and the battery were inspected for damage due to the crash and from possible intrusion of the right side of the cargo area. The hybrid battery was located over the rear axle, centered under the cargo area of the vehicle **(Figure 9)**. The battery was covered by an aluminum cover and a carpeted panel that made up the forward section of the cargo area floor. The intrusion of the C-pillar and displacement of the rear seat backs restricted the full removal of the aluminum cover. The battery was inspected and photographed with these covers elevated.

The battery compartment was vented to right side of the vehicle by a plastic duct that extended to the right side of the rear bumper fascia **(Figure 10)**. The electrical connections and fuse were under a service panel on the left side of the hybrid battery. There was no damage to the cells of the hybrid battery or leakage of electrolyte. The intrusion of the C-pillar and side panel aft of the C-pillar resulted in displacement of the plastic duct of approximately 3 cm (1.2 in) to the left. There was no damage to the battery pack.

**Figure 9: Hybrid battery centered over rear axle behind rear seat**

**Figure 10: Right side of hybrid battery and ventilation duct**

***Occupant Demographics/Data***
***2005 Toyota Prius***

| | |
|---|---|
| Driver Age/Sex: | 52-year old/Male |
| Height: | 183 cm (72 in) |
| Weight: | 95 kg (210 lb) |
| Eyewear: | None |
| Seat Track Position: | Full-rear |
| Manual Safety Belt Use: | Lap and shoulder belt |
| Usage Source: | Vehicle inspection |
| Egress from vehicle: | Exited under own power |
| Mode of Transport: | Private vehicle to residence |
| Type of Medical Treatment: | None |

***Driver Injuries***

| Injury | Severity (AIS 90/Update 98) | Injury Source |
|---|---|---|
| Neck pain | Not coded under AIS | Impact force |
| Right hip pain | Not coded under AIS | Belt buckle/center console |

Source – Driver Interview

***Driver Kinematics***

The 52-year-old male driver was seated in a full-rear track position and was restrained by the manual three-point lap and shoulder safety belt system. Prior to the crash, the driver had started up a hill and increased throttle on a snow-covered roadway as he entered a shallow curve to the left. During this action, the driver lost directional control of the vehicle and it began to rotate counterclockwise and entered the oncoming traffic lane. As he detected the bus, the driver braced with both hands against the steering wheel rim at the 9 and 3 o'clock positions.

The initial right side impact with the bus deployed the right IC air bag. As a result of the side impact, the driver initiated a lateral trajectory to the right within the front left seating position. During his lateral trajectory, his right hip contacted the center console and the vehicle safety belt buckle, causing a scuff on the console from the vehicle safety belt buckle and a crack in the left side of the console **(Figure 11)**. This contact sequence

resulted in a complaint of pain to the hip without contusion. The driver's right forearm scuffed the top of the console as it traveled across the console from left to right. As the driver loaded into the center console, his upper torso loaded the safety belt, causing a section to stretch and the belt to abrade where it passed through the sliding latchplate. As his upper torso loaded the safety belt, his head continued to the right, causing the neck strain. The driver did not engage the IC air bag. He did not seek treatment for his injuries.

**Figure 11: Driver contact to center console**

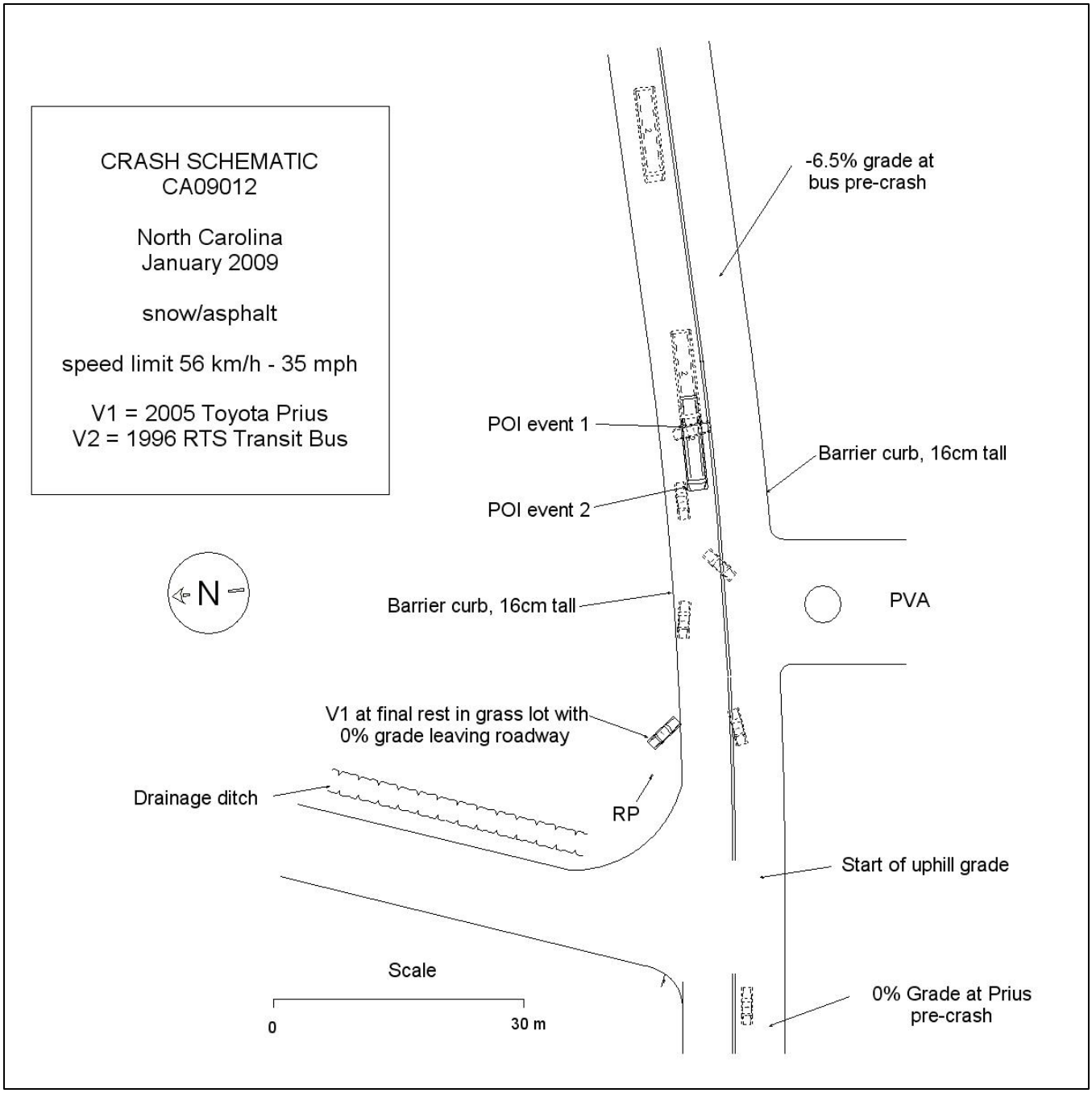


**Figure 12: Scene Schematic**