U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

NHTSA
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DOT HS 812 112D **February 2015**

Crashworthiness Research of Prototype Hydrogen Fuel Cell Vehicles: Task Order 7 Project Report

Appendix D
Transportation Research Center Inc. Report on the Rear Crash

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Test Performed By: John Shultz, Test Supervisor

Report Approved May 7, 2012 by:

Jeffery W. Sankey,
Manager, Project Operations

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Section 1.0

Purpose and Test Procedure

Purpose

This 47.3 km/h (target speed) moving barrier rear impact test was conducted for Battelle by Transportation Research Center Inc. (TRC Inc.). The purpose of this test was to research the crashworthiness of the subject vehicle, a modified hydrogen fuel cell electric vehicle, in the FMVSS 303-Type moving barrier rear impact mode. The vehicle was modified by Battelle to isolate the rear fuel container and to provide redundant vent lines for releasing pressure after the test.

Test Procedure

This test was conducted per Battelle's instructions. The rear fuel container was pressurized with helium to a nominal pressure of 500 psi and maintained at pressure for one hour prior to impact.

The test vehicle was instrumented with fourteen (14) accelerometers to measure longitudinal axis accelerations; eleven (11) accelerometers to measure lateral axis accelerations; eleven (11) accelerometers to measure vertical axis accelerations, and six (6) displacement transducers.

The vehicle was impacted by a rigid moving barrier. The moving barrier's specified velocity range was 46.5 to 48.1 km/h.

The test vehicle contained two (2) Part 572B adult male anthropomorphic test devices (dummies). The dummies were positioned in the left front and right front outboard designated seating positions. Each dummy was restrained by a three-point unibelt. The dummies were not instrumented.

The forty-two (42) data channels were digitally sampled and recorded at 10,000 samples per second and processed per SAE J211 Mar95.

The crash event was recorded seven (7) high-speed digital motion picture cameras operating at 1000 frames per second and one (1) real time motion picture camera.

Following the impact, additional helium sensor data was acquired by the National Renewable Energy Laboratory and electrical isolation measurements were acquired by Battelle.

The vehicle data are summarized in Section 2.0. The camera measurements are presented in Section 3.0. Appendix A contains the still photographic prints. Appendix B contains the vehicle data plots. Appendix C contains the FARO measurement data.

Section 2.0

Rear Impact Test Summary

Test Results Summary

This 48.0 km/h rear impact test was conducted by TRC Inc. on April 11, 2012.

The test vehicle was a modified Hydrogen Fuel Cell Electric vehicle. The vehicle's test weight was 2064.8 kg.

The moving barrier's test weight was 1814.4 kg. The moving barrier's impact speed was 48.0 km/h.

There was no evidence of gas escaping from the pressurized fuel system during the impact or during the one-hour period following the impact. Following the one-hour hold period, the pressure was released from the fuel system by using a remote-controlled robot to cut a lower-pressure nitrogen line, causing a pilot-operated valve to open a vent line to the high-pressure in the modified fuel system.

Data Acquisition Explanations

The Front Container, Passenger Y-axis acceleration data channel exceeded the full scale value at approximately 9 milliseconds and recorded no valid data after that time.

The Battery, Passenger Z-axis acceleration data channel exceeded the full scale value at approximately 26 milliseconds and recorded no valid data after that time.

The Engine X-axis acceleration data channel did not return to zero after the impact event.

The Battery, Passenger X-axis acceleration data channel lost data between approximately 35 and 85 milliseconds and 155 and 175 milliseconds.

Table 1 Crash Test Summary

Test type:	Rear Impact	
Test date:	April 11, 2012	
Test time:	14:20	
Ambient temperature:	6 ° C	
Vehicle:	Modified Hydrogen Fuel Cell Electric Vehicle	
Vehicle test weight:	2064.8 kg	
Moving barrier test weight:	1814.4 kg	
Impact angle[1]:	180°	
Impact velocity[2]:	Primary = 48.0 km/h Secondary = 48.1 km/h	
Distance from moving barrier to vehicle:	Entering Velocity Trap = 660 mm Exiting Velocity Trap = 50 mm	
Dummies:	Driver	Front Passenger
Type:	Ballast	Ballast
Location:	Left Front	Right Front
Restraint:	Seat belt	Strapped in
Number of data channels:	0	0
Number of cameras:		
High-Speed:	7	
Real-Time:	1	

[1] With respect to tow track centerline.
[2] Speed trap measurement (± .08 km/h accuracy)

Table 2 Test Vehicle Information

Vehicle/body style:	Modified Hydrogen Fuel Cell Electric Vehicle
Color:	Silver
Transmission data:	__ speed, __ manual, _X_ automatic, _X_ fwd, __ rwd, __ 4wd
Date vehicle received:	April 4, 2012
Odometer reading:	18136
Dealer's name and address:	Not applicable

Accessories:

Power steering	Yes	Automatic transmission	Yes
Power brakes	Yes	Automatic speed control	Yes
Power seats	No	Tilting steering wheel	Yes
Power windows	Yes	Telescoping steering wheel	No
Tinted glass	Yes	Air conditioning	Yes
Radio	Yes	Anti-lock brakes	Yes
Clock	Yes	Rear window defroster	Yes
Other:	None		

Certification data from vehicle's label:[1]

Vehicle manufactured by:		
Date of manufacture:		
VIN:		
GVWR:		kg
GAWR:	Front:	kg
	Rear:	kg

Tires on vehicle (mfr., line, size):	Hankook, Optimo, P235/60R16
Tire pressure with maximum capacity vehicle load:	Front: 300 kPa Rear: 300 kPa
Spare tire (mfr., line, size):	None
Type of seats:	Front: Bucket Rear: Split bench
Type of front seat backs:	Manual adjustable

[1] The vehicle did not contain a label stating certification data.

Table 2 Test Vehicle Information, Continued

Location of "Recommended Tire Pressure" label:[1]

Data from vehicle's "Recommended Tire Pressure" label:[1]

"As tested" tire pressure:

	LF	221 kPa;	RF	221 kPa;	LR	221 kPa;	RR	221 kPa

Test vehicle attitude:

Delivered attitude:	LF	732 mm;	RF	738 mm;	LR	770 mm;	RR	773 mm
Pre-test attitude:	LF	718 mm;	RF	716 mm;	LR	758 mm;	RR	759 mm
Post-test attitude:	LF	721 mm;	RF	713 mm;	LR	790 mm;	RR	803 mm

Weight of test vehicle as received (with maximum fluids):

Right front	552.2 kg	Right rear	335.2 kg
Left front	562.6 kg	Left rear	339.2 kg
Total front weight	1114.8 kg	(62.3% of total vehicle weight)	
Total rear weight	674.4 kg	(37.7% of total vehicle weight)	
Total delivered weight	1789.2 kg		

Target test weight: [2]

Total weight	2065.0 kg

Weight of test vehicle with required dummies and cargo weight:

Right front	662.6 kg	Right rear	375.4 kg
Left front	655.4 kg	Left rear	371.4 kg
Total front weight	1318.0 kg	(63.8% of total vehicle weight)	
Total rear weight	746.8 kg	(36.2% of total vehicle weight)	
Total test weight	2064.8 kg		

Weight of ballast secured in vehicle: 11.3 kg on front passenger floor; and 6.4 kg on front instrumentation rack.

Components removed to meet target test weight: None

CG rearward of front wheel centerline: 952mm

Longitudinal movement of test vehicle from impact point: 86.2 feet
Lateral movement of test vehicle from impact point: 2.4 feet right

[1] The vehicle did not contain a label stating tire and capacity data.

[2] The target weight for this test was provided by Battelle.

Table 3 Moving Barrier Data

Moving barrier's test weight:

Left front	706.2 kg	Left rear	211.6 kg
Right front	575.2 kg	Right rear	321.4 kg
Total front weight	1281.4 kg		
Total rear weight	533.0 kg		
Total test weight	1814.4 kg		

Table 4 Test Conditions

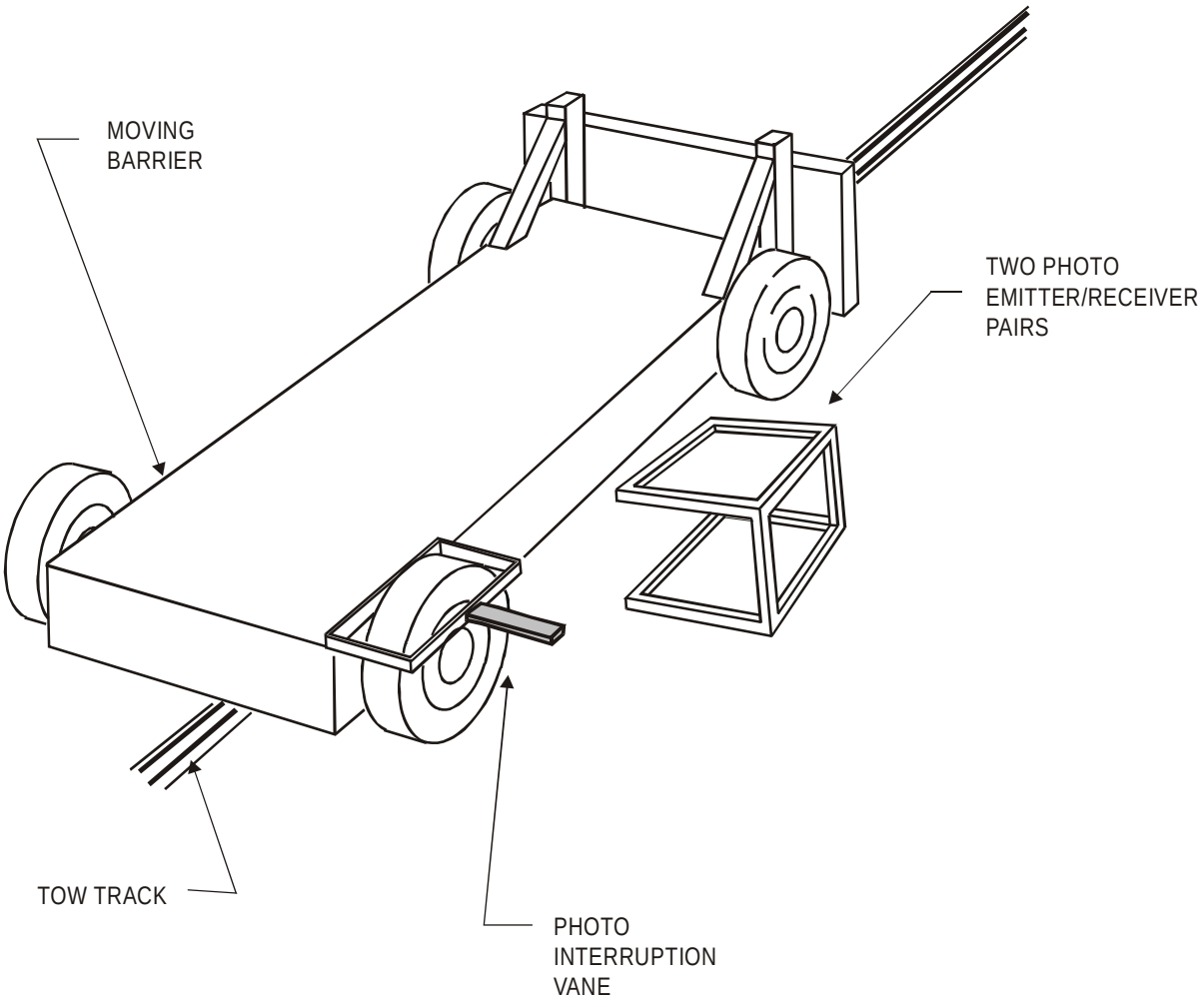
Test number:	120411
Date of test:	April 11, 2012
Time of test:	14:20
Ambient temperature at impact area:	6° C

Vehicle Data

	Actual	Intended
Subject vehicle test weight (kg):	2064.8	2065.0
Moving barrier test weight (kg):	1814.4	1769.0 - 1859.8
Moving barrier velocity (km/h)[1]:	48.0	46.5 - 48.1

[1] As measured over final 660 mm of travel.

Figure 1 Impact Velocity Measurement System



The vane clears the final emitter/receiver pair 50 millimeters before impact.

The emitter/receiver pairs have a spacing of 610-millimeters.

Table 5 Vehicle Accelerometer Locations and Data Summary

Accel. No.	Location		Positive Direction Max. (g)	Positive Direction Time (ms)	Negative Direction Max. (g)	Negative Direction Time (ms)
1	Vehicle CG	X	28.0	47.3	-5.2	67.3
		Y	2.9	48.9	-7.7	37.7
		Z	13.0	32.0	-13.6	24.6
		R	28.7	47.3		
2	Vehicle Body	X	22.1	39.1	-1.6	94.0
		Y	7.6	10.7	-9.3	23.0
		Z	10.0	39.8	-15.8	22.4
		R	24.6	39.1		
3	Front Container, Passenger[1]	X	105.4	24.6	-19.8	42.0
		Y	---	---	---	---
		Z	23.5	55.8	-31.6	28.2
		R	---	---		
4	Front Container, Driver	X	46.6	24.7	-30.7	43.8
		Y	12.9	45.2	-15.6	23.7
		Z	24.5	54.5	-32.1	31.2
		R	51.9	24.4		
5	Middle Container, Passenger	X	127.1	23.7	-22.9	42.1
		Y	14.8	45.8	-10.7	23.2
		Z	17.3	57.6	-32.7	22.7
		R	131.2	23.6		
6	Middle Container, Driver	X	59.1	22.1	-28.0	44.0
		Y	13.9	45.9	-8.0	23.0
		Z	16.4	56.2	-15.0	22.8
		R	61.2	22.2		
7	Rear Container, Passenger	X	81.9	8.7	-69.8	23.5
		Y	13.3	21.0	-8.9	32.2
		Z	34.6	9.8	-38.1	38.2
		R	88.2	8.9		
8	Rear Container, Driver	X	88.4	10.6	-23.8	21.6
		Y	12.9	20.9	-9.4	32.9
		Z	33.5	12.0	-43.3	22.6
		R	93.8	10.8		

[1] See Data Acquisition Explanations

Table 5 Vehicle Accelerometer Locations and Data Summary, Continued

Accel. No.	Location		Positive Direction Max. (g)	Positive Direction Time (ms)	Negative Direction Max. (g)	Negative Direction Time (ms)
9	Engine[1]	X	21.3	39.2	-3.7	86.6
		Y	4.1	31.8	-2.7	14.6
		Z	5.7	33.4	-6.6	10.0
		R	21.4	39.0		
10	Battery, Driver	X	50.1	28.6	-33.1	17.9
		Y	75.1	15.6	-51.3	7.2
		Z	21.1	20.2	-22.1	34.2
		R	75.9	15.6		
11	Battery, Passenger[1]	X	---	---	---	---
		Y	21.6	34.5	-20.3	21.3
		Z	---	---	---	---
		R	---	---		
12	Front Container, Pitch	X	71.9	10.3	-46.9	23.4
13	Middle Container, Pitch	X	41.5	28.0	-21.8	43.6
14	Rear Container, Pitch	X	81.4	24.5	-21.4	42.9

[1] See Data Acquisition Explanations.

Section 3.0

Camera Measurements

Figure 2 Camera Locations

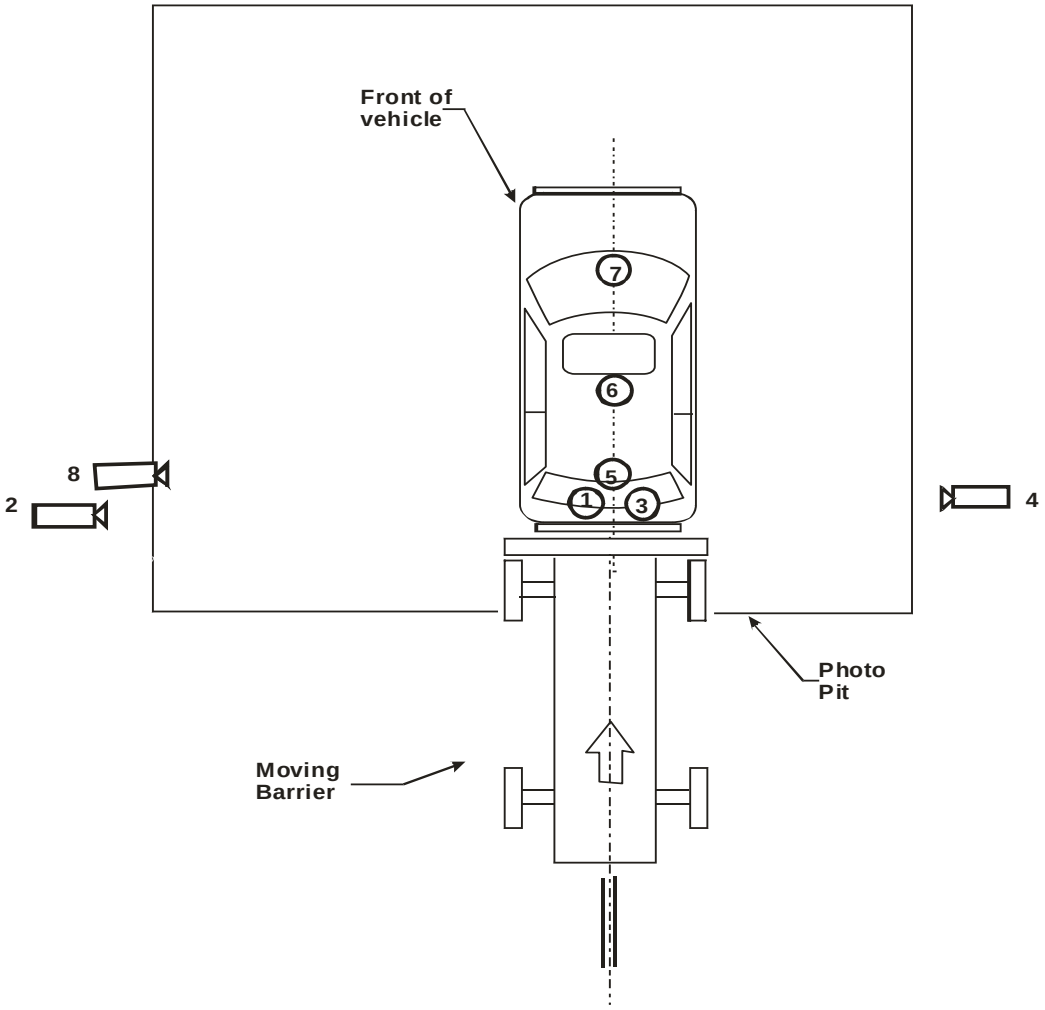


Table 6 Camera Information

Camera Number	Location	Type	Lens (mm)	Speed (fps)	Purpose of Camera Data
1	Overhead	Redlake-HGLE	8.5	1000	Vehicle dynamics
2	Left side real-time	Canon	Zoom	30	Vehicle dynamics
3	Overhead tight	Redlake-HGLE	25	1000	Impact alignment
4	Right side	Redlake-HGLE	12.5	1000	Vehicle dynamics
5	Pit rear	Redlake-HGLE	16	1000	Vehicle dynamics
6	Pit mid	Redlake-HGLE	12.5	1000	Vehicle dynamics
7	Pit front	Redlake-HGLE	12.5	1000	Vehicle dynamics
8	Left side	Redlake-HGLE	12.5	1000	Vehicle dynamics

Appendix A

Photographs

Figure A-1 Pre-Test Front View

Figure A-2 Post-Test Front View

Figure A-3 Pre-Test Left Front View

Figure A-4 Post-Test Left Front View

Figure A-5 Pre-Test Left Side View

Figure A-6 Post-Test Left Side View

Figure A-7 Pre-Test Left Rear View

Figure A-8 Post-Test Left Rear View

Figure A-9 Pre-Test Rear View

Figure A-10 Post-Test Rear View

Figure A-11 Pre-Test Right Rear View

Figure A-12 Post-Test Right Rear View

Figure A-13 Pre-Test Right Side View

Figure A-14 Post Test Right Side View

Figure A-15 Pre-Test Right Front View

Figure A-16 Post-Test Right Front View

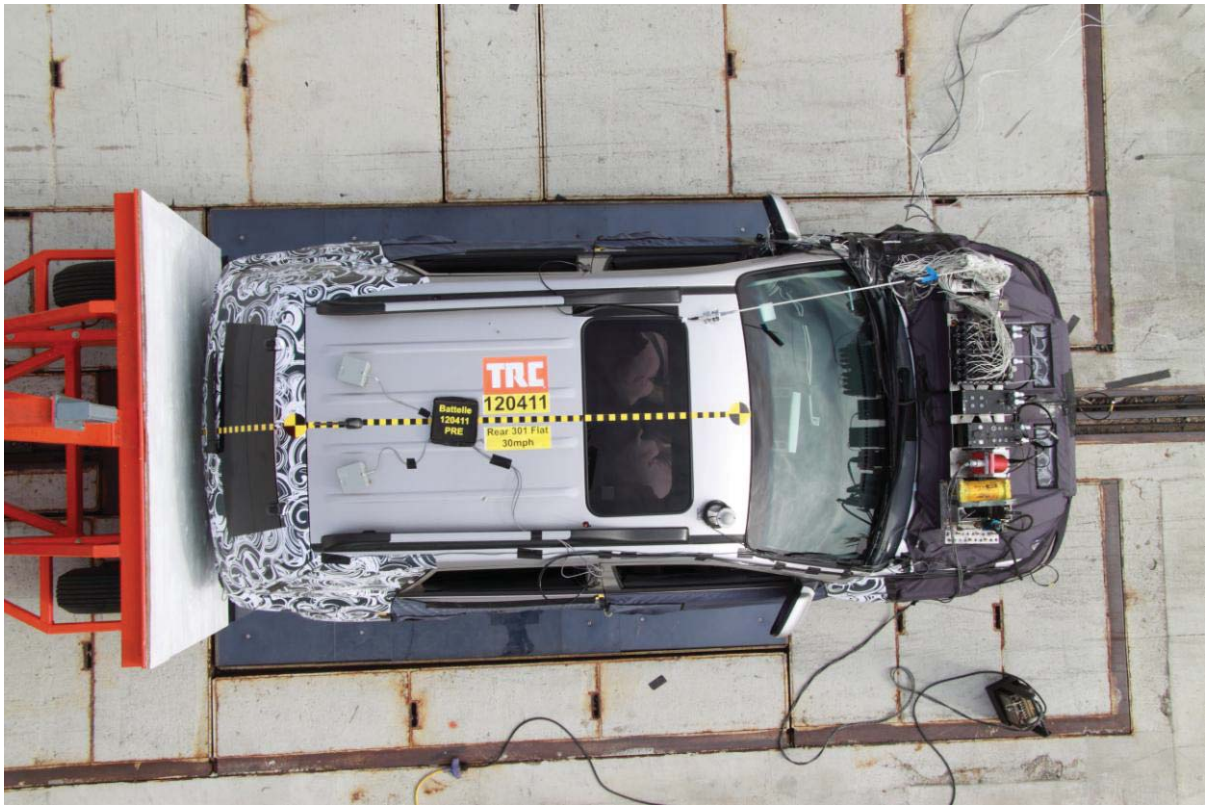


Figure A-17 Pre-Test Overhead View

Figure A-18 Post-Test Overhead View

Figure A-19 Pre-Test Overhead Close Up View

Figure A-20 Post-Test Overhead Close Up View

Figure A-21 Pre-Test Left Side Doors Open View

Figure A-22 Pre-Test Right Side Doors Open View

Figure A-23 Pre-Test Underbody - View 1

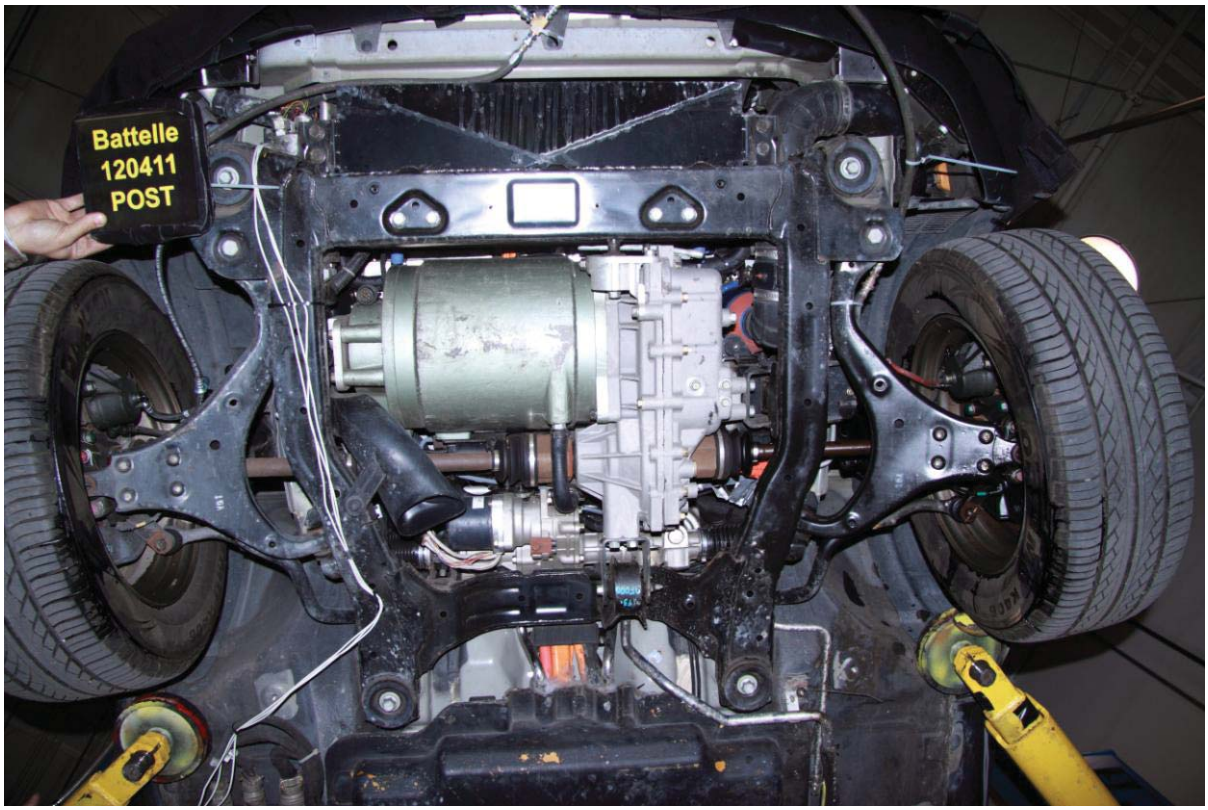


Figure A-24 Post-Test Underbody - View 1

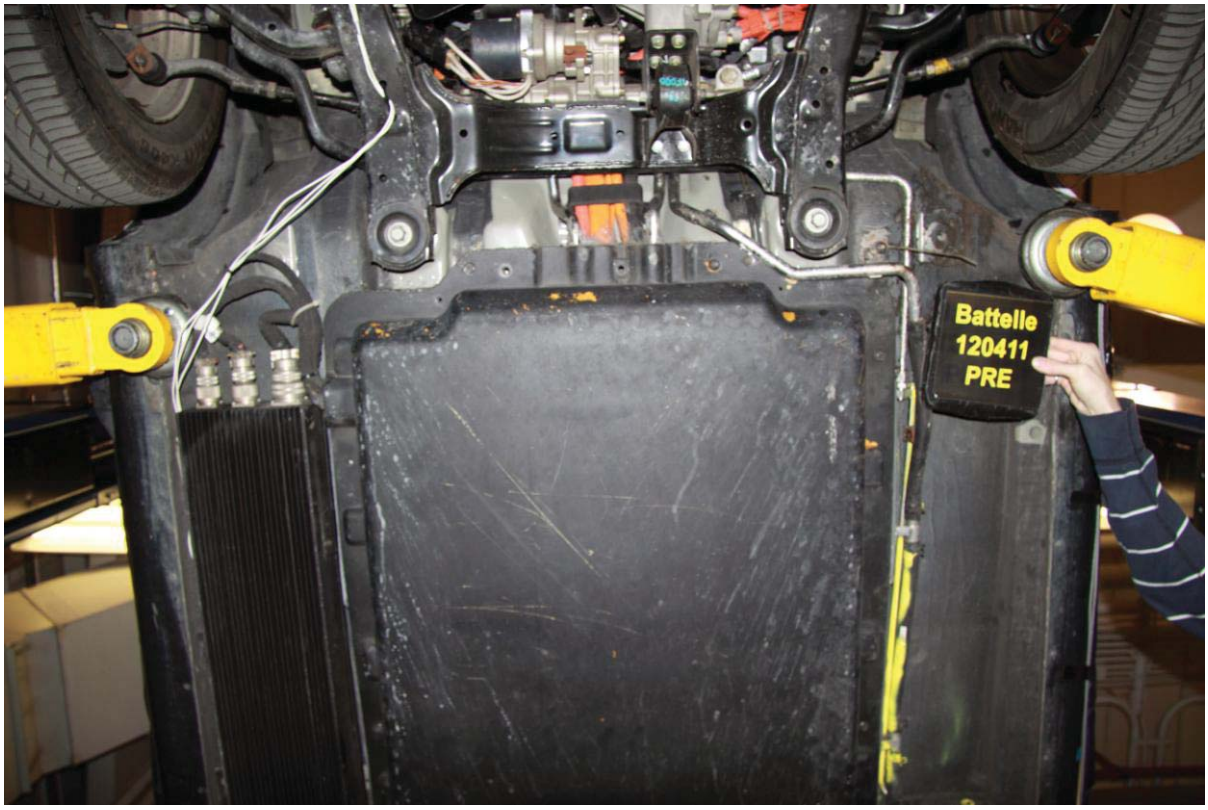


Figure A-25 Pre-Test Underbody - View 2

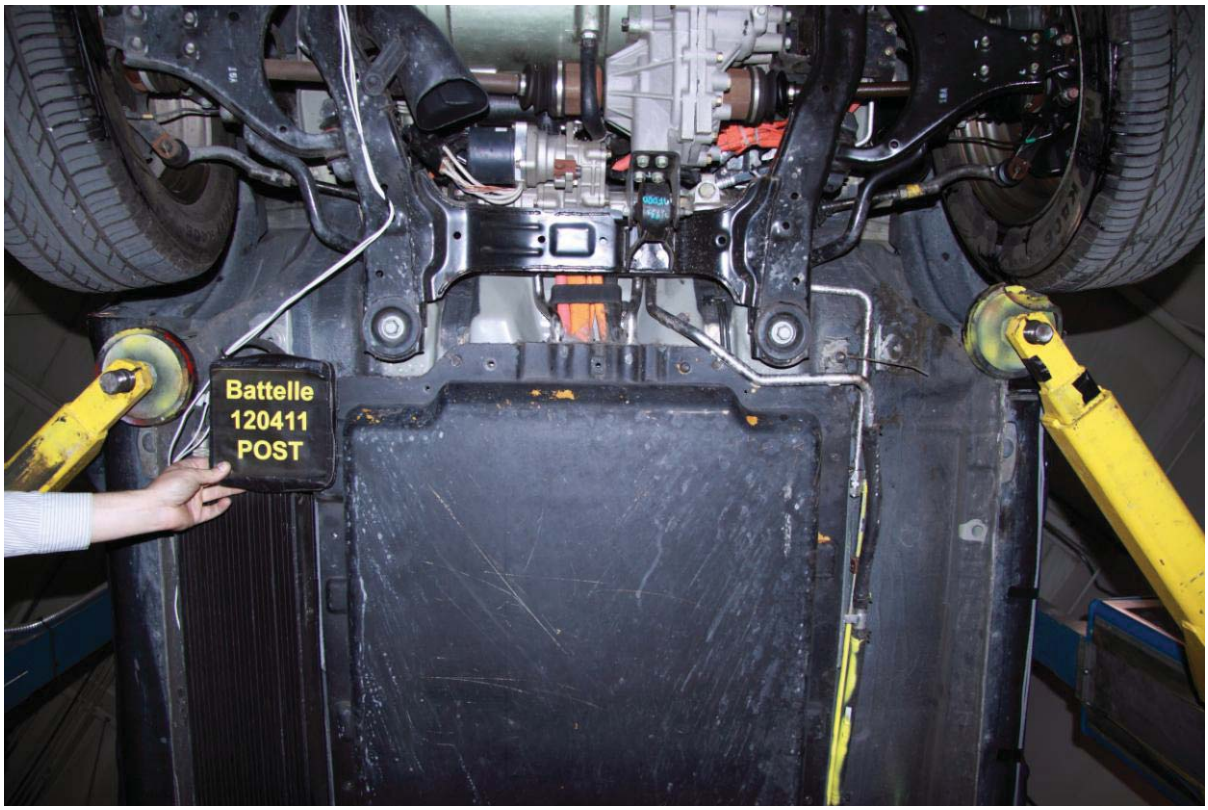


Figure A-26 Post-Test Underbody - View 2

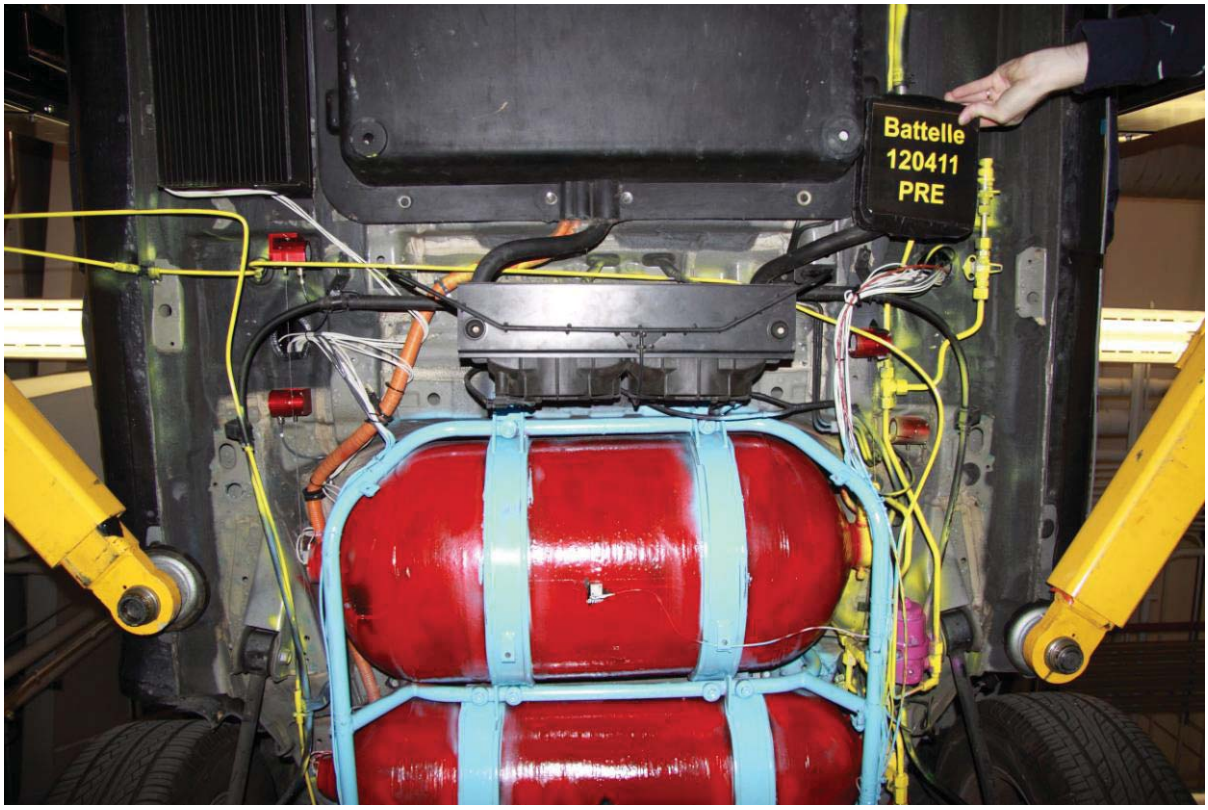


Figure A-27 Pre-Test Underbody - View 3

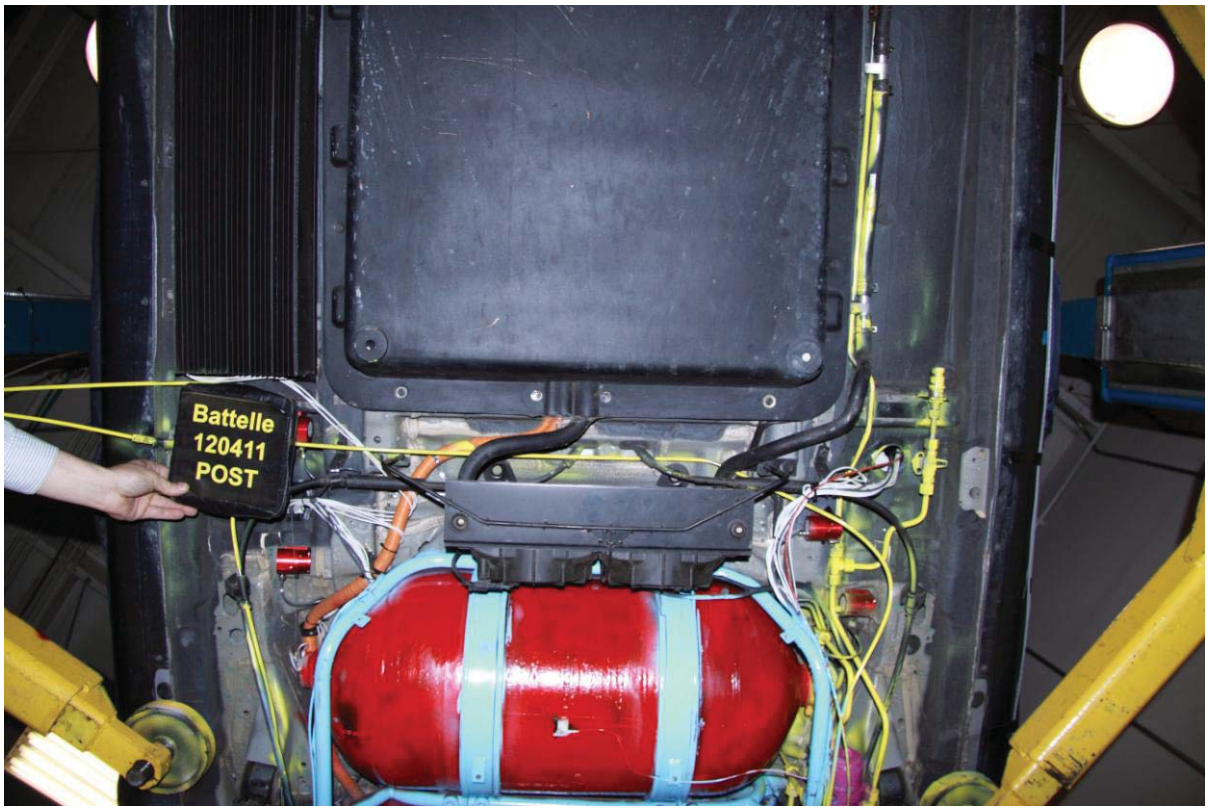


Figure A-28 Post-Test Underbody - View 3

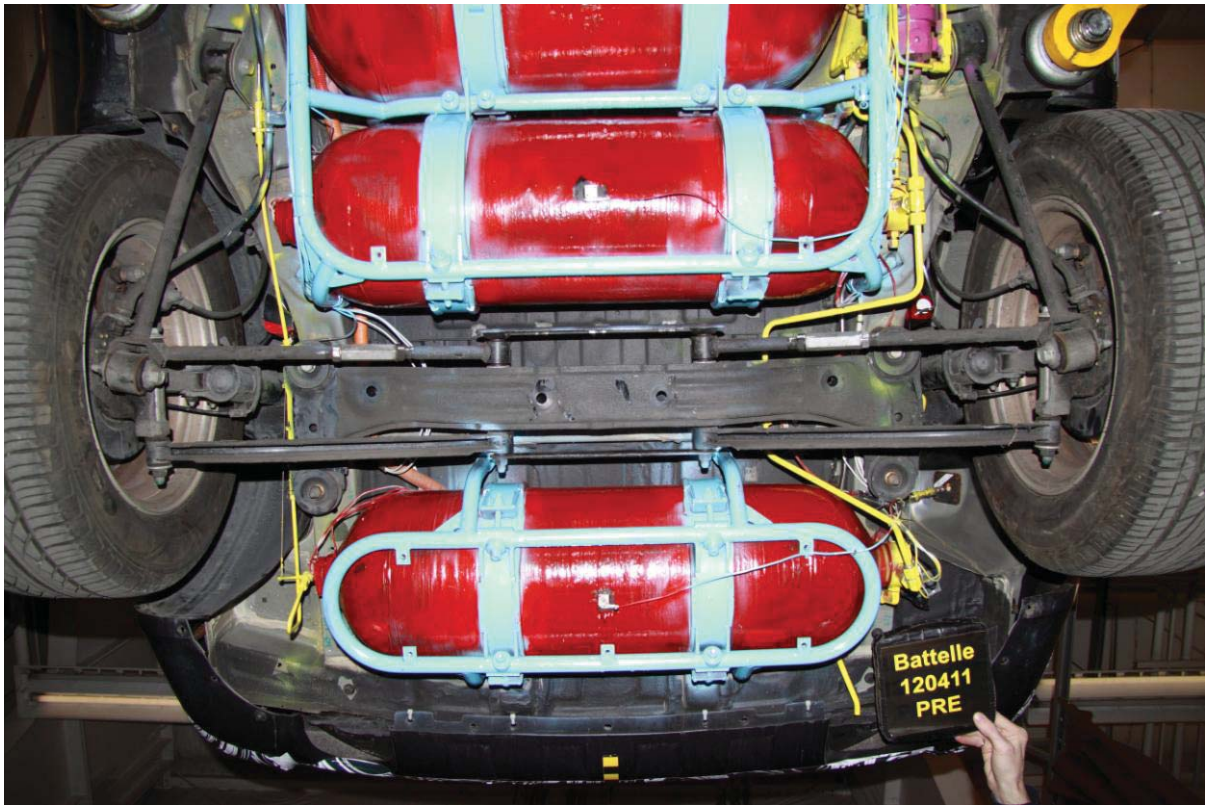


Figure A-29 Pre-Test Underbody - View 4

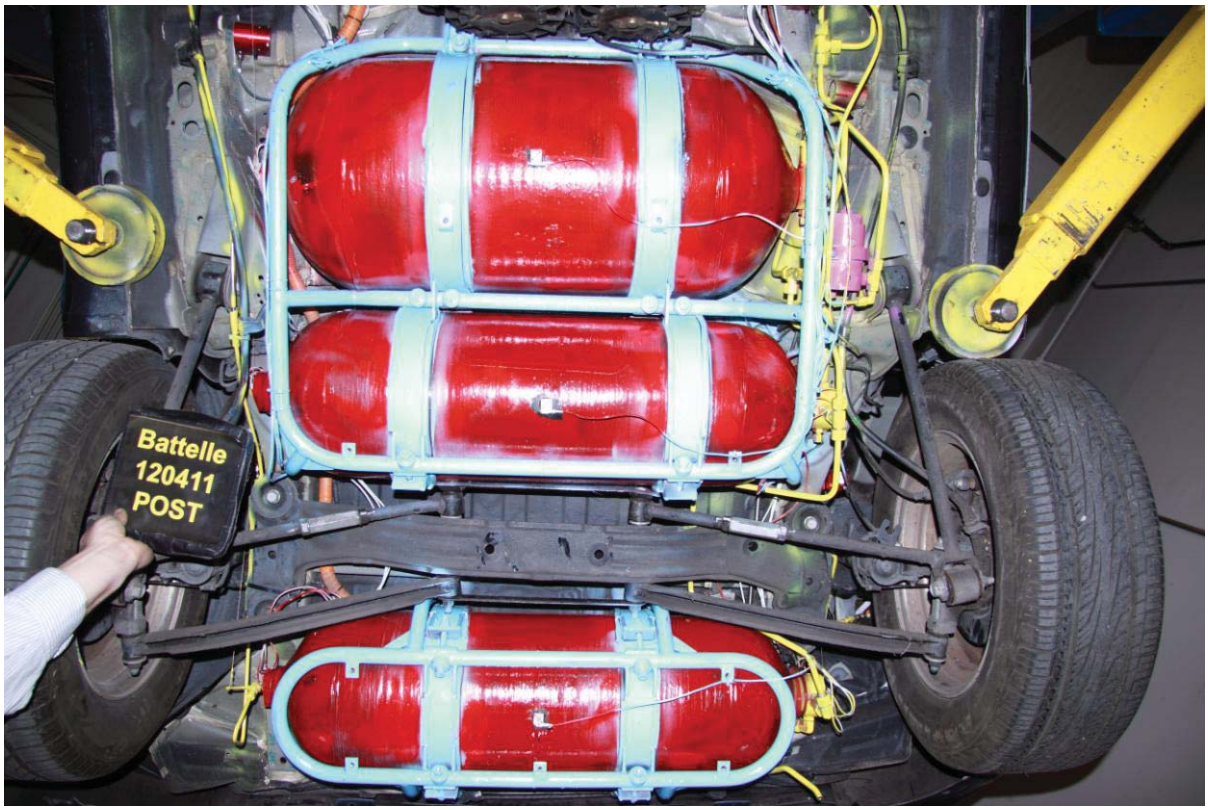


Figure A-30 Post-Test Underbody - View 4

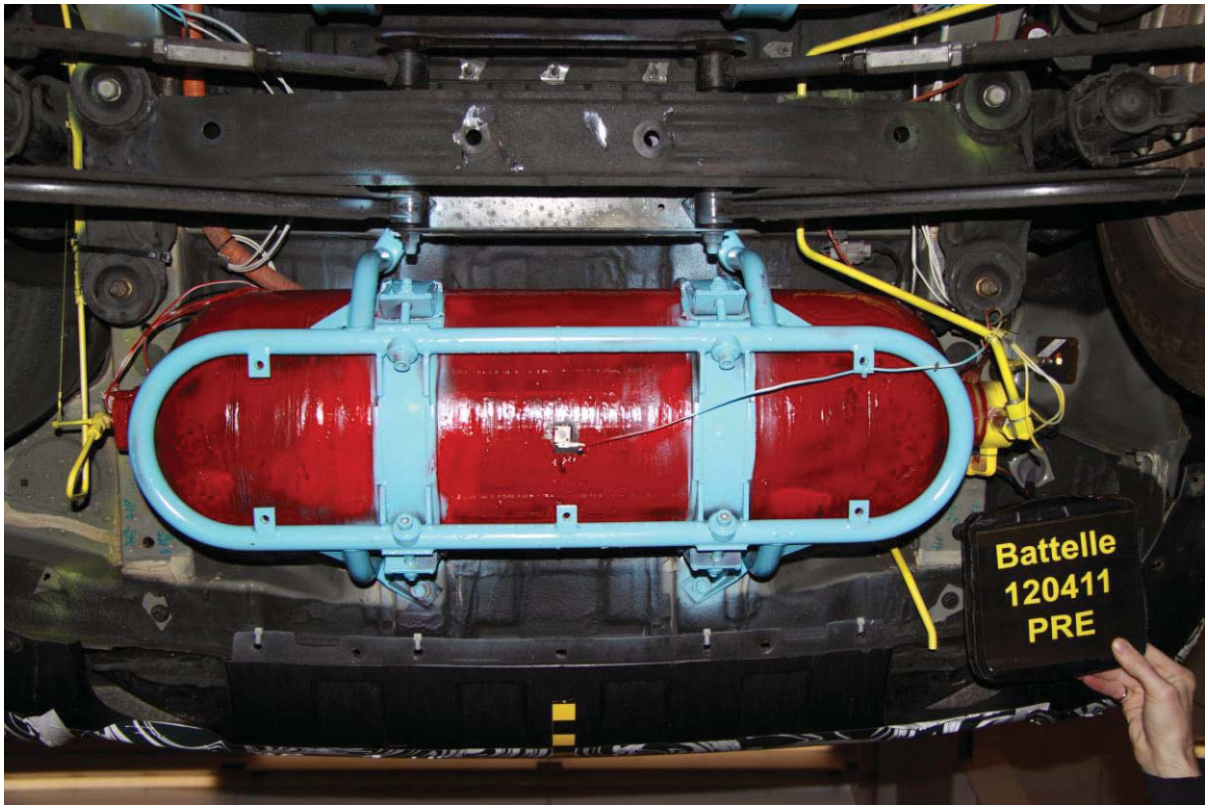


Figure A-31 Pre-Test Underbody - View 5

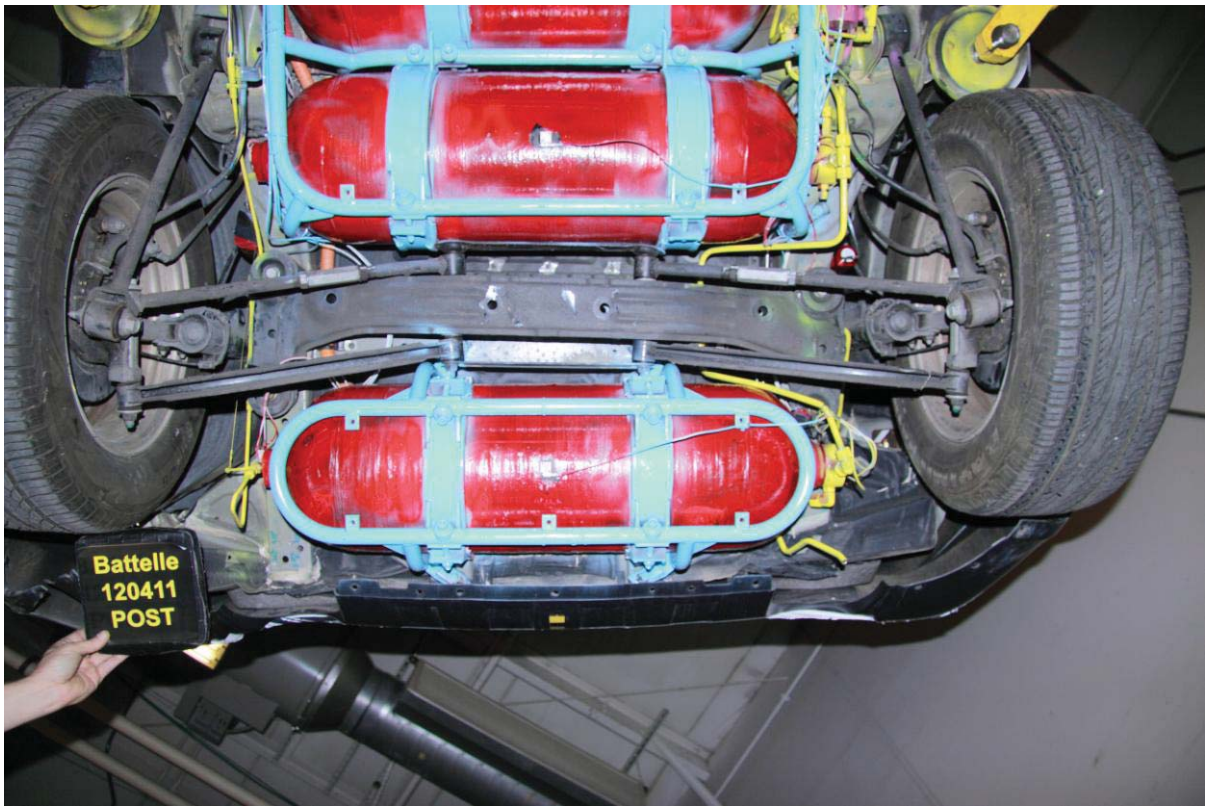


Figure A-32 Post-Test Underbody - View 5

Figure A-33 Pre-Test Fuel Containers - View 1

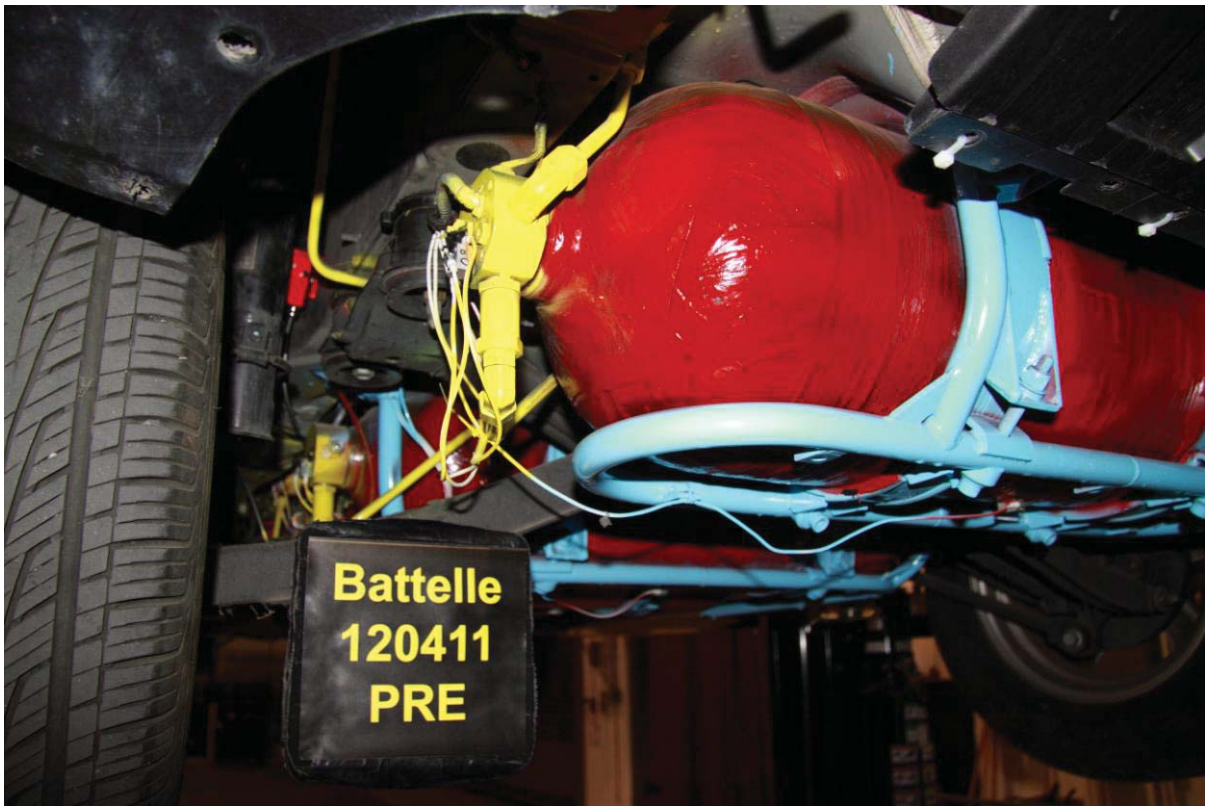


Figure A-34 Pre-Test Fuel Containers - View 2

Figure A-35 Pre-Test Fuel Containers - View 3

Figure A-36 Pre-Test Fuel Containers - View 4

Figure A-37 Pre-Test Fuel Containers - View 5

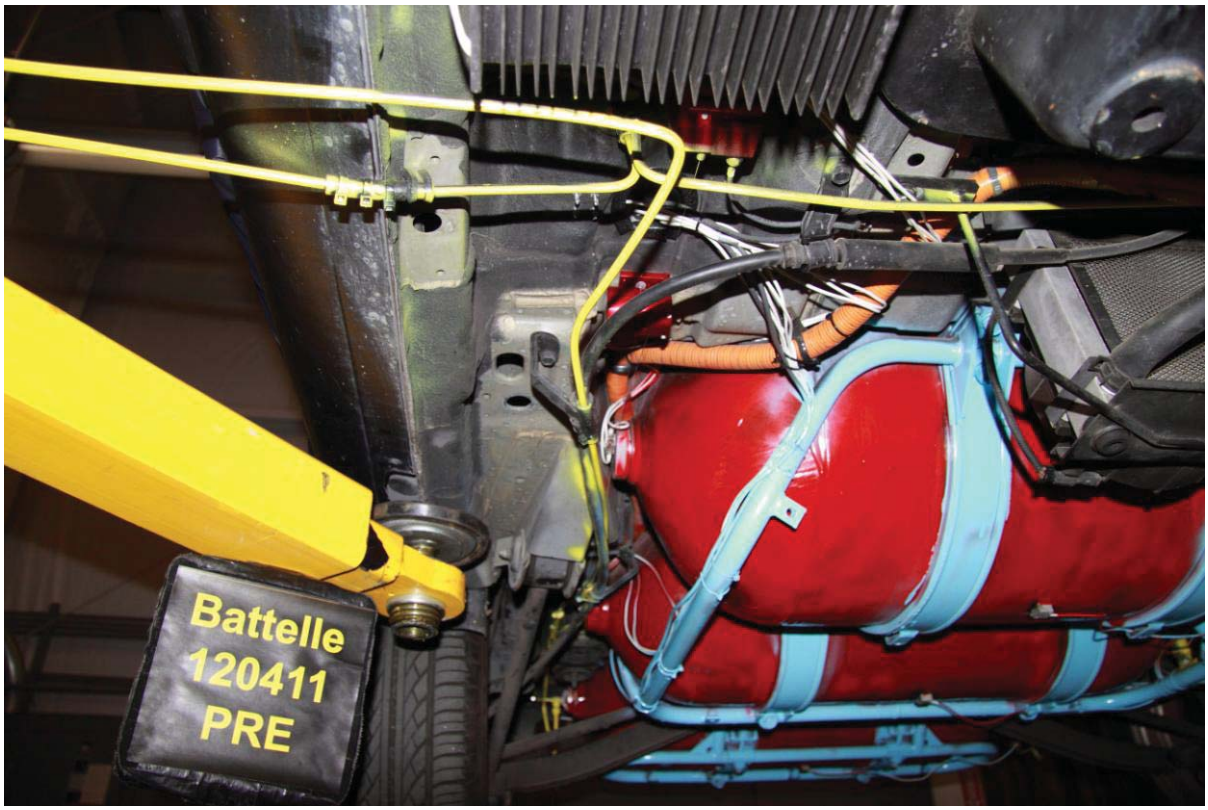


Figure A-38 Pre-Test Fuel Containers - View 6

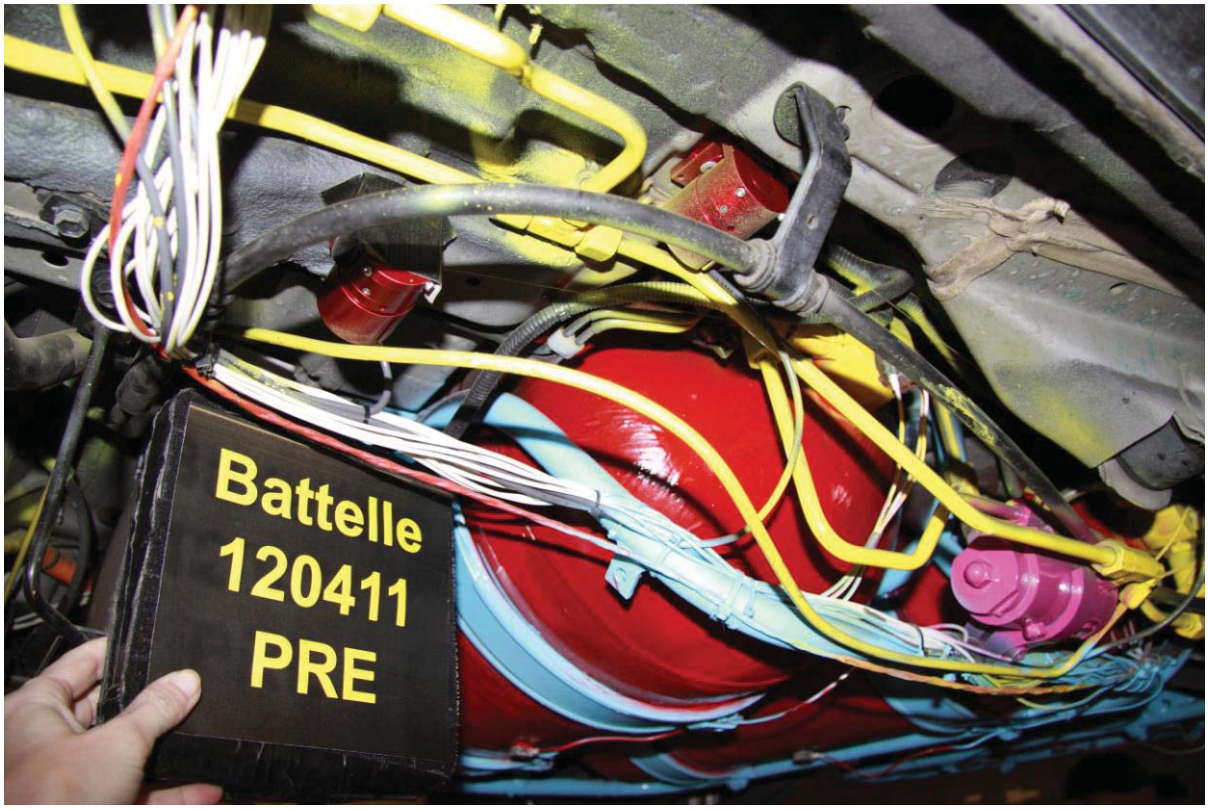


Figure A-39 Pre-Test Fuel Lines - View 1

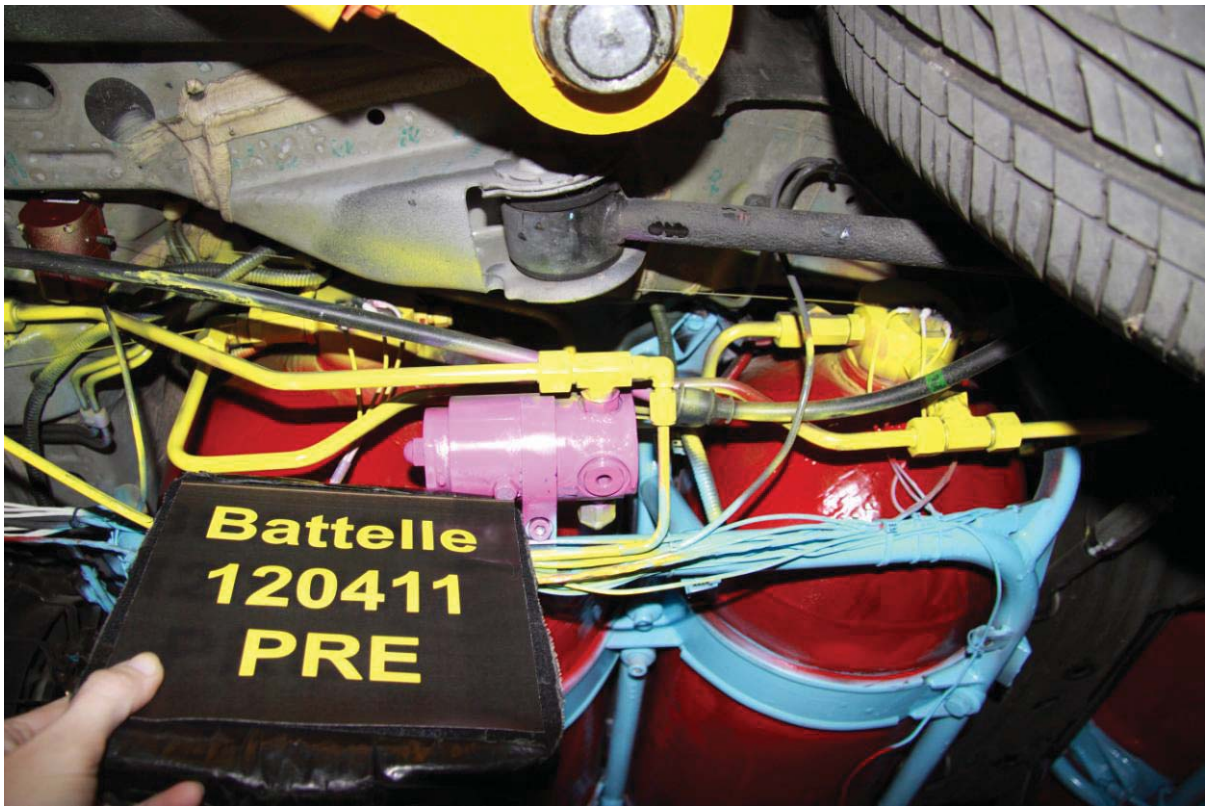


Figure A-40 Pre-Test Fuel Lines - View 2

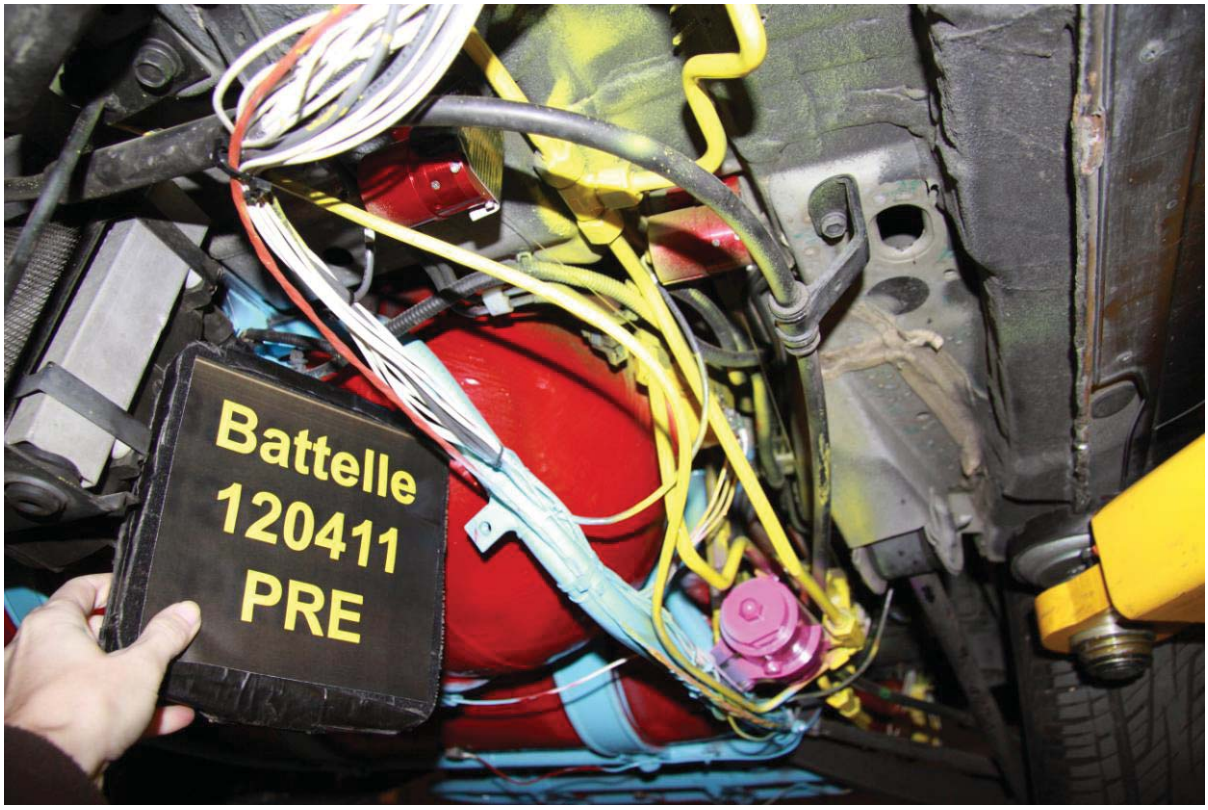


Figure A-41 Pre-Test Fuel Lines - View 3

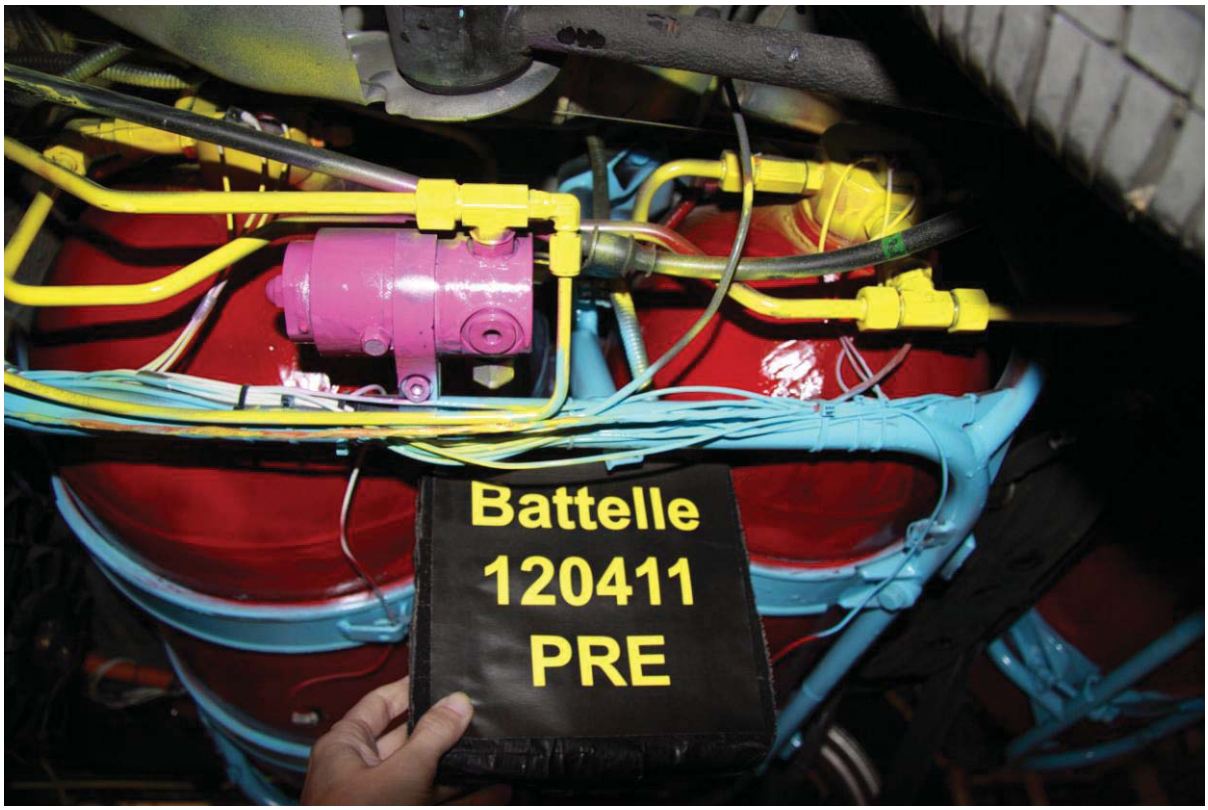


Figure A-42 Pre-Test Fuel Lines - View 4

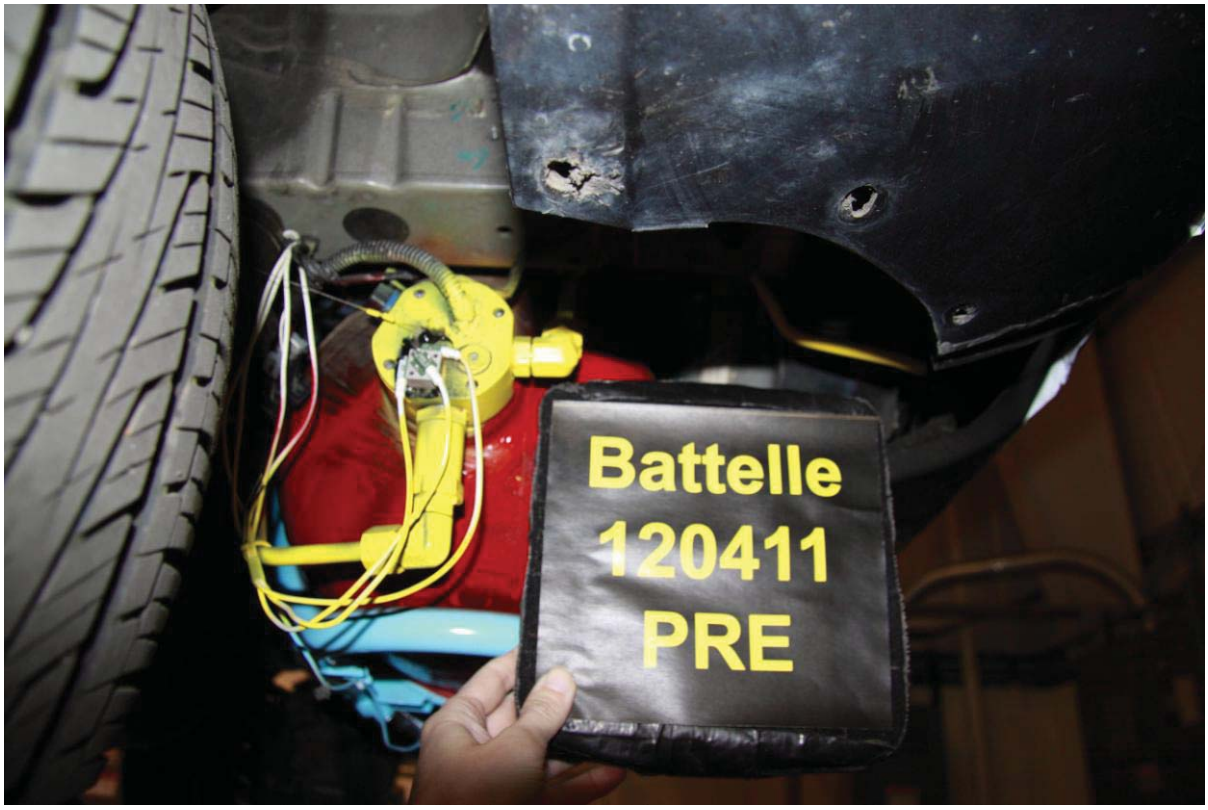


Figure A-43 Pre-Test Fuel Lines - View 5

Figure A-44 Pre-Test Fuel Lines - View 6

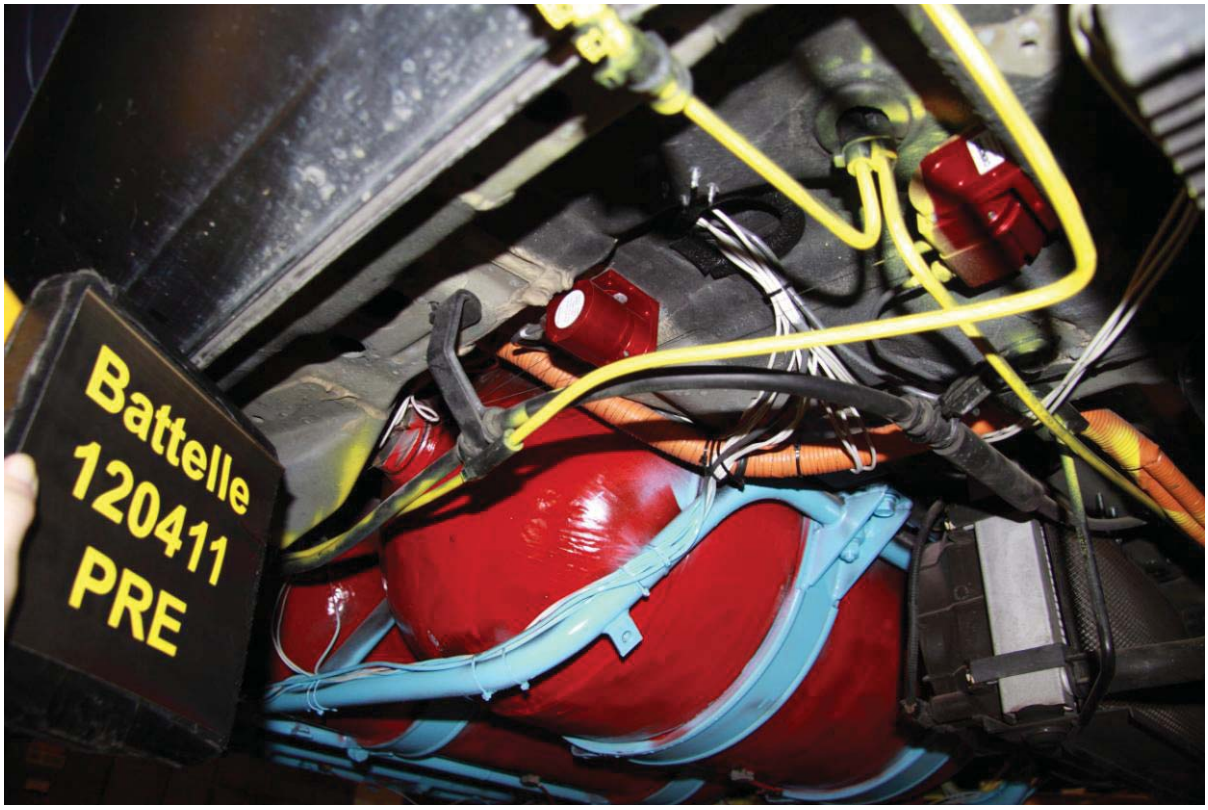


Figure A-45 Pre-Test Fuel Lines - View 7

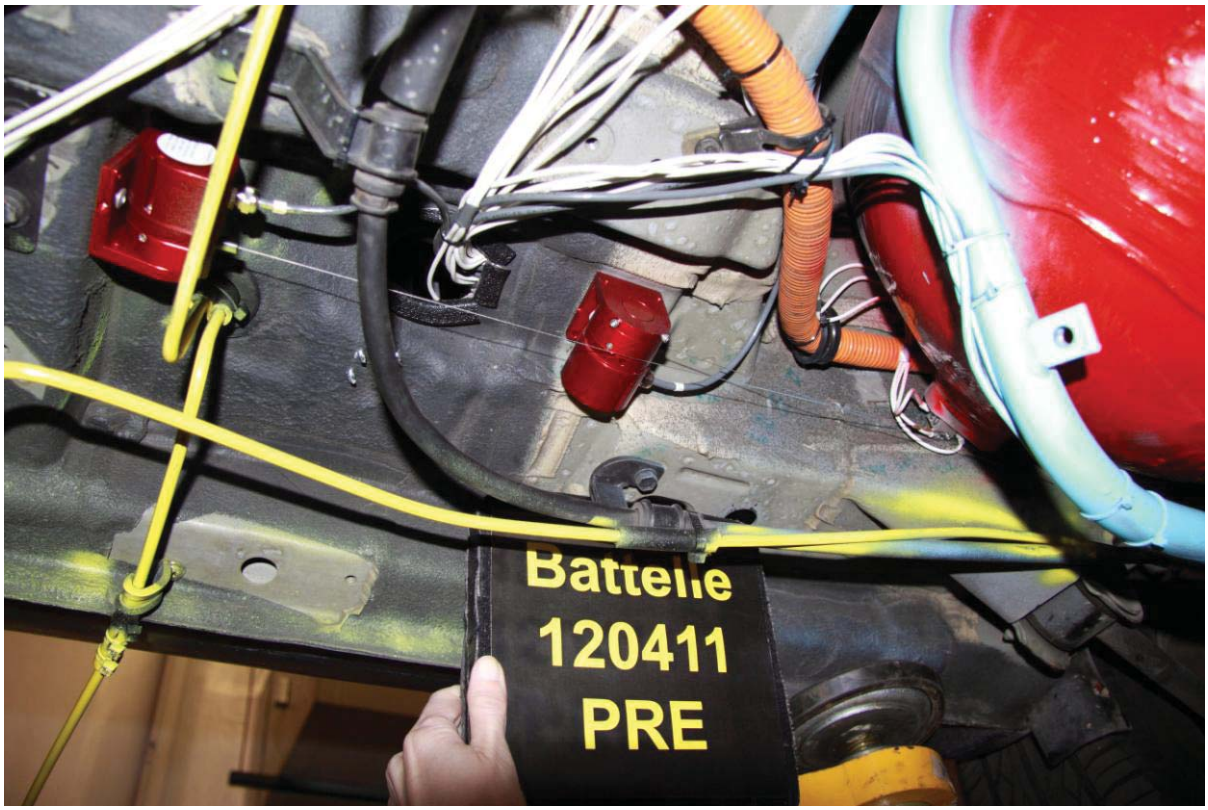


Figure A-46 Pre-Test Fuel Lines - View 8

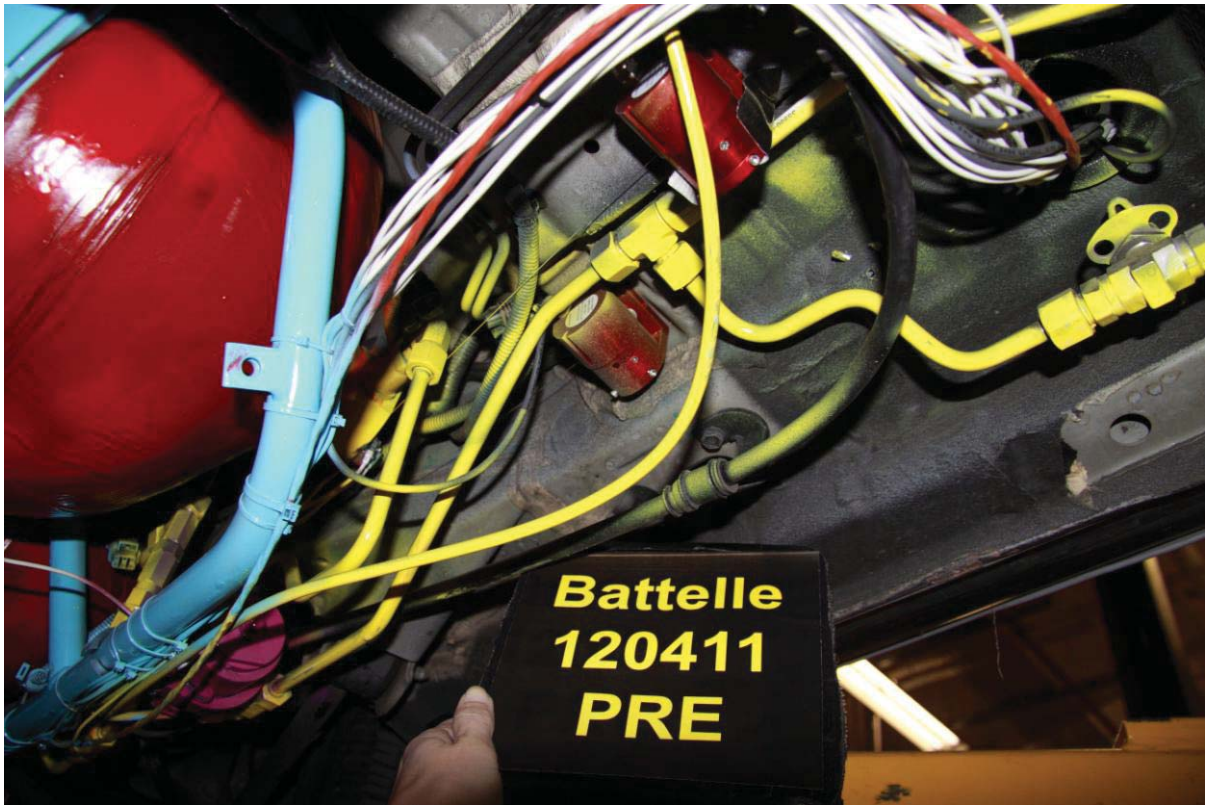


Figure A-47 Pre-Test Fuel Lines - View 9

Figure A-48 Pre-Test Fuel Lines - View 10

Figure A-49 Pre-Test Fuel Filler

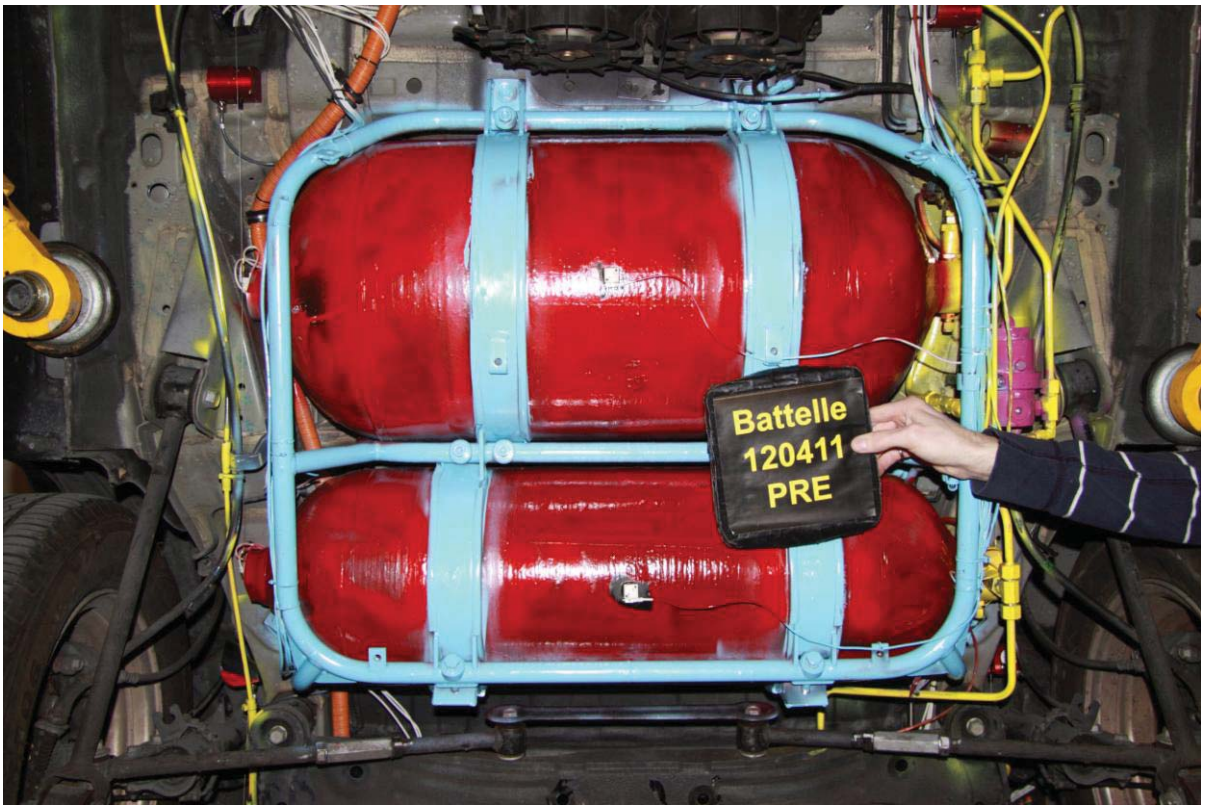


Figure A-50 Pre-Test Fuel Tank Overall View

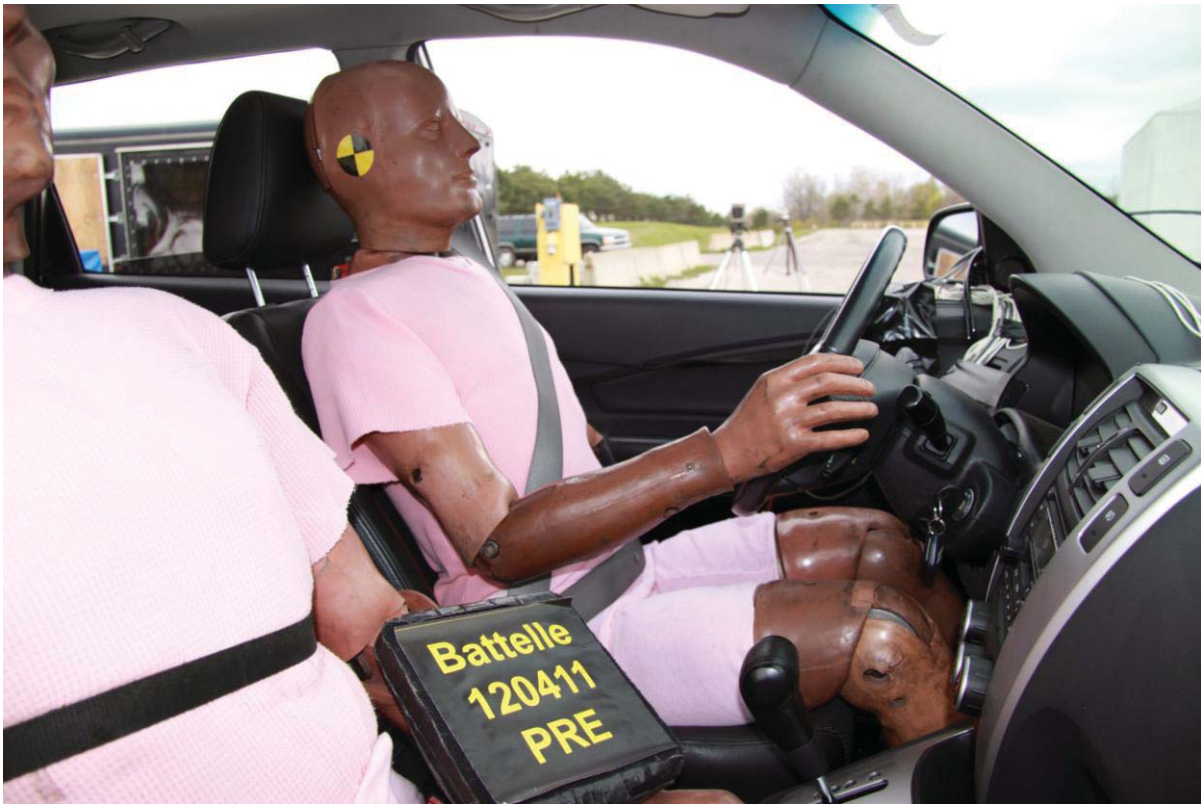


Figure A-51 Pre-Test Driver Dummy View

Figure A-52 Pre-Test Passenger Dummy View

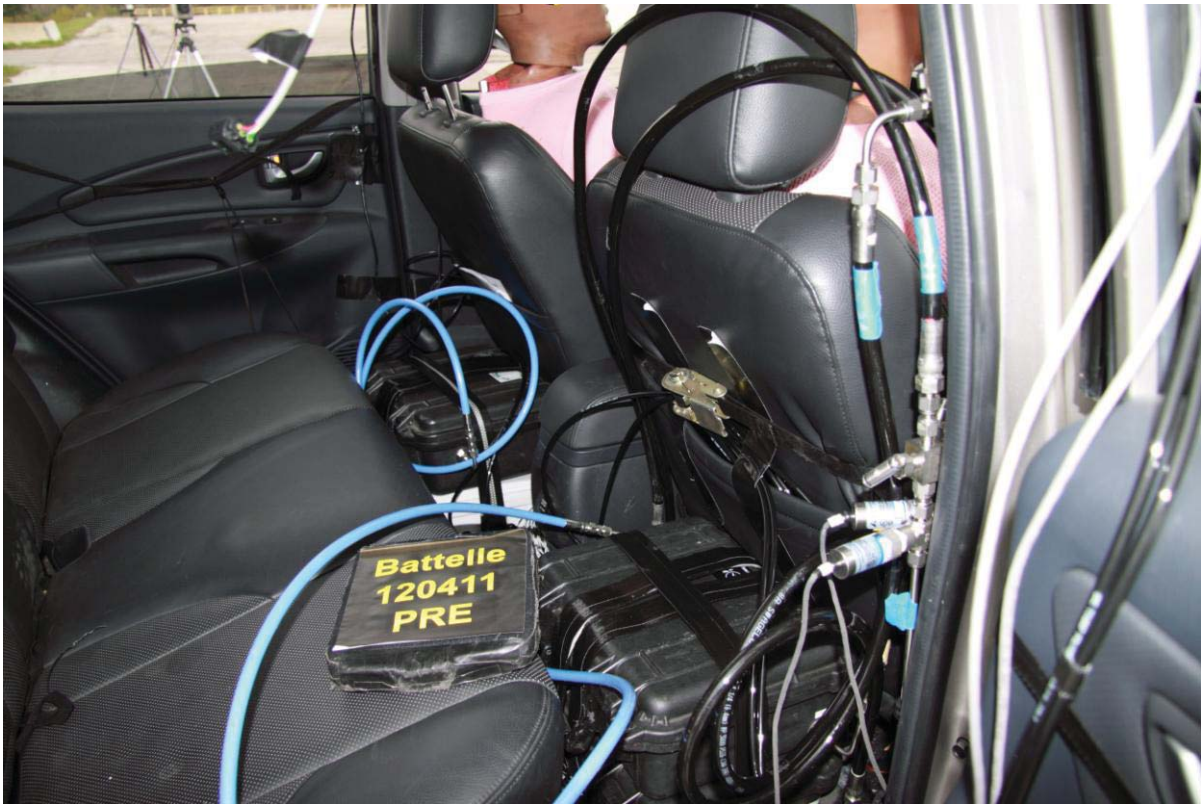


Figure A-53 Pre-Test Instrumentation View

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Figure A-54 Pre-Test Moving Barrier with Vehicle - Left Side Overall

Figure A-55 Pre-Test Moving Barrier with Vehicle - Right Side Overall

Figure A-56 Pre-Test Moving Barrier Front

Figure A-57 Post-Test Moving Barrier Front

Appendix B

Data Plots

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

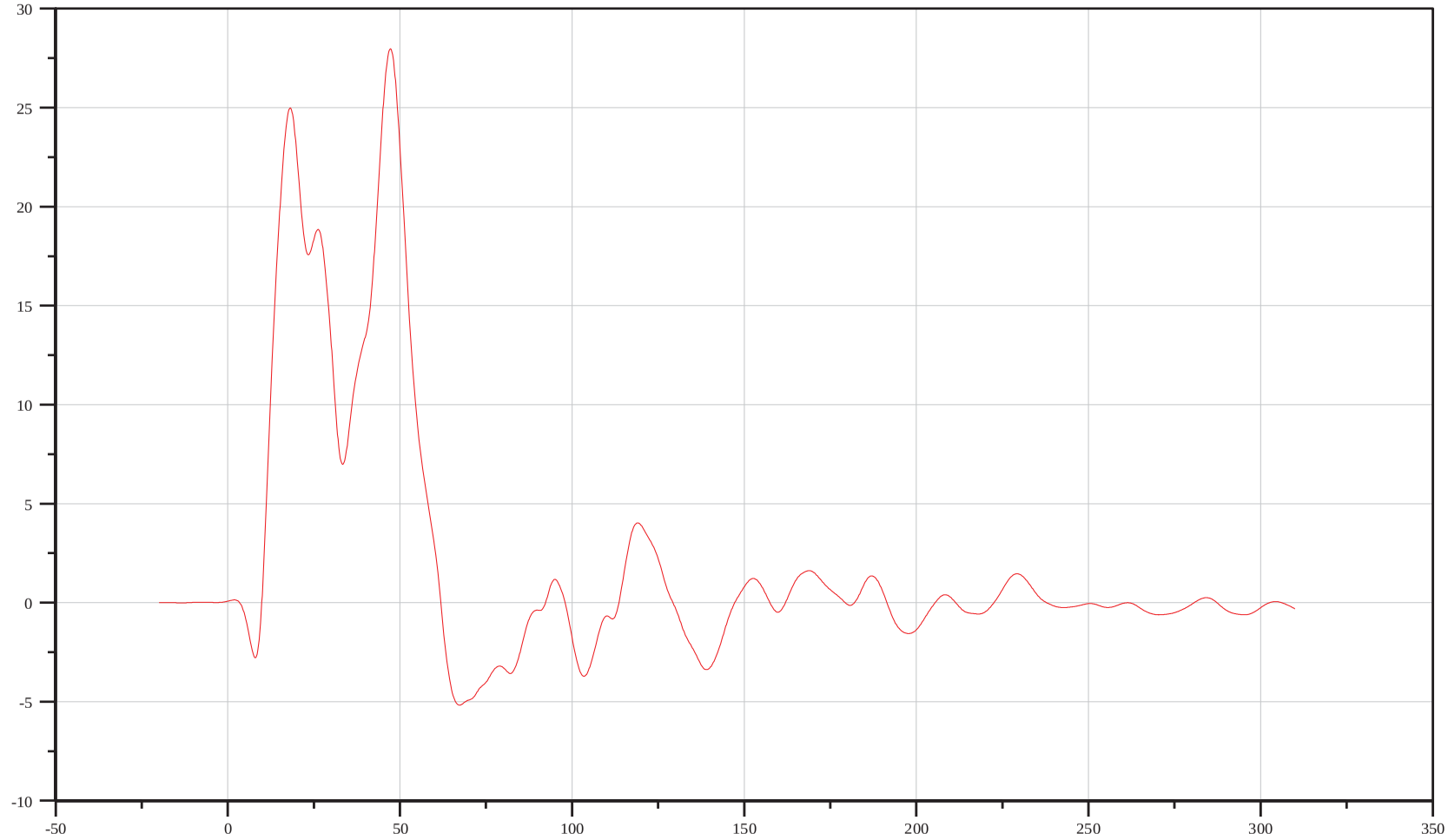
Vehicle CG X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHCCG0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-5.18 g at 67.30 ms

Max. Value
27.98 g at 47.30 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

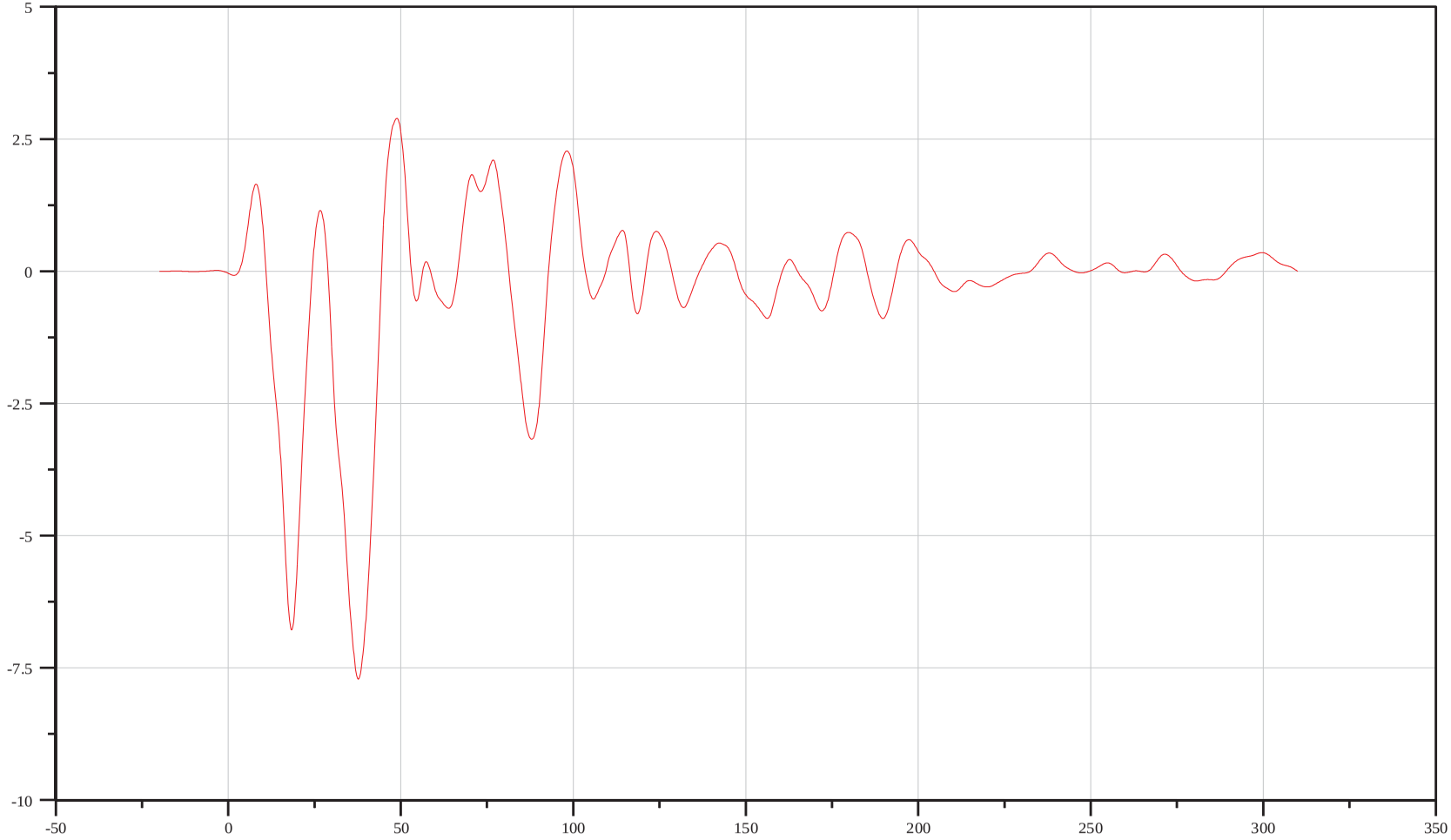
Vehicle CG Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHCCG0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-7.71 g at 37.70 ms

Max. Value
2.89 g at 48.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

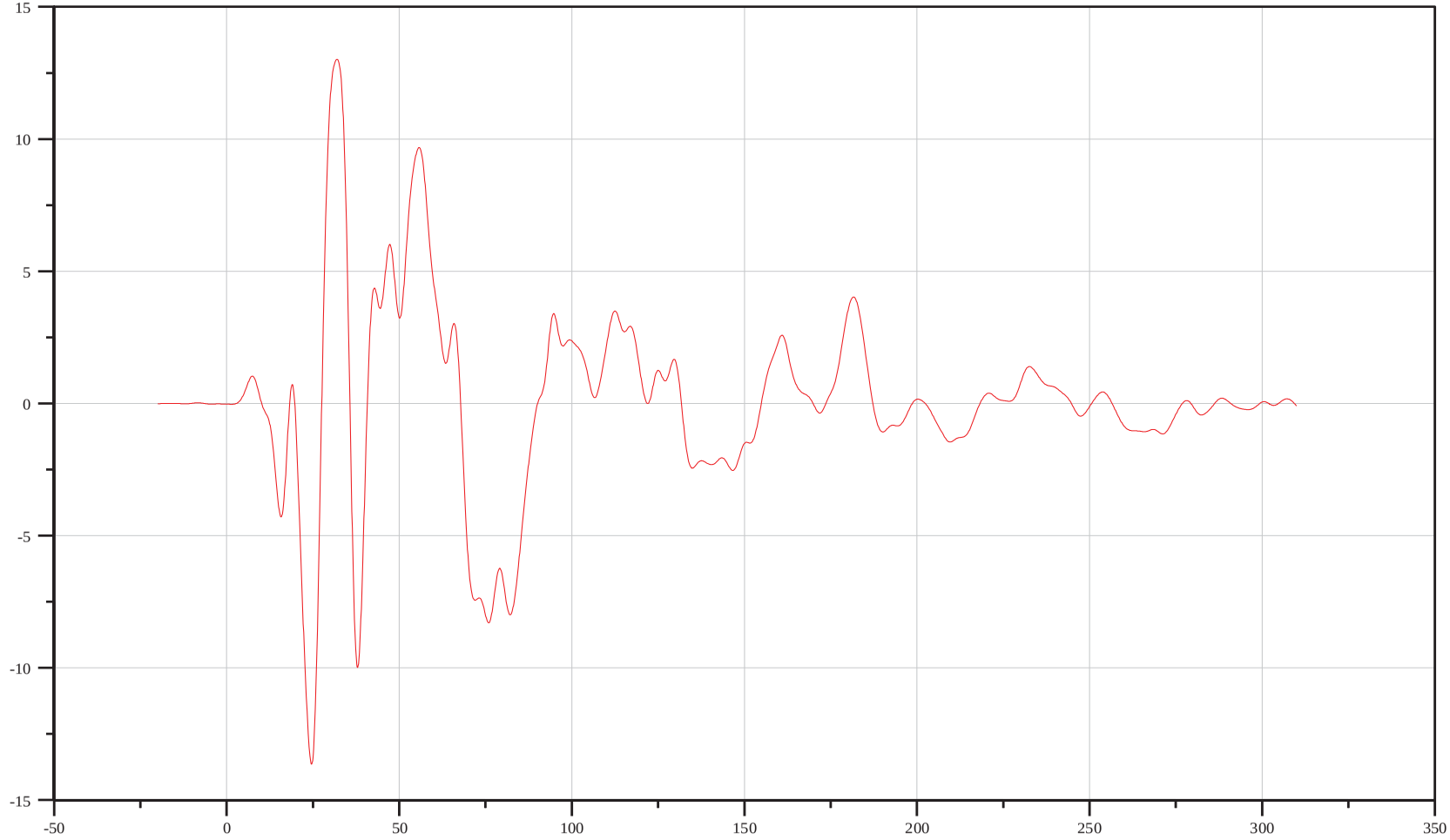
Vehicle CG Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHCCG0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-13.65 g at 24.60 ms

Max. Value
13.01 g at 32.00 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

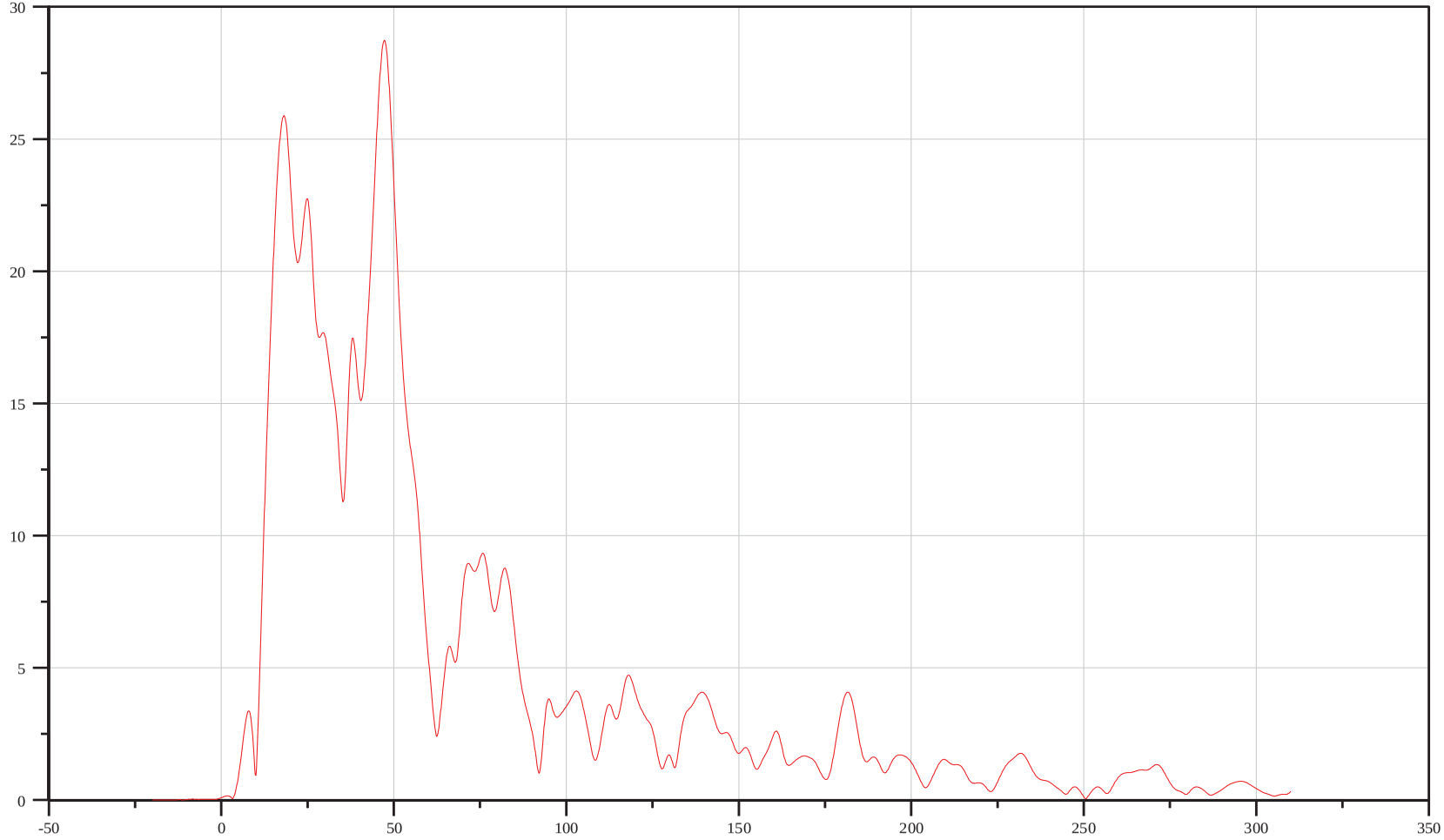
Vehicle CG Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHCCG0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.01 g at -15.90 ms

Max. Value
28.74 g at 47.30 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

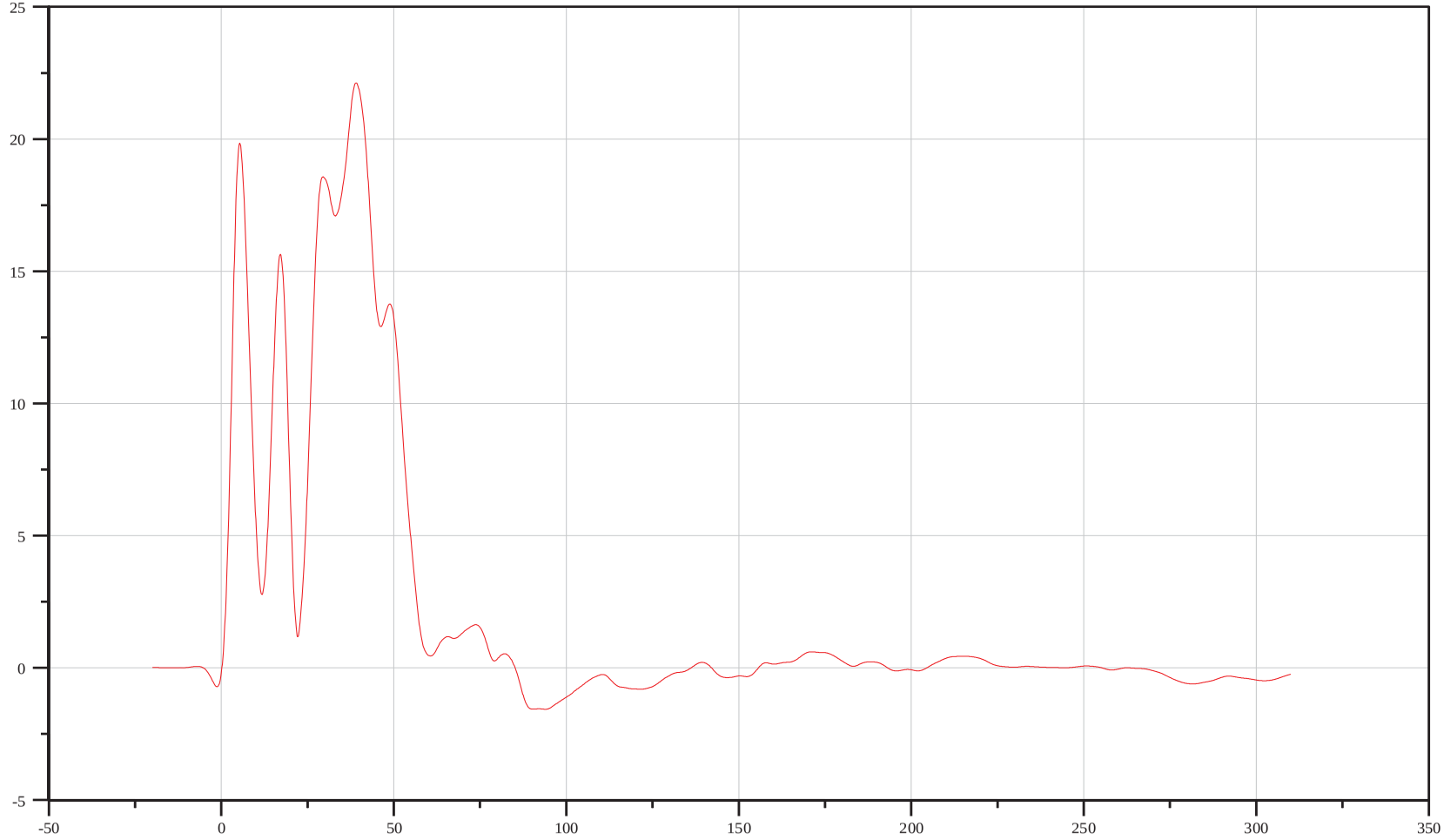
Vehicle Body X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHC000000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-1.57 g at 94.00 ms

Max. Value
22.12 g at 39.10 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

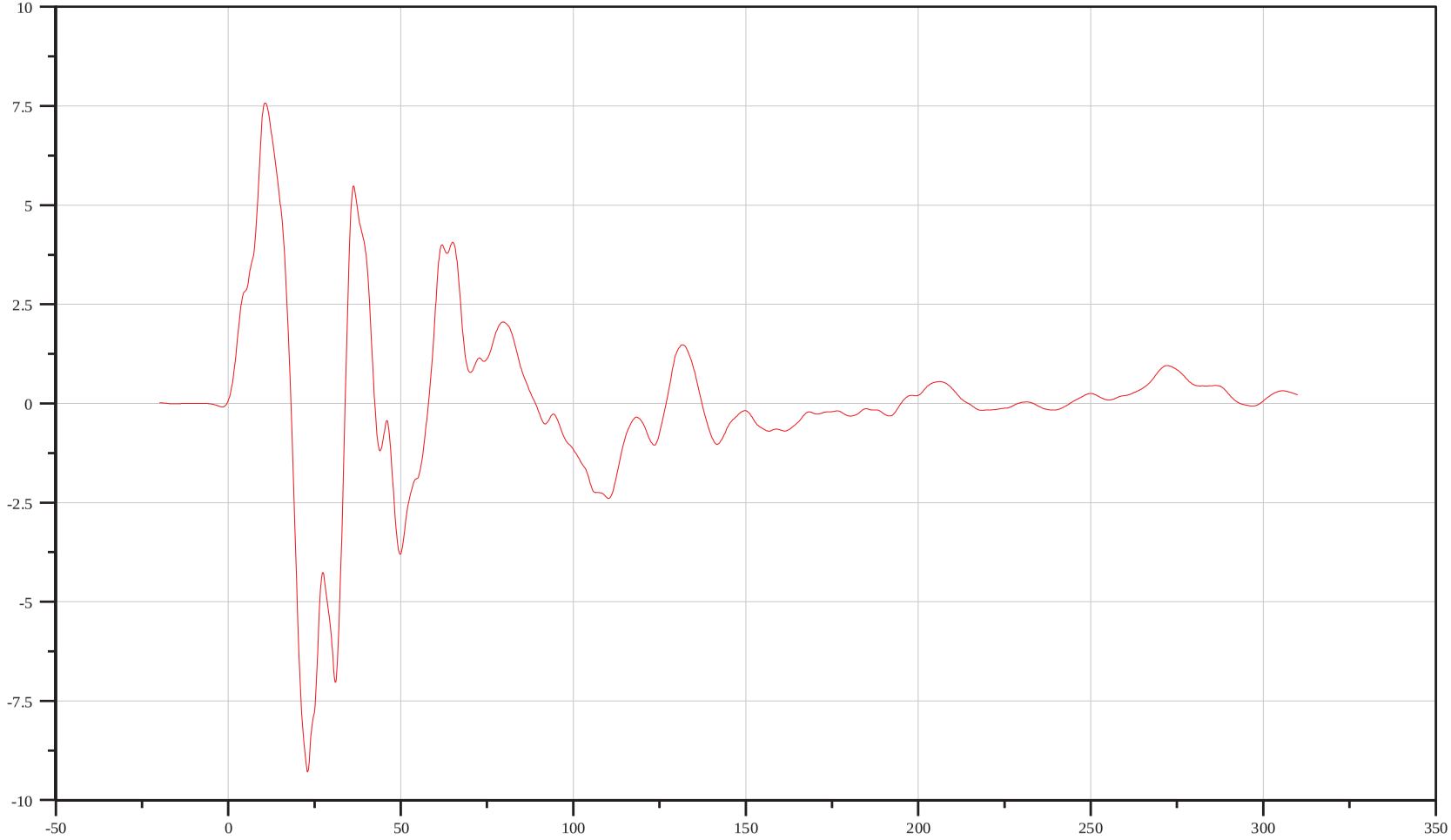
Vehicle Body Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHC000000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-9.29 g at 23.00 ms

Max. Value
7.57 g at 10.70 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

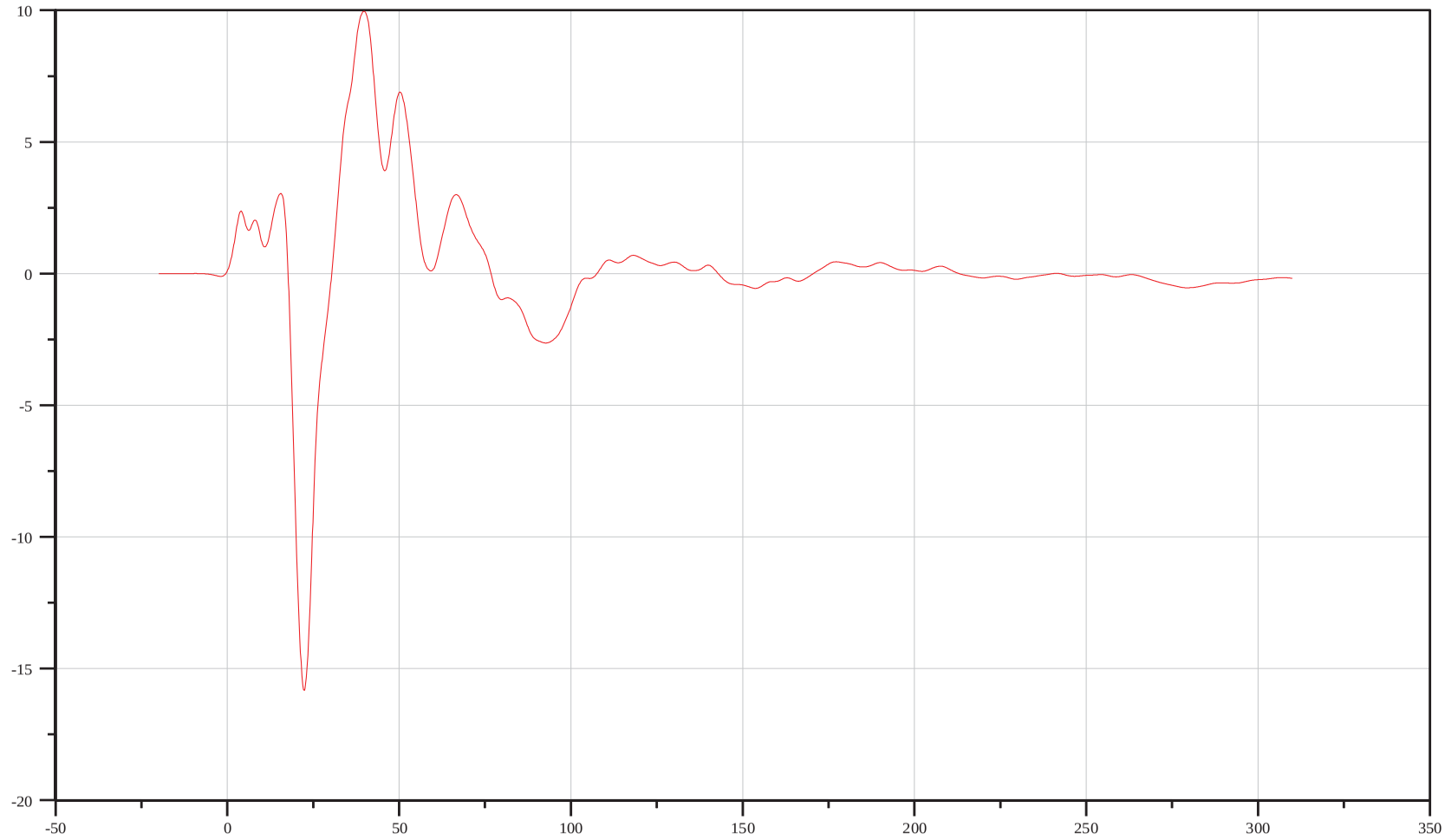
Vehicle Body Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHC000000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-15.83 g at 22.40 ms

Max. Value
9.96 g at 39.80 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

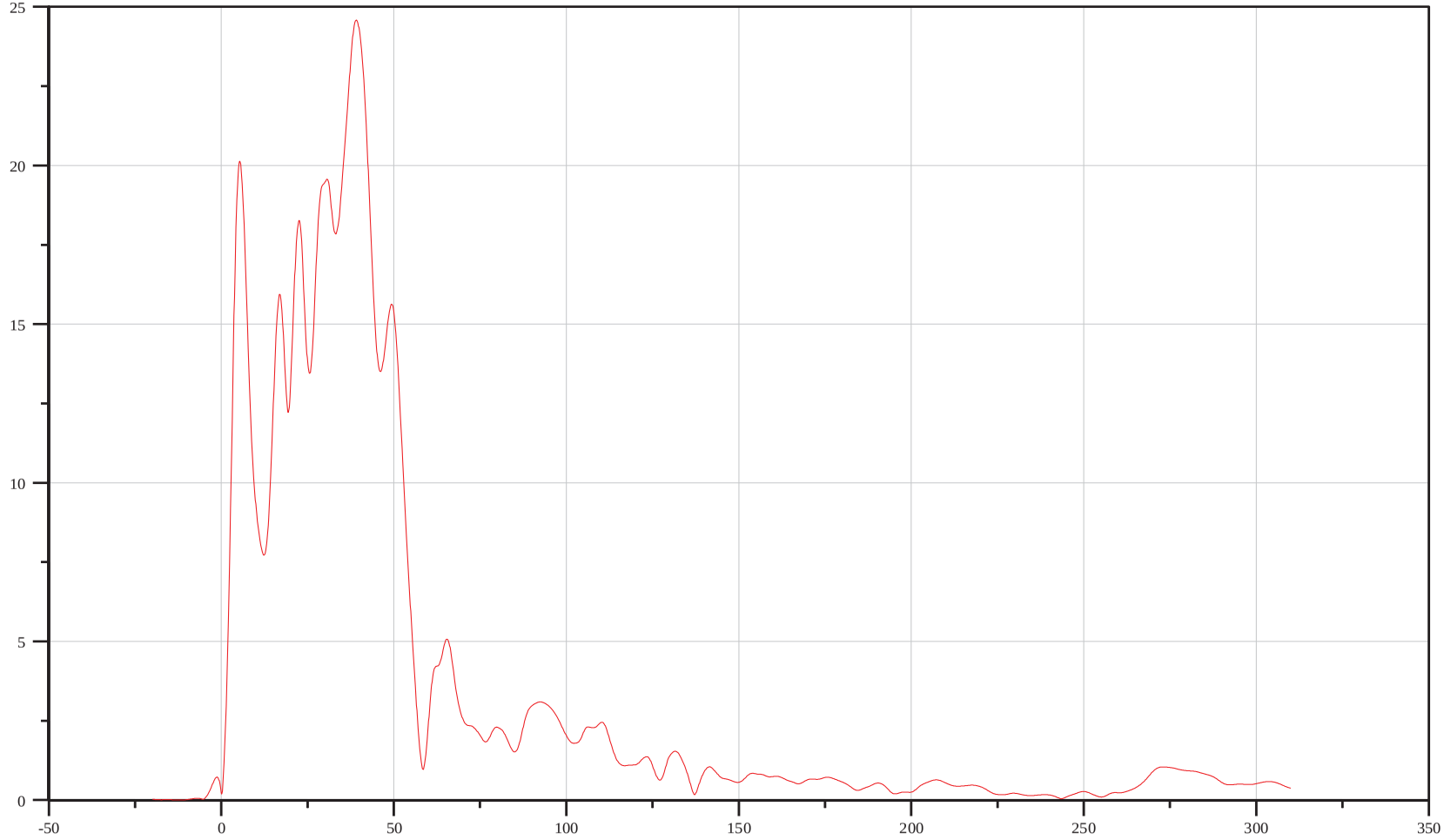
Vehicle Body Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10VEHC000000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.00 g at -11.10 ms

Max. Value
24.58 g at 39.10 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

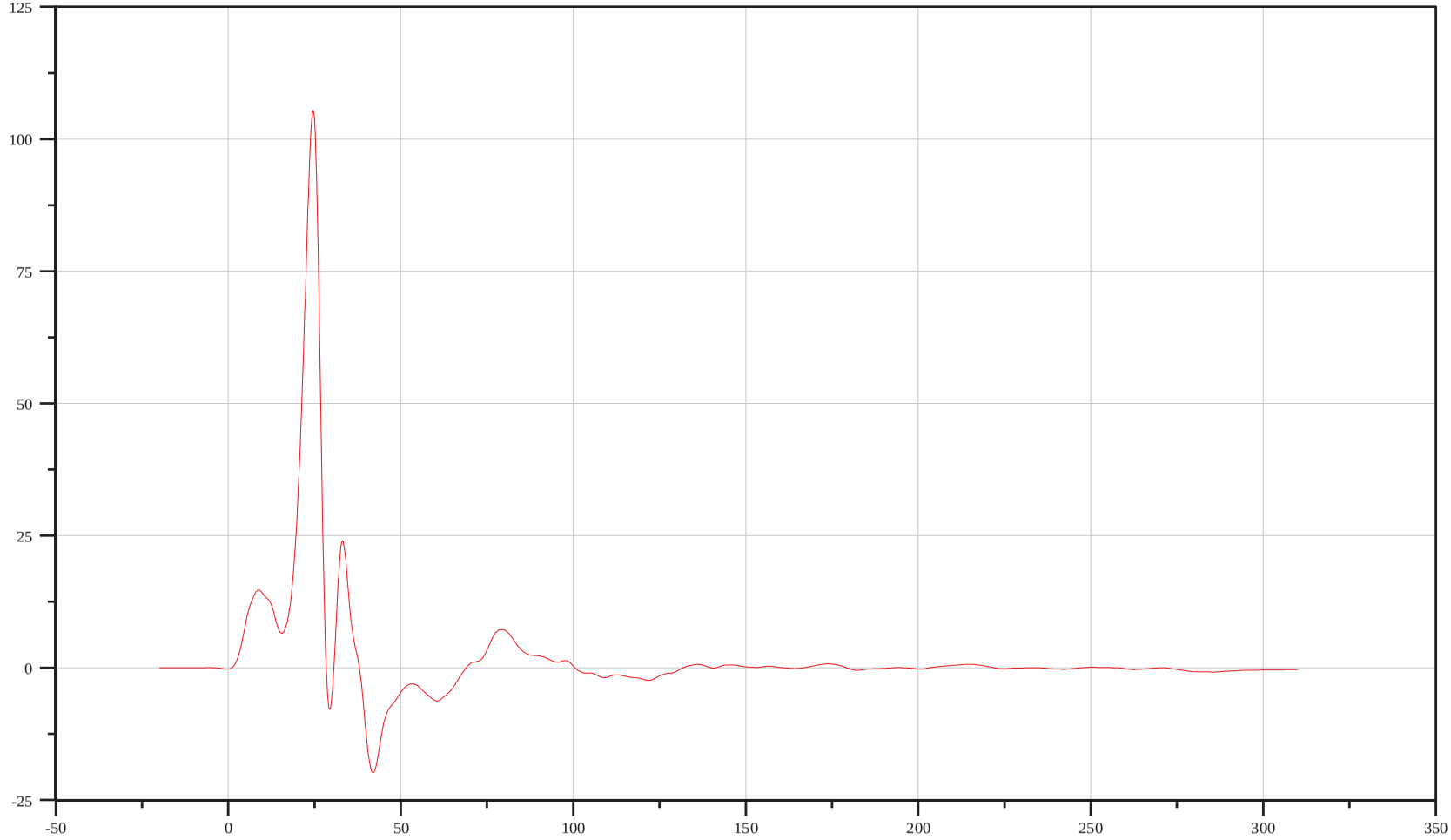
Front Container, Passenger X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTFR0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-19.83 g at 42.00 ms

Max. Value
105.42 g at 24.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

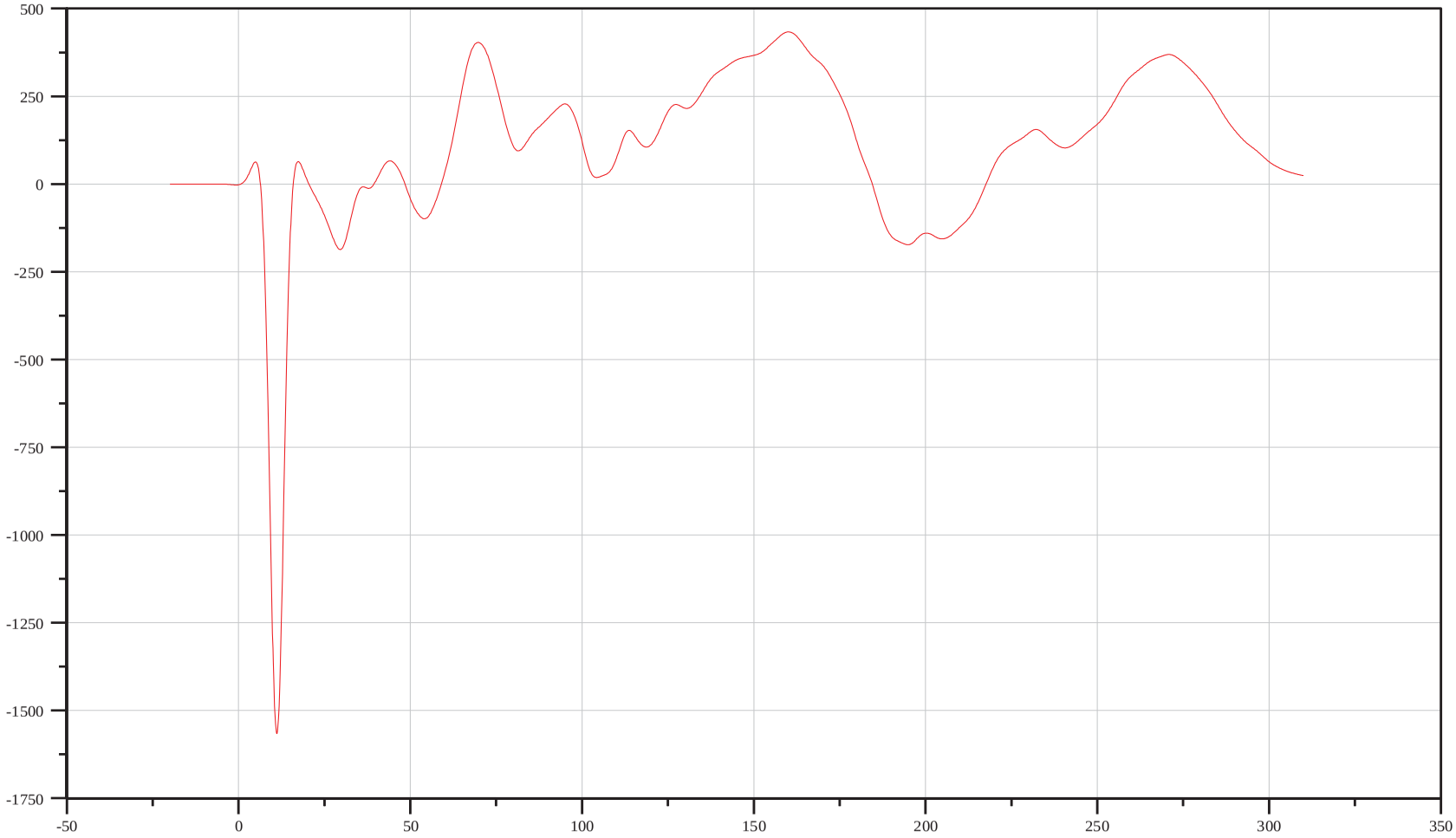
Front Container, Passenger Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTFR0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-1,565.67 g at 11.10 ms

Max. Value
433.52 g at 160.10 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

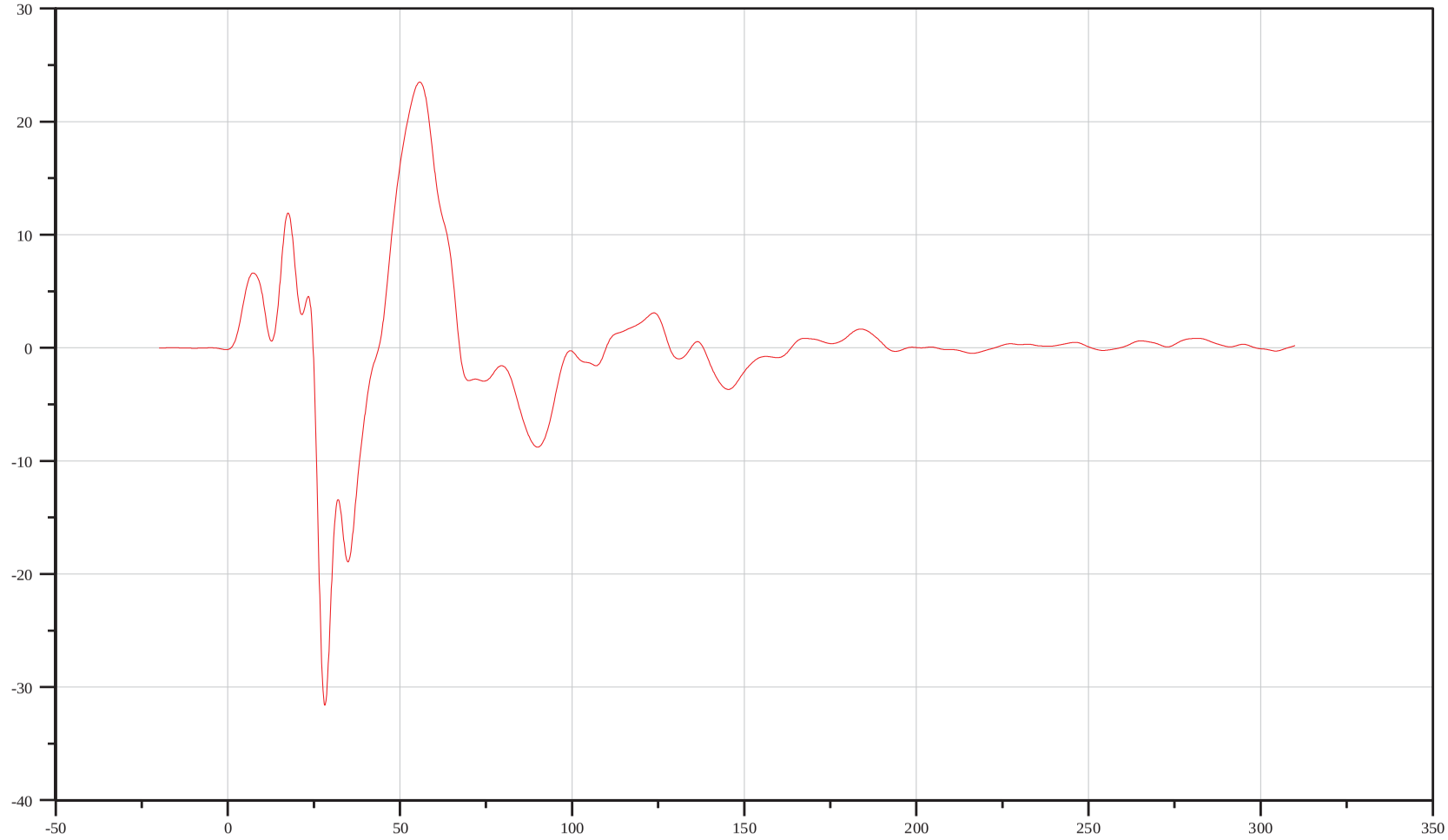
Front Container, Passenger Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTFR0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-31.62 g at 28.20 ms

Max. Value
23.50 g at 55.80 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

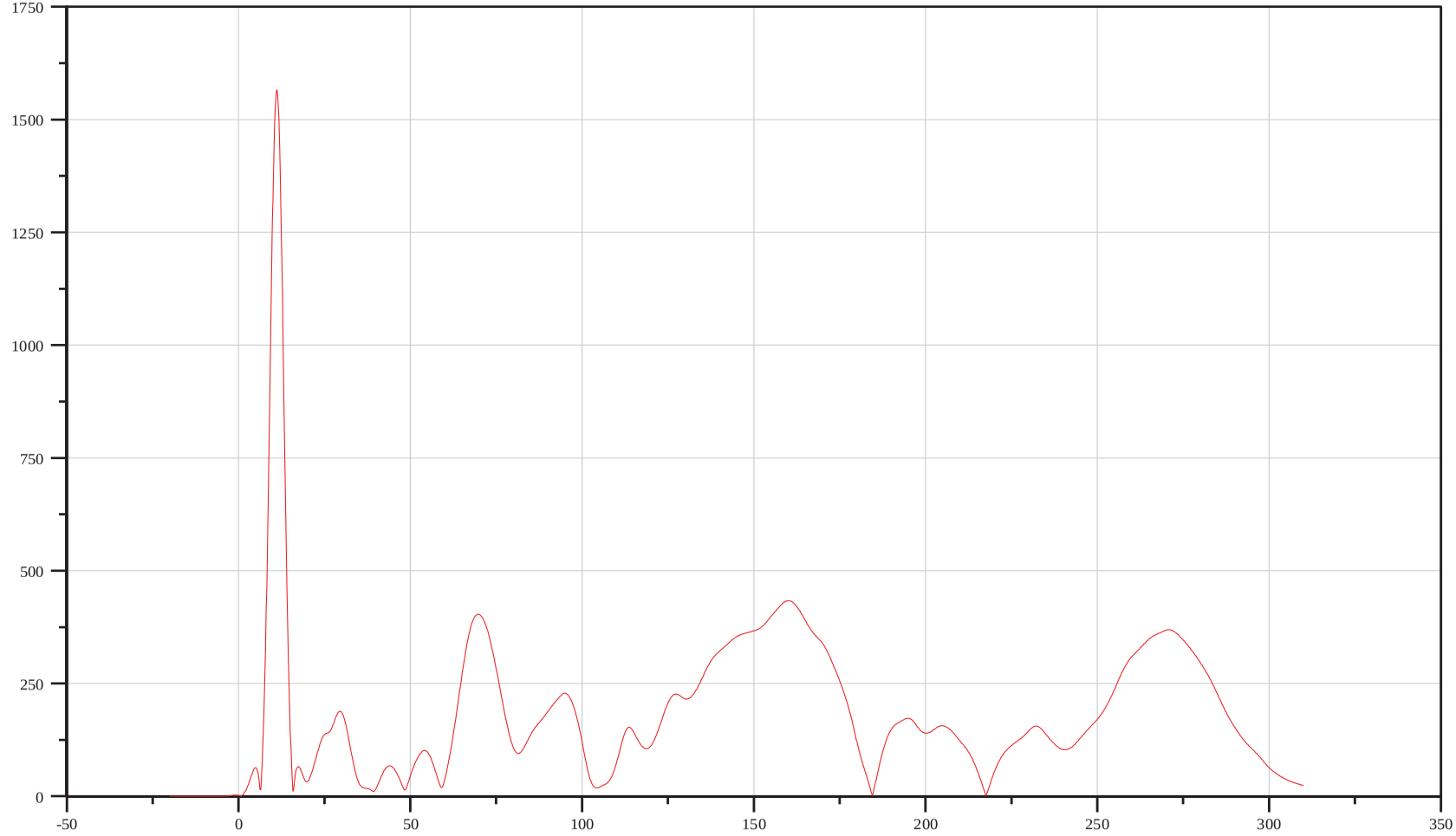
Front Container, Passenger Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTFR0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.02 g at -13.60 ms

Max. Value
1,565.72 g at 11.10 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

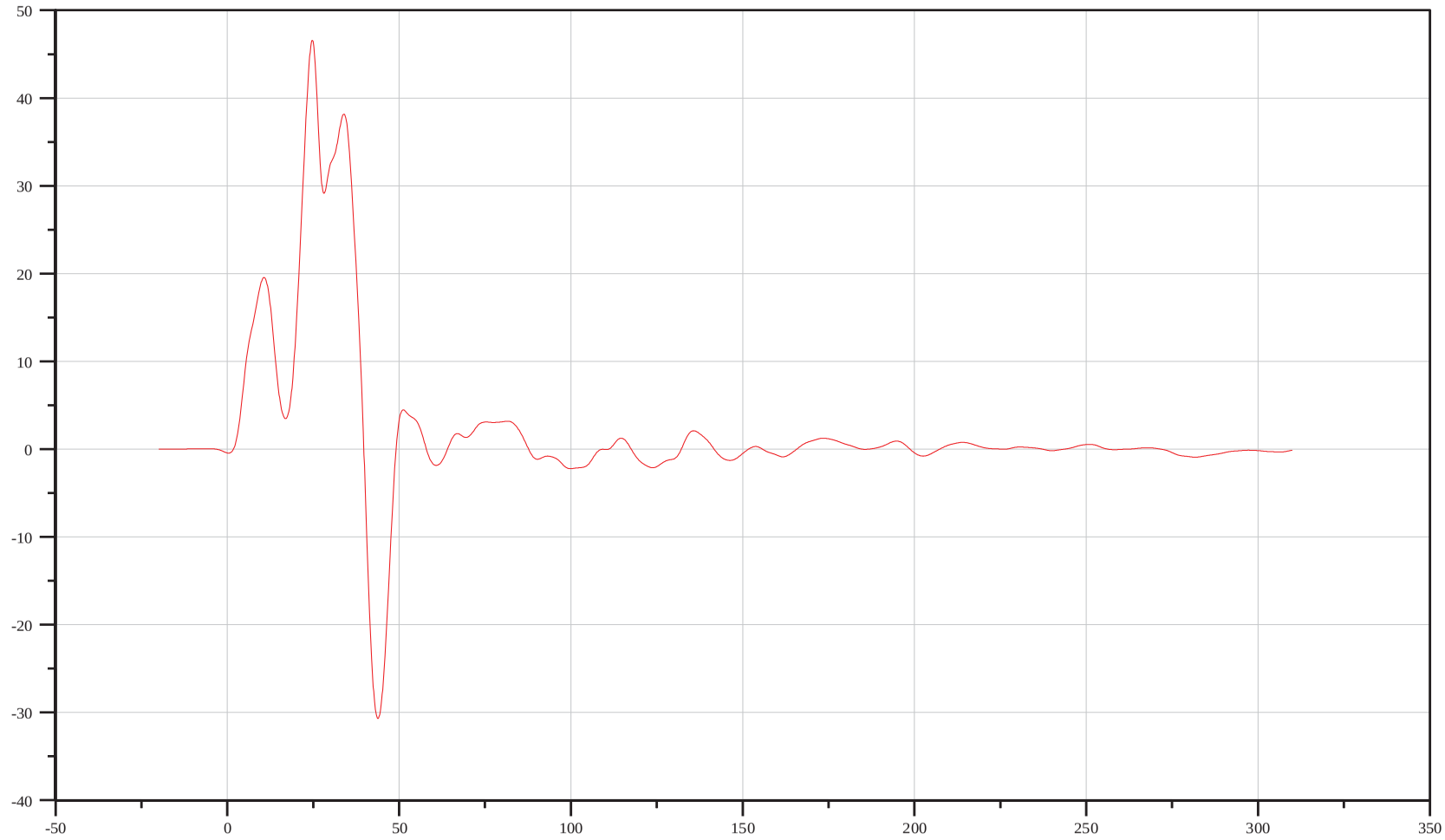
Front Container, Driver X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTFR0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-30.69 g at 43.80 ms

Max. Value
46.58 g at 24.70 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

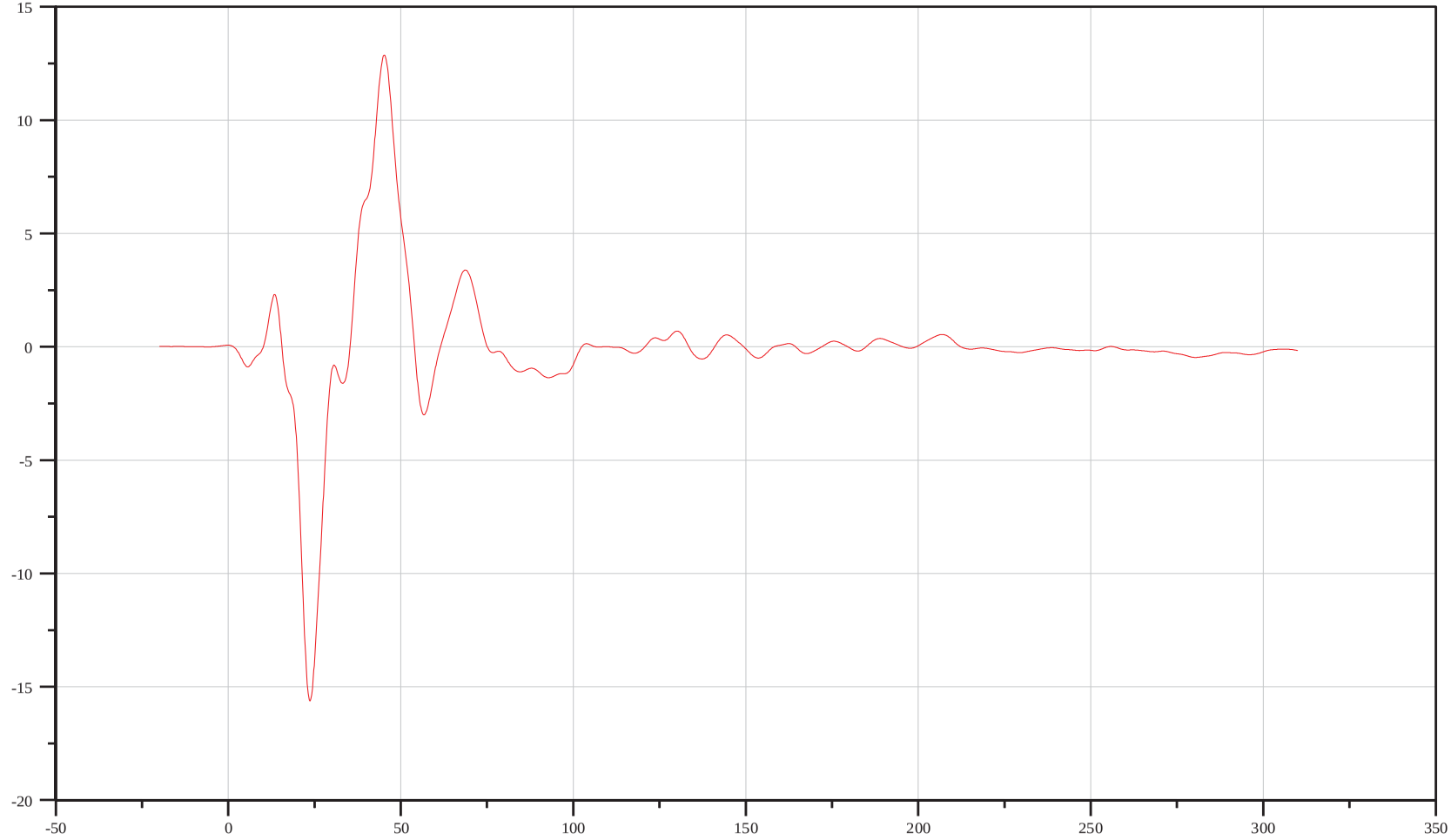
Front Container, Driver Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTFR0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-15.63 g at 23.70 ms

Max. Value
12.87 g at 45.20 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

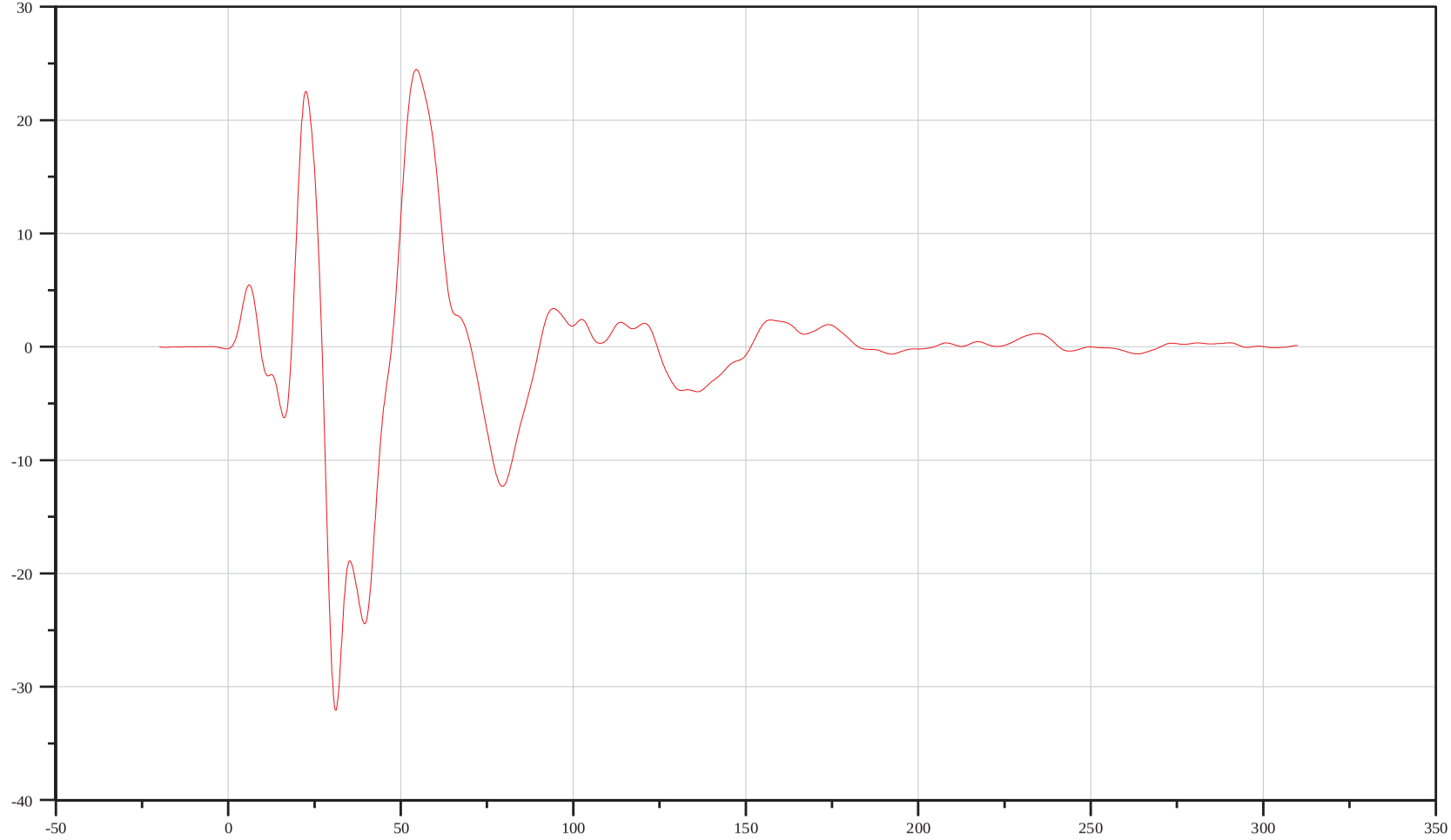
Front Container, Driver Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTFR0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-32.08 g at 31.20 ms

Max. Value
24.48 g at 54.50 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

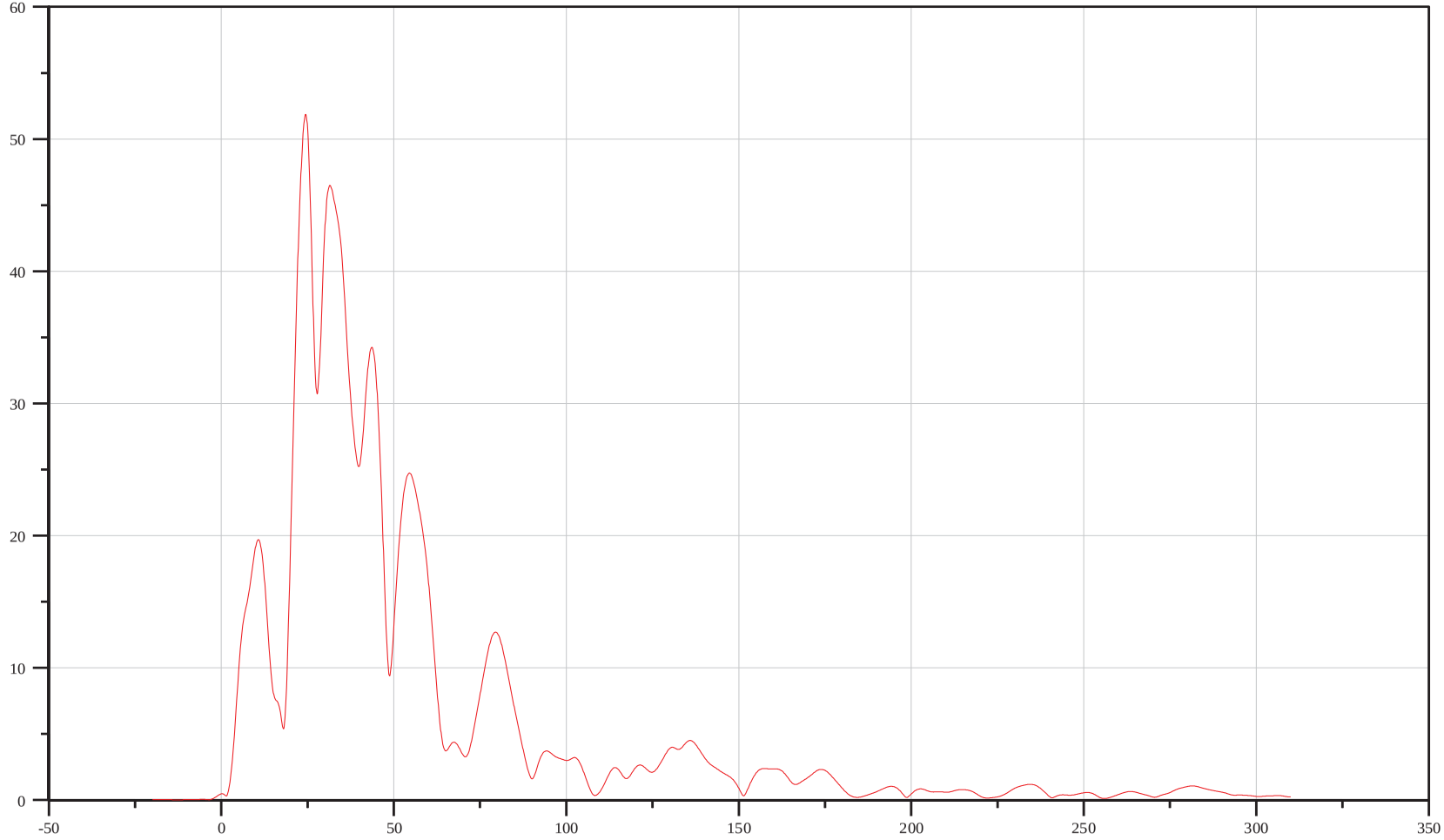
Front Container, Driver Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTFR0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.02 g at -12.60 ms

Max. Value
51.87 g at 24.40 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

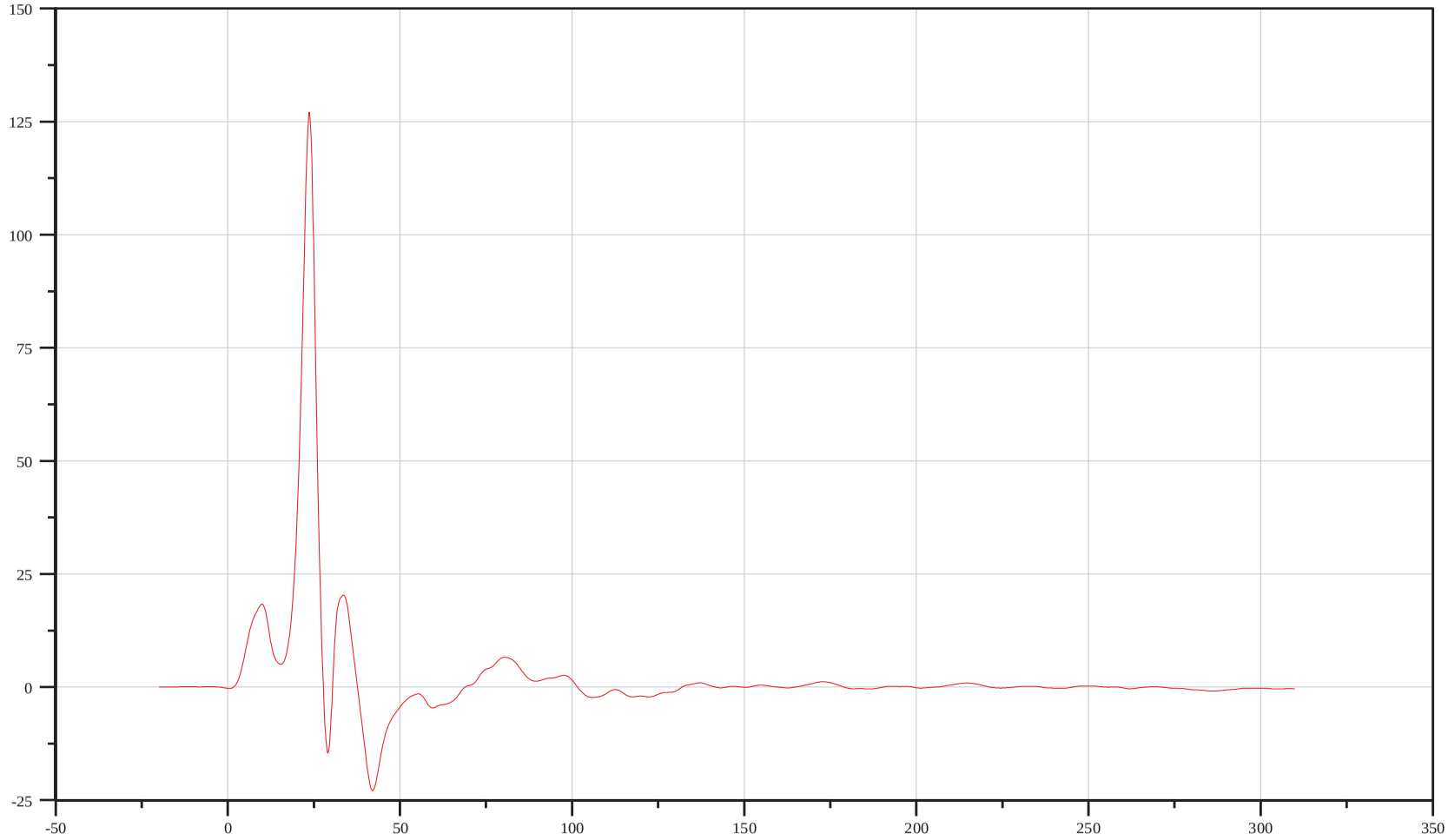
Middle Container, Passenger X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTMI0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-22.90 g at 42.10 ms

Max. Value
127.10 g at 23.70 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

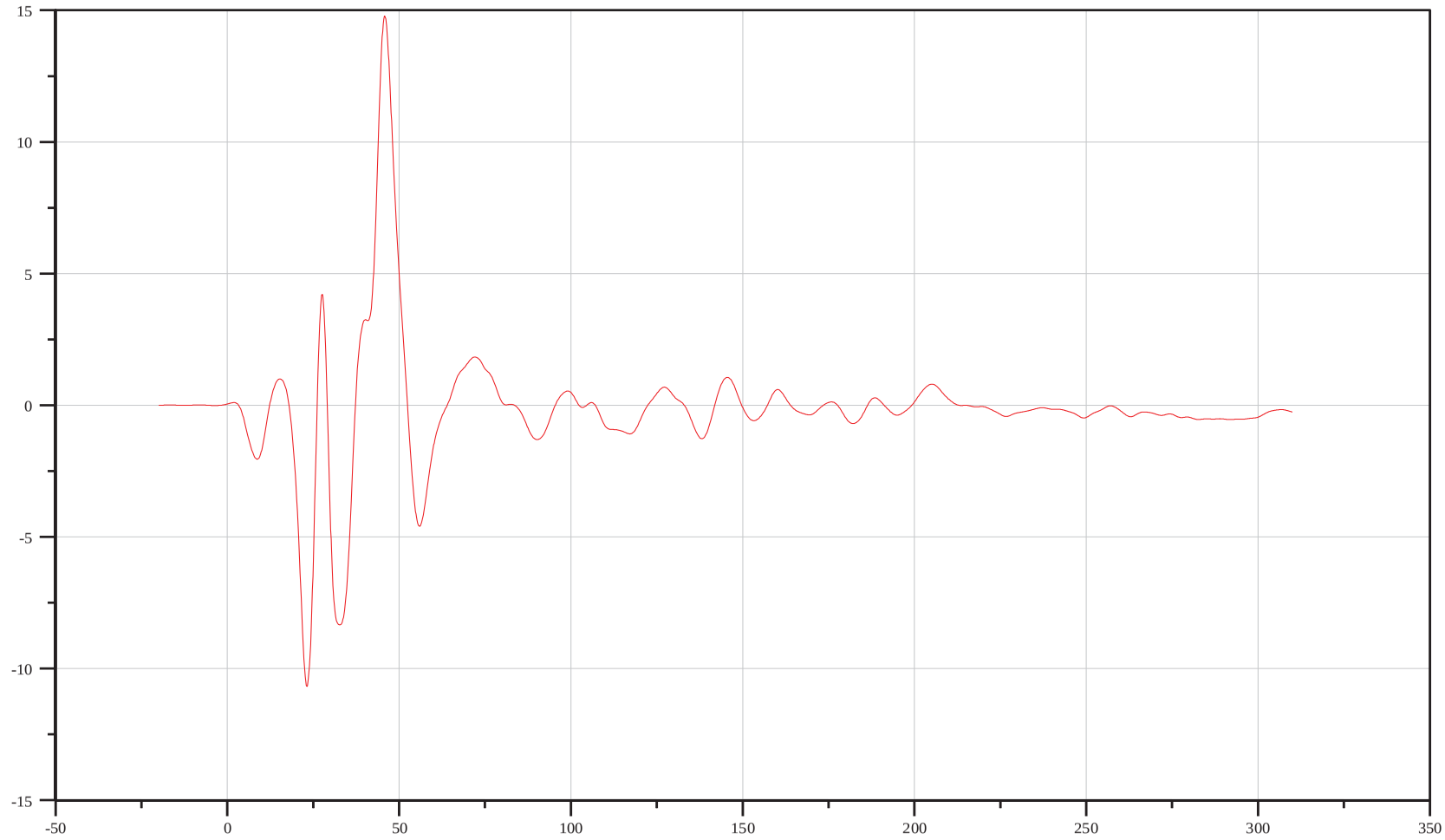
Middle Container, Passenger Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTMI0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-10.67 g at 23.20 ms

Max. Value
14.78 g at 45.80 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

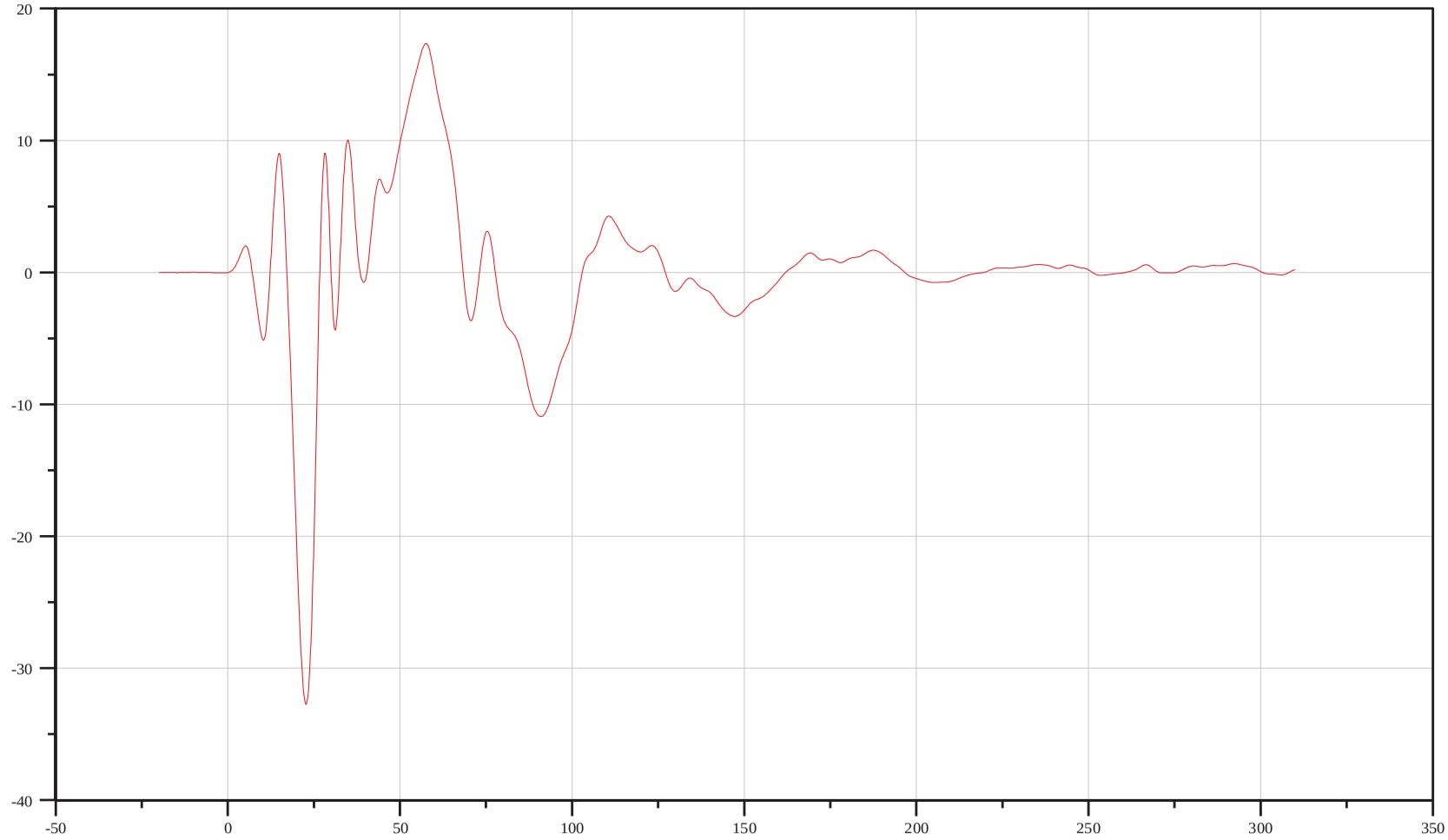
Middle Container, Passenger Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTMI0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-32.74 g at 22.70 ms

Max. Value
17.35 g at 57.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

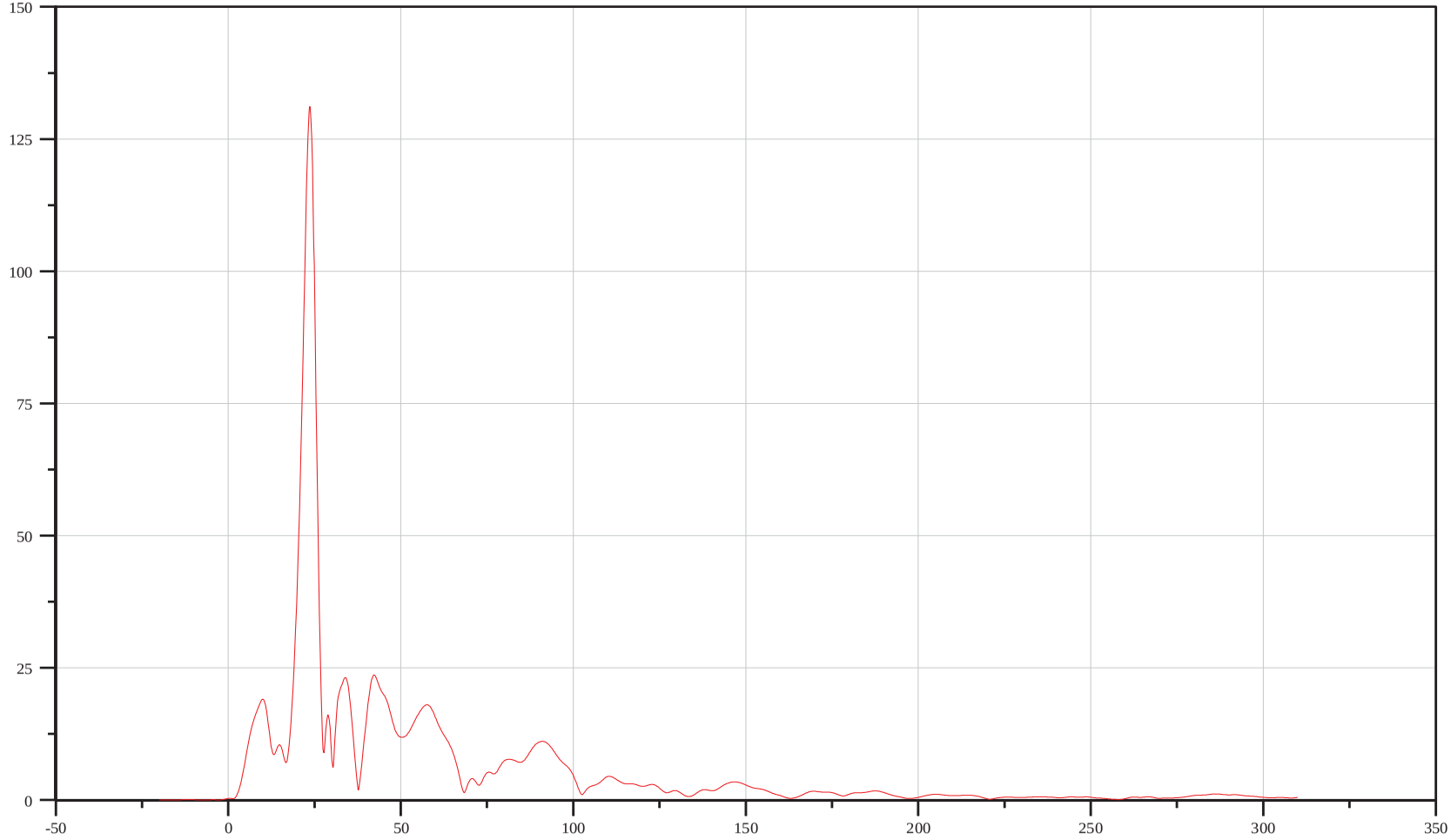
Middle Container, Passenger Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTMI0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.01 g at -19.20 ms

Max. Value
131.15 g at 23.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

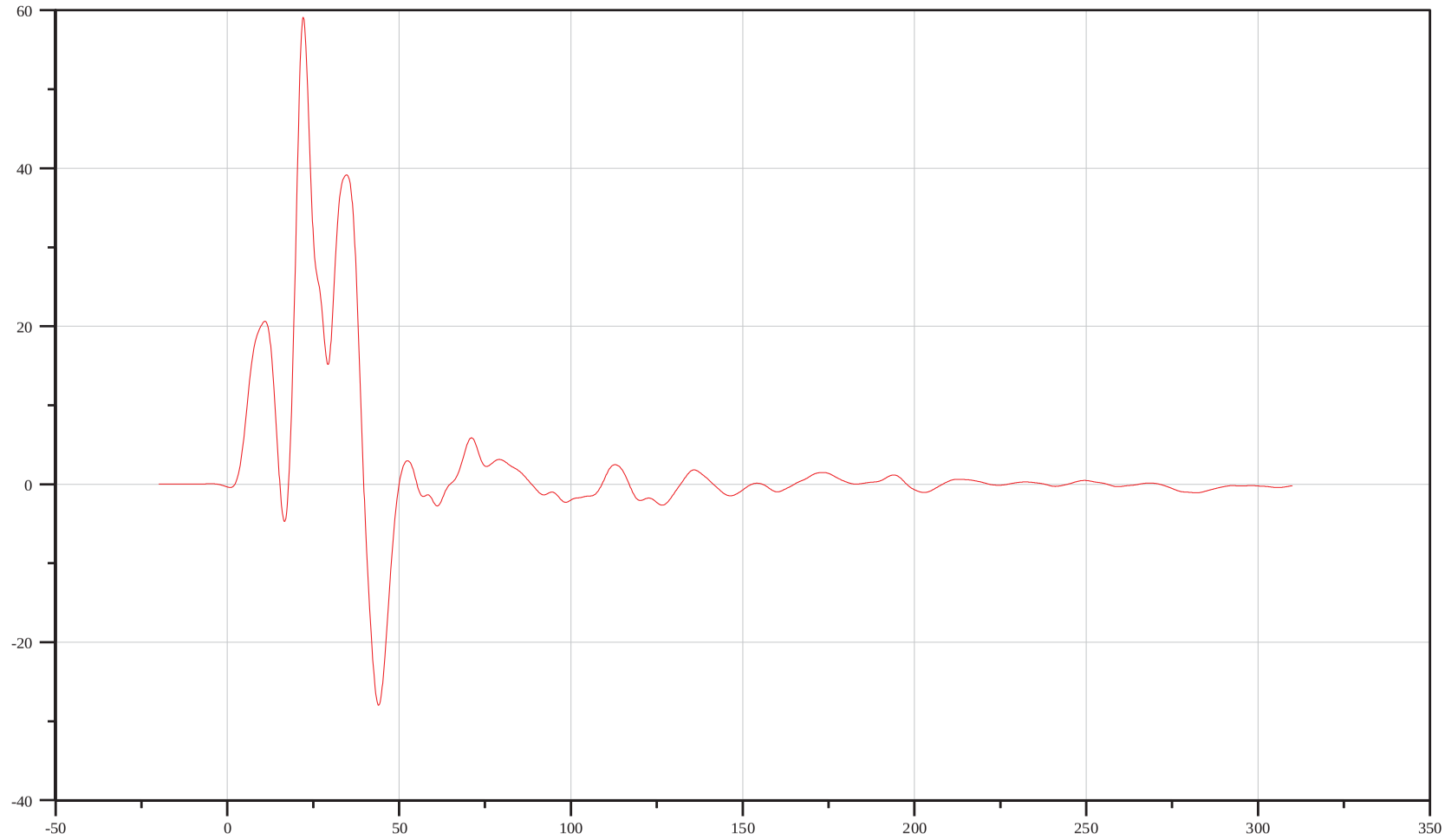
Middle Container, Driver X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTMI0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-27.97 g at 44.00 ms

Max. Value
59.11 g at 22.10 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

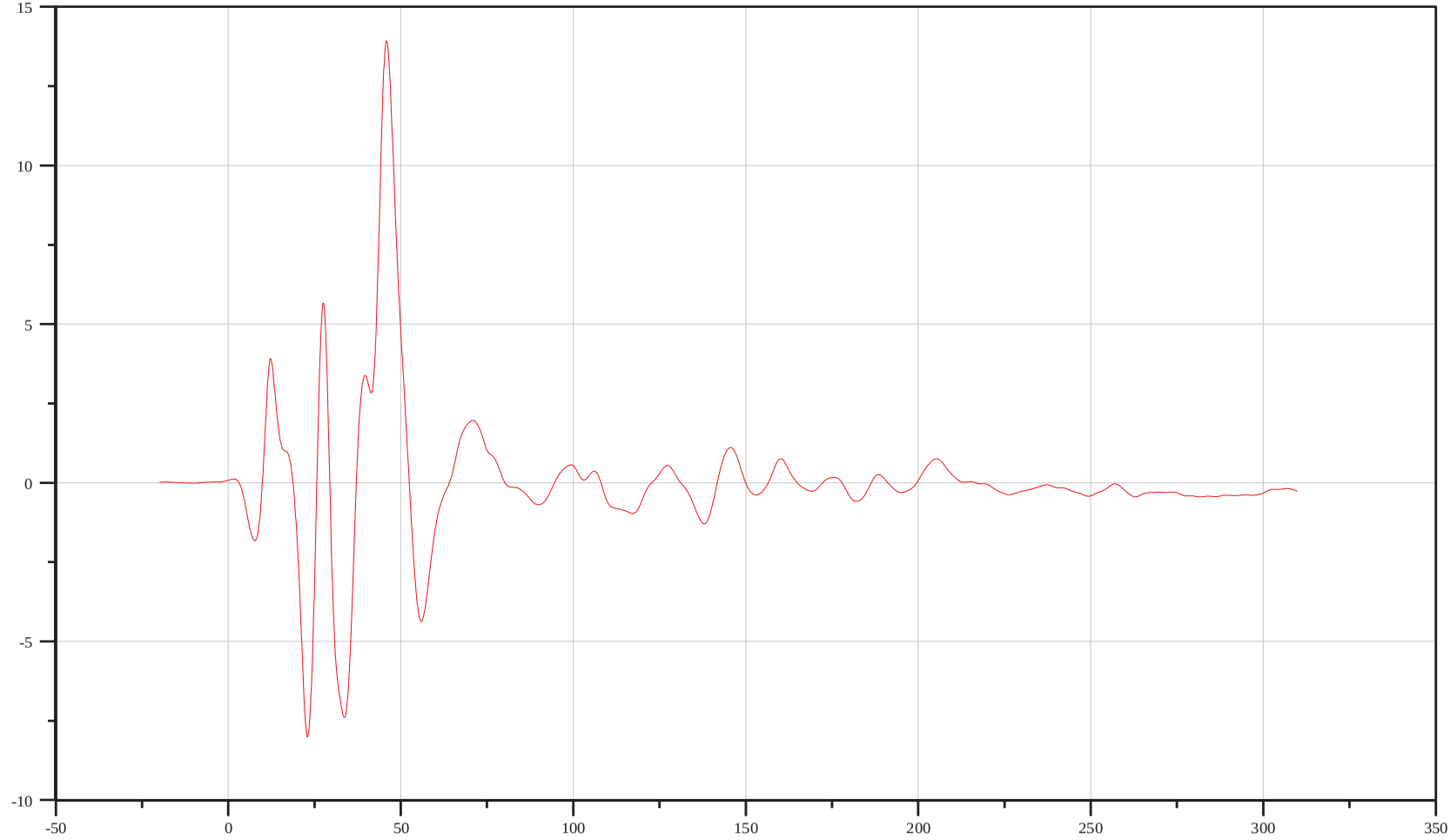
Middle Container, Driver Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTMI0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-8.01 g at 23.00 ms

Max. Value
13.93 g at 45.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

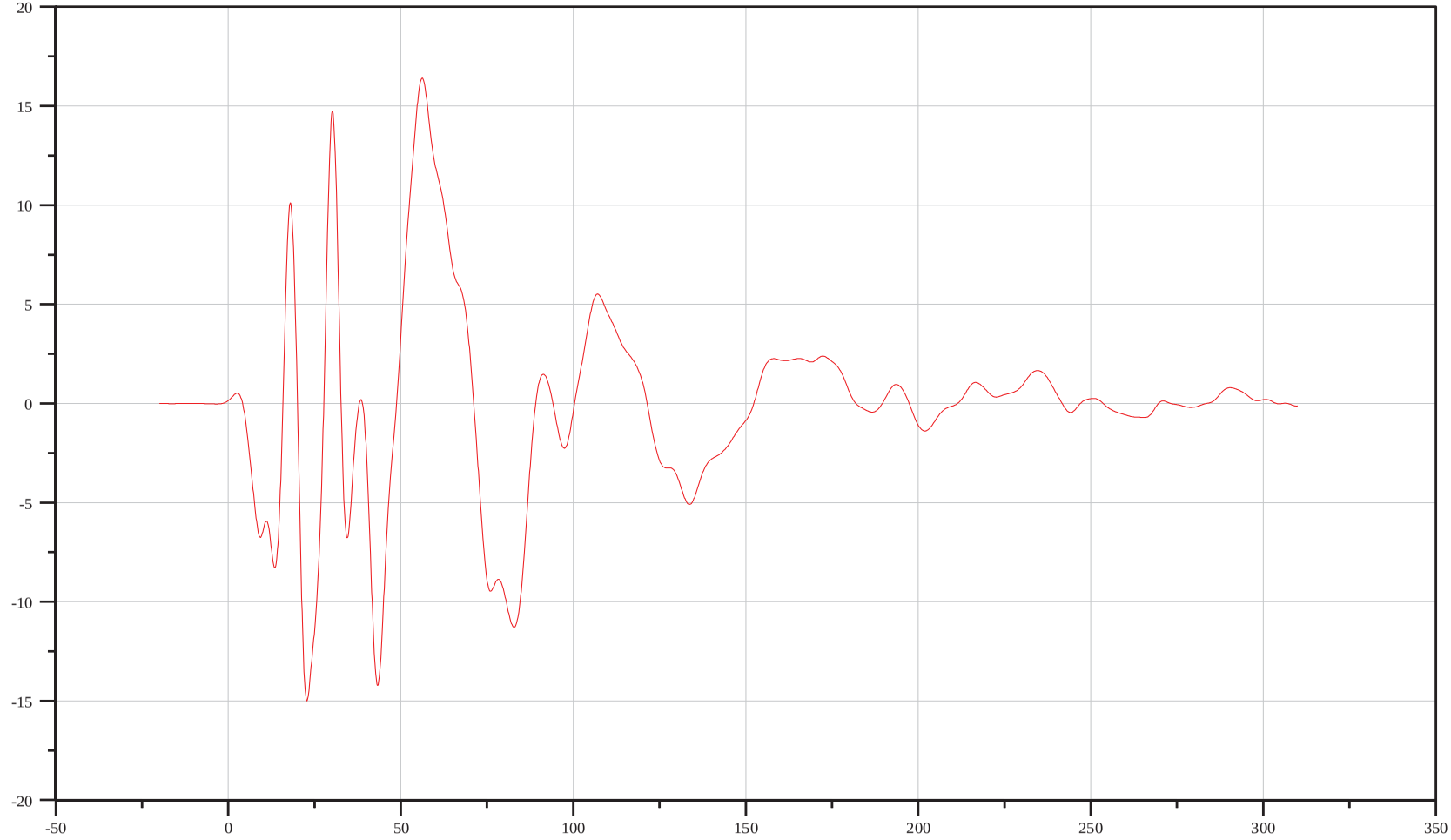
Middle Container, Driver Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTMI0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-15.00 g at 22.80 ms

Max. Value
16.41 g at 56.20 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

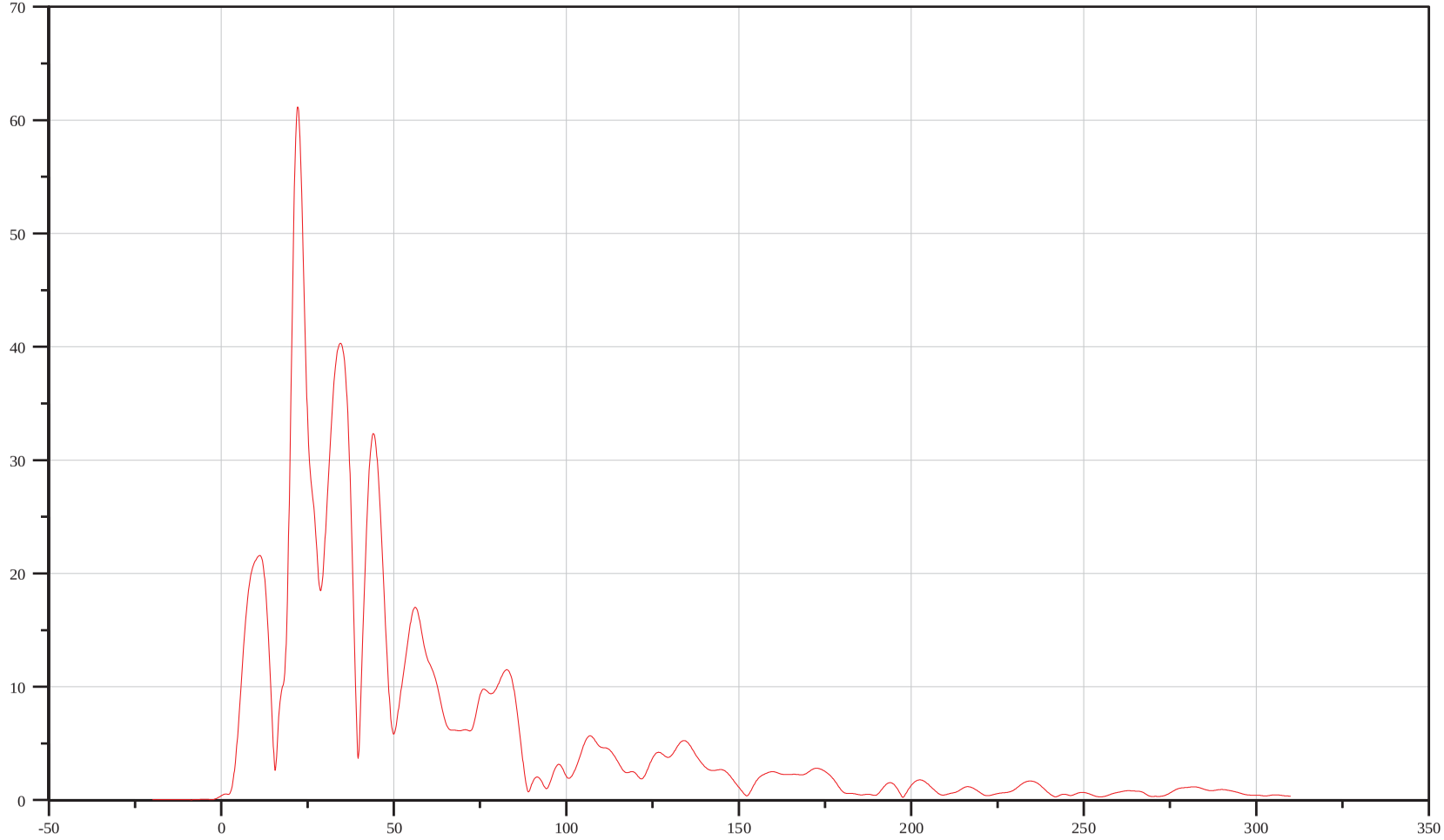
Middle Container, Driver Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTMI0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.03 g at -8.70 ms

Max. Value
61.16 g at 22.20 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

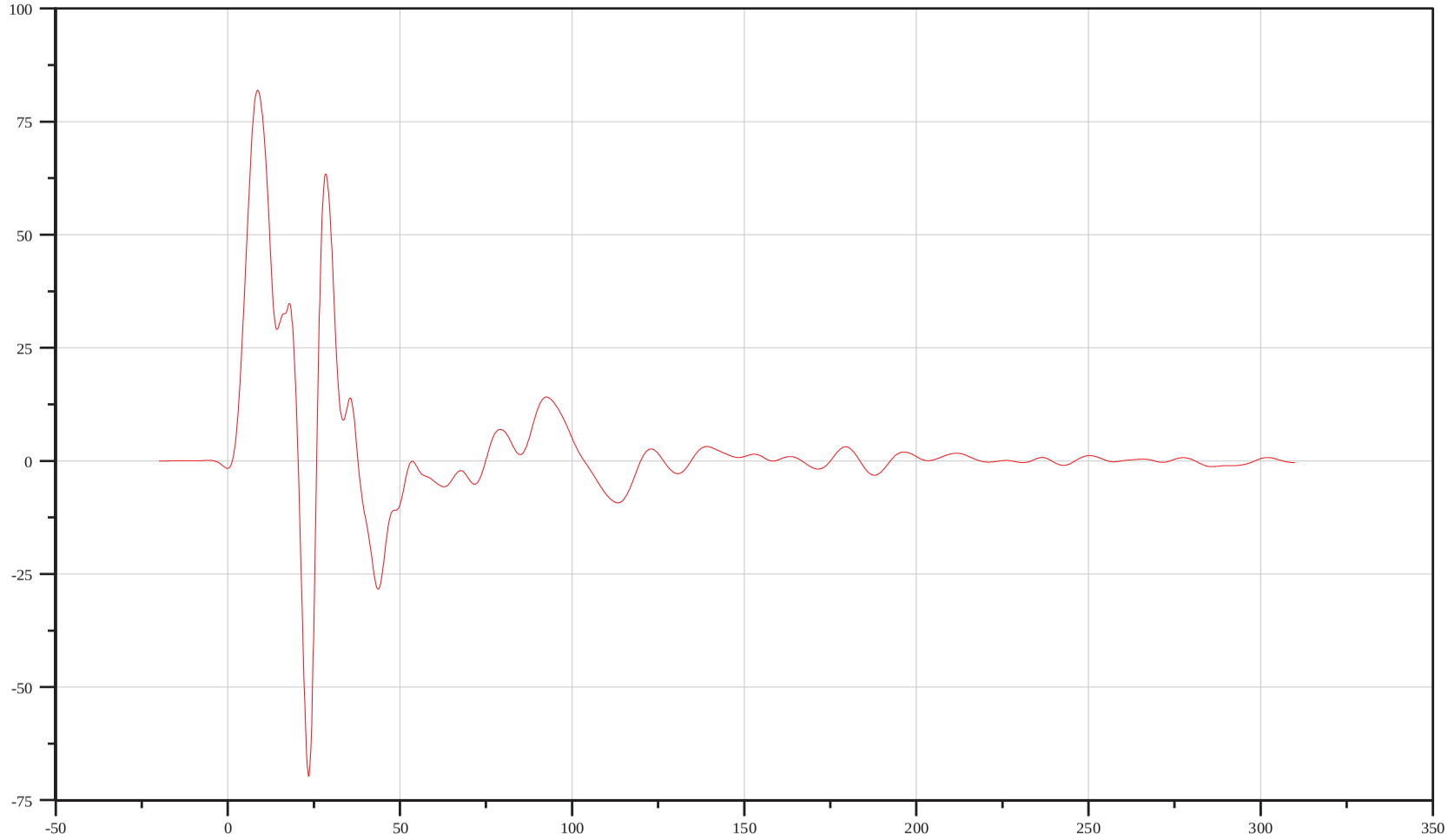
Rear Container, Passenger X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTRE0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-69.76 g at 23.50 ms

Max. Value
81.93 g at 8.70 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

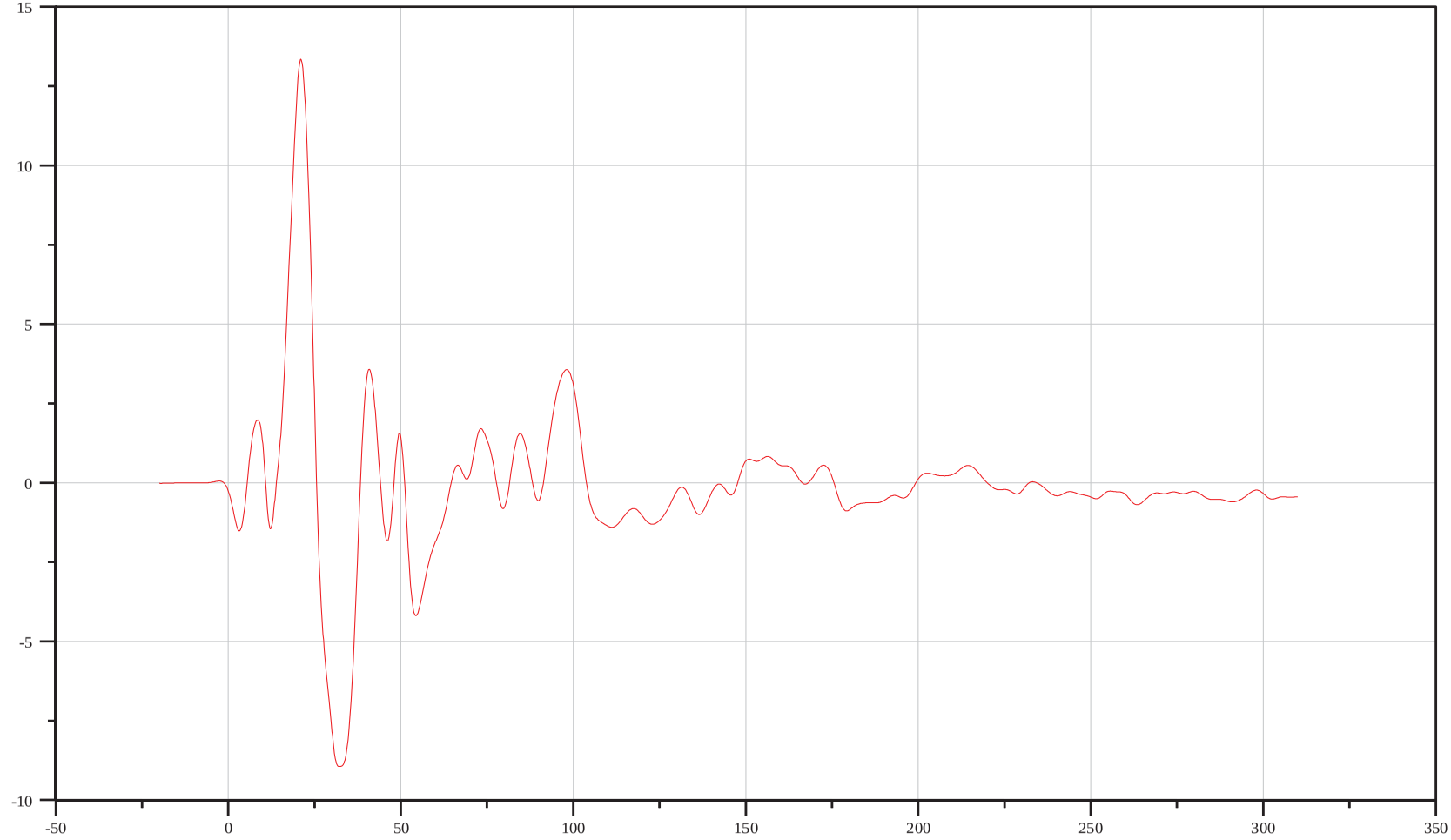
Rear Container, Passenger Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTRE0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value	Max. Value
-8.94 g at 32.20 ms	13.35 g at 21.00 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

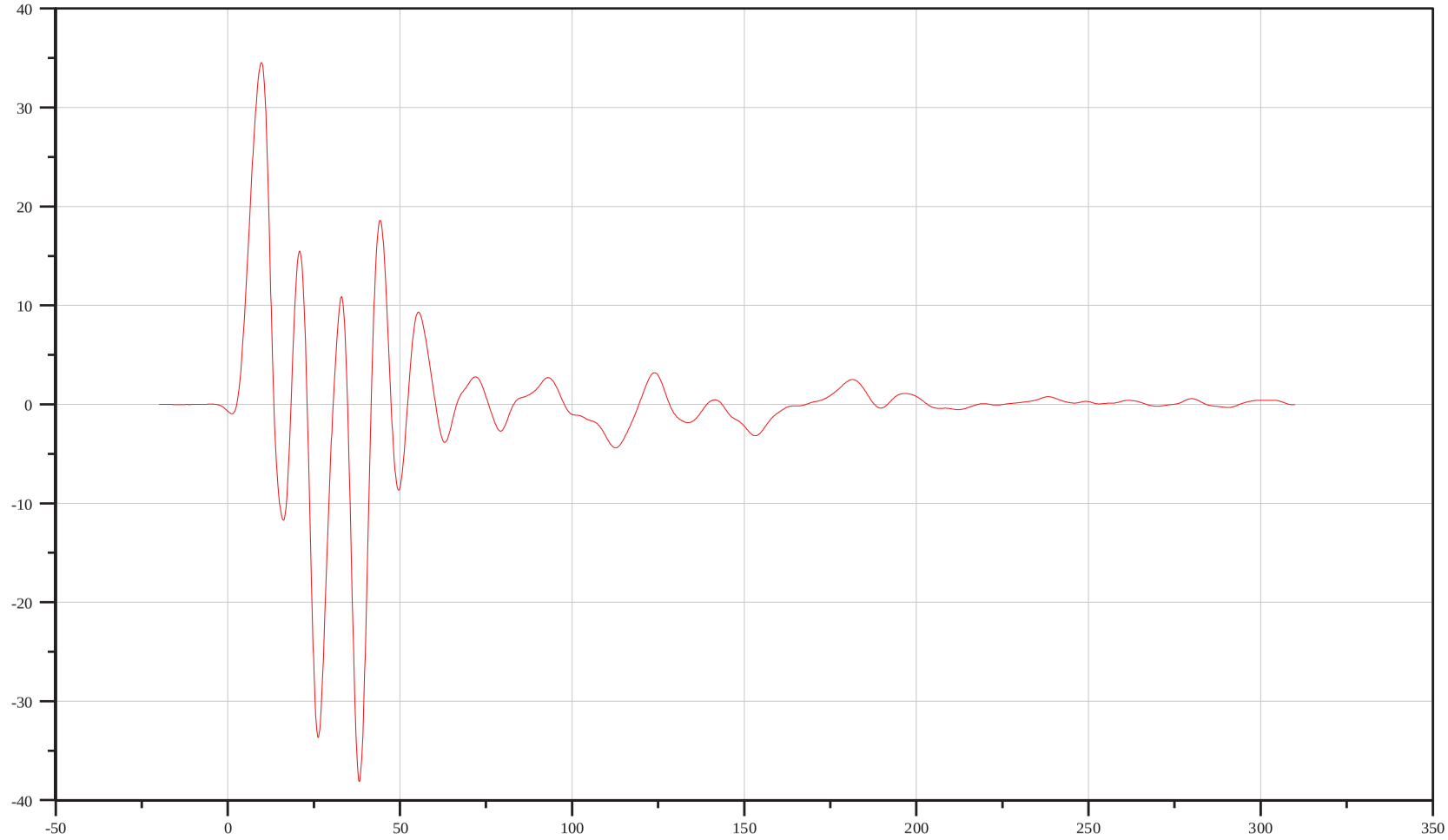
Rear Container, Passenger Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTRE0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-38.12 g at 38.20 ms

Max. Value
34.55 g at 9.80 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

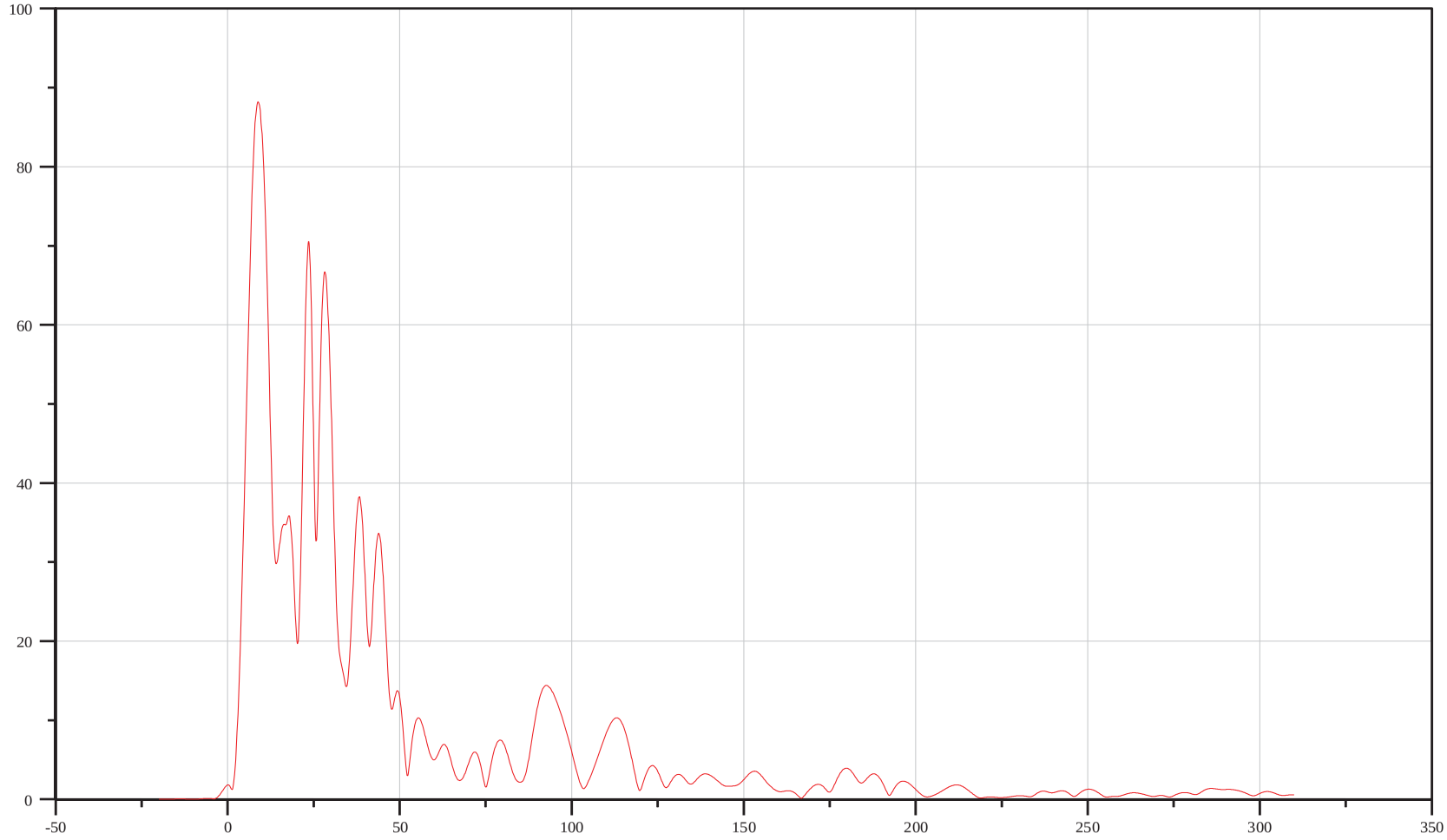
Rear Container, Passenger Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTRE0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.02 g at -17.50 ms

Max. Value
88.22 g at 8.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

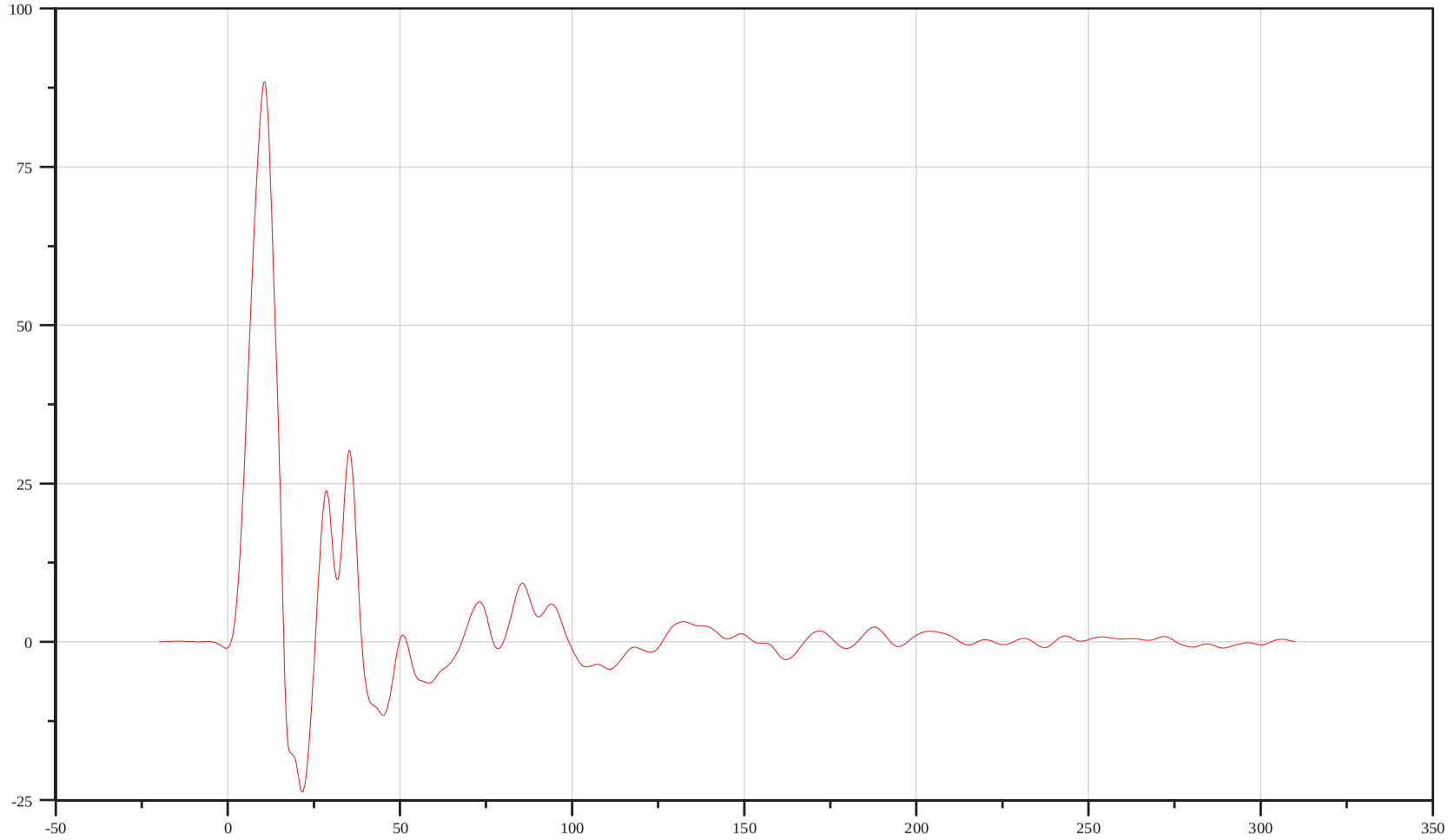
Rear Container, Driver X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTRE0000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-23.76 g at 21.60 ms

Max. Value
88.44 g at 10.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

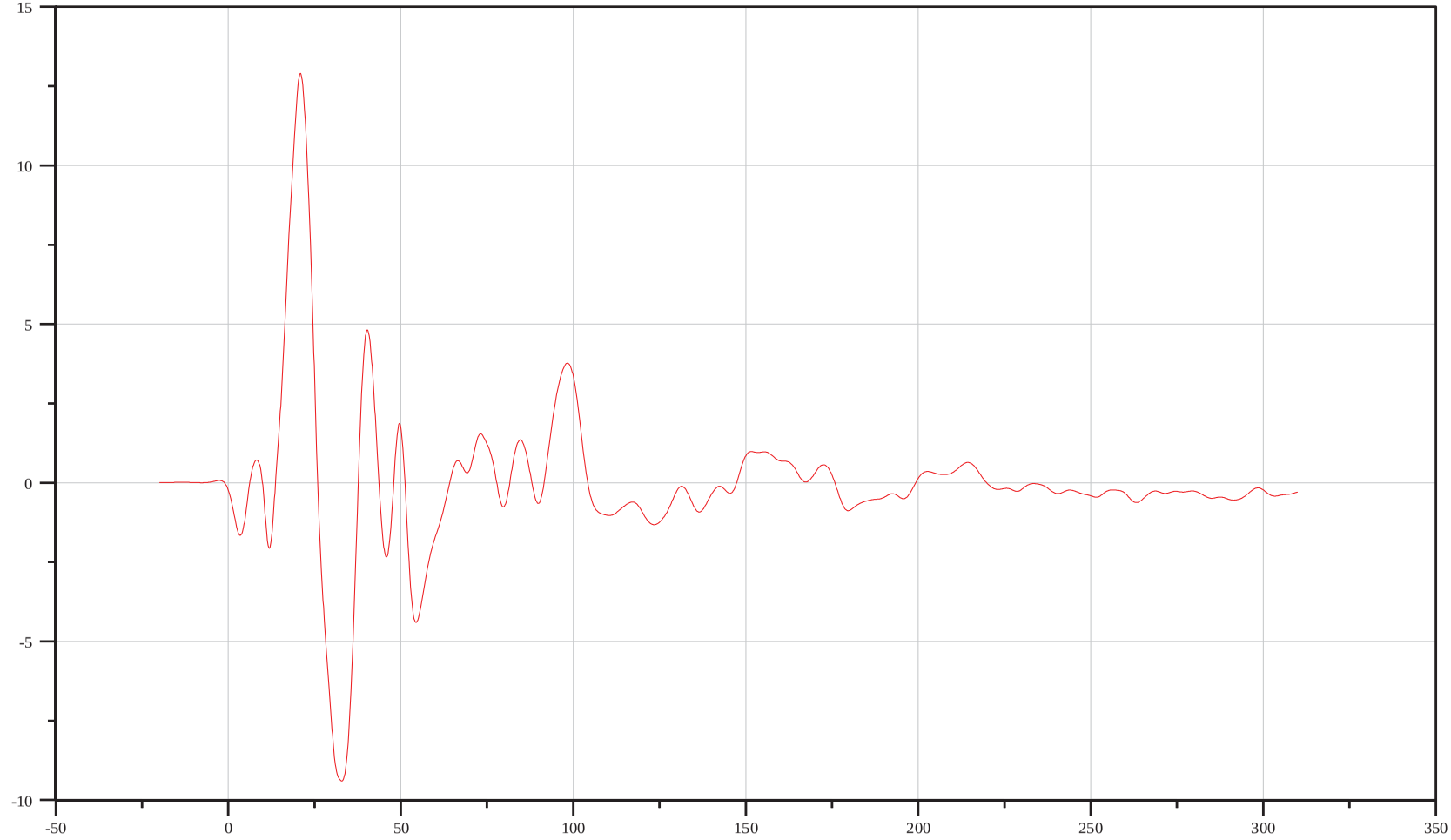
Rear Container, Driver Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTRE0000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-9.40 g at 32.90 ms

Max. Value
12.91 g at 20.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

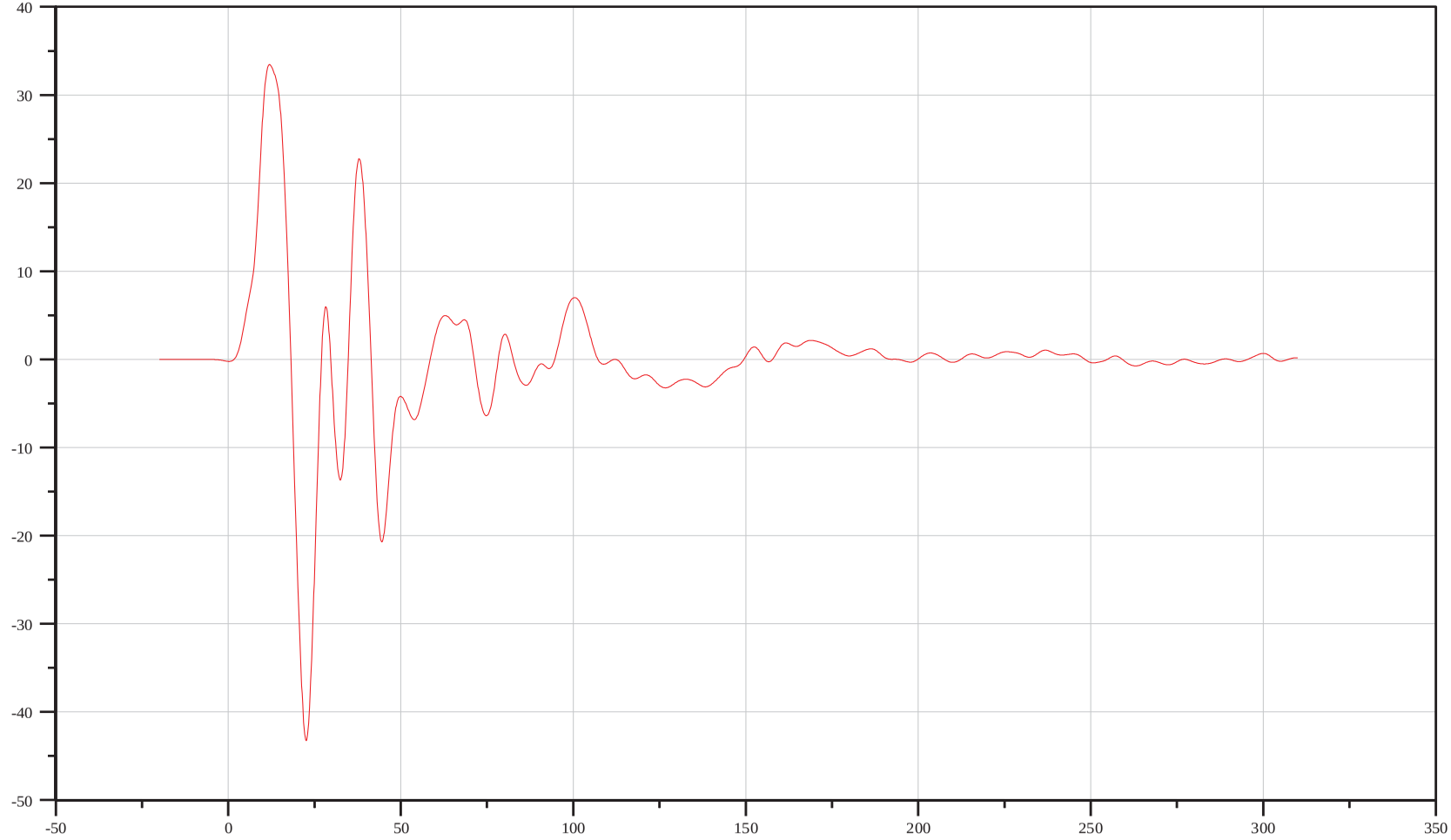
Rear Container, Driver Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTRE0000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-43.26 g at 22.60 ms

Max. Value
33.45 g at 12.00 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

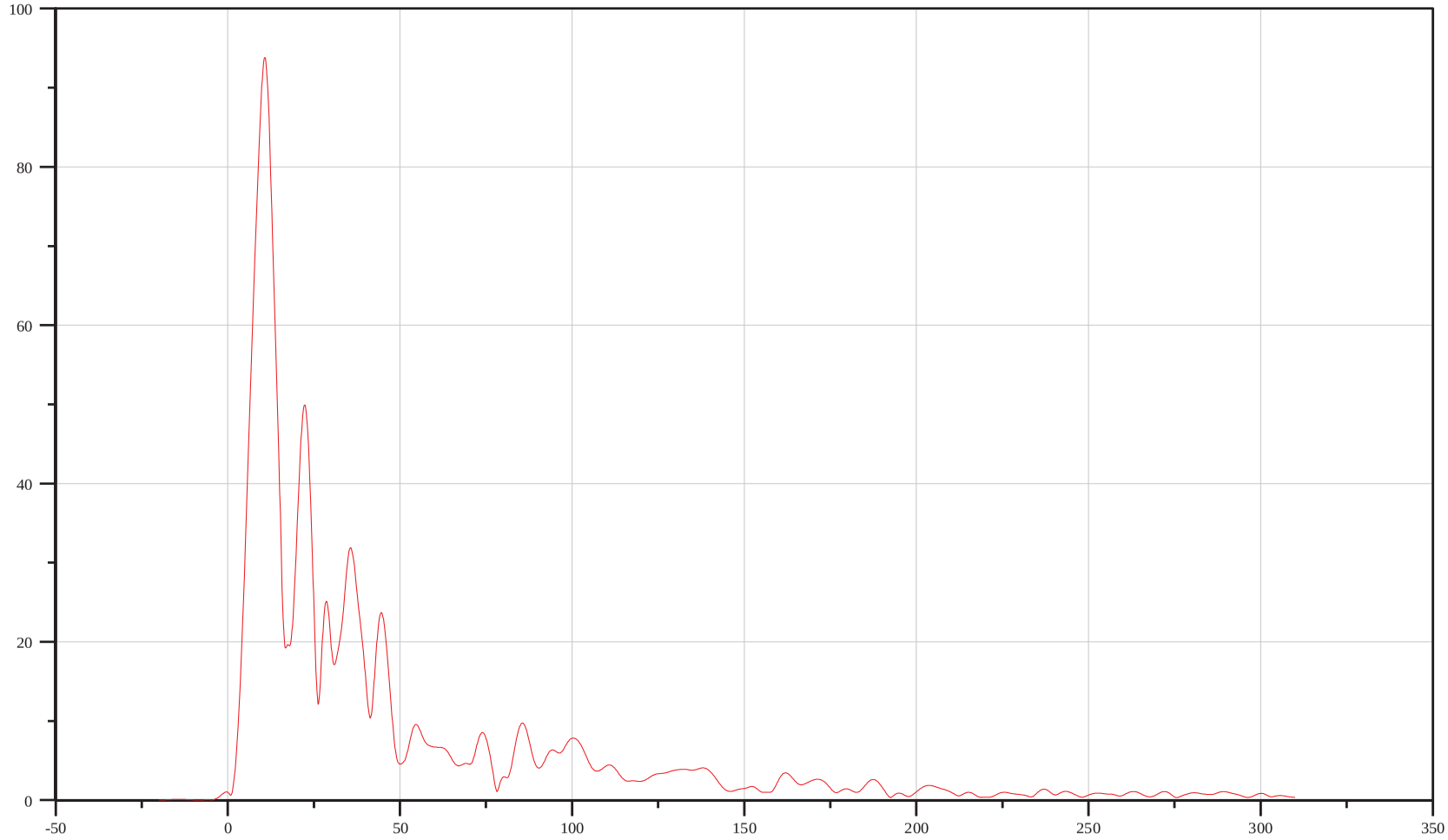
Rear Container, Driver Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTRE0000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.02 g at -8.50 ms

Max. Value
93.81 g at 10.80 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

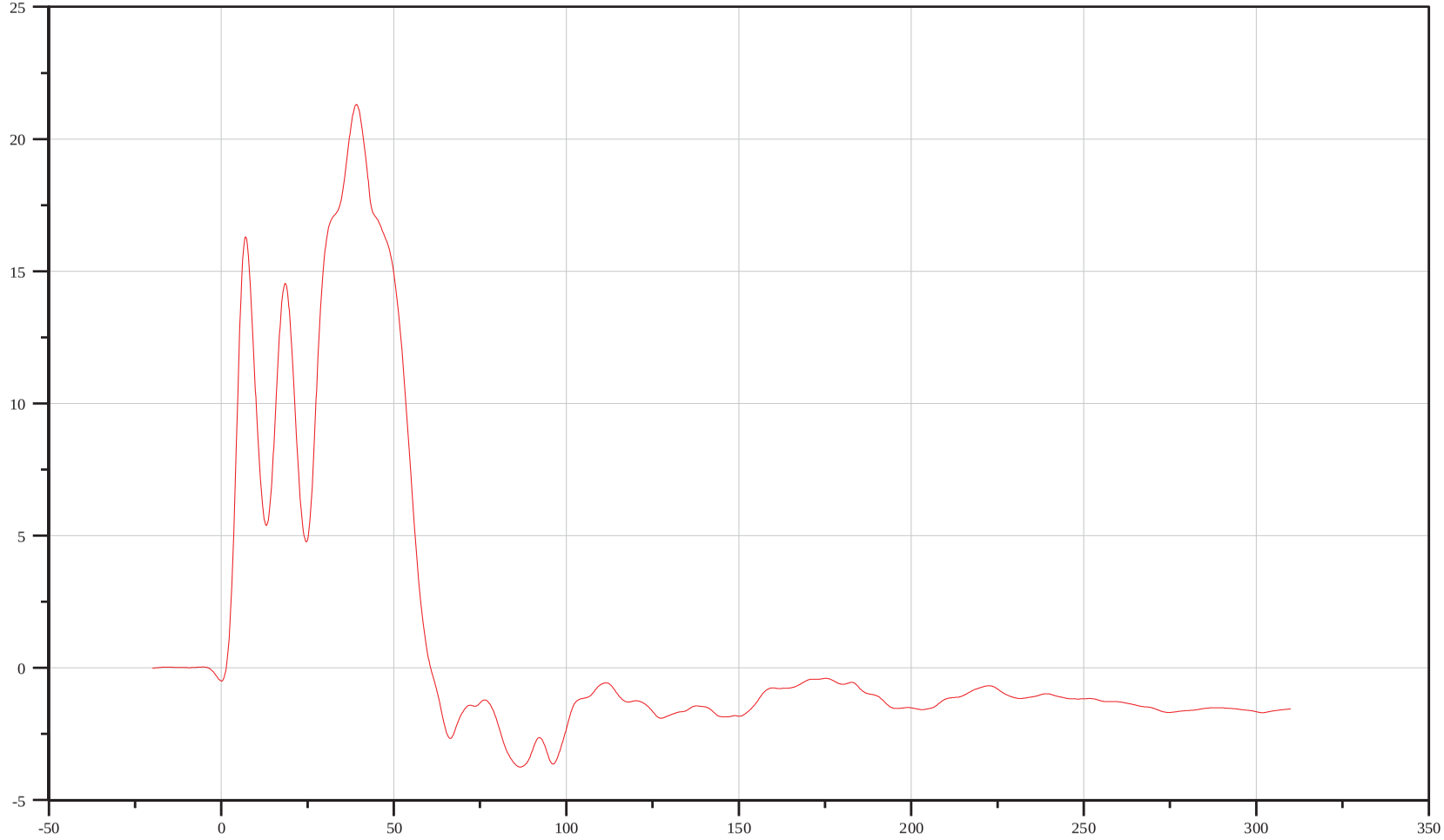
Engine X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10ENGN000000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-3.75 g at 86.60 ms

Max. Value
21.31 g at 39.20 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

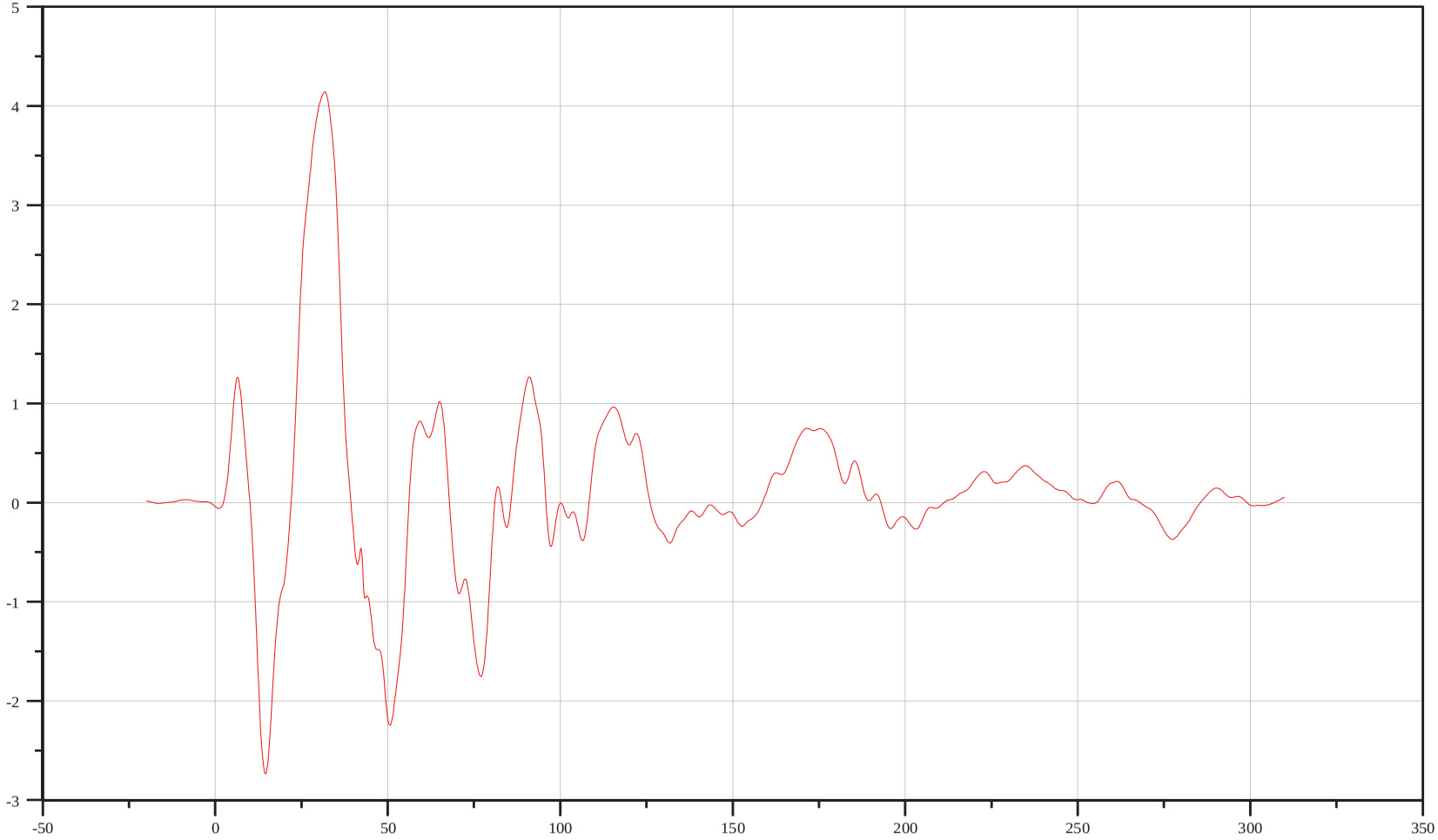
Engine Y-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10ENGN000000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-2.74 g at 14.60 ms

Max. Value
4.14 g at 31.80 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

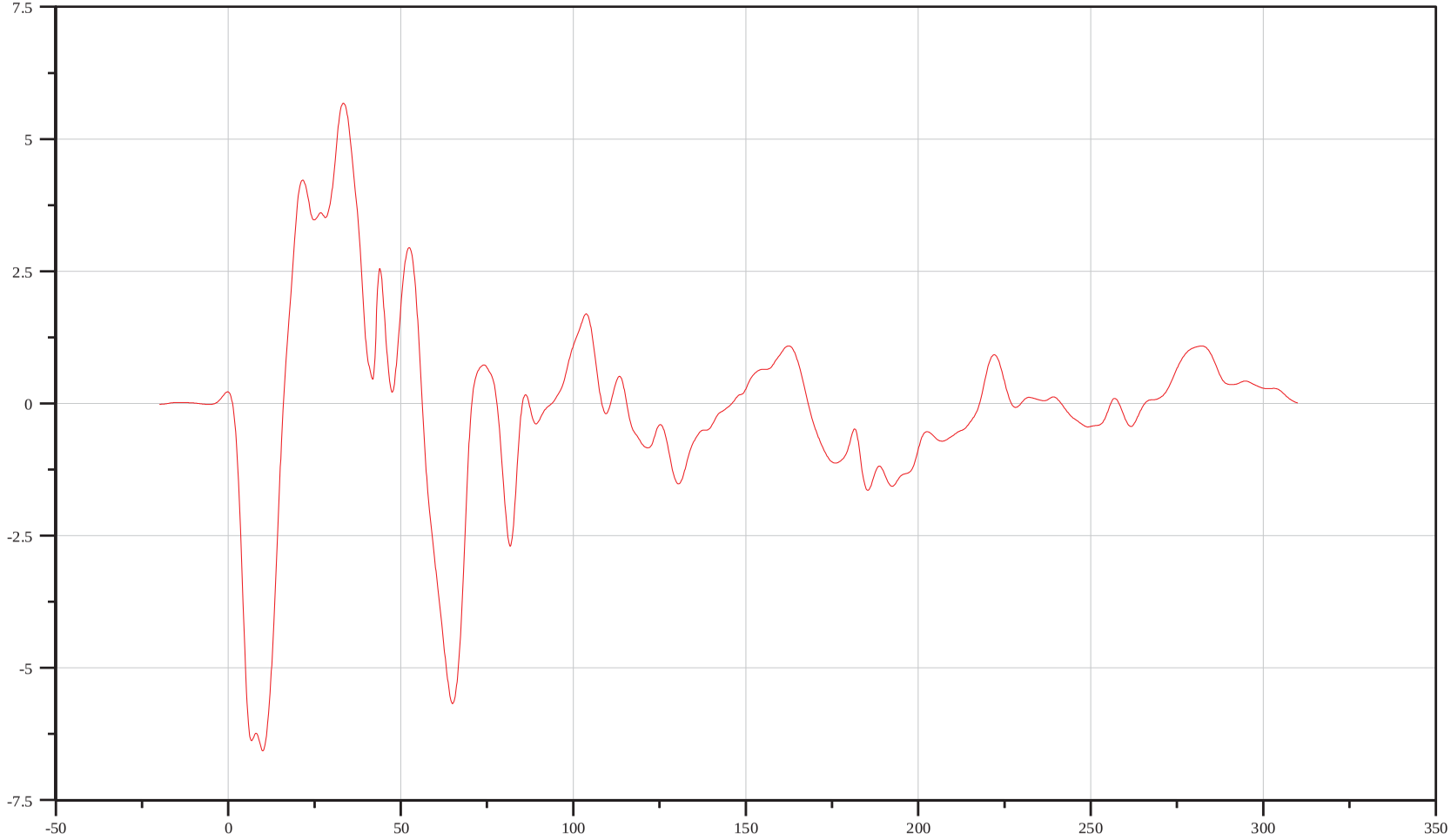
Engine Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10ENGN000000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-6.57 g at 10.00 ms

Max. Value
5.68 g at 33.40 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

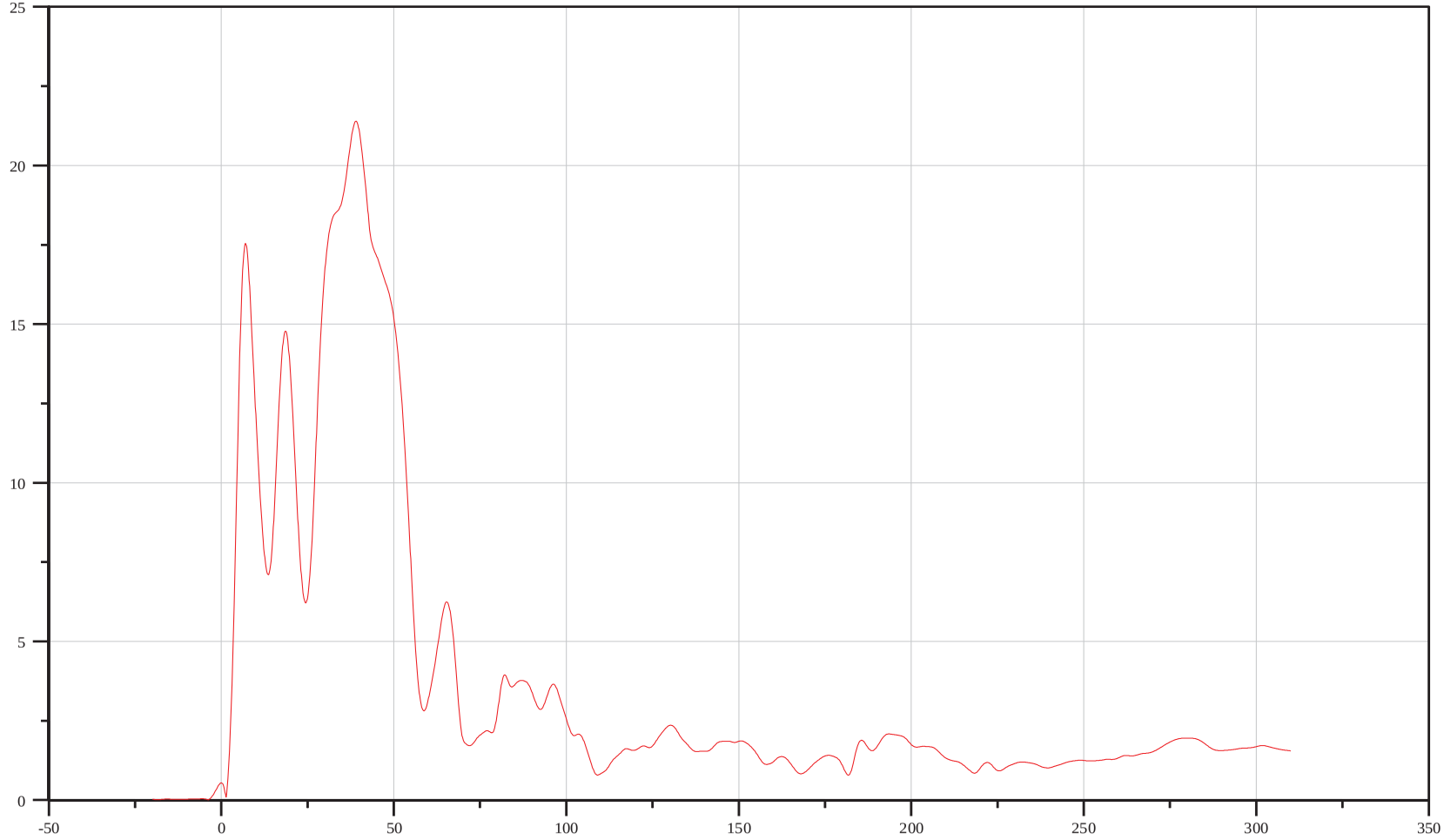
Engine Resultant Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

10ENGN000000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.01 g at -3.80 ms

Max. Value
21.39 g at 39.00 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

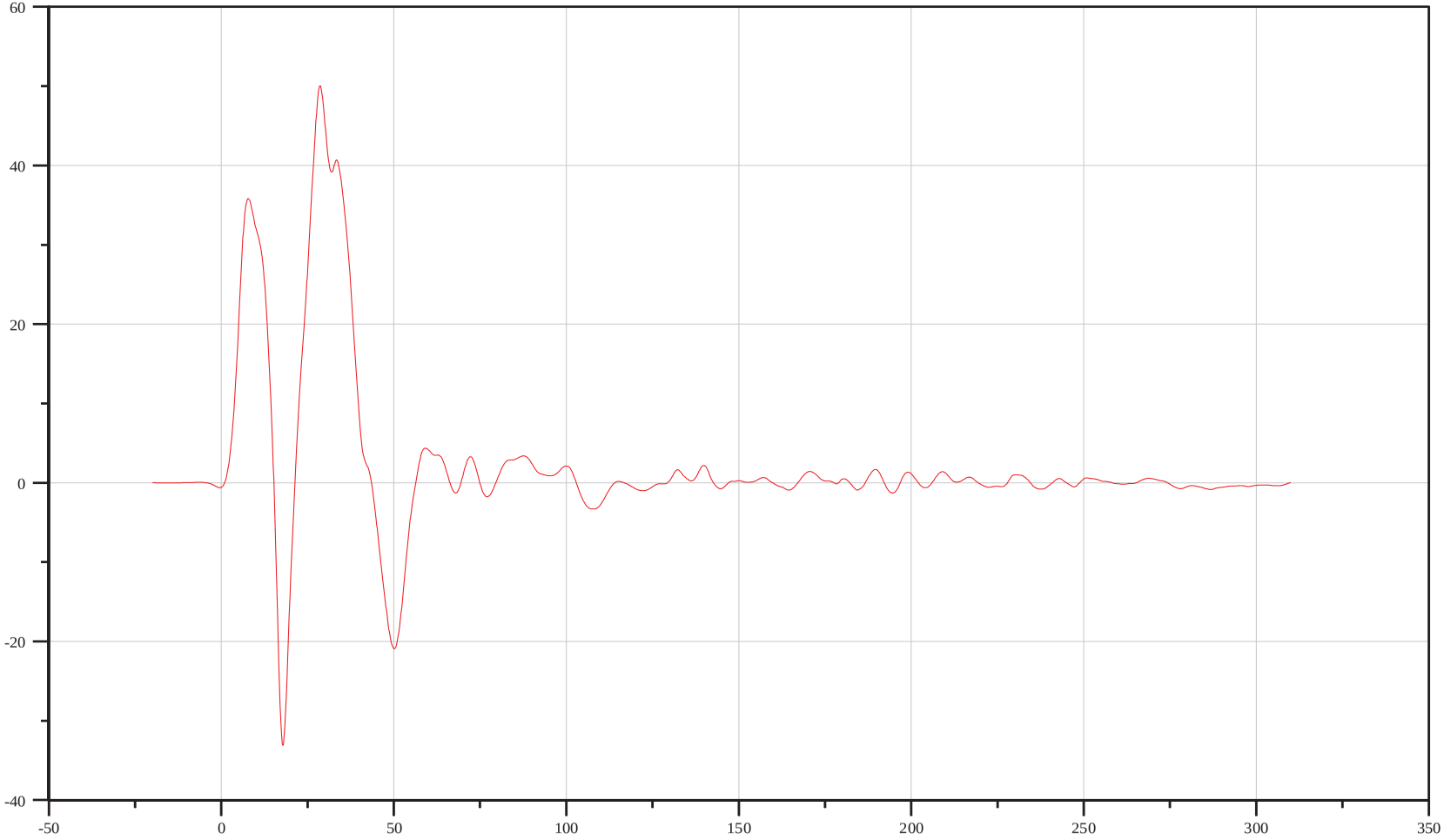
Date: 04/12/2012
Time: 08:12

Battery, Driver X-Axis Acceleration

Customer: Battelle

11BATT000000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-33.09 g at 17.90 ms

Max. Value
50.06 g at 28.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

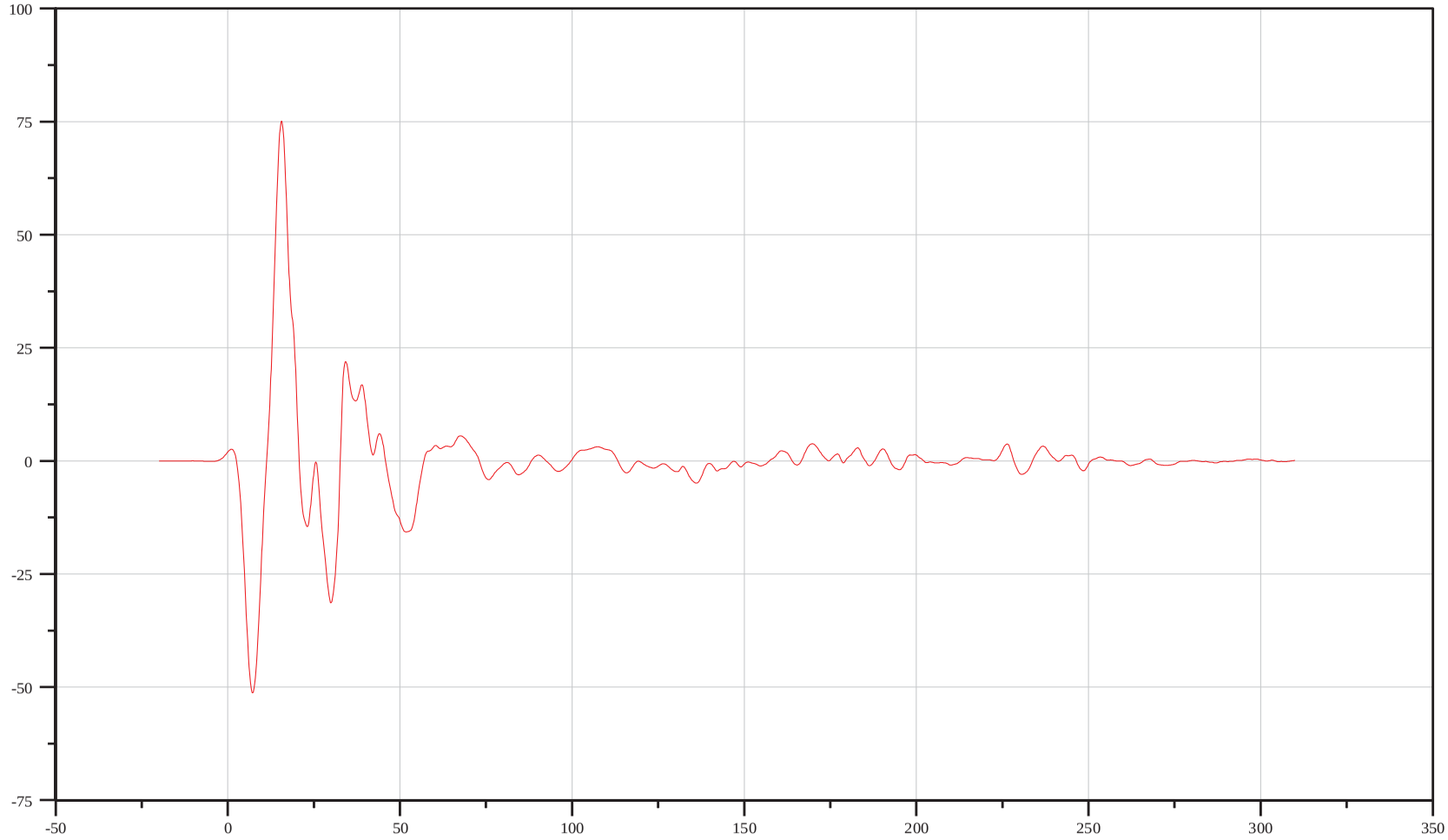
Date: 04/12/2012
Time: 08:12

Battery, Driver Y-Axis Acceleration

Customer: Battelle

11BATT000000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-51.27 g at 7.20 ms

Max. Value
75.11 g at 15.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

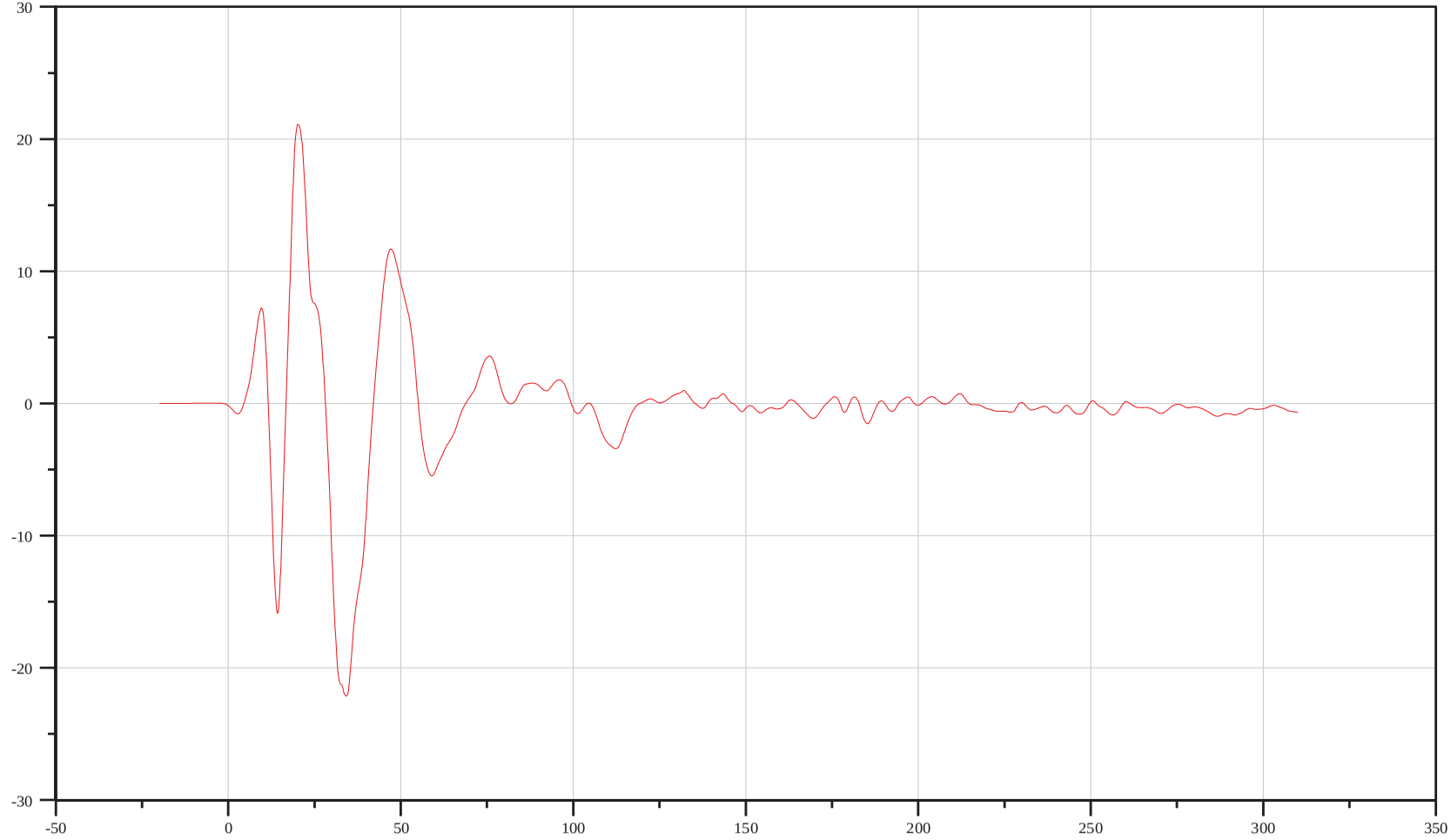
Battery, Driver Z-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11BATT000000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-22.14 g at 34.20 ms

Max. Value
21.11 g at 20.20 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

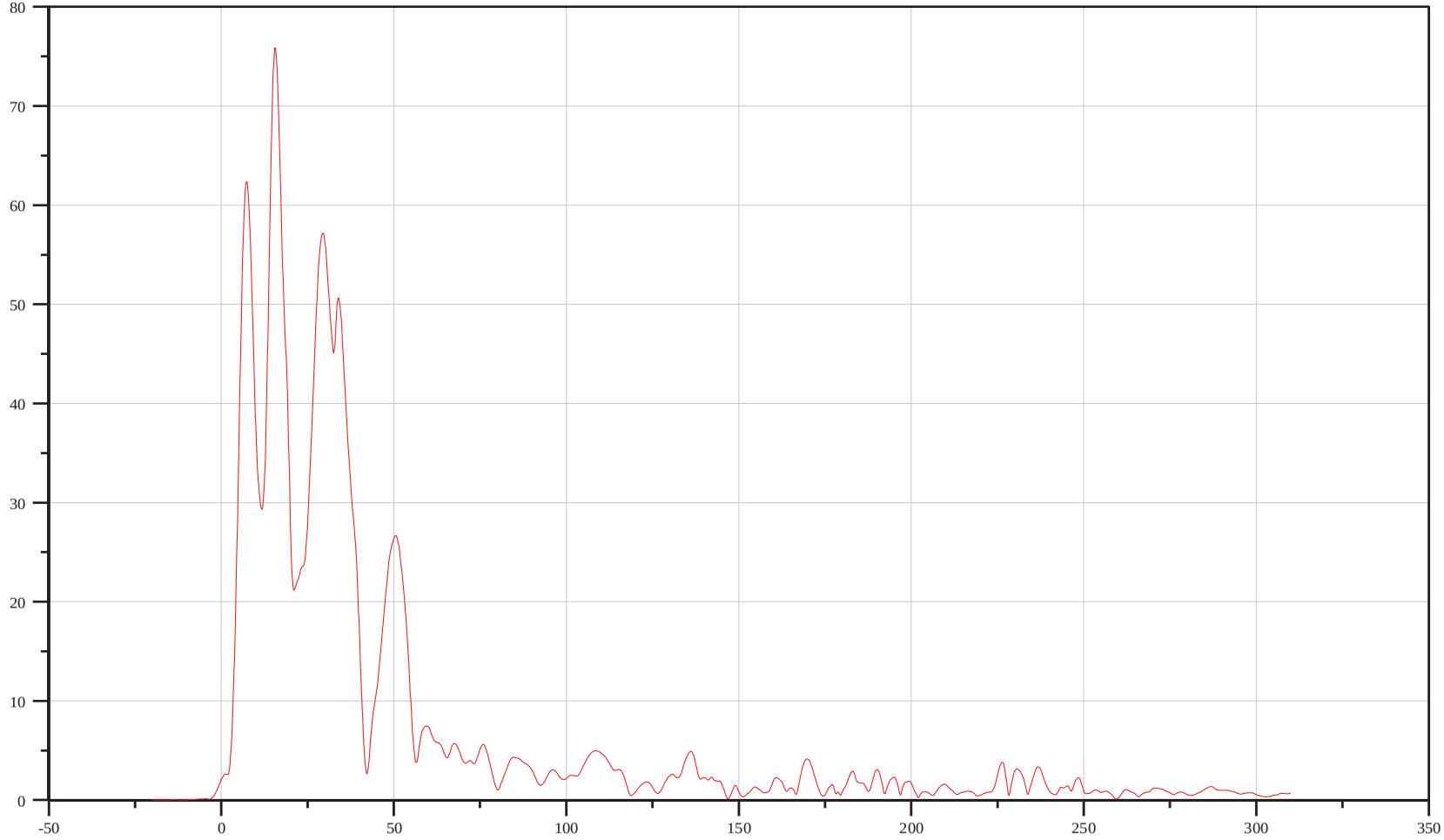
Date: 04/12/2012
Time: 08:12

Battery, Driver Resultant Acceleration

Customer: Battelle

11BATT000000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.01 g at -11.30 ms

Max. Value
75.89 g at 15.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

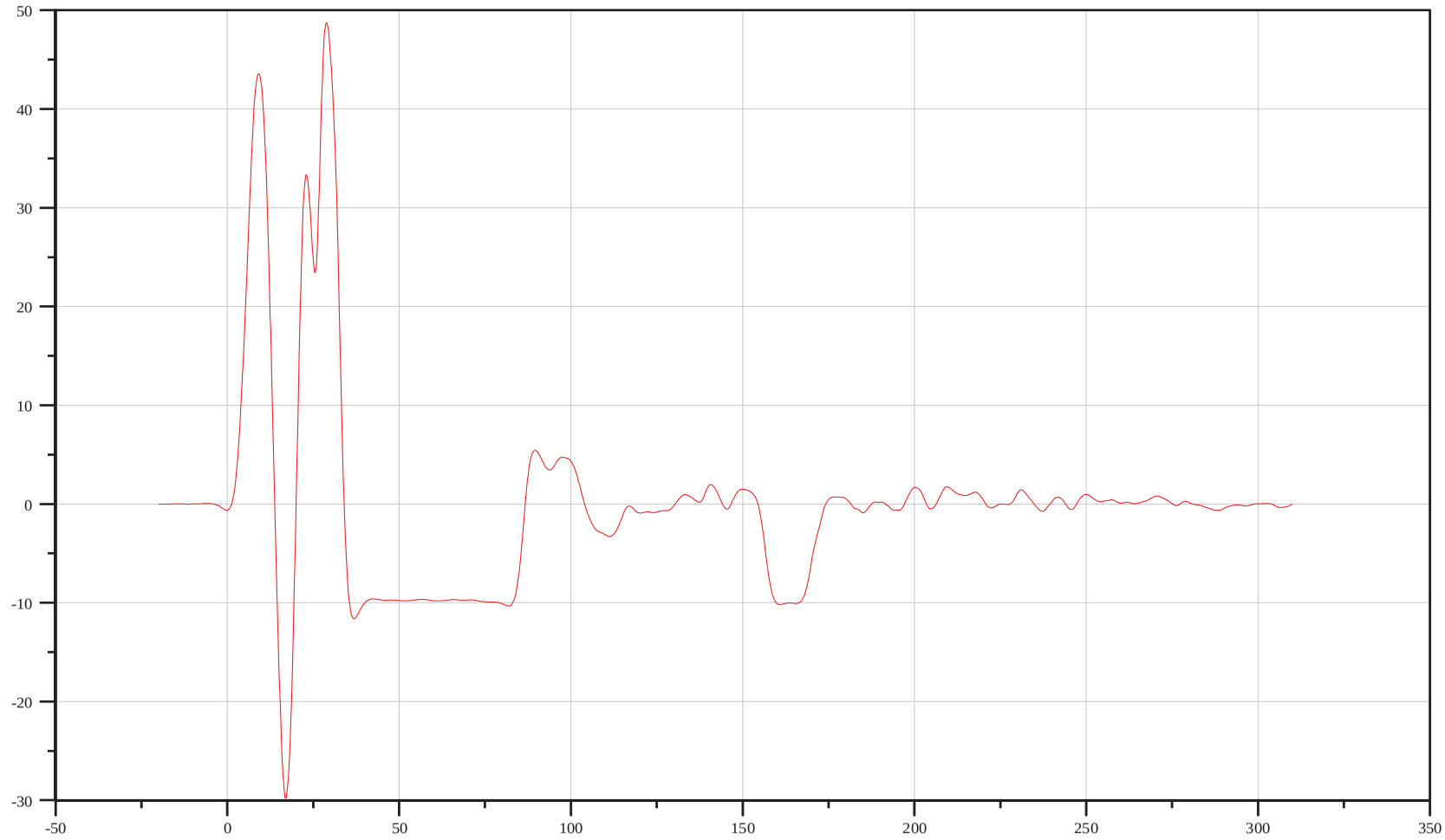
Date: 04/12/2012
Time: 08:12

Battery, Passenger X-Axis Acceleration

Customer: Battelle

13BATT000000ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-29.81 g at 17.00 ms

Max. Value
48.74 g at 28.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

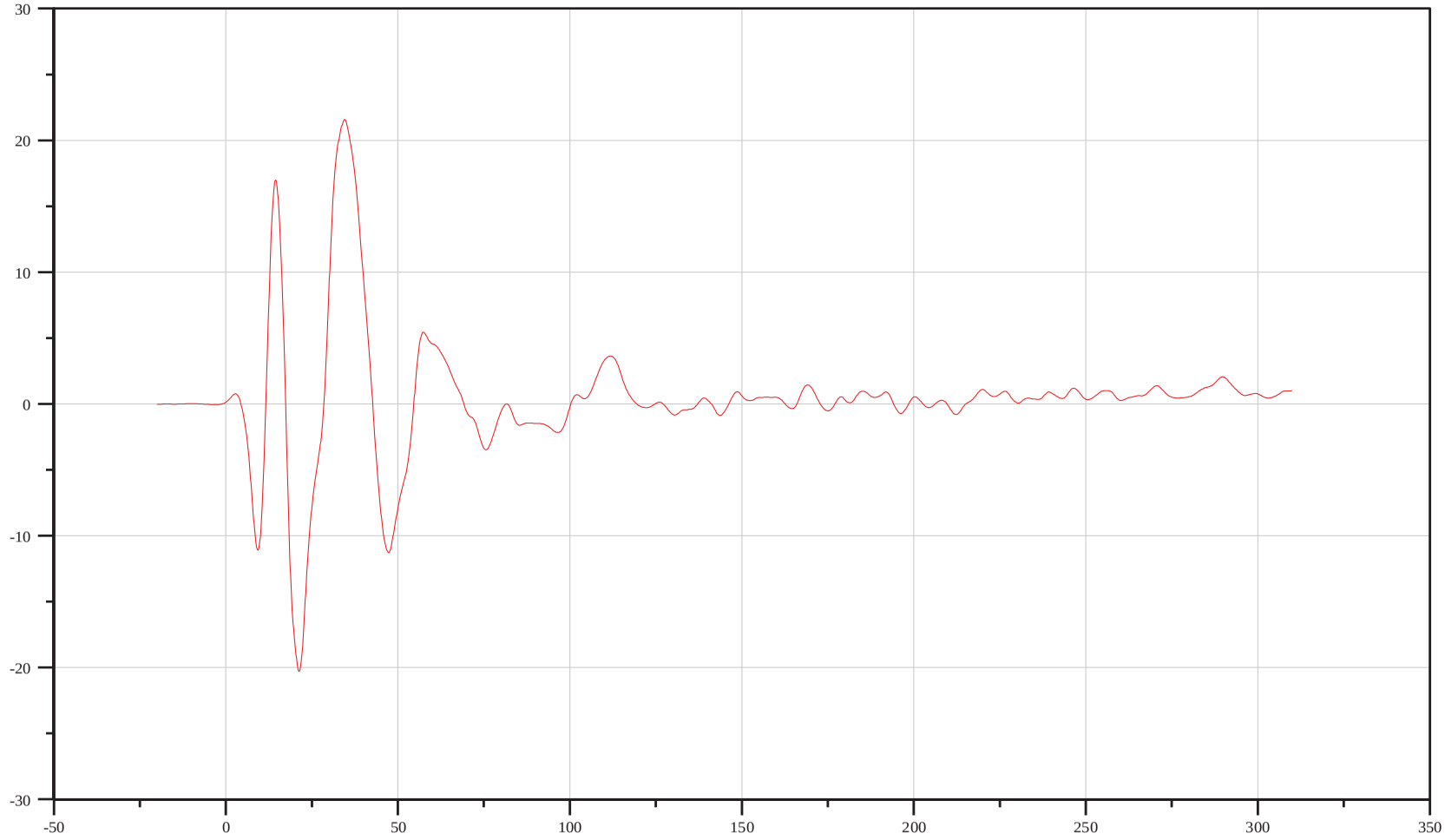
Date: 04/12/2012
Time: 08:12

Battery, Passenger Y-Axis Acceleration

Customer: Battelle

13BATT000000ACYD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-20.29 g at 21.30 ms

Max. Value
21.58 g at 34.50 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

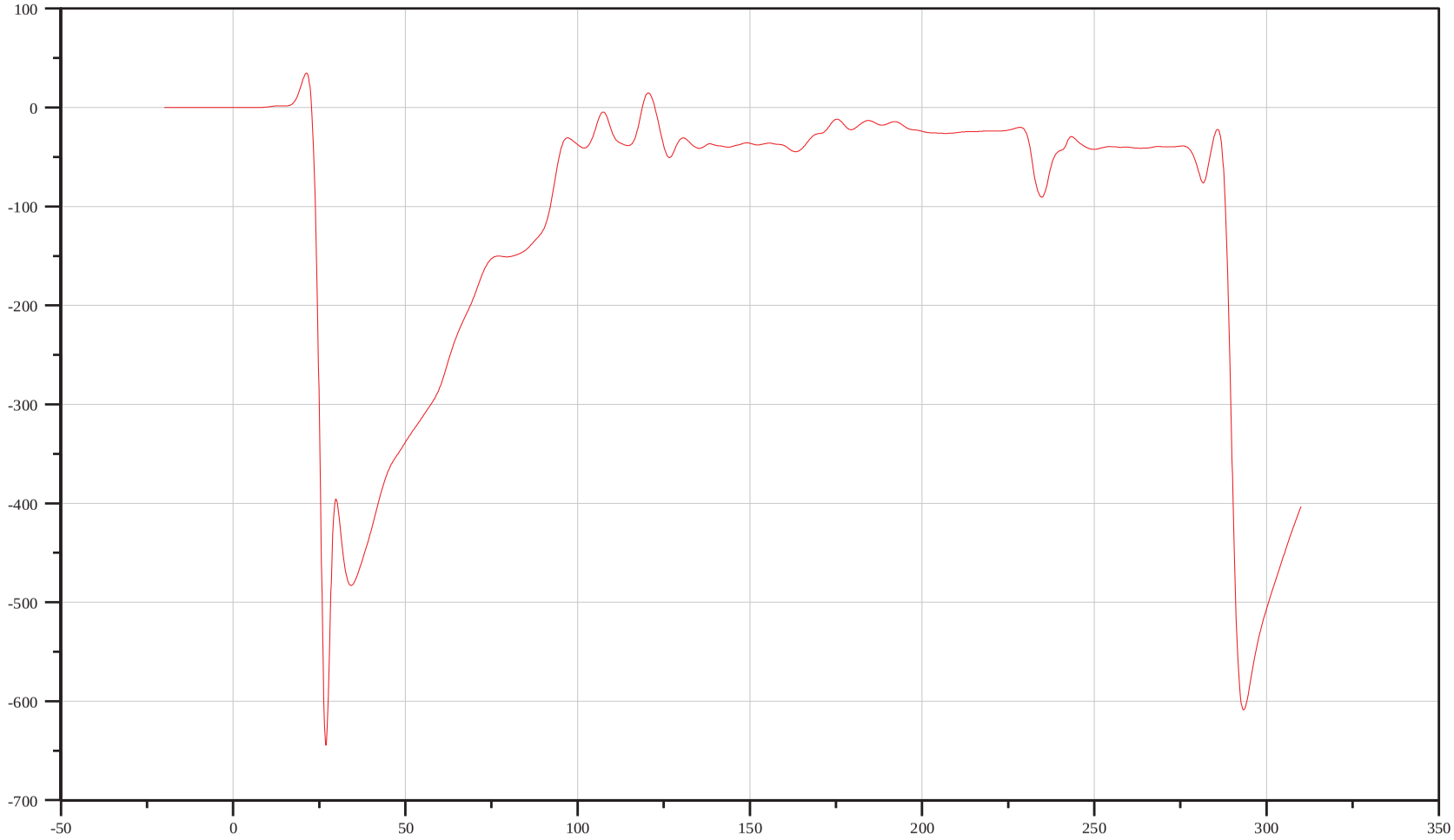
Date: 04/12/2012
Time: 08:12

Battery, Passenger Z-Axis Acceleration

Customer: Battelle

13BATT000000ACZD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-644.35 g at 26.90 ms

Max. Value
34.80 g at 21.30 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

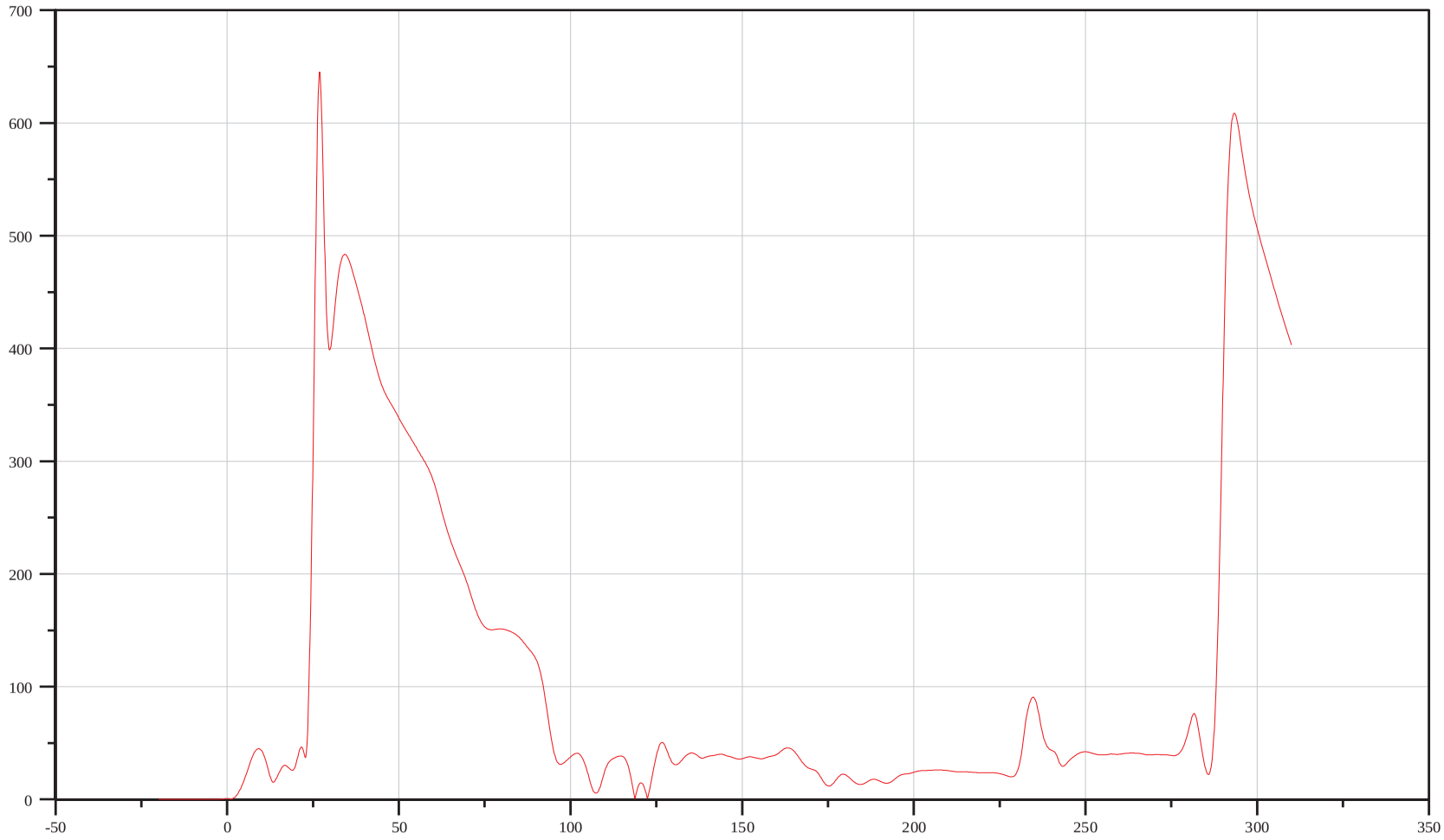
Date: 04/12/2012
Time: 08:12

Battery, Passenger Resultant Acceleration

Customer: Battelle

13BATT000000ACRD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
0.02 g at -16.40 ms

Max. Value
645.26 g at 26.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

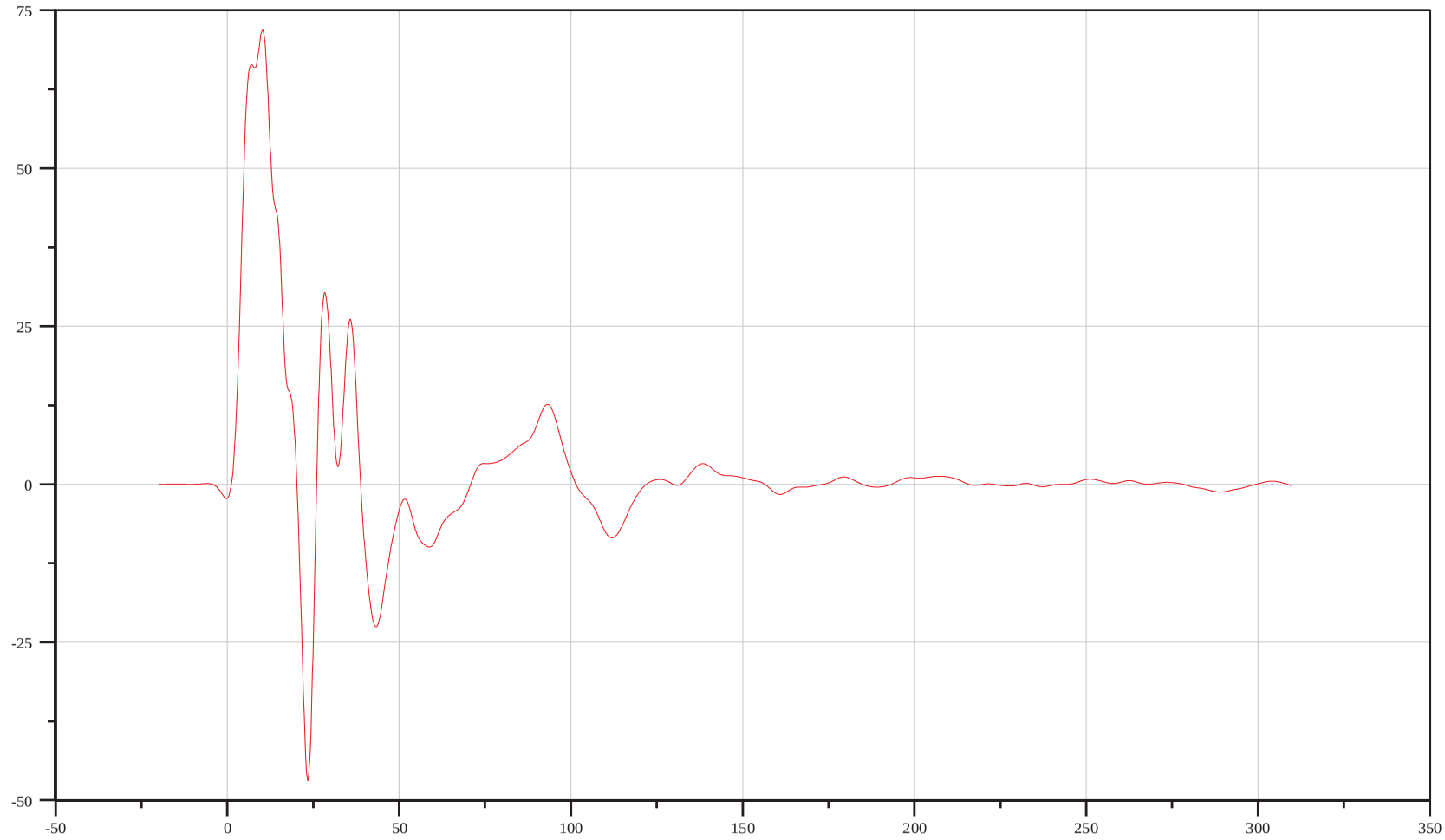
Front Container, Pitch X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTFRPI00ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-46.88 g at 23.40 ms

Max. Value
71.88 g at 10.30 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

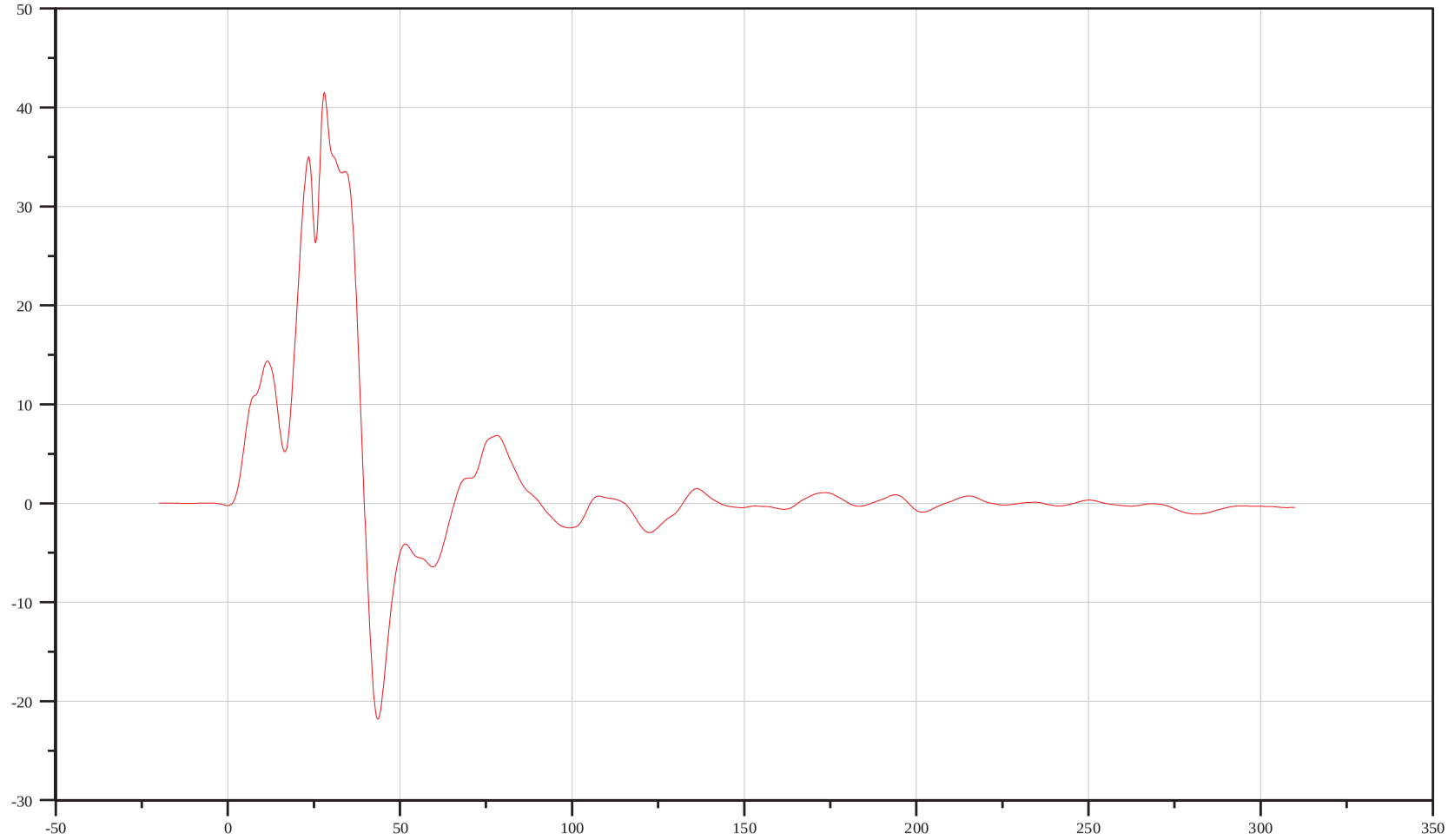
Middle Container, Pitch X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTMIPE00ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-21.82 g at 43.60 ms

Max. Value
41.51 g at 28.00 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

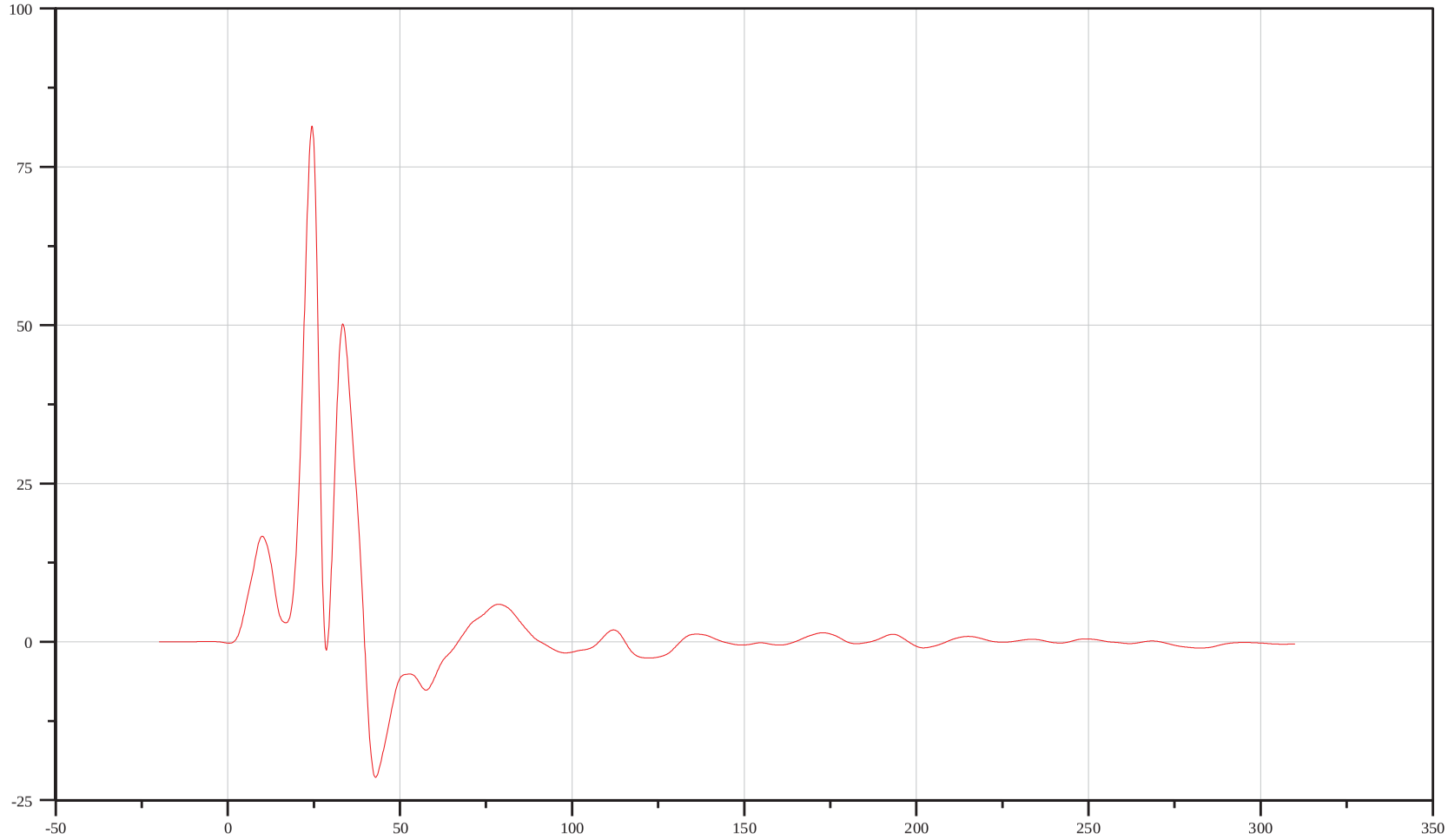
Rear Container, Pitch X-Axis Acceleration

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTREPI00ACXD

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_60

Min. Value
-21.39 g at 42.90 ms

Max. Value
81.45 g at 24.50 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

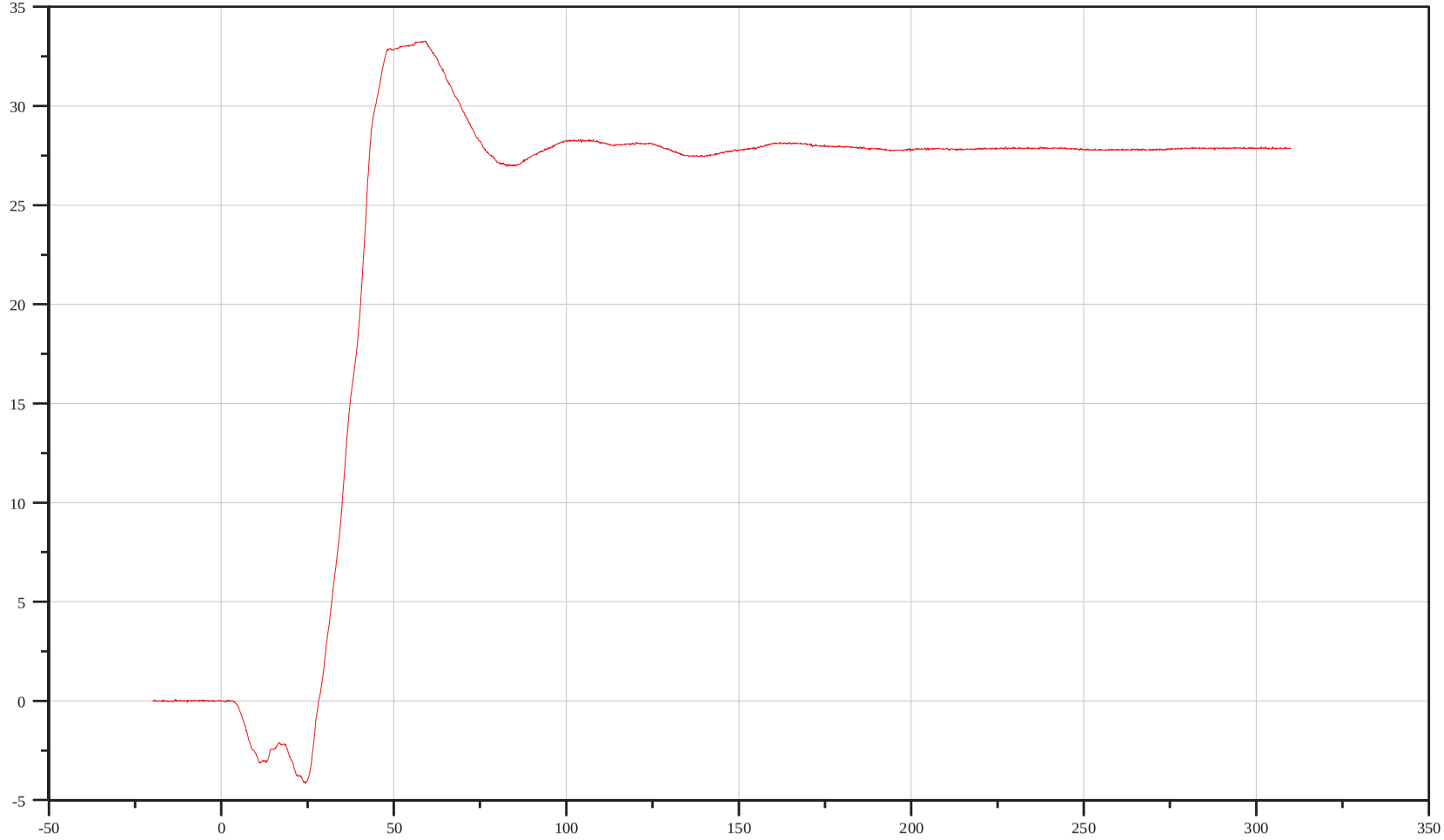
Front Container, Driver X-Axis Displacement

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTFR0000DSXA

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_1000

Min. Value
-4.16 mm at 24.30 ms

Max. Value
33.28 mm at 58.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

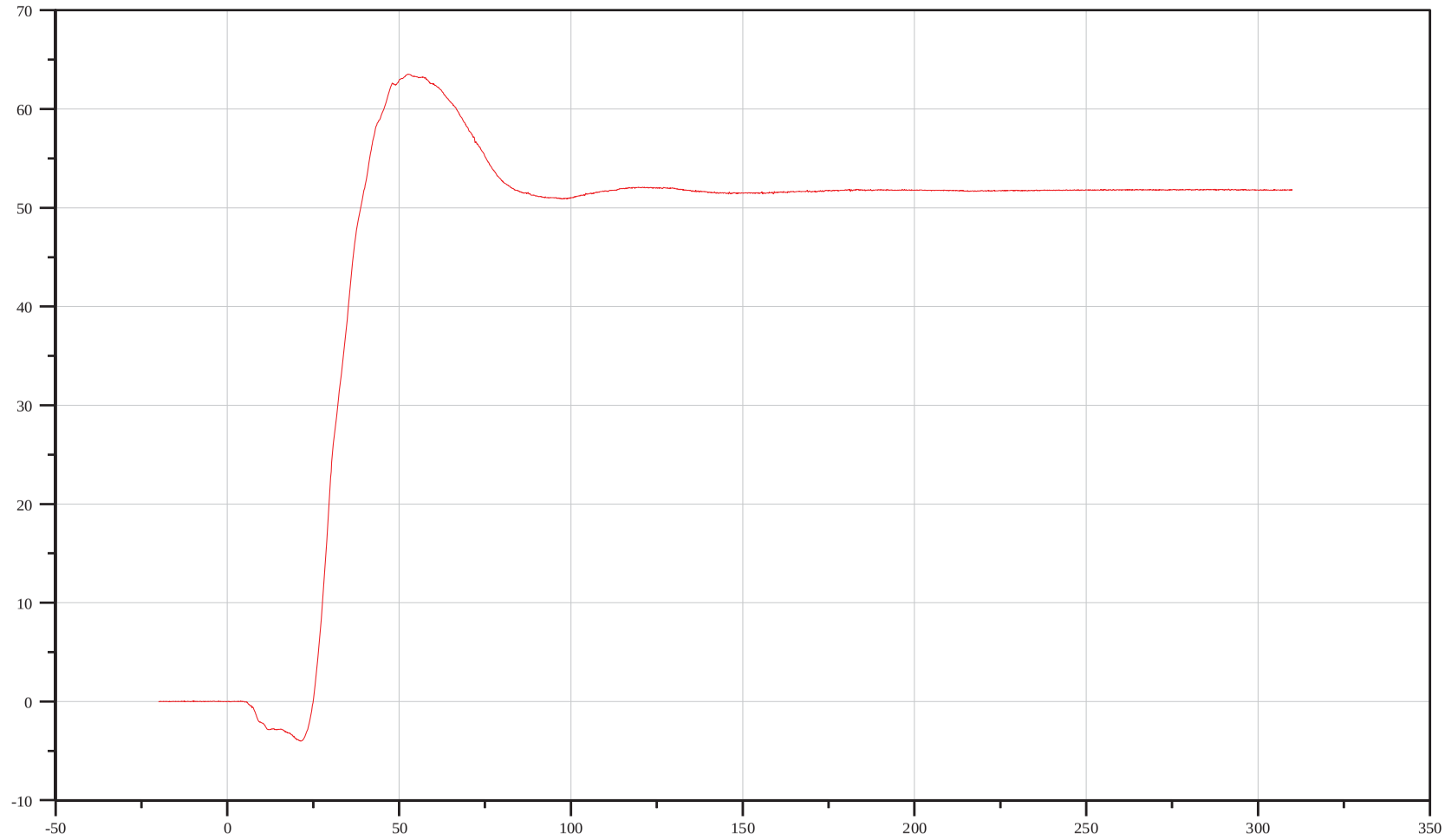
Front Container, Passenger X-Axis Displacement

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTFR0000DSXA

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_1000

Min. Value
-4.02 mm at 21.20 ms

Max. Value
63.55 mm at 52.60 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

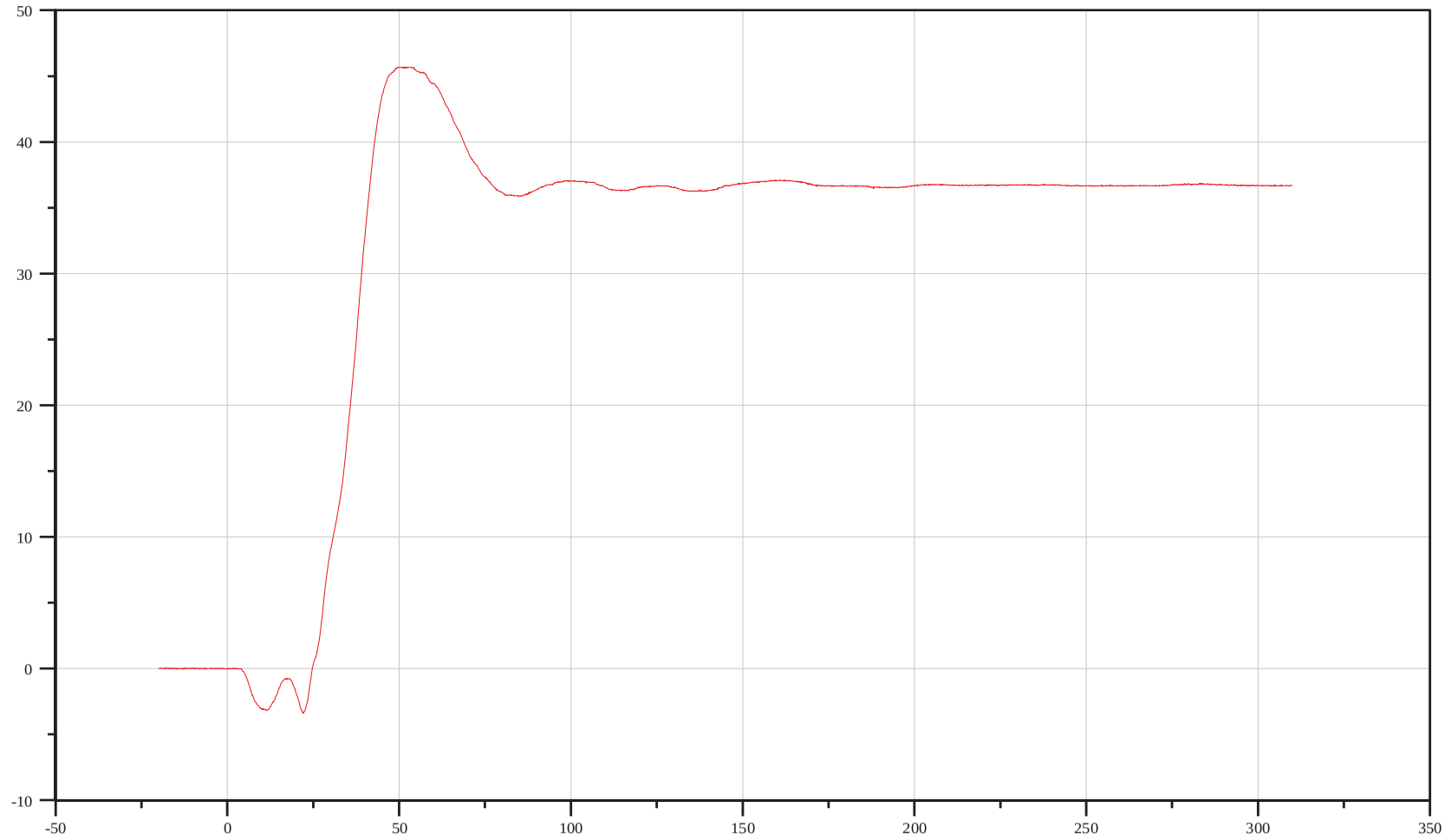
Middle Container, Driver X-Axis Displacement

Date: 04/12/2012
Time: 08:12

Customer: Battelle

11CONTMI0000DSXA

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_1000

Min. Value
-3.39 mm at 22.20 ms

Max. Value
45.69 mm at 49.70 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

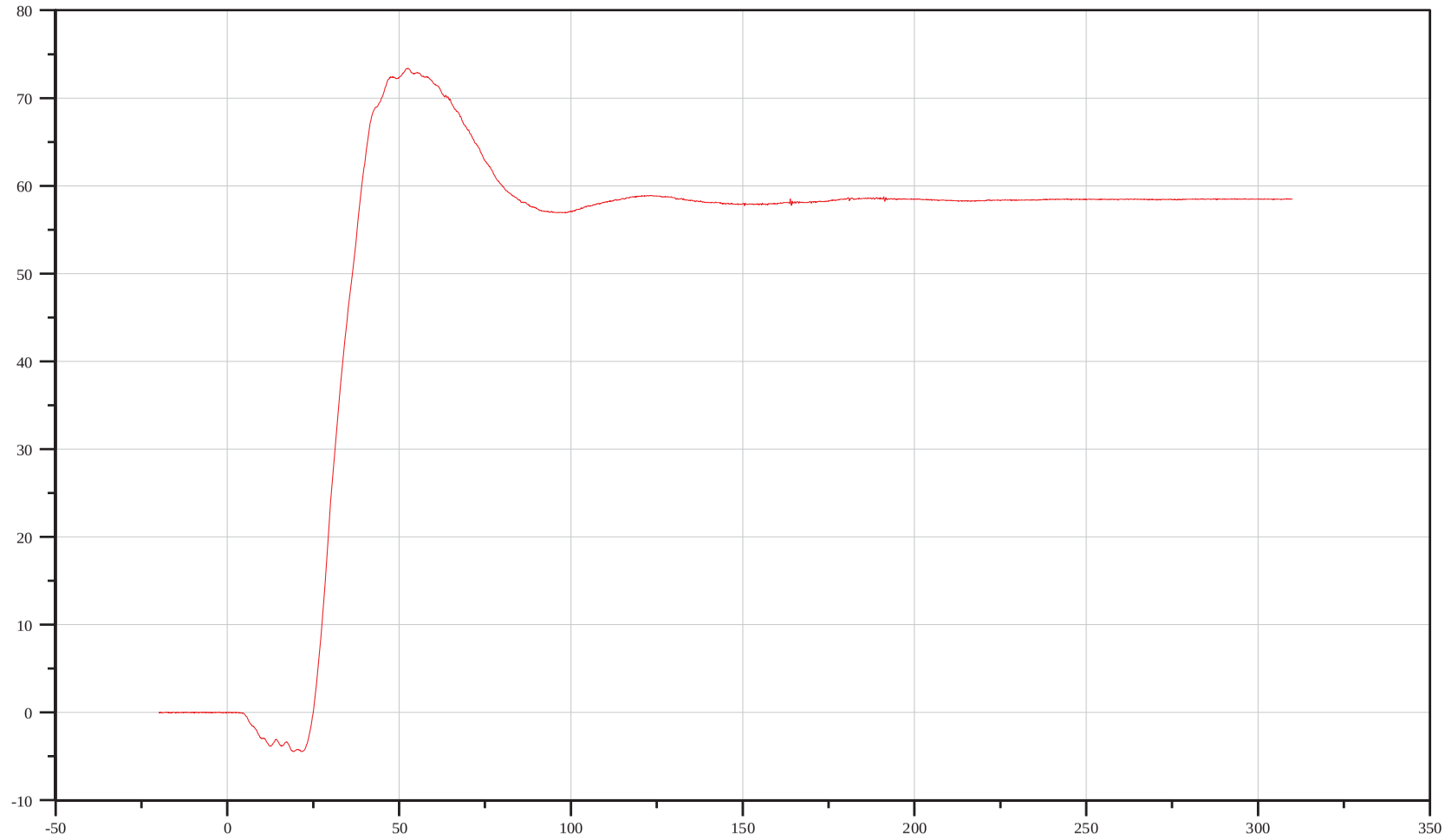
Middle Container, Passenger X-Axis Displacement

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTMI0000DSXA

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_1000

Min. Value
-4.47 mm at 19.20 ms

Max. Value
73.39 mm at 52.40 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

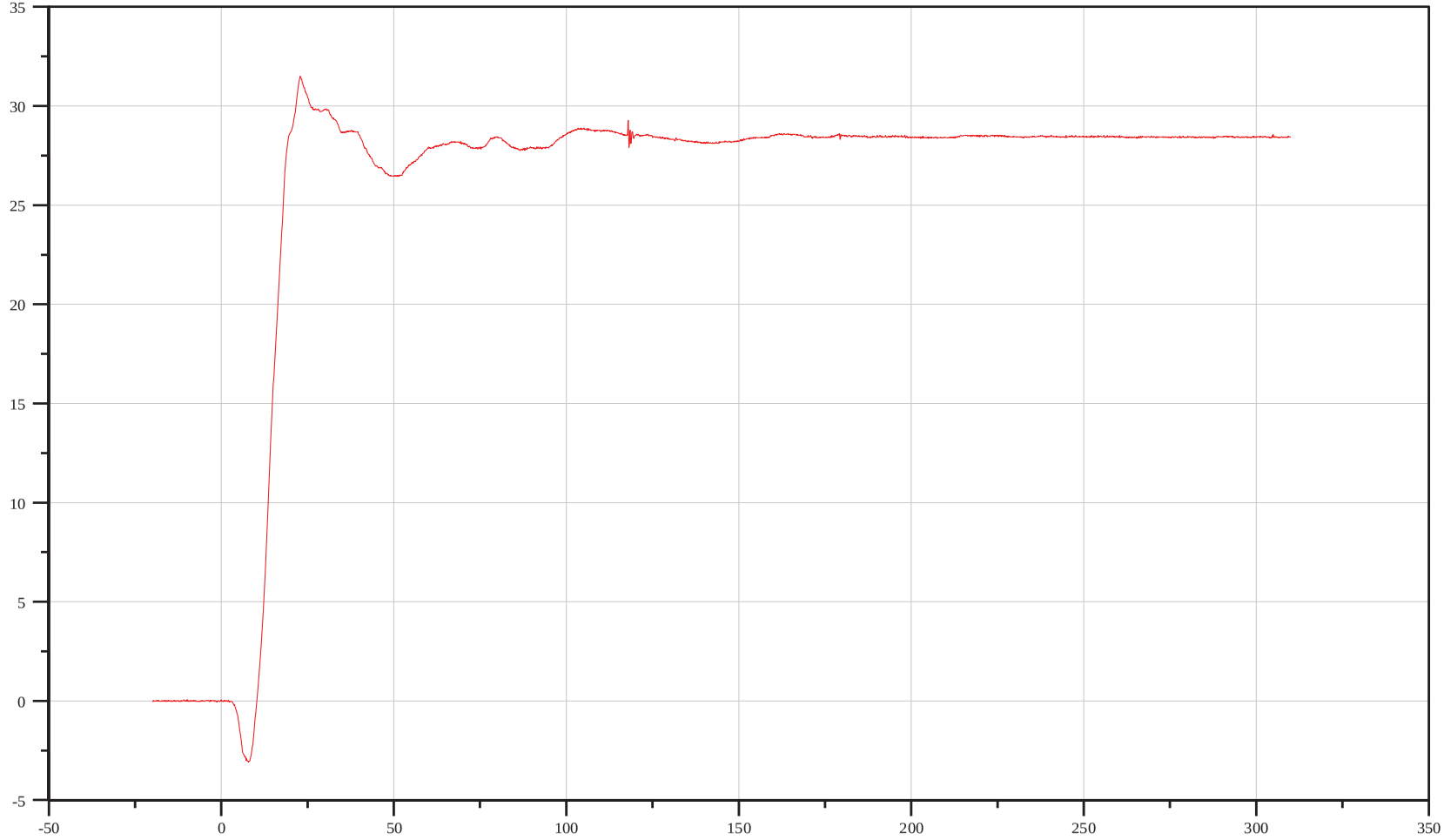
Date: 04/12/2012
Time: 08:12

Rear Container, Driver X-Axis Displacement

Customer: Battelle

11CONTRE0000DSXA

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_1000

Min. Value
-3.09 mm at 7.90 ms

Max. Value
31.50 mm at 22.90 ms

Rigid Moving Barrier Into Rear of Hydrogen Fuel Cell Vehicle

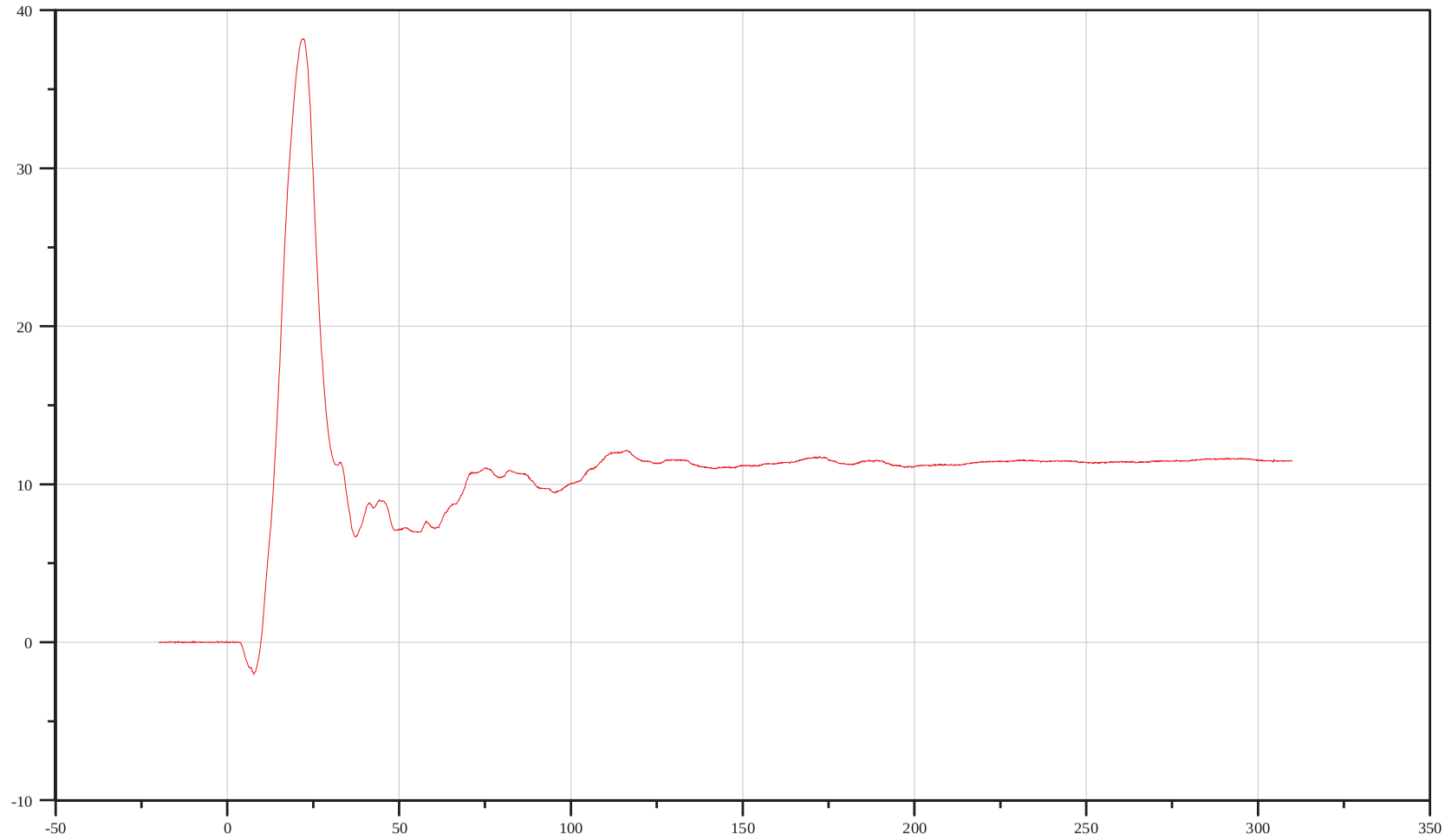
Rear Container, Passenger X-Axis Displacement

Date: 04/12/2012
Time: 08:12

Customer: Battelle

13CONTRE0000DSXA

TRC Inc. Test Lab: CTF
Test Number: 120411



Filter: CFC_1000

Min. Value
-2.04 mm at 7.60 ms

Max. Value
38.22 mm at 22.00 ms

Appendix C

FARO Measurements

120411 FARO Measurements									
	Pre-Test			Post-Test			Difference		
	X	Y	Z	X	Y	Z	X	Y	Z
Left Front Axle	882	-846	-391	884	-847	-390	-2	1	-1
Right Front Axle	882	847	-386	879	846	-381	3	1	-5
Vehicle Body	2406	614	-330	2403	617	-326	3	-3	-4
Right Front Upper Lead	1424	804	361	1414	809	360	10	-5	1
Right Front Lower Lead	1427	842	-316	1425	844	-313	2	-2	-3
Right Front Lower Trail	2388	842	-308	2383	852	-298	5	-10	-10
Right Front Upper Trail	2406	803	393	2396	815	402	10	-12	-9
Right Rear Upper Lead	2464	800	394	2446	811	403	18	-11	-9
Right Rear Lower Lead	2453	844	-303	2450	851	-294	3	-7	-9
Right Rear Upper Trail	3018	843	-289	3013	862	-268	5	-19	-21
Right Rear Lower Trail	3373	770	428	3352	811	461	21	-41	-33
Right Rear Axle	3514	834	-385	3475	850	-402	39	-16	17
Vehicle CG (IP)	1397	19	381	1390	9	373	7	10	8
Steering Center	1835	-346	336	1832	-340	341	3	-6	-5
Headline	1836	-346	819	1834	-341	820	2	-5	-1
Left A-Post	1417	-763	85	1420	-763	84	-3	0	1
Left Front Upper Lead	1418	-809	352	1418	-806	354	0	-3	-2
Left Front Lower Lead	1421	-844	-320	1424	-843	-321	-3	-1	1
Left Front Lower Trail	2377	-852	-316	2381	-848	-310	-4	-4	-6
Left Front Upper Trail	2405	-809	380	2403	-806	388	2	-3	-8
Left Rear Axle	3511	-851	-404	3508	-813	-413	3	-38	9
Left Rear Upper Lead	2458	-812	377	2452	-801	388	6	-11	-11
Left Rear Lower Lead	2443	-850	-323	2447	-846	-311	-4	-4	-12
Left Rear Lower Trail	3005	-851	-314	3012	-847	-296	-7	-4	-18
Left Rear Upper Trail	3369	-791	409	3363	-786	436	6	-5	-27
Fuel Neck Mount 1	3829	-779	217	3788	-760	236	41	-19	-19
Fuel Neck Mount 2	3879	-776	214	3839	-758	227	40	-18	-13
Fuel Neck Mount 3	3879	-805	174	3831	-785	187	48	-20	-13
Fuel Neck Mount 4	3828	-807	175	3781	-786	195	47	-21	-20
Fuel Neck Center	3856	-789	194	3815	-777	211	41	-12	-17
Left Rear Door Ring 1	2460	-765	225	2460	-756	233	0	-9	-8
Left Rear Door Ring 2	3338	-772	231	3323	-762	255	15	-10	-24
Left Rear Door Ring 3	2517	-606	832	2516	-590	839	1	-16	-7
Left Rear Door Ring 4	3009	-816	-252	3011	-801	-240	-2	-15	-12
Left Rear Door Ring 5	2502	-797	-266	2508	-789	-258	-6	-8	-8
Left Rear Door Ring 6	3192	-611	805	3193	-589	833	-1	-22	-28
C1	4257	-717	-141	4045	-668	-102	212	-49	-39
C2	4290	-439	-141	4022	-400	-108	268	-39	-33
C3	4308	-160	-139	4037	-120	-100	271	-40	-39
C4	4310	124	-138	4037	163	-97	273	-39	-41
C5	4296	406	-135	4024	445	-95	272	-39	-40
C6	4267	686	-132	4055	724	-95	212	-38	-37

120411 FARO Measurements									
	Pre-Test			Post-Test			Difference		
	X	Y	Z	X	Y	Z	X	Y	Z
Rear Centerline	4311	-1	-144	4039	24	-101	272	-25	-43
Battery Driver X	3781	-211	-36	3745	-171	-14	36	-40	-22
Battery Passenger X	3800	415	-41	3737	456	-26	63	-41	-15
Rear Bumper Beam 1	4171	-566	-174	3941	-546	-161	230	-20	-13
Rear Bumper Beam 2	4232	-478	-179	3968	-443	-158	264	-35	-21
Rear Bumper Beam 3	4260	-364	-174	3974	-328	-148	286	-36	-26
Rear Bumper Beam 4	4269	-246	-174	3984	-211	-143	285	-35	-31
Rear Bumper Beam 5	4280	-129	-173	3995	-95	-138	285	-34	-35
Rear Bumper Beam 6	4282	-13	-172	3999	23	-135	283	-36	-37
Rear Bumper Beam 7	4281	104	-170	3998	140	-133	283	-36	-37
Rear Bumper Beam 8	4271	219	-171	3990	256	-135	281	-37	-36
Rear Bumper Beam 9	4264	335	-170	3983	370	-136	281	-35	-34
Rear Bumper Beam 10	4239	448	-173	3972	487	-141	267	-39	-32
Rear Bumper Beam 11	4178	539	-170	3943	618	-141	235	-79	-29
Rear Bumper Beam 12	4172	-566	-258	3965	-547	-237	207	-19	-21
Rear Bumper Beam 13	4234	-474	-253	3989	-439	-225	245	-35	-28
Rear Bumper Beam 14	4260	-364	-256	3996	-327	-224	264	-37	-32
Rear Bumper Beam 15	4269	-248	-254	4004	-211	-219	265	-37	-35
Rear Bumper Beam 16	4280	-130	-254	4014	-94	-217	266	-36	-37
Rear Bumper Beam 17	4282	-12	-253	4016	25	-213	266	-37	-40
Rear Bumper Beam 18	4281	101	-253	4016	139	-213	265	-38	-40
Rear Bumper Beam 19	4271	219	-251	4007	257	-212	264	-38	-39
Rear Bumper Beam 20	4264	335	-251	4001	372	-215	263	-37	-36
Rear Bumper Beam 21	4239	449	-246	3986	489	-210	253	-40	-36
Rear Bumper Beam 22	4177	541	-252	3975	602	-214	202	-61	-38
Right A-Post	1427	781	81	1419	766	83	8	15	-2
Right Rear Door Ring 1	2468	768	224	2458	765	239	10	3	-15
Right Rear Door Ring 2	3348	758	230	3313	790	275	35	-32	-45
Right Rear Door Ring 3	2521	600	826	2506	605	845	15	-5	-19
Right Rear Door Ring 4	3044	816	-226	3031	813	-205	13	3	-21
Right Rear Door Ring 5	2517	798	-269	2513	794	-252	4	4	-17
Right Rear Door Ring 6	3200	593	801	3187	607	852	13	-14	-51
Front Container Driver	2892	-465	-351	2855	-456	-336	37	-9	-15
Front Container Passenger	2909	498	-328	2847	505	-297	62	-7	-31
Front Container Pitch X	2904	23	-529	2862	33	-506	42	-10	-23
Mid Container Driver	3291	-495	-400	3257	-481	-371	34	-14	-29
Mid Container Passenger	3290	495	-365	3225	512	-321	65	-17	-44
Mid Container Pitch X	3274	-0	-524	3234	16	-486	40	-16	-38
Rear Container Driver	3842	-514	-380	3740	-477	-389	102	-37	9
Rear Container Passenger	3849	476	-357	3720	514	-363	129	-38	6
Rear Container Pitch X	3865	-7	-500	3733	30	-510	132	-37	10

DOT HS 812 112D
December 2015

U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

10846D-0204-v2