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Evaluation of FMVSS No. 305a Electric-Powered Vehicles: Water Exposure Safety

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16. Abstract

A Notice of Proposed Rulemaking (NPRM) was published on April 15, 2024 (89 FR 26704; Docket No. NHTSA-2024-0012) proposed to upgrade and sunset FMVSS No. 305 with FMVSS No. 305a and include new comprehensive performance requirements and risk mitigation strategies for the rechargeable electrical energy storage system (REESS) of battery electric vehicles. The proposed requirements set a level of protection of the REESS against external fault inputs, ensure the REESS operations are within the manufacturer-specified functional range, and increase the likelihood of safe operation of the REESS and other electrical systems of the vehicle during and after water exposure during normal vehicle operations. To evaluate the proposed test protocols with respect to protection against water exposure, the National Highway Traffic Safety Administration's Vehicle Research and Test Center selected an electric vehicle and performed the water exposure test methods as outlined in section S14 of the NPRM. Testing identified two discrepancies from the NPRM and in turn highlighted two revisions to the FMVSS No. 305a procedures in the final rule that was published on December 20, 2024 (89 FR 104318; Docket No. NHTSA-2024-0091): the nozzle size for the vehicle-washing test and the time duration for the driving-through-standing-water test.

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automatic disconnect	device that when triggered, conductively separates a high-voltage source from the electric power train or the rest of the electric power train.
breakout harness	connector wires that are connected for testing purposes to the REESS on the traction side of the automatic disconnect.
connector	device providing mechanical connection and disconnection of high-voltage electrical conductors to a suitable mating component, including its housing.
rechargeable electrical energy storage system (REESS)	system that provides electric energy for electrical propulsion.
service disconnect	device for deactivation of an electrical circuit when conducting checks and services of the vehicle electrical propulsion system.
state-of-charge (SOC)	the available electric charge in a REESS expressed as a percentage of its normal operating capacity specified by the manufacturer and not as a percentage of the total charge (stored energy) in the REESS.
thermal event	condition when the temperature in the REESS is significantly higher than the maximum operating temperature.
thermal runaway	uncontrolled increase of cell temperature caused by exothermic reactions inside the cell.
thermal propagation	sequential occurrence of thermal runaway in a REESS triggered by thermal runaway of a cell in the REESS.

Executive Summary

Federal Motor Vehicle Safety Standard (FMVSS) No. 305, *Electric-powered vehicles: electrolyte spillage and electrical shock protection*, does not have any requirements for the safe operation of the rechargeable electrical energy storage systems (REESS) in battery electric vehicles. REESSs are designed and manufactured to operate safely within a specific environmental range. Environmental effects such as exposure to water and moisture may deteriorate the electrical isolation of high-voltage components in the powertrain. This may first lead to electric system degradation and eventually lead to an unsafe electrical system for vehicle occupants, operators (during charging) or by-standers. Under extreme conditions, fire can originate from compromised electrical components due to water ingress.

In the notice of proposed rulemaking (NPRM) published on April 15, 2024,[1] NHTSA proposed to adopt GTR No. 20's physical water test requirement, where a vehicle shall maintain electrical isolation resistance after the vehicle is exposed to water under normal vehicle operation, such as in a car wash or while driving through standing water.[2] The proposed physical test procedure has two series of tests, informally referred to as the "vehicle washing" test and the "driving through standing water" test. Electrical isolation is determined at the conclusion of each test and once again after 24 hours. The test procedure outlined in the NPRM aims to enhance the safe operation of the REESS and other electrical systems during and after water exposure in normal vehicle operations. This procedure was validated through physical testing, which included two water exposure tests:

- Vehicle-Washing Test (S14.1): Simulates washing a vehicle; and
- Driving-Through-Standing-Water Test (S14.2): Simulates driving through standing water.

Two key discrepancies were identified from the NPRM during the validation:

- Nozzle size for the vehicle-washing test: International Electrotechnical Commission (IEC) 60529 dimensions need updating from 6 mm to 8 mm.
- Test duration for the driving-through-standing-water test: Proposed 5-minute limit was exceeded, requiring 7.5 minutes due to vehicle reorientation.

[1] FMVSS No. 305a, *Electric-powered vehicles: Electric powertrain integrity global technical regulation No. 20, Incorporation* by reference, 49 CFR Part 571, 89 FR 26704 [Docket Submission. Docket No. NHTSA-2024-0012 in Regulations. gov].

[2] The final rule was published on December 20, 2024 (89 FR 104318) and largely adopted the NPRM with changes.

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Objectives

The objective of this study was to evaluate the test procedures in the FMVSS No. 305a NPRM that include proposed requirements that increase the likelihood of safe operation of the REESS and other electrical systems of the vehicle during and after water exposure during normal vehicle operations. The water exposure safety assessment consists of two water exposure tests. The vehicle-washing test, which simulates the vehicle being washed, and the driving-through-standing-water test, which simulates driving through standing water.

S14. Water exposure safety.

S14.1. Vehicle-washing test.

S14.2. Driving-through-standing-water test.

NHTSA's Vehicle Research and Test Center procured two vehicles to support the water exposure testing. They were two 2024 model year Polestar 2 vehicles with single-motor, rear-wheel drive purchased new from a local Polestar dealer. Each vehicle was evaluated in both the vehicle-washing test and the driving-through-standing-water test proposed in the NPRM for FMVSS No. 305a S14.

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Test Procedure – Vehicle Washing

Vehicle Set-Up

The testing was performed in a lab with floor drains to allow for test water to drain away from the vehicle and not accumulate during testing. The vehicle-washing testing was conducted with the vehicle placed in Park and the vehicle ignition in the "off" (propulsion system not energized) position. All windows and doors were closed to prevent water getting in. The Polestars were charged prior to testing to a state-of-charge > 95 percent.

A breakout harness was connected to the REESS on the traction side of the automatic disconnect per Volvo's recommendations. This was to support voltage measurements to determine electrical isolation from high-voltage sources. The breakout harness[3] was connected to a device provided by Volvo that facilitated direct access to the high-voltage circuit of the REESS. This device can be seen in Figure 1. The breakout device was connected to the vehicle via the manual service disconnect (MSD) port located in the floor directly behind the first-row passenger seat. The location of the MSD is shown in Figure 2.

Figure 1. Breakout device provided by Volvo

[3] To assure safe access to the REESS high-voltage circuit, the manufacturer is required by FMVSS No. 305a to specify the location for connecting the breakout harness and may also provide appropriate breakout harnesses for testing the vehicle. Volvo provided this device for research testing.

Figure 2. Location of MSD behind first-row passenger seat

The manual service disconnect was removed and the breakout device inserted per Volvo's direction. The breakout device in the installed position can be seen in Figure 3.

Figure 3. Breakout device installation

A test interface port (Figure 4), commonly referred to as a breakout box, was connected to the breakout device to provide ports for measuring the high voltage of the REESS and the voltages between both the negative and positive side of the high-voltage source and the electrical chassis as seen in Figure 5.

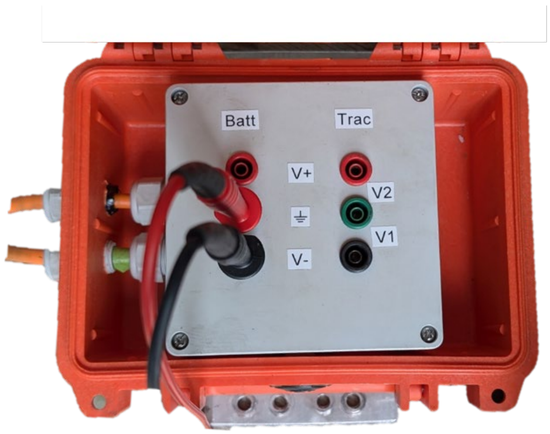


Figure 4. Breakout box/interface port

Electrical Isolation Baseline Measurement

A baseline isolation measurement per S7.6 of FMVSS 305 was performed to verify electrical isolation prior to testing. The vehicle was placed in drive with the vehicle ignition in the "on" (propulsion system energized) position by sitting in the vehicle with the key fob and depressing the brake while simultaneously cycling the gear select from Drive to Park. The propulsion system would time out and return to the vehicle "off" position after a few minutes. The voltage measurements must be taken prior to the vehicle ignition timing out.

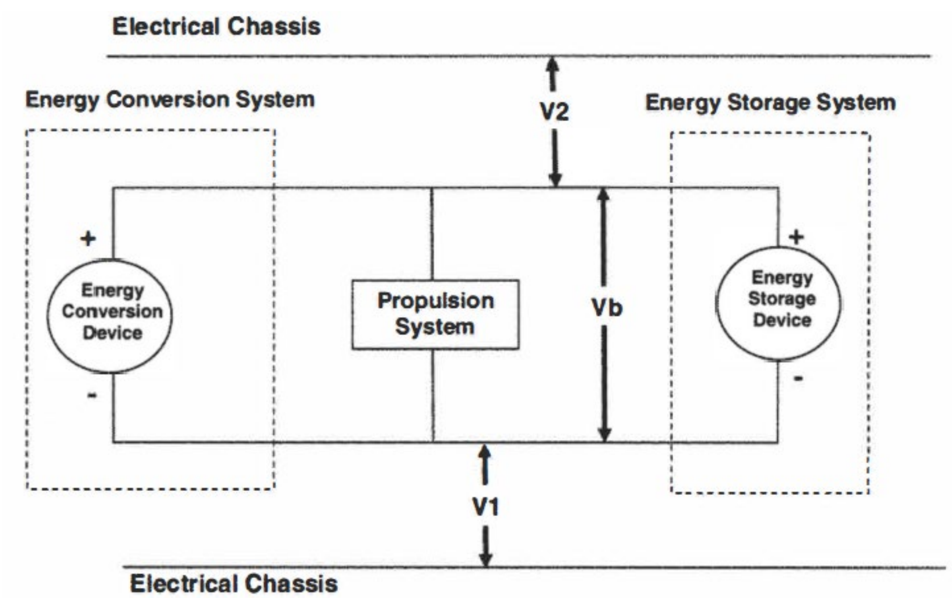


Figure 5. Voltage measurements of the high-voltage source

The electrical isolation was evaluated per section S7.6 of FMVSS 305. The voltages were measured as shown in Figure 5 and the high-voltage source voltage (Vb) was recorded.

The voltage V1 between the negative side of the high-voltage source and the electrical chassis was measured and recorded.

The voltage V2 between the positive side of the high-voltage source and the electrical chassis was measured and recorded.

The electrical isolation voltages V1’ and V2’ were measured next. These measurements include a known resistance added in parallel between the high-voltage source and the electrical chassis.

Voltage V1’ was measured by inserting a known resistance (Ro) between the negative side of the high-voltage source and the electrical chassis. With the Ro installed, V1' was measured as shown in Figure 6 between the negative side of the high-voltage source and the electrical chassis. A resistor value of 220K ohms was used for this measurement.

The resistor value of 220K ohms was selected solely to establish a known value for calculating the electrical isolation resistance (Ri). The electrical isolation resistance serves as the key metric for assessing if high-voltage isolation is maintained.

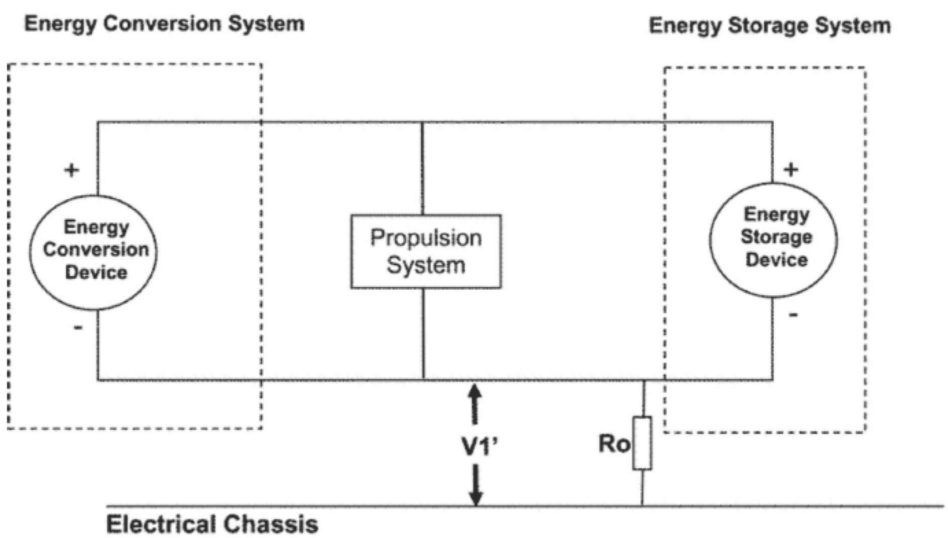


Figure 6. Measurement of V1’ voltage across resistor between negative side of the high voltage and the electrical chassis

V2' was measured and recorded in a similar manner as seen in Figure 7.

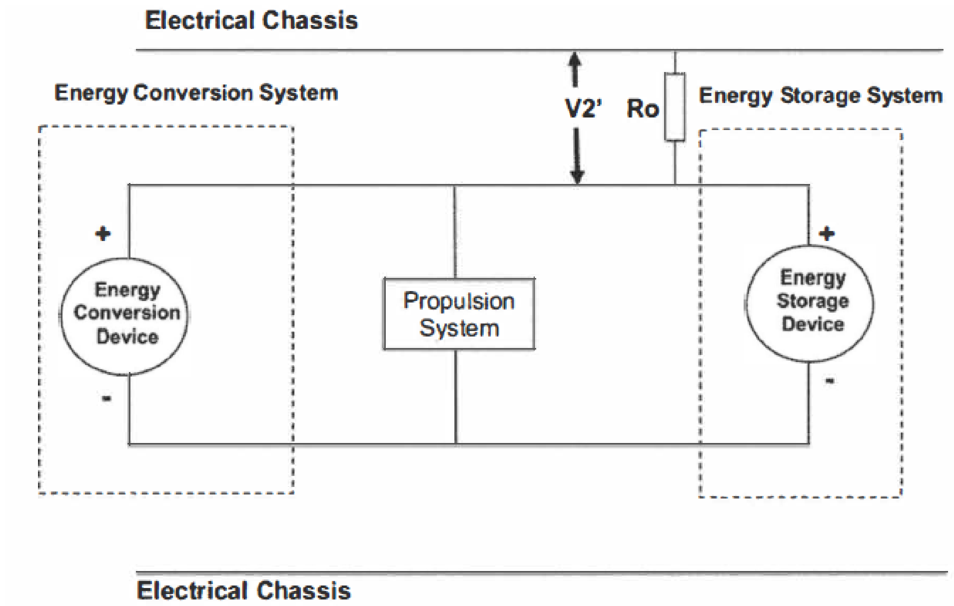


Figure 7. Measurement of V2' voltage across resistor between positive side of the high voltage and the electrical chassis

The electrical isolation resistance (Ri) was calculated according to the formulas shown below.

IF V1 > V2:

$$Ri = Ro\,(1+V2/V1)((V1-V1')/V1')$$

IF V2 > V1:

$$Ri = Ro\,(1+V1/V2)((V2-V2')/V2')$$

The Ri (in ohms) was divided by the working voltage of the high-voltage source (in volts) to obtain the electrical isolation (in ohms/volt). The electrical isolation of the high-voltage source, determined in accordance with the procedure specified in FMVSS No. 305 S7.6, must be greater than or equal to one of the following:

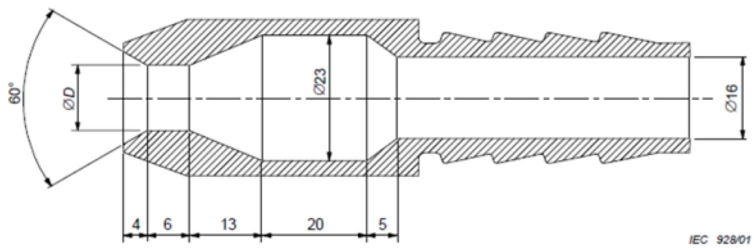
500 ohms/volt for an AC high-voltage source; or

100 ohms/volt for an AC high-voltage source if it is conductively connected to a DC high-voltage source.

The electrical isolation was calculated and recorded. This can be seen in Tables 1 and 2.

Vehicle-Washing Test

A vehicle-washing test was performed according to that proposed in the NPRM for FMVSS No. 305a S14.1. The vehicle is to be sprayed from any direction with a stream of freshwater from a standard test nozzle shown in Figure 8 that has a nozzle internal diameter of 6.3 mm, delivery rate of 11.9 to 13.2 L/min, and water pressure at the nozzle between 30 kPa to 35 kPa.



Dimensions in millimetres

D is 6.3 mm as specified in (a) above.

Figure 8. Standard nozzle for IPX5 water exposure test per the NPRM

Market research to find the standard nozzle resulted in nozzles available for purchase that did not match the dimensions specified in the NPRM. The nozzle available for purchase met the dimensional specifications per IEC standard 60529, 2013. The nozzle dimensional specifications per IEC 60529 can be seen in Figure 9. A nozzle matching the IEC 60529 dimensions was purchased to conduct the testing.

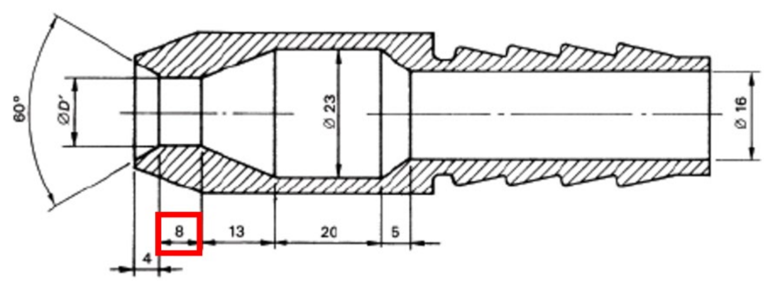


Figure 9. Standard nozzle, IEC standard 60529, 2013

The test procedure requires that the vehicle surface is exposed to the water stream from the standard nozzle for a duration of 1 minute per square meter or for 3 minutes, whichever is greater. The water stream is applied to the underside of the vehicle by approaching the vehicle and spraying upwards. The distance from the nozzle to the tested vehicle is 3.0 to 3.2 m, which may be reduced, if necessary, to ensure the surface is wet when spraying upwards.

The surface area of the vehicle was divided into 6 surfaces: top, bottom, driver side, passenger side, front side, and rear side. This can be seen in Figure 10.

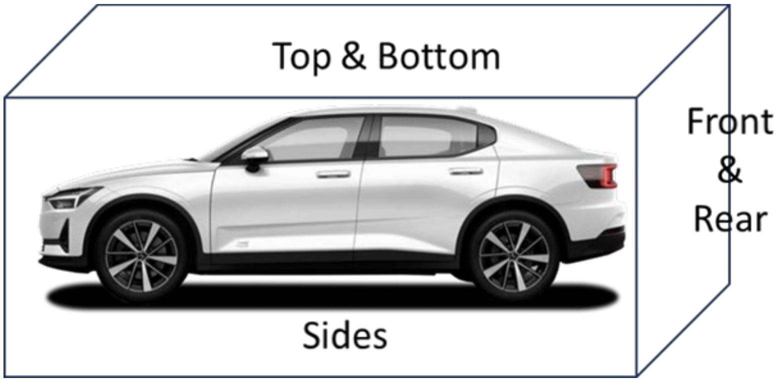


Figure 10. Vehicle surface areas

Based on the measured surface area, the surfaces were exposed to water for the following durations.

Driver side: 5 min.

Passenger side: 5 min.

Top surface: 7 min.

Bottom surface: 7 min.

Front surface: 1 min.

Back surface: 1 min.

The test set-up shown in Figure 11 was used to meet the test parameters during vehicle washing with respect to both flow rate and water pressure. This consisted of an inline valve, digital flow meter, and pressure gauge. The pressure gauge was located as close to the outlet nozzle as possible to reduce pressure loss between the gauge and nozzle.

Test Parameters

Flow rate: 11.9-13.2 L/min

Water pressure: 30-35 kPa

Distance from nozzle to vehicle: 3-3.2 meters

Total duration: 60-75 seconds per square meter of surface area

Figure 11. Vehicle-washing test set-up

During the vehicle washing assessment, the specified flow rate and pressure could not be achieved simultaneously. When the flow rate met specifications, the pressure was too low (Case #1). Conversely, when the pressure met specifications, the flow rate was too high (Case #2).

- Test Parameter Settings #1: Pressure: 21.4 kPa, Flow Rate: 13.1 L/min
- Test Parameter Settings #2: Pressure: 31.0 kPa, Flow Rate: 15.1 L/min

After visually comparing the water output from the nozzle using these two settings, it was determined that the level of water exposure to the vehicle's exterior or internal components would be similar when using either setting. Therefore, it was decided to conduct the vehicle-washing test with the second setting, which had a higher flow rate and pressure within the specified limits.

Electrical Isolation Post-Test Measurement

The post-test electrical isolation was checked immediately after the test and again after 24 hours. This was the same procedure as described previously in the electrical isolation baseline measurement. The vehicle was stored away from the building in a temporary shelter to prevent inadvertent exposure to environmental elements. This can be seen in Figure 12. The International Fire Code (IFC 2024) states that vehicles with damaged or defective batteries be stored protected from the weather and not less than 20 ft. from any building, public street, or public means of egress. This is done to mitigate the potential for fire damage to the main building in the event of a post-test fire resulting from thermal runaway in the lithium-ion battery.

Figure 12. Temporary vehicle storage

Results

The electrical isolation met the required 100 ohms/volt minimum for an AC high-voltage source if it is conductively connected to a DC high-voltage source for all three measurements: pre-test, immediately post-test, and 24 hours post-test. See Table 1 and Table 2. These were expected results since there are no significant gaps in the vehicle exterior panels, aero shielding, or closure panels. The absence of any significant gaps prevents direct water exposure to high-voltage modules, harnesses, and connectors during testing.

	Pre-Test	**Post-Test**	**Post-Test**
		Immediate	**24 Hour**
Vb, Battery Voltage, Pre-Test, volts	464.7	464.5	463.7
Propusion Battery to Vehicle Chassis:			
V1, volts	445.2	445.1	444.4
V2, volts	449.9	451.0	450.3
Ro, Ω	220,000.0	220,000.0	220,000.0
Electrical Isolation Measurement:			
V1', volts	178.5	178.5	178.2
V2', volts	180.7	180.8	180.5
Ri1, Ω	660,881.9	661,520.8	661,520.8
Ri2, Ω	652,071.4	653,265.2	653,265.2
Ri, Ω	652,071.4	653,265.2	653,265.2
Electrical Isolation Value, Ri/Vb, Ω/V	1,403.2	1,403.2	1,403.2
Is the measured Electrical Isolation Value greater than or equal to 100 Ω/V?	**Yes**	**Yes**	**Yes**

Table 1. Isolation measurements for vehicle 1 (vehicle-washing test)

	Pre-Test	**Post-Test**	**Post-Test**
		Immediate	**24 Hour**
Vb, Battery Voltage, Pre-Test, volts	434.4	434.3	465.6
Propusion Battery to Vehicle Chassis:			
V1, volts	416.5	416.4	446.6
V2, volts	421.9	421.0	451.9
Ro, Ω	220,000.0	220,000.0	220,000.0
Electrical Isolation Measurement:			
V1', volts	166.9	166.9	179.0
V2', volts	169.1	169.0	181.2
Ri1, Ω	662,288.5	661,392.3	661,392.3
Ri2, Ω	653,578.7	652,510.3	652,510.3
Ri, Ω	653,578.7	652,510.3	652,510.3
Electrical Isolation Value, Ri/Vb, Ω/V	1,504.6	1,504.6	1,504.6
Is the measured Electrical Isolation Value greater than or equal to 100 Ω/V?	**Yes**	**Yes**	**Yes**

Table 2. Isolation measurements for vehicle 2 (vehicle-washing test)

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Test Procedure – Driving Through Standing Water

Vehicle Set-Up

A breakout device and interface port (breakout box) were attached in a similar manner as was done with the vehicle-washing test. The interface port was placed on the exterior of the roof of the vehicle. This allowed for isolation measurements to be taken without opening the vehicle and was out of reach from inadvertent water exposure during testing. The interface port was also placed in a sealed, water resistant, non-metallic box. All windows and doors were closed to prevent water ingress into the vehicle. The vehicles were charged to a state of charge (SOC) > 95% prior to testing.

Driver Protection Strategy

An emergency driver exit strategy was developed to ensure driver safety in the event of a vehicle loss of high-voltage isolation and/or a vehicle thermal event. The driver wore electrically insulated gloves and dielectric overboots. The boots were 14 inches high and rated to 20kV. The width of the wade pool allowed for enough room for the driver to exit the vehicle in the event of an emergency.

Electrical Isolation Baseline Measurement

A baseline isolation measurement per S7.6 of FMVSS 305 was performed to verify electrical isolation prior to testing. This was completed in the same manner as was done in the vehicle-washing test.

Driving Through Standing Water

The NPRM test procedure is as follows. The vehicle is driven through a pool of standing freshwater (10 m deep, for a total range of 500 m, at a vehicle speed of 20 km/hr). The pool represents a low-lying portion of a road that can get flooded in excessive rain.

If the wade pool used is less than 500 m long, then the vehicle is driven through the wade pool several times. The total time, including the periods outside the wade pool, would have to be less than 5 minutes.

The wade pool used in our test was 30 m long with a 15 m ramp at both ends (Figure 13).

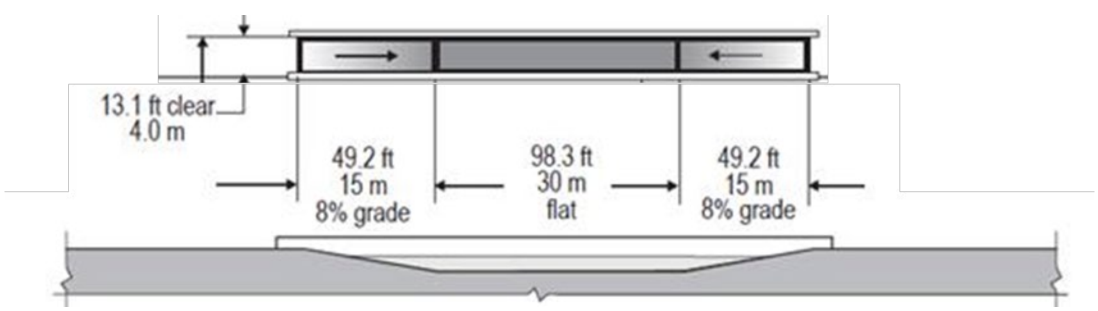

Figure 13. Wade pool length

The vehicle was driven through the wade pool 17 times to meet the 500 m requirement. This can be seen in Figure 14.

Figure 14. Wade pool testing

The total test time to complete the 17 trips through the wade pool, at a vehicle speed of 20 km/hr, was 7.5 minutes. This was greater than the 5 minutes maximum test time proposed in the NRPM. The testing did include a 180° turn at the end of each lap, which may not have been considered in the NPRM.

Electrical Isolation Post-Test Measurement

The post-test electrical isolation was checked immediately after the test and again after 24 hours. This was the same procedure as described in the electrical isolation baseline measurement. The vehicle was stored away from the building in a temporary shelter to prevent inadvertent exposure to environmental elements. This can be seen in Figure 12.

Results

The electrical isolation met the required 100 ohms/volt minimum for an AC high-voltage source if it is conductively connected to a DC high-voltage source for all three measurements: pre-test, immediately post-test, and 24 hours post-test. See Table 3 and Table 4.

	Pre-Test	Post-Test	Post-Test
		Immediate	**24 Hour**
Vb, Battery Voltage, Pre-Test, volts	461.3	460.0	459.5
Propusion Battery to Vehicle Chassis:			
V1, volts	442.0	440.8	440.1
V2, volts	448.0	446.7	446.1
Ro, Ω	220,000.0	220,000.0	220,000.0
Electrical Isolation Measurement:			
V1', volts	177.2	176.7	176.5
V2', volts	179.5	179.5	178.7
Ri1, Ω	661,979.7	662,035.5	662,035.5
Ri2, Ω	653,754.2	650,649.5	650,649.5
Ri, Ω	653,754.2	650,649.5	650,649.5
Electrical Isolation Value, Ri/Vb, Ω/V	1,417.2	1,417.2	1,417.2
Is the measured Electrical Isolation Value greater than or equal to 100 Ω/V?	**Yes**	**Yes**	**Yes**

Table 3. Isolation measurements for vehicle 1 (driving through standing water)

	Pre-Test	Post-Test	Post-Test
		Immediate	**24 Hour**
Vb, Battery Voltage, Pre-Test, volts	462.3	460.8	459.2
Propusion Battery to Vehicle Chassis:			
V1, volts	443.7	442.2	440.4
V2, volts	448.7	447.4	445.5
Ro, Ω	220,000.0	220,000.0	220,000.0
Electrical Isolation Measurement:			
V1', volts	177.8	177.2	176.6
V2', volts	179.8	179.3	178.6
Ri1, Ω	661,727.8	661,882.5	661,882.5
Ri2, Ω	654,375.9	654,090.7	654,090.7
Ri, Ω	654,375.9	654,090.7	654,090.7
Electrical Isolation Value, Ri/Vb, Ω/V	1,415.5	1,415.5	1,415.5
Is the measured Electrical Isolation Value greater than or equal to 100 Ω/V?	**Yes**	**Yes**	**Yes**

Table 4. Isolation measurements for vehicle 2 (driving through standing water)

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Summary

FMVSS No. 305a sunsets FMVSS 305 to enhance the safe operation of the REESS and other electrical systems during and after water exposure in normal vehicle operations. In this study, the test procedures for water exposure outlined in the NPRM, which were largely adopted in the final rule, were validated through physical testing.

The testing consisted of two water exposure tests. The vehicle-washing test simulates the vehicle being washed, and the driving-through-standing-water test simulates driving through standing water.

S14.1 Vehicle-washing test.

S14.2 Driving-through-standing-water test.

Two discrepancies between the testing and the proposed test procedure in the NPRM were identified.

The dimensions of the standard nozzle required for the vehicle-washing test, as defined by IEC 60529 for IPX5 water-exposure testing, were found to be inaccurate. One dimension needs to be updated from 6 mm to 8 mm as in Figure 9.

The maximum test time of 5 minutes as proposed in the NPRM for the driving-through-standing-water test could not be met due to the additional drive time between runs to reorient the vehicle to enter the wade pool. The time to reorient the vehicle may not have been considered in the NPRM. The overall time for the validation testing was found to be longer than the proposed 5-minute maximum, amounting to 7.5 minutes.

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