ASSAULT & BATTERY: COMPARISON OF UL 1973/9540 AND TELCORDIA GENERIC REQUIREMENTS FOR ABUSE TESTING

Randy Schubert
Network Engineer
Ericsson
Basking Ridge, NJ

Richard Kluge
Director – NI&SS
Ericsson
Basking Ridge, NJ

Abstract

National Building and Fire Codes and many Local Regulations require that energy storage systems (ESS) including standby battery systems, be Listed to UL Standards or similar International Standards by an approved testing laboratory. UL 1973, UL Standard for Safety Batteries for Use in Stationary and Motive Auxiliary Power Applications and UL 9540 Energy Storage Systems and Equipment, are widely adopted by the Codes such as NFPA 855, NFPA 1, and the International Fire Code (IFC) and apply to most battery installations. Recent Battcon presentations outlined the UL standards and building and fire code criteria and explained where specific UL Listings are required in the codes. While the UL Standards are comprehensive and effectively address safety for end-users, they do not always address abuse conditions that may apply to certain industry specific installation environments. The telecommunication industry battery requirements GR-4228 (VRLA), GR-3150 (lithium), GR-3020 (Ni-Cd), GR-3168 (NiMH), GR-3176 (Sodium Metal Chloride), and GR-3181 (Nickel Zinc) provide a more diverse set of test criteria simulating environments and exposures that batteries may encounter in outside plant and indoor environments. This paper highlights benefits of the telecom industry requirements for abuse that should be considered when selecting and qualifying ESS. The following conditions where differences between UL Standards and Telcordia Generic Requirements occur include physical drops, water immersion, short-circuit, simulated brush fire, crush, salt fog, and mixed flowing gas. This paper will review common disaster situations we encountered and how these requirements and tests simulate these situations and ensure safety. Additional assessments provided through accelerated aging and life testing specified in GRs provide the user with valuable performance and reliability information not gleaned through UL listing. IEEE standards and guidelines also acknowledge certain abuse conditions or combination of conditions that may require consideration for safe ESS deployment.

Introduction

Severe and widespread flooding during Superstorm Sandy (2013), Hurricanes Katrina (2005) and Ida (2021), nearly annual wildfires in California and western states impacting outside plant equipment, chemical exposures, and direct physical damages from drops or impacts; abuse conditions to batteries happen in real world installations. Less severe but still meaningful stresses such as temperature and humidity excursions, ingress of salt fog in marine environments, accidental short-circuits, contamination, and electrostatic discharge can also occur. The testing requirements for batteries to achieve UL listing (or equivalent) are designed to ensure safety of the products in a broad spectrum of installations and uses and compare well to many of the requirements listed in Telcordia GRs. Some installations supporting the telecom industry are more susceptible to certain risks and exposures based on common deployment locations. In addition to the safety for life and property from catastrophic events like fires, the Telcordia standards also look at reliability during and after numerous electrical, mechanical and environmental exposures. Even neglected maintenance or skipped inspections over many years may lead to failures and should be considered.

Common abuse scenarios are discussed on the following pages. When comparing UL Standards and Telcordia Generic Requirements for some of these testing parameters, certain UL requirements limit the testing criteria to batteries utilized in Light Electric Rail (LER) or Vehicle Auxiliary Power (VAP) applications but do not apply these more severe criteria to stationary battery installations. Additionally, certain test criteria specify cell, subassembly, or complete system testing. These details and corresponding pass – fail criteria should be reviewed when comparing different requirements.

Common Disaster Scenarios

Immersion: The insurance industry data routinely lists flooding related losses as the most pervasive weather damages and financial losses for the industry. With telecommunications infrastructure distributed throughout the country and more populous areas needing expanded services for broadband access, underground and grade level battery cabinets in the outside plant and open battery strings in indoor facilities are common. With cities located in close proximity to rivers and coastlines, water immersion into equipment spaces is not an uncommon occurrence. More localized exposures such as water main ruptures and errant lawn sprinklers have been known to impact outside plant installations as well. Any battery technology needs to remain safe during water exposure and must not present hazards to first responders or service personnel that enter the site after the water recedes. So, safety during initial response hours as well as days after the exposure must be considered. Testing for both partially immersed and totally submerged batteries with 2-foot water head in a 1% saltwater solution while under float charge are included in most Telcordia Generic Requirements for batteries. Cabinets also have additional water intrusion tests as outlined in cabinet and battery enclosure GRs and new IEEE guidelines for water intrusion tests are in progress. In contrast, UL 1973 calls out resistance to moisture to be performed per IEC 60529 based on the IP rating of the battery enclosure and intended use for the Listing.

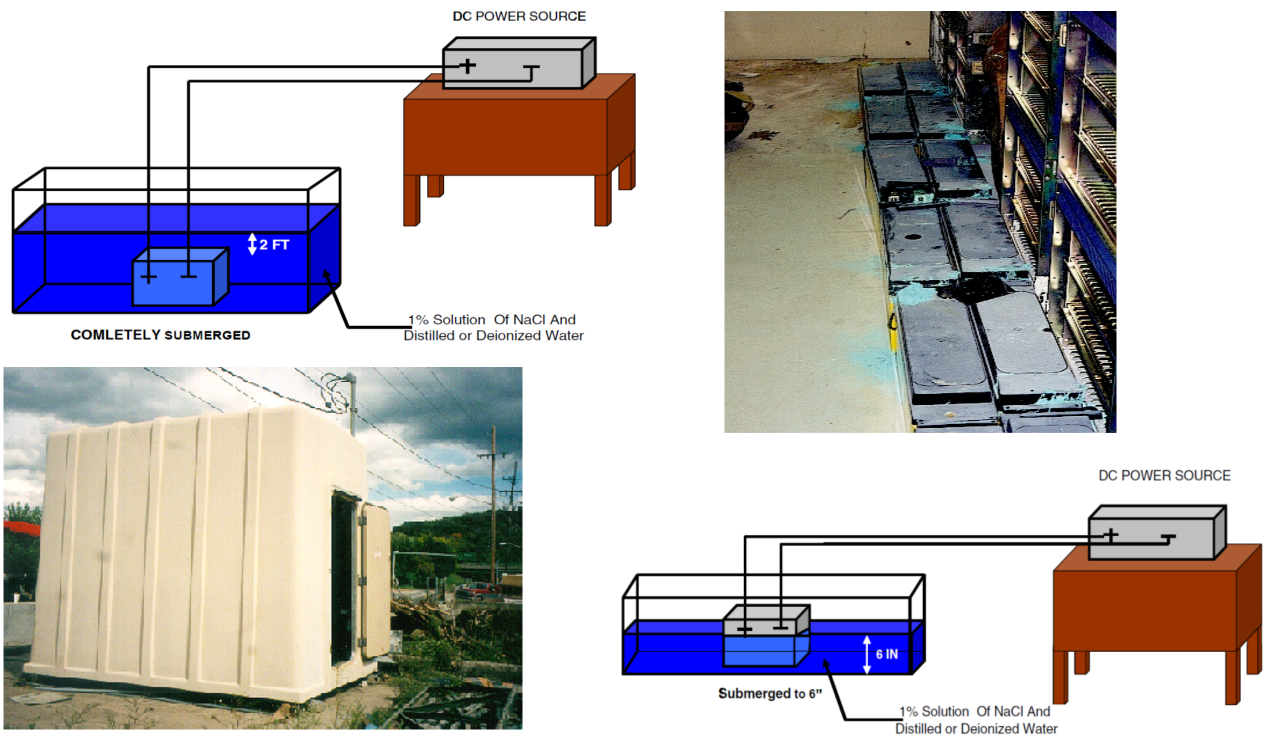
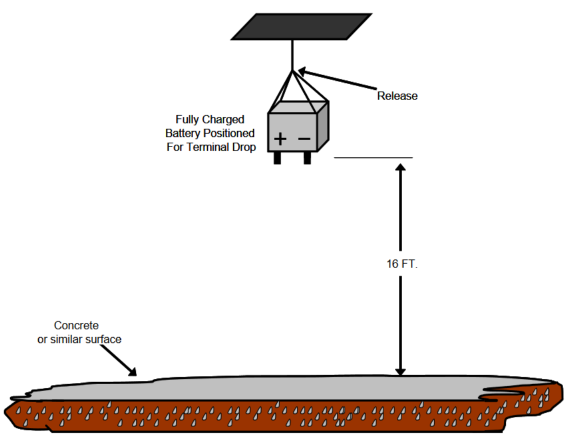


Figure 1. Immersion Test and Flooded CEV and Hut Example

An area of distinction between UL and Telcordia GR tests is in the interpretation of the *intended design environment* for a Listing compared with possible exposures and disaster scenarios. Both UL 9540 and UL 1973 specify testing for moisture ingress and other adverse environments. However, the listing standards only require these tests for batteries or battery system enclosures that are designed for environments or applications likely to undergo water ingress. Deploying a product that is <u>not designed</u> for use in such applications to a high moisture environment would violate the Listing. The GR does not let the user pick performance level based on an ideal environment. GRs often look at what a battery <u>may</u> be exposed to in the telecommunications environments in the event of extreme conditions. Testing the effects of those conditions is performed even if the battery is not intended to be operated in that environmental exposure. An end user should be aware of the limitations of the UL listing on product deployment, evaluate their specific risks and determine if additional GR tests are warranted.

Mechanical Impact (Drop Tests): UL 1973 Edition 3 drop test criteria are called out in Section 33 and alternative drop tests for lead-acid and nickel-cadmium batteries are described in Annex H Table H.1. These drops resemble traditional Telcordia GR-63 drop tests of 1 to 4 inches depending on weight of the sample for single cell or multi-cell/monobloc units. For other battery types such as lithium, UL 1973 Section 33 describes drop testing of the units at heights between 1 inch and 40 inches. An observation period of 1 hour is called out after the impact to ensure latent fire or failure does not develop as a result of internal damage from the drop. Telecommunications installations that utilize batteries include underground controlled environmental vaults (CEVs) and controlled environmental manholes (CEMHs). Drops from aerial cabinet installations also are a consideration. Telcordia Standards for VRLA and Ni-Cd batteries similarly follow GR-63 drop testing, but lithium and sodium nickel chloride batteries include more severe drops up to 16 feet height as might occur in a poorly executed CEV installation. There is a waiting and observation period of 24 hours after the test. Testing has shown thermal events occurring many hours after completion of battery impact tests.



Device Under Test Weight	Drop Height (UL Sec 33)	GR-63 (Unpackaged)	GR-63 (Packaged)
7 kg or less	100 cm (39.4 in)	-	-
>7kg to <100 kg	10 cm (3.9 in)	-	-
>100 kg	2.5 cm (1 in)	2.5 cm (1 in)	-
0 to < 10 kg	-	10 cm (3.9 in)	100 cm 39.4 in
10 kg to 25 kg	-	7.5 cm (3 in)	15 to <20 kg 31.5 in 20 to <30 kg 23.6 in
>25 kg to 50 kg	-	5 cm (2 in)	30 to <40 kg 19.7 in 40 to <50 kg 15.7 in
>50 kg	-	2.5 cm (1 in)	300 cm 11.8 in
All		16 ft	N/A

Figure 2. Mechanical Shock & Drop Testing

A related test in UL 1973 is impact shock. This testing involves dropping an object directly onto the battery, enclosure or device under test, or swinging an object like a pendulum onto the battery's side surfaces. The UL Standard specifies a 5 ft-lb (6.8 J) impact force using a 2-inch diameter steel sphere weighing 1.18 pounds from a height of 50.8 inches. This impact testing is not specified in the Telcordia battery GRs, however GR-487 and GR-3108 for enclosures such as cabinets require similar impact tests, and these tests would apply in the case of a battery in an exposed enclosure. The end-user should consider how the battery system is configured to determine applicable tests.

Crush: UL crush testing outlined in UL 1973 Edition 3 Section 30 is applicable to LER and VAP applications only. There are static force tests to an enclosure outlined in UL 1973 Appendix H for lead acid batteries but not specific crush tests. The UL testing absolutely addresses the significant risk of a vehicle accident to ensure batteries will not catch fire or explode and is a critical test for those scenarios. While these severe damage scenarios are not expected for most stationary applications, some installations could undergo crush events. An example is a battery installation in a roadside cabinet or hut. We have even responded to a derailed train impacting a telecom hut battery installation. For chemistries such as lithium or sodium metal halide, the Telcordia GRs call out crush resistance based on UL criteria which uses a force of 9000 pounds at 1 inch per second as shown Figure 3. The test criteria apply to stationary applications. With the unknowns related to chemistries in newer energy storage technologies, some consideration for safety of stationary applications where they may come into extreme damage is warranted.

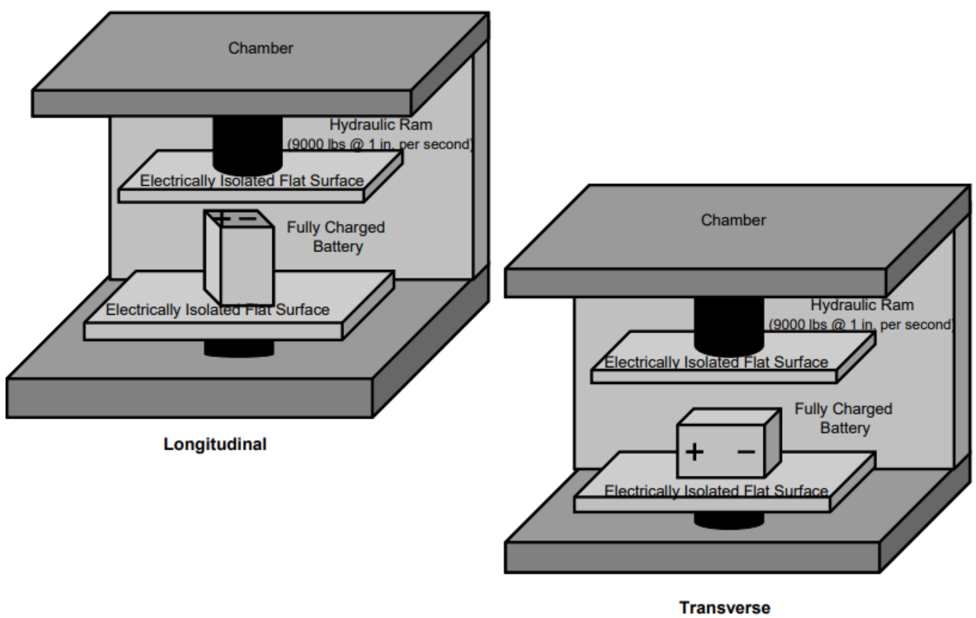


Figure 3. GR-3150 Crush Testing Configuration

Simulated Brush Fire: The Telcordia simulated brushfire exposes batteries to a fast temperature rise that can occur when an enclosure, such as a battery or electrical equipment cabinet is located in the path of a brushfire or wildfire. A fast-moving fire might not cause combustion of the equipment, but a rapid rise in internal temperature is expected. UL 1973 has a thermal cycling test, but this does not simulate the higher temperatures expected for brush fire exposure. Additionally, the UL 1973 testing is for LER Motive and VAP applications only. UL 1973 Appendix E has additional high temperature criteria for lithium cells, but these differ from the temperature exposure in the Telcordia GRs. The Telcordia test ramps the temperature up to 165 °C (329 °F) at a rate of 7 °C per minute. No fire or explosion is permitted although electrolyte leakage is permitted and anticipated during the test. UL 1973 has an actual external fire exposure test that places the battery in a hydrocarbon fuel fire for 20 minutes with the criteria for no explosion or related projectile hazard.

Figure 4. Evaluation of Outside Plant Equipment after Wildfires in New Mexico

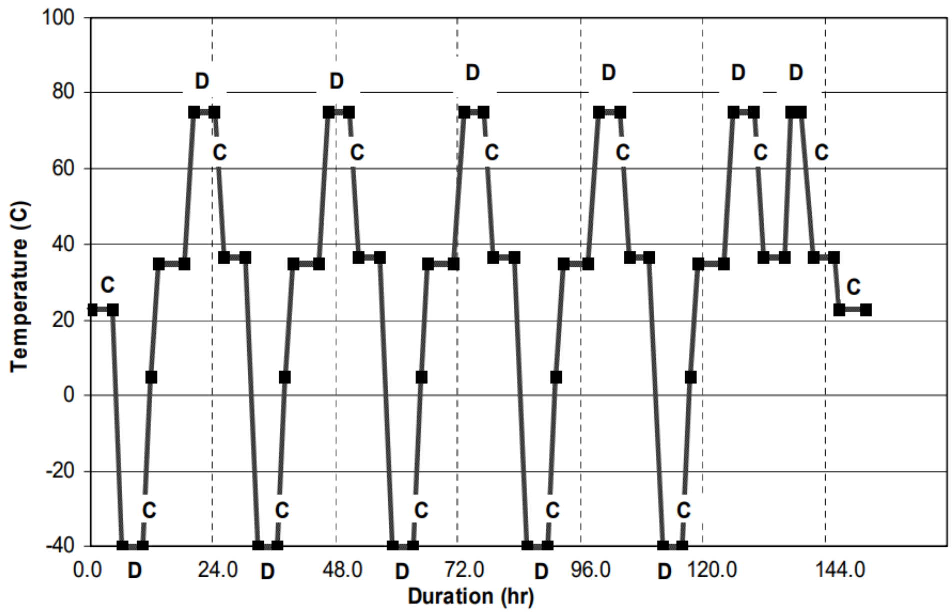
Airborne Contaminants: According to the Telcordia GRs, all batteries must operate for the intended life of the product at the average annual concentration of common airborne pollutants. These conditions may be more of a risk for the electronics associated with BMS systems than for any other battery components. Historically this testing was useful to provide an indication if production changes and material changes on circuit boards would lead to premature corrosion or susceptibility to certain contaminants. If a BMS becomes corroded due to these exposures or other exposures, it is important to determine if the product fails in a safe manner. Batteries without a BMS or active electronics also have a requirement for mixed flowing gas to ensure the metallic hardware shows no adverse effects and that ingress of gases do not cause failures. Equipment deployed in outside plant environments have different and generally higher expected levels of gas concentrations than those indoors. The mixture of gases include chlorine, hydrogen sulfide, sulfur dioxide, and nitrogen dioxide. Figure 5 lists the contaminants of concern in the Telcordia GRs.

Contaminant	Concentration
Airborne particles (TSP - Dichot 15)*	90 $\mu g/m^3$
Coarse particles	50 $\mu g/m^3$
Fine particles	50 $\mu g/m^3$
Water soluble salts	30 $\mu g/m^3$
Sulfates	30 $\mu g/m^3$
Nitrates	12 $\mu g/m^3$
Volatile Organic Compounds (boiling point > 30ºC)	400 ppb 1600 $\mu g/m^3$
Sulfur dioxide	150 ppb
Hydrogen sulfide	40 ppb
Ammonia	50 ppb
Oxides of nitrogen: NO NO_2 HNO_3	 500 ppb 250 ppb 50 ppb
Ozone	250 ppb
Gaseous chlorine (HCl + Cl_2)	6 ppb

Figure 5. Typical Pollutant Exposures in the Atmosphere

While UL 1973 does not call out airborne pollutants or mixed flowing gas testing, UL 9540 has criteria for failure mode and effects analysis so safety following a BMS failure is addressed. Both UL 9540 and UL 1973 specify the BMS cannot be the primary safety device for the battery and that a failure of the BMS will not cause a dangerous condition.

Simulated Telecom Environmental Cycles: When it comes to temperature and humidity exposure, uncontrolled installation environments place great stress on the reliability and performance of the battery system. The telecom environmental cycles for batteries intended for the outside plant are more severe and more numerous than used in traditional GR-63 testing for indoor products in air-conditioned spaces. Simulated Telecom Environmental Cycling includes discharge and re-charge intervals during the test. UL 1973 has thermal cycling testing outlined in Section 38 but limits the criteria to LER and VAP applications not including stationary. There is a cycling test outlined in Annex E11.8 for secondary lithium cells with temperatures up to 85 °C. The UL test specifies no venting, leakage, rupture, fire, explosion, or Open Circuit Voltage (OCV) change greater than 10% of the pre-test value. In an additional thermal test lead-acid cells or multicell batteries are heated to their manufacturer maximum specifications for charging and cannot exceed their designated material specifications.



Charge (C) and discharge (D) battery per Test Procedure 4-3

Figure 6. Simulated Telecommunications Environment Cycles

Short Circuit: A low resistance short between the battery positive and negative terminals for an extended period of time should not cause an explosion or fire. The UL Standard specifies a short-circuit duration until the battery is completely discharged or nearly zero state of charge or until center module temperature peaked and 7 hours elapse. The Telcordia requirements include a 24-hour short-circuit duration as well as a 1-minute duration. While it is not expected to fully re-charge, the 1-minute short circuit requires the battery to be capable of being re-charged to 90% of its original capacity. This assumes no physical damage occurred during the 1-minute short. An additional short-circuit test to the BMS is called out in Telcordia GR-1089. The GR-1089 tests apply short circuits to voltage sources and converters on circuit boards within the BMS. These must be tolerated with no reduction in safety. Also, there should be information available on safety in the event of an internal short circuit.

UL 1973 calls out numerous electrical tests that include electromagnetic immunity, electrical fast transient, electrostatic discharge, surge immunity, overcharge, fast rate charging, and over-discharge in Sections 15 to 27. Some differences in parameters for ESD and surge are found, but overall, there is general agreement. The Telcordia battery GRs have tests to ensure rated battery capacities, limit degradation of capacity after a series of exposures and use conditions, as well as tests for charge retention, shelf life, and life expectancy.

A summary of various environmental, mechanical, and electrical test criteria where there are differences between UL and Telcordia Requirements is presented in Table 1. This is not all inclusive as there are several differences between the various GRs and UL Standards for different chemistries.

Table 1. Comparison Table

Category/Test	UL 1973 / IEC	Telcordia Generic Requirements
Environmental		
Immersion	Section 39 (resistance to moisture)	1% salt water
Salt fog	Section 40, H3.4.1	Battery GRs
Thermal Cycling	Section 38 (LER & VAP only) E11.8	Simulated Telecom Cycles or Operational Temperature & Humidity
Airborne Contaminants	N/A	GR-63 NEBS, Battery GRs
Mechanical		
Impact Drop Test	Section 33 (rack mounted)	GR-63 NEBS, Battery GR, GR-3150
Crush	Section 30 (LER & VAP only), E11.3 Lithium	GR-3176, GR-3181
Vibration	Section 28 (LER & VAP only), E11.6 Lithium	GR-63 NEBS, Battery GRs
Shock	Section 29(LER & VAP only)	N/A
Impact	Section 32	Not performed on battery modules. Cabinets and enclosures utilize similar testing in GR-487, GR-3108, GR-3033
Electrolyte Leakage	Annex C (flowing electrolyte)	GR-4228 VRLA
Electrical		
Short-Circuit (terminals)	Section 17, E11.1 lithium, B2.1 sodium beta	All Battery GRs (1 minute and 24 hour), circuit board short circuits for BMS in GR-1089
Electrostatic Discharge	Section 27.2 +/- 6 kV Contact +/- 8 kV Air	NEBS GR-1089 +/- 8 kV Contact +/- 15 kV Air
Overcharge	Section 46	All Battery GRs
Over discharge	Section 52	All Battery GRs

Category/Test	UL 1973 / IEC	Telcordia Generic Requirements
Emissions and Immunity	Section 27	Batteries with BMS
Charging	N/A	Compatibility with telecom rectifier system
Charge Retention / Shelf Life	N/A	All Battery GRs
UL 9540 unit and module tests align with UL 1973. Additional system level tests and FMEA criteria are added in UL 9540. Fire test information is documented in UL 9540A.		

Safety Tests or Performance Tests

The pass / fail criteria for the UL and Telcordia Standards are similar for safety related test criteria. Performance criteria provided in many of the electrical tests in GRs are intended to ensure battery capacity is not adversely impacted after a series of electrical stresses, mechanical stresses and environmental exposures. In addition, life testing and life test data is required by the GRs. These life tests are designed to assist the end user in selecting a battery chemistry and technology that make economic sense in addition to operational safety. For both UL and GR, pass / fail criteria for each test are specified. These typically include explosion, fire, venting, leakage, rupture, and loss of protection controls as safety criteria. Where specified, operation, capacity and performance are additional passing criteria.

Summary

The requirements for UL Listings for energy storage systems in Fire and Building Codes are beneficial for the safety of ESS installations. Battery system users should be aware of the topics addressed by listing criteria and where additional risks or exposures not well addressed by the listing are anticipated. To account for these risks, users should consider additional information, test data, or discussions with the manufacturer to ensure the product will withstand anticipated disaster conditions safely. Areas prone to flooding, marine environments, temperature extremes, drops from height, or other installation environments should be reviewed. For common telecommunications deployments in the outside plant or in existing buildings, safety and performance based on applicable generic requirements should be considered.

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