

OPERATIONAL GUIDELINES
FOR HANDLING USED BATTERIES
IN THE OFF-GRID SOLAR SECTOR

BATTERY PA

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Authors

Federico Magalini
Alexander Clarke
Josephine Courtois
Marco Ottaviani

With thanks to Veronica Di Bella and Nomsa Fulbrook-Kagwe of CDC Group for their contribution to these guidelines.

These guidelines were made possible through the support of CDC Plus, CDC Group's technical assistance facility, funded by UK Aid, which is funded by the UK Government's Foreign, Commonwealth and Development office.



1 INTRODUCTION

The off-grid solar (OGS) sector in Africa is growing rapidly thanks to falling costs, combined with improvements in the energy efficiency of end-use technologies. A new World Bank Group and GOGLA report¹ published in March 2020 shows that the OGS industry has grown into a \$1.75 billion annual market, providing lighting and other energy services to 420 million users in Africa.

Moreover, the OGS sector is instrumental for the achievement of the United Nations Sustainable Development Goal (SDG) 7, which aims to provide universal access to modern energy and increase the global percentage of renewable energy.

Improvements in efficiency and costs of OGS systems have been continuously achieved due to technological advancements of batteries, which are the most expensive component of an OGS device.

OGS devices commonly use both lithium-ion and lead-acid batteries. Historically, these technologies almost exclusively used lead-acid batteries, owing to their wide availability, robustness and cost-effectiveness.

In recent years, development of lithium-ion battery technologies, falling prices and increased availability have resulted in a switch from lead-acid to lithium-ion batteries. Lithium-ion batteries are more efficient at storing power per unit mass and have a longer lifecycle compared to the older lead-acid technology.



Despite such benefits and market success, there is an increasing concern about the end-of-life management of off-grid energy products, particularly batteries.

All battery types contain substances with potentially hazardous effects. Lead-acid batteries have the highest toxicity potential and they commonly find their way to recycling facilities even if, the standard treatment of lead-acid batteries in many countries is far from environmentally sound.

Although the chemical composition of lithium-ion batteries can vary significantly between different types and sub-types, heavy metals in lithium-ion batteries are absent.

Lithium-ion batteries have low toxicity and low recycling value (except for those containing cobalt) and are unattractive for local and global recycling markets. As a result, they are more likely to be disposed of in an uncontrolled manner.

This document was created as part of a CDC-funded pilot project in Kenya, aimed at blueprinting a local collection and treatment solution for OGS products.

This guide serves as support to organisations operating in the off-grid sector with:

- storage of batteries;
- handling and disassembly;
- firefighting procedures and good practices; and
- transport of used batteries, which trigger requirements related to packaging, waste classification and labelling, as well as training for staff.

2 STORAGE OF USED BATTERIES

For the waste holder or handler, the risks associated with the storage of used batteries differ in relation to their electrochemistry (see Table 1). To alleviate these risks, batteries

must be separated and stored in areas delimited and identified with labels indicating: lead-acid batteries, Nickel-Cadmium batteries or lithium-ion batteries.

Table 1: Risks associated with different battery electrochemistry

Types of battery hazard	Lead-acid	Nickel-Cadmium	Lithium-ion
Risk of short circuit	Yes	Yes	Yes
Combustibility of the battery case	Yes	Yes	No
Flammability of the electrolyte	No	No	Yes
Electrolyte	Aqueous corrosive dilute solution of sulfuric acid pH 1	Aqueous corrosive dilute solution of sodium or potassium hydroxide pH 14	Non-aqueous flammable
Dangerous reaction from the mixing of electrolyte	Yes	Yes	Yes
Suitable containers for transport (see 5)	Battery boxes, plastic containers	Battery boxes, plastic containers	Boxes and drums (PG II approved required)

With lithium-ion batteries, there is a specific risk to be aware of. In the event of a short circuit, a thermal runaway can start with the rapid disassembly and fire of its elements. The thermal runaway is an uncontrolled reaction that increases the internal pressure of the cells making up the battery, with the consequent leakage of flammable electrolytes, smoke, fire and explosions.

Such a fire is easily generated, but difficult to put out. Burned batteries reach temperatures of 700-800 °C and can have a cascading effect when the fire spreads to neighbouring cells.

A recent report prepared in 2020 by the main European recycling associations² clearly highlighted the increasing risks

related to lithium batteries, with 76% of respondents reporting an increase of the frequency of thermal incidents at their facilities in an assessment conducted over the last two years. In fact, seven respondents out of 44 reported hot spots occurring on a daily basis.

The majority of thermal incidents occurred in the transport phase (30%) and in the treatment of appliances phase (39% in the initial dismantling and 21% in the subsequent mechanical process).

To understand if a thermal runaway is about to occur, the temperature can rise within the battery cells. It is therefore recommended to use thermal cameras to constantly monitor the temperature of stored batteries, and alert the

¹ See: 'Off-Grid Solar Market Trends Report 2020', published at lightingglobal.org.

² See: 'Characterisation of fires caused by batteries in WEEE', published at weee-forum.org.

2 STORAGE OF USED BATTERIES

fire-fighting teams in the case of rising localised temperatures.

Given the types of hazard outlined, it is important to store batteries appropriately and limit risk as much as possible.

After removal from equipment, batteries must be stored in designated and controlled areas that have suitable characteristics to keep the batteries in good condition, before being sent to an intermediate process facility or to the recycling facility.

An automatic shutdown system can also be installed, and large quantities of water can be made ready to cool batteries and reduce the likelihood of cell-to-cell thermal propagation.

Battery storage characteristics are as follows:

- Protected from direct sunlight, rain, excessive humidity (not higher than 70%) and high temperatures (do not exceed 40 °C).
- Well-ventilated premises, where 3-4 air changes per hour are guaranteed.
- Areas not subject to flooding.
- Located far from sites of flammable materials, electrical substations and generators.
- Premises that are easy to evacuate and accessible by emergency teams and vehicles.

3 HANDLING AND DISASSEMBLY OF USED BATTERIES

All exhausted batteries must be handled with care to prevent short circuits leading to the battery burning or the container rupturing, resulting in electrolyte leakage. Any electrolyte leaks can be absorbed with a suitable absorbent material.

Handling and preparation of the Solar Home System (SHS) and batteries for the subsequent treatment and dismantling phases must be carried out by personnel trained in the safety of charged equipment and batteries (including high voltage in some cases).

Lithium-ion batteries that show signs of damage or are experiencing temperature fluctuations must be isolated and monitored to verify the onset of thermal runaway. In order to avoid fire propagation, this isolation should take place in areas sufficiently away from storage areas.

Exhausted batteries can still have a high residual charge, which can be dangerously released in the event of a short circuit. Therefore, all disassembly operations must be performed by personnel trained in safety and management of live equipment, according to the instructions provided by the battery manufacturer.

4 FIREFIGHTING PROCEDURES AND GOOD PRACTICES

Despite the operational and technical measures companies can take with the recycling of waste electrical and electronic equipment (WEEE), dangers remain from lithium-ion batteries due to their potential to set large volumes of combustible materials on fire. Incidents like hotspots, sparks or small fires still occur regularly with the handling and storage of WEEE.

The European Electronics Recyclers Association (EERA)³ outlines several measures aimed at preventing incidents turning into full-scale fires. It recommends organisations make the following considerations:

- A mobile scrap handler with a long extension arm or large capacity wheel loader allows for the speedy separation of burning material to a safe area.
- High-volume sprinkler systems or turret extinguishing systems should be turned on immediately when detecting a problem. Fixed installations are preferable over fire hoses that must be unrolled and operated manually. Portable fire extinguishers are not suitable as their extinguishing capacity is too small and the operator must go too near to the fire.

- It is essential to 'flood' fires with large volumes of water to keep surrounding materials cool.
- An alarm system (preferably automatic) must be in place to warn on-site staff of the danger, and to alert external firefighting services. External help must be alerted immediately to save time until their arrival.
- Management must accept potentially false alarms as preferable to delayed action.
- External firefighting services should be familiar with the location and layout of the site. It is advised that regular joint exercises with the facilities staff and external fire services take place. Firefighting strategies must be discussed with external fire services, which will often want to extinguish fires by using large amounts of water.
- Staff should be trained regularly in the recognition of dangers and emergency response in case of fires.
- Only staff trained in the use of firefighting equipment should remain to fight a fire, all other staff should be directed to assembly points.
- There must be a clear commitment by management and staff to withdraw from dangers from fire, heat, smoke or collapsing structures.

5 TRANSPORT OF USED BATTERIES AND EQUIPMENT

Irrespective of the status of goods (new ones) or waste (used/exhausted), transport of batteries falls within the scope of dangerous goods transport regulations. Therefore, specific requirements are expected in the areas of:

- packaging;
- waste classification;
- marking, labelling and transport documents; and
- training.

During transport, cells and batteries must be protected to prevent short circuits, including a protection against contact with conductive materials within the same packaging.

Examples of protection against short circuits include, but are not limited to:

- individual protection of the battery terminals;
- inner packaging to prevent contact between cells and batteries;
- batteries with recessed terminals designed to protect against short circuits; or
- the use of an electrically non-conductive and non-combustible cushioning material to fill empty space between the cells or batteries in the packaging.

³ See: 'Sharing experienced and best practices with batteries in WEEE', published by European Electronics Recyclers Association.

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TRANSPORT OF USED BATTERIES AND EQUIPMENT

The collection procedures, transport to treatment and recycling facilities must simultaneously satisfy all the regulations in force for the protection of health, environment and transport safety. For this reason, the preparations for shipment must be carried out by personnel trained in the transport of dangerous goods. Batteries must be:

- correctly classified;
- packed in suitable packaging;
- transported by authorised carriers; and
- packaged appropriately – marked and labelled to highlight the presence of dangerous goods.

The transport document for dangerous goods and waste must be prepared and the documents required for the transport of waste must accompany the transport.

Individuals involved in the transportation of dangerous called (termed 'participants') should take appropriate measures to avoid damage or injury, and to minimise any potential hazardous effects from their cargo.

When there is an immediate risk to public safety, the participants should immediately notify the emergency services and make available the necessary information.

Classification of used batteries and equipment

Depending on the type, batteries can be transported in approved packaging or in suitable containers to retain any small electrolyte losses. We can make an important subdivision based on the nature of the electrolyte used, whether aqueous or non-aqueous (see Table 1), because they largely determine the danger characteristics in case of leakage from the battery container.

A further subdivision system outlined by the Basel Convention (see Table 2) is based on the characteristics of hazards to the environment and to humans from battery waste. Batteries are classified as hazardous if they contain heavy metals (Pb and Cd). Batteries that contain no heavy metals are classed as non-hazardous. Both types are sent for treatment and recycling with different management requirements and documentation.

Batteries also need to be classified according to their risk/hazard characteristics for transport (road, maritime and air transport modes), which is the potential danger derived from leaks, short-circuit, rapid disassembly and fire. These classifications are as follows:

- **Lead-acid batteries**
 - o UN 2794, BATTERIES, WET, FILLED WITH ACID
 - o UN 2800, BATTERIES, WET, NON SPILLABLE
- **Nickel-Cadmium batteries**
 - o UN 2795, BATTERIES, WET, FILLED WITH ALKALI
 - o UN 2800, BATTERIES, WET, NON SPILLABLE
- **Lithium-ion batteries**
 - o UN 3480 LITHIUM ION BATTERIES
 - o UN 3481 LITHIUM ION BATTERIES CONTAINED IN EQUIPMENT

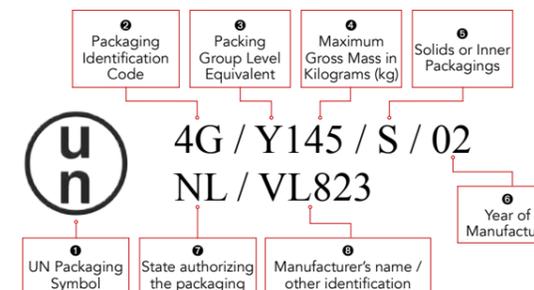
Packaging and labelling

Batteries shall be packed in good quality packaging, strong enough to withstand shocks and loadings normally encountered during carriage, including trans-shipment between cargo transport units and warehouses, as well as removal from a pallet or overpack.

Packaging shall be sealed so as to prevent any loss of contents during transport. No residue of dangerous goods shall adhere to the outside of the packaging.

Approved packaging shall be manufactured and tested under a quality assurance programme that satisfies the competent authority and conforms to the original prototype tested.

The packaging should bear marks which are durable, legible and readily visible, constituted by a sequence of symbols, letters and numbers, such as the example shown here:



For plastics-approved packaging, the period of use permitted for the carriage of dangerous goods shall be five years from the date of manufacture reported in United Nations (UN) packaging marks.

The goods should be classified according to UN nomenclature. The UN number preceded by the letters "UN" shall be clearly and durably marked on each package. Dimension of the mark shall be at least 12 mm high and shall be readily visible and legible and shall be able to withstand open weather exposure without a substantial reduction in effectiveness.

For packages of 30 litres capacity or less, or of 30 kg maximum net mass, marks shall be at least 6 mm in height.

EXAMPLES:



Labels shall be in the form of a square set at an angle of 45° (diamond-shaped) with minimum dimensions of 100 mm by 100 mm, except in the case of small packages that can only bear smaller labels; this exception is not valid for air transport. They shall have a line 5 mm inside the edge and running parallel with it.



Lead-acid batteries
Nickel-Cadmium batteries



Lithium-ion batteries

The packaging instructions for dangerous goods, corresponding to the various types of batteries, must be strictly followed.

ADR 2021 regulation⁴ define specific packing instructions for waste Lead-acid batteries (P801(2)) and Lithium-ion batteries (P909).

Table 2: Subdivision system of batteries outlined by the Basel Convention and European Waste Catalogue

	Basel Convention	European Waste Catalogue
Hazardous wastes: Lead-acid batteries Nickel-Cadmium batteries	A1160: Waste Lead-acid batteries, whole or crushed A1170: Unsorted waste batteries excluding mixtures of only list B batteries Waste batteries not specified on list B containing Annex I constituents to an extent to render them hazardous	16 06 01* Lead-acid batteries 16 06 02* Nickel-Cadmium batteries
Non-hazardous wastes: Lithium-ion batteries	B1090: Waste batteries conforming to a specification, excluding those made with Lead, Cadmium or Mercury	16 06 05 other batteries and accumulators

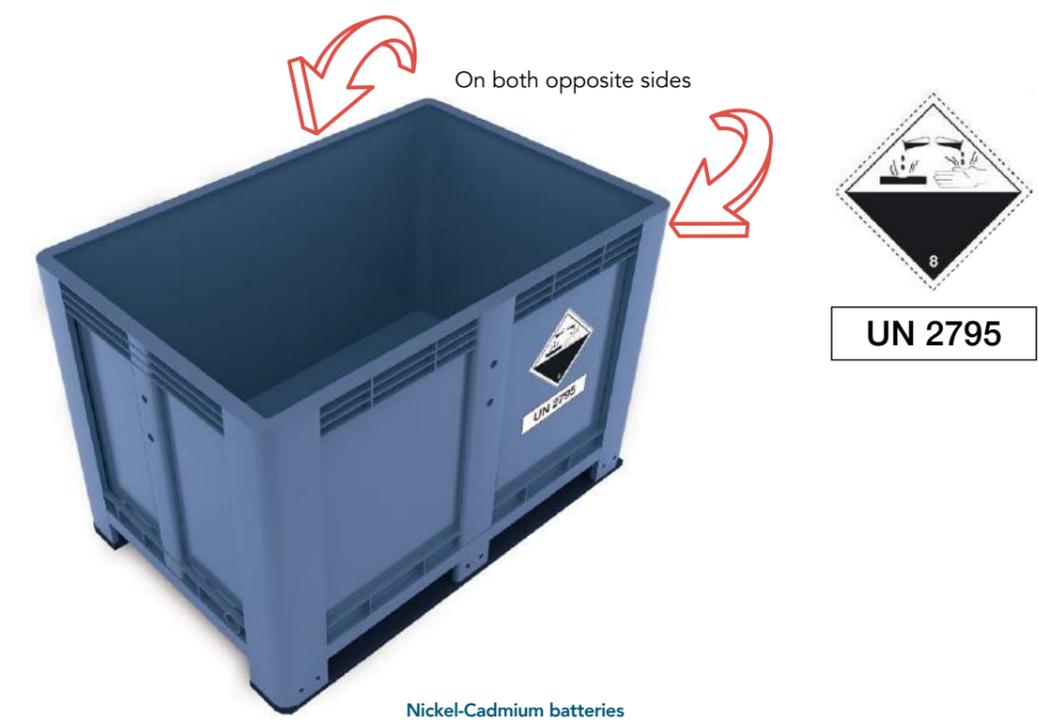
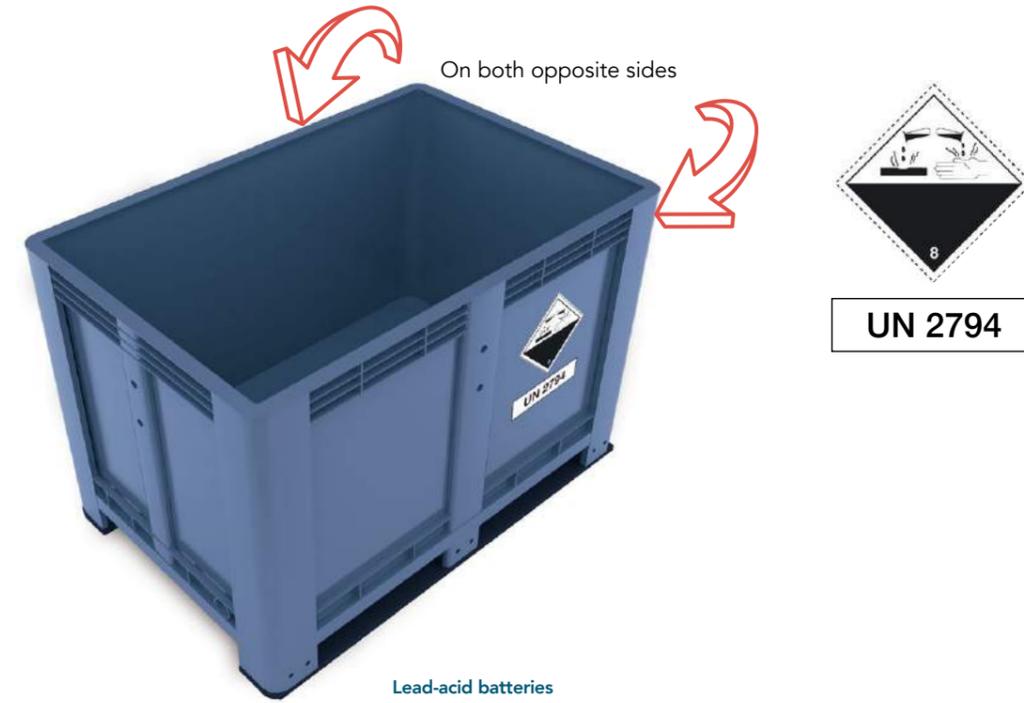
⁴ See: Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), published by the United Nations Economic Commission for Europe.

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TRANSPORT OF USED BATTERIES AND EQUIPMENT

Table 3: Packing instructions P801(2) from ADR 2021 for Lead-acid and Nickel-Cadmium batteries

P801(2)	PACKING INSTRUCTION	P801(2)
This instruction applies to UN nos. 2794, 2795 and 3028 and used batteries of UN no. 2800.		
(2) Stainless steel or plastic bins may also be used to carry used batteries. Additionally, the following conditions shall be met:		
(a)	The bins shall be resistant to the electrolyte that was contained in the batteries;	
(b)	The bins shall not be filled to a height greater than the height of their sides;	
(c)	The outside of the bins shall be free of residues of electrolyte contained in the batteries;	
(d)	Under normal conditions of carriage, no electrolyte shall leak from the bins;	
(e)	Measures shall be taken to ensure that filled bins cannot lose their content;	
(f)	Measures shall be taken to prevent short circuits (e.g. batteries are discharged, individual protection of the battery terminals, etc.); and	
(g)	The bins shall be either: (i) covered; or (ii) carried in closed or sheeted vehicles or containers.	



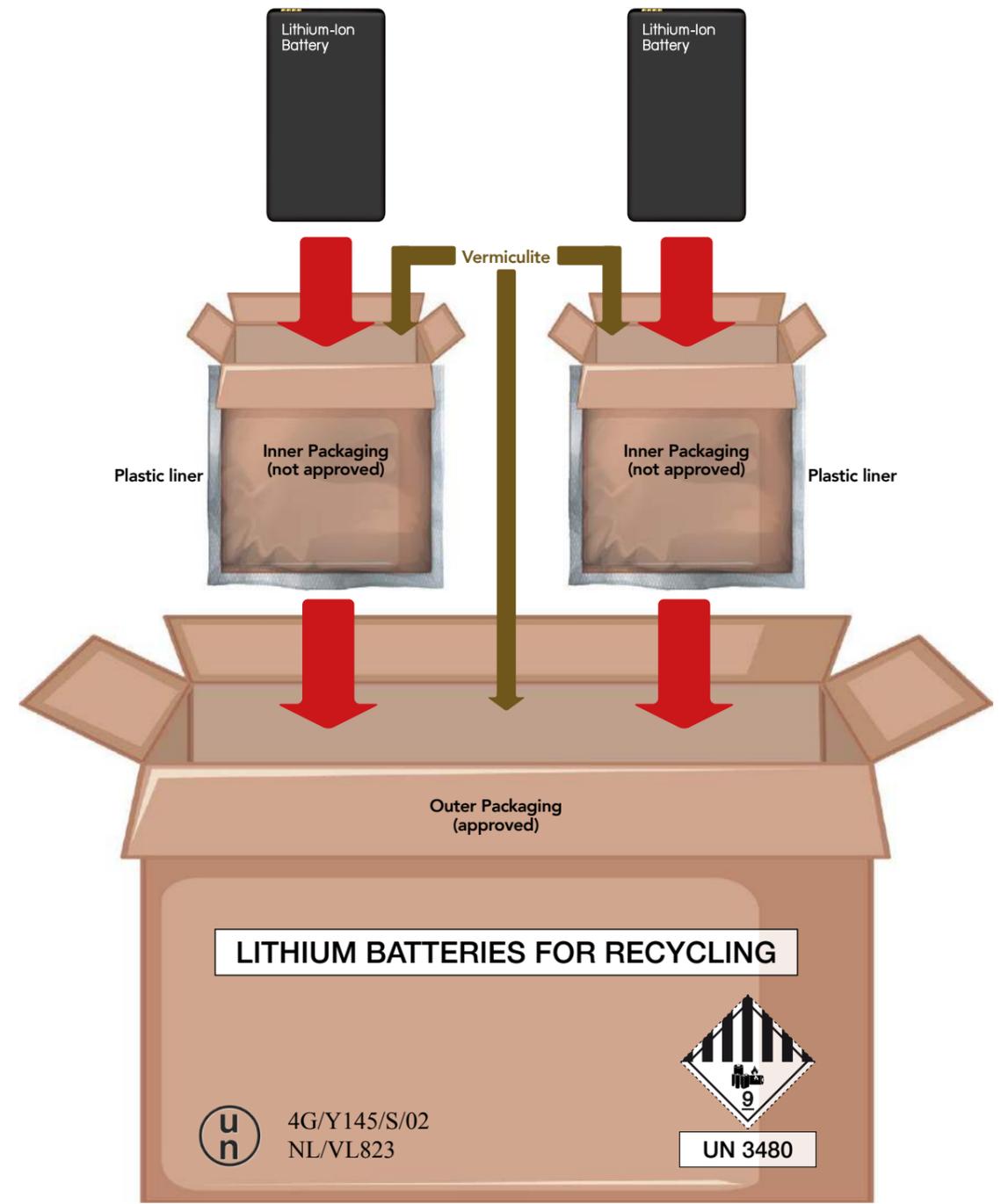
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TRANSPORT OF USED BATTERIES AND EQUIPMENT

Table 4: Packaging instructions from ADR for lithium batteries

P909	PACKING INSTRUCTION	P909
This instruction applies to UN Nos. 3090, 3091, 3480 and 3481 carried for disposal or recycling, either packed together with or packed without non-lithium batteries.		
(1)	<p>Cells and batteries shall be packed in accordance with the following:</p> <p>(a) The following packagings are authorised, provided that the general provisions of 4.1.1 and 4.1.3, are met: Drums (1A2, 1B2, 1N2, 1H2, 1D, 1G); Boxes (4A, 4B, 4N, 4C1, 4C2, 4D, 4F, 4G, 4H2); and Jerricans (3A2, 3B2, 3H2).</p> <p>(b) Packagings shall conform to the packing Group II performance level.</p> <p>(c) Metal packagings shall be fitted with an electrically non-conductive lining material (e.g. plastics) of adequate strength for the intended use.</p>	
(2)	<p>However, lithium-ion cells with a Watt-hour rating of not more than 20Wh, lithium-ion batteries with a Watt-hour rating of not more than 100Wh, lithium metal cells with a lithium content of not more than 1g and lithium-metal batteries with an aggregate lithium content of not more than 2g may be packed in accordance with the following:</p> <p>(a) In strong outer packaging up to 30kg gross mass meeting the general provisions of 4.1.1, except 4.1.1.3, and 4.1.3.</p> <p>(b) Metal packagings shall be fitted with an electrically non-conductive lining material (e.g. plastics) of adequate strength for the intended use.</p>	
(3)	For cells or batteries contained in equipment, strong outer packagings constructed of suitable material, and of adequate strength and design in relation to the packaging capacity and its intended use, may be used. Packagings need not meet the requirements of 4.1.1.3. Equipment may also be offered for carriage unpackaged or on pallets when the cells or batteries are afforded equivalent protection by the equipment in which they are contained.	
(4)	In addition, for cells or batteries with a gross mass of 12kg or more employing a strong, impact resistant outer casing, strong outer packagings constructed of suitable material and of adequate strength and design in relation to the packaging's capacity and its intended use, may be used. Packagings need not meet the requirements of 4.1.1.3.	
Additional requirements:		
1	Cells and batteries shall be designed or packed to prevent short circuits and the dangerous evolution of heat.	
2	<p>Protection against short circuits and the dangerous evolution of heat includes, but is not limited to:</p> <ul style="list-style-type: none"> - Individual protection of the battery terminals, - Inner packaging to prevent contact between cells and batteries, - Batteries with recessed terminals designed to protect against short circuits, or - The use of an electrically non-conductive and non-combustible cushioning material to fill empty space between the cells or batteries in the packaging. 	
	Cells and batteries shall be secured within the outer packaging to prevent excessive movement during carriage (e.g. by using a non-combustible and electrically non-conductive cushioning material or through the use of a tightly closed plastics bag).	

Package shall bear "LITHIUM BATTERIES FOR RECYCLING" or "LITHIUM BATTERIES FOR DISPOSAL" with lettering size of at least 12 mm high



UN approved packaging mark

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TRANSPORT OF USED BATTERIES AND EQUIPMENT

Obligations of the main participants

All the persons involved in the shipment of the batteries play a specific role and requirements are defined as follow.

Consignor/Loader

The consignor of dangerous goods is required to hand over for carriage only consignments that conform to the requirements of the following transport regulation:

- ascertain that the dangerous goods are classified and authorised for carriage;
- furnish the carrier with information and data in a traceable form and, if necessary, the required transport documents and accompanying documents (authorisations, approvals, notifications, certificates, etc);
- use only packaging approved for and suited to the carriage of the substances concerned and bearing the marks prescribed by the UN;
- comply with the requirements on the means of dispatch and on forwarding restrictions; and
- when loading packages, comply with the prohibitions on mixed loading, taking into account dangerous goods already in the vehicle or large container and requirements concerning the separation of foodstuffs, other articles of consumption or animal feedstuffs.

Carrier

The carrier shall ascertain:

- that the dangerous goods to be carried are authorised for carriage;
- that all information prescribed, related to the dangerous goods to be carried, has been provided by the consignor before carriage, that the prescribed documentation is on board the transport unit;
- visually that the vehicles and loads have no obvious defects, leakages or cracks, missing equipment, etc.;
- verify that the vehicles are not overloaded;
- that the placards, marks and orange-coloured plates prescribed for the vehicles have been affixed; and
- that the equipment prescribed by the transport regulation for the transport unit, vehicle crew and certain classes is on board the transport unit.

If the carrier observes an infringement of the requirements of the transport regulation, the consignment shall not be forwarded until the matter has been rectified. If, during the journey, an infringement potentially jeopardising the safety of the operation is observed, the consignment shall be halted as soon as possible, bearing in mind the requirements of traffic safety, of the safe immobilisation of the consignment, and of public safety. The transport operation may only be continued once the consignment complies with applicable regulations.

The competent authority(ies) concerned by the rest of the journey may grant an authorisation to pursue the transport operation. The carrier shall provide the vehicle crew with the instructions in writing as prescribed in the ADR.

Consignee/Unloader

Before and during unloading, check whether the packaging, the vehicle or container have been damaged to an extent which would endanger the unloading operation.

The consignee has the obligation to verify, after unloading, that the requirements of transport regulations have been complied with.

Training

Safety depends on the correct execution of the required procedures. Therefore, it is of great importance to train the personnel who contribute to the transport and handling of dangerous goods. Not following the guidelines outlined within this document could result in a severe impact on the environment and public health.

This information is likely to be new to some authorities, recyclers and many used battery handlers in developing countries. It is therefore vitally important that training is given to improve the knowledge and understanding of those on the frontline, dealing with used batteries on a day-to-day basis.

The training should be periodically supplemented with refresher training to take account of changes in regulations which typically occur every two years.

Records of training should be kept by the employer and made available to the employee, or competent authority, upon request.

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