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Use and maintenance of KASI-system lithium batteries

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Use and maintenance of KASI-system lithium batteries

This thesis was completed as an assignment for Combitech Oy. The objective of the thesis was to establish a database for the lithium batteries utilized in the KASI system by the target groups, including the Finnish Defense Forces and Saab Technologies. The thesis primarily focuses on three distinct types of lithium batteries and their handling, storage, maintenance, and transportation.

There is no official guide or dataset available for the use and maintenance of lithium batteries in the KASI system. Therefore, the aim was to create a dataset with the assistance of various sources. The sources employed in the thesis mainly include the Finnish Safety and Chemical Agency, Tukes, the guidelines provided by the Finnish Defense Forces on lithium batteries, instructions from the battery manufacturer SAFT, and the university database Turku AMK FINNA.

Keywords:

Lithium batteries, Handling of lithium batteries, Maintenance of lithium batteries, Storage of lithium batteries, Transport of lithium batteries

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Eero Salminen

KASI-järjestelmän litiumakkujen käyttö- ja ylläpito

Opinnäytetyö tehtiin toimeksiantona Combitech Oy:lle. Opinnäytetyön tavoitteena oli luoda tietokokonaisuus KASI-järjestelmässä käytetyistä litiumakuista niitä käyttäville kohderyhmille, kuten puolustusvoimille ja Saab-teknologialle. Opinnäytetyö keskittyy pääasiassa kolmeen erityyppiseen litiumakkuun ja niiden käsittelyyn, varastointiin, ylläpitoon ja kuljetukseen.

KASI-järjestelmästä ei ole virallista ohjetta tai tietokokonaisuutta litiumakkujen käytöstä ja huollosta, joten tavoitteena oli luoda tietokokonaisuus eri lähteiden avulla. Lisäksi opinnäytetyössä vertaillaan kolmen eri päälähteen eroavaisuuksia. Opinnäytetyössä käytetyt lähteet ovat pääosin Turvallisuus- ja kemikaalivirasto Tukes, Puolustusvoimien ohjeet litiumakuista, akkuvalmistajan eli SAFT:in ohjeet sekä koulun tietokanta Turku AMK FINNA.

Asiasanat:

Litiumakut, Litiumakkujen käsittely, Litiumakkujen ylläpito, Litiumakkujen varastointi, Litiumakkujen kuljetus

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List of abbreviations

ECOSOC	Economic and Social Council
ICAO	The International Civil Aviation Organization
IMO	The International Maritime Organization
ECE	The United Nations Economic Commission for Europe
OTIF	Intergovernmental Organisation for International Carriage by Rail
TI	Transport of Dangerous Goods by Inland Waterways
DGR	Dangerous Goods Regulations
IMDG	International Maritime Dangerous Goods
ADR	European Agreement concerning the International Carriage of Dangerous Goods
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail

1 Introduction

The client for this thesis is Combitech Oy, a company owned by SAAB AB. Combitech provides service and maintenance services for Saab, which has supplied its services to the Finnish Defense Forces. The Finnish Defense Forces utilize the KASI system, which is maintained by Combitech. The KASI system is a simulator system that enables realistic training through simulation equipment. KASI stands for Double Sided Simulator System. Within the KASI system, simulation devices operate with three types of lithium batteries: single-cell rechargeable lithium batteries, two-cell rechargeable lithium batteries, and three-cell rechargeable lithium batteries.

Instructions for the use and maintenance of lithium batteries include guidelines from the Finnish Safety and Chemicals Agency, Tukes, instructions from the Finnish Defense Forces, and instructions from the battery manufacturer SAFT, which produces the batteries for SAAB. However, there is no a single official set of instructions for the use and maintenance of lithium batteries.

The aim of this thesis was to compile information from various sources to create a comprehensive resource on the use and maintenance of lithium batteries. The goal was for the Finnish Defense Forces and battery manufacturer SAFT to be able to utilize this information regarding the use and maintenance of lithium batteries.

The purpose is to first provide general information on the use and maintenance of lithium batteries and then delve into greater detail about the three different types of lithium batteries used in the KASI system. The thesis also aims to make observations regarding whether the information from different sources on the use and maintenance of lithium batteries differs in any way.

The thesis primarily focuses on the storage, transport, handling, and maintenance of lithium batteries.

2 Principle of lithium batteries

Lithium batteries consist of a negative and positive electrode and an electrolyte. The electrodes are called the anode and cathode. The function of the electrolyte is to isolate the positive and negative electrodes from each other, allowing lithium ions to move between the anode and the cathode. The operating principle of the battery is that when the battery discharges, electrons are released from the anode during oxidation, and they travel to the cathode, creating an electric current between them. When the electrons arrive at the cathode, a reduction reaction occurs as the cathode receives electrons. When charging the battery, the principle is exactly the same, but the reaction takes place in the opposite direction, i.e., the electrons travel from the cathode to the anode. Lithium batteries have been in use since the 1990s. (Dahlin & Strom 2010, vii-1.)

2.1 Applications of lithium batteries

Lithium battery technology is extremely popular, and one of the reasons for this is that they can be used in various practical applications. Lithium batteries are especially popular in consumer electronics, such as smartphones, tablets, or laptops. However, lithium batteries are not only used in consumer electronic devices, as they are also used as a backup power source for electric cars or solar panel systems. (Scrosati etc. 2013, ix-xi.)

2.2 Advantages and disadvantages of lithium batteries

In general, lithium batteries are quite safe, and incidents resulting from them are rarely reported. Lithium batteries are widely used for various purposes, and if handled properly, they are quite safe. Lithium batteries are also generally quite small, so working with them is quite convenient. (Tukes 2019, 6-7.)

Even though lithium batteries are very safe with proper handling, their users should also have sufficient knowledge of the dangers associated with batteries, what kind of danger mechanisms exist in batteries, and under what conditions and how it is safe to use, maintain, and transport them. In addition, the user must know how to act in the event of a dangerous situation. Various dangers are associated with lithium batteries, e.g., fire hazards, chemical hazards, explosion hazards, and electric shock hazards. In particular, the risk of fire is the greatest of those dangers, and it is based on the fact that when packing a large amount of energy into a small space, the risk of the energy being released uncontrollably cannot be avoided. (Tukes 2019, 7-8.)

2.3 Disposal of lithium batteries

Lithium batteries and devices containing them require proper disposal and recycling due to the risks they pose. Such batteries should not be placed in regular household waste bins or recycling containers for several reasons. Firstly, lithium-ion batteries can pose a fire hazard if they become damaged or swollen. This danger is associated with chemical reactions inside the battery that can trigger a fire. Additionally, damaged batteries can be hazardous when handled and may leak chemicals or even explode if mishandled. Secondly, lithium-ion batteries contain toxic substances that can cause environmental harm if they are allowed to spread in landfills. (EPA 2023.)

If a lithium-ion battery is damaged or swollen, a careful assessment of the situation is necessary. If there is no immediate risk of a fire, it is advisable to contact the product manufacturer, the retailer, or the local waste management authority to obtain instructions for proper disposal. The damaged battery or device should be stored in a secure location, away from flammable materials. One approach is to place the lithium-ion battery in a container filled with a fire-extinguishing substance, such as sand or cat litter. It is important to note that damaged lithium-ion batteries should never be placed in regular household waste bins or recycling containers, as this could pose a risk during transportation or at the landfill. Instead, these batteries should be taken to

specialized recycling facilities or hazardous waste recycling centers, as outlined in the provided instructions. This ensures that the batteries are handled appropriately and, at the same time, reduces environmental impacts. (EPA 2023.)

2.4 Transportation and storage of lithium batteries

Lithium batteries are classified as hazardous substances in transport. Various United Nations organizations such as the Economic and Social Council (ECOSOC), the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), and the United Nations Economic Commission for Europe (ECE) work at the core of transport regulations, as well as the Intergovernmental Organisation for International Carriage by Rail (OTIF) in rail transport. VAK transport regulations, such as Transport of Dangerous Goods by Inland Waterways (TI), Dangerous Goods Regulations (DGR), International Maritime Dangerous Goods (IMDG), European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), and Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), are based on the organizations in question. International regulations are generally followed in Europe. (Tukes 2019, 36-41.)

These organizations and regulations focus on the safe transport of hazardous materials. Their aim is to establish standards and rules that ensure the protection of people, the environment, and property during the transportation of hazardous materials. These regulations are based on international cooperation and agreements that define how hazardous materials can be safely transported across different modes of transportation and regions around the world.

Lithium batteries can be stored either in a separately designated and delimited area for battery storage, in another storage facility in a clearly demarcated area, or in another storage facility in its own area. It is possible to store batteries either as individual cells or as ready-to-use batteries. When storing batteries, it

is important to ensure fire-safe and dry conditions where the temperature is optimal for the batteries. (Tukes 2019, 47.)

2.5 ADR 188

Lithium batteries fall under regulation ADR 188. ADR stands for "Accord européen relatif au transport international des marchandises Dangereuses par Route," which translates to "European Agreement concerning the International Carriage of Dangerous Goods by Road" in English. ADR is an international agreement that governs the safe transport of dangerous goods by road in Europe. ADR 188 refers to a particular section in the annex of the ADR agreement that deals with the transportation requirements and guidelines for a specific dangerous substance. The number 188 defines the rules and regulations related to the transportation of this particular substance, including packaging requirements, labeling, and safety measures. (TNT 2017, 2-4.)

3 Kasi-system lithium batteries

The lithium batteries within the KASI system comprise various battery types, but in this context, the focus is on three distinct types: a single-cell battery, a two-cell battery, and a three-cell battery. These batteries are rechargeable lithium batteries designed for use in simulator equipment utilized by the defense forces.

3.1 Single-cell battery

A single-cell lithium battery consists of one lithium-ion or lithium-polymer cell. It is compact and provides a single voltage. Single-cell batteries are well-suited for smaller devices. (Saab training systems 2023.)

In the KASI system, single-cell lithium batteries are used e.g. for simulator weapons, simulator explosives and shooting boards. When transporting single-cell batteries, a dangerous goods transport sticker must be used. (Saab training systems 2023, 3.)

The single-cell lithium battery has a capacity of 6.8 amp hours and has 3.75 volts. The battery in question is charged with a 4.1 or 4.2 volt battery charger. The capacity of a lithium battery determines the amount of energy it can store, commonly measured in milliampere-hours (mAh) or ampere-hours (Ah). A higher capacity means longer usage time. Voltage, on the other hand, indicates the battery's output voltage, which generally remains stable. (Saab training systems 2023, 5.)

The following is a figure of a single-cell lithium battery from the KASI system.

Figure 1 KASI-system single cell lithium battery

3.2 Two-cell battery

A two-cell lithium battery consists of two lithium cells connected in series. This provides a higher voltage compared to a single-cell battery. (Saab training systems 2023.)

In the KASI system, two-cell lithium batteries are mainly used for simulator vests, but also for a few other simulator devices. The battery in question is clearly the most popular in the KASI system. The batteries in question must be transported in a plywood box under the mitigating ADR special regulation 188. ADR stands for the European Agreement on the International Road Transport of Dangerous Goods. (Saab training systems 2023.)

The two-cell lithium battery has a capacity of 13.6 amp hours and has 3.65 volts. The battery in question is charged with a 4.1 or 4.2 volt battery charger. (Saab training systems 2023, 5.)

The following is a figure of a single-cell lithium battery from the KASI system.

Figure 2 KASI-system two-cell lithium battery

3.3 Three-cell battery

A three-cell lithium battery consists of three lithium cells connected in series. It provides an even higher voltage and more capacity than the previous two. (Saab training systems 2023.)

The KASI-system's three-cell lithium batteries are really only used for Anti-Tank simulator weapons. The batteries in question have a different charger than the two aforementioned batteries. Three-cell batteries must also be transported in a plywood box under the mitigating ADR special regulation 188. (Saab training systems 2023, 5.)

The three-cell lithium battery has a capacity of 6.1 amp hours and has 11.25 volts. (Saab training systems 2023, 6.)

The following is a figure of a single-cell lithium battery from the KASI system.

Figure 3 KASI-system three-cell lithium battery

3.4 Storage of KASI-system lithium batteries

KASI-system lithium batteries must be stored in a dry and cool place. It is important to have a steady temperature, because changing temperatures may reduce the life of the battery. Short-circuiting a lithium battery may cause a burn, leakage or ventilation hazard, so it is important to keep the batteries in their original packaging without mixing them until use. (SAFT 2023, 3.)

Table 1 below shows the safety limits related to the storage and charging of lithium batteries in the KASI-system. (SAFT 2023, 4.)

	Continuous	**Occasional**
Storage	Max +30°C (86°F)	-40°C (-40°F) to +60°C (140°F)
During discharge	-30°C (-22°F) to +60°C (140°F)	-40°C (-40°F) to +60°C (140°F)
During charge	0°C (32°F) to 50°C (122°F)	0°C (32°F) to 50°C (122°F)

Table 1 Temperature safety limits for KASI-system reachagable lithium batteries

As can be deduced from the temperatures above, a good storage and charging place for the battery could be, for example, a container. In summer, however, care must be taken to cool and ventilate the container so that the temperature does not exceed the permitted safety limits.

3.5 Transport of KASI-system lithium batteries

The transport of KASI system lithium batteries is subject to the VAK Act, i.e. the transport of dangerous goods. More precisely, the transport of lithium batteries takes place under the mitigating ADR special regulation 188. When transporting lithium batteries, the free limit is 333 kilograms. If that limit is exceeded, an ADR permit is required from the driver of the batteries. In any case, an ADR inspected vehicle is not required. Transports under the free limit, i.e. under 333 kilograms, must be accompanied by a consignment note containing VAK information or a transport document that shows the information of the material to be transported, as well as an attached safety instruction. In international ADR transports, the language of the waybill must be the official language of the country of departure. ADR-approved plywood battery transport boxes are used to transport KASI system lithium batteries. (Finnish Defense Forces 2023.)

In figure 4 below, is shown an ADR-approved plywood transportation box for lithium batteries.

Figure 4 Transport box for KASI system lithium batteries

If the equipment supplier's transport packaging is not available or due to the small number of batteries, it is not reasonable to use the boxes in question, then packaging suitable for transporting hazardous materials suitable for lithium batteries is used. In this case, the batteries are packed in layers, so there is an insulating layer between the batteries. In addition, it is ensured that the batteries are not short-circuited by putting them in, for example, Minigrip bags. (Finnish Defense Forces 2023.)

Class 9 and the UN3480 marking are used for the temporary transport of KASI system lithium-ion batteries. Class 9 refers to a category in the United Nations classification of dangerous goods, encompassing a variety of hazardous materials that do not fit into more specific categories. UN3480 is a specific code in the UN classification, and it stands for "Lithium Ion Batteries." The label is shown in Figure 5 below. (Serpac 2017.)

Figure 5 Marking of temporary transport of KASI system lithium batteries

4 Comparing information sources on lithium batteries

The above information about lithium batteries originates from the Finnish Safety and Chemicals Agency Tukes, instructions from the Finnish Defense Forces and instructions from the battery manufacturer SAFT. The purpose of this chapter is to compare how information obtained from different sources varies in terms of storage, transport, handling and maintenance of lithium batteries. The purpose is to find out if the information from the sources is up-to-date and if there are large differences between the sources.

4.1 Source information for transport

- **Finnish Safety and Chemicals Agency Tukes**
    - The transport of lithium ion batteries is subject to the VAK directive. The VAK directive has been put into practice nationally in the VAK legislation and related regulations of the Transport Safety Agency TRAFI. (Tukes 2019, 37.)
    - Each cell or battery type must be shown to meet all the test requirements of the manual in order for lithium-ion batteries to be accepted for shipment under their assigned product designations (UN3480 and UN3481), (ADR). (Tukes 2019, 37.)
    - In accordance with these requirements, batteries and/or cells must have e.g. 1. Overpressure regulating device. 2. They must be equipped to prevent external short circuits. 3. They must be effectively equipped to prevent dangerous back current, and in addition, the quality system must be followed in the manufacture of cells and batteries. (Tukes 2019, 38.)
    - For lithium ion batteries that are damaged or defective and that do not meet the type testing requirements of the manual, separate transport requirements have been set in the VAK legislation, e.g. in terms of packaging. (Tukes 2019, 38.)

- **Instructions from the Finnish Defense Forces**
    - The VAK Act, i.e. the transport of dangerous goods. (UN 3480).
    - The transport limit is 333 kg, if it is exceeded, the driver must have an ADR permit. (ADR 188). (Finnish Defense Forces 2023.)
    - Transport takes place in ADR-approved plywood transport boxes. (Finnish Defense Forces 2023.)
    - A consignment note containing VAK information and safety instructions must be attached to the transport. (Finnish Defense Forces 2023.)

- **Instructions from the battery manufacturer SAFT**
    - Shipment of new and used lithium batteries are classified as dangerous goods. (SAFT 2023.)
    - If shipped as such (UN 3480). If shipped contained in equipment or packed with equipment (UN 3481). (SAFT 2023.)
    - Road transport under the ADR Act. (SAFT 2023.)
    - Package must be labeled and marked according to applicable regulations and accompanied by a Shipper's Declaration for Dangerous Goods. (SAFT 2023.)

Regarding the transport of lithium batteries, it can be quickly seen from the table that the instructions of Tukes, the Finnish Defense Forces and the battery manufacturer SAFTI contain the necessary information. Especially Tukes info on the subject is very comprehensive and even the most comprehensive of all sources. In any case, the instructions of the Defense Forces and SAFT are also completely valid and sufficient.

4.2 Source information for storage

- **Finnish Safety and Chemicals Agency Tukes**
    - Lithium batteries must be stored either 1. In a separately designated or limited area for storing batteries. 2. In connection with other storage space, but in a clearly defined area, I.e. in a fireproof cabinet,

separate from the load. 3. In connection with other storage space in its own area, for example on its own shelf. (Tukes 2019, 46.)

- The regulations in question must be followed when storing, because there are dangers in storing lithium batteries. The dangers are 1. Heat escape which can cause fire to spread to the surrounding batteries and as a result to the entire building. 2. Risks associated with moving the batteries, which can, for example, cause damage to the lithium batteries and even the aforementioned thermal runaway if they fall. (Tukes 2019, 46.)
- It is recommended to store new lithium batteries in an area specially designed for them or at least in a fire-proof space. (Tukes 2019, 46.)
- Based on the risk assessment, e.g. due to the vulnerability of the environment or the large number of batteries to be stored, it may be necessary to equip battery storage facilities with special protection mechanisms, e.g. with shelf sprinkling. (Tukes 2019, 47.)
- Used batteries or batteries found or suspected to be defective should always be kept separately from new ones, as this improves both certainty about the condition of the batteries being used and reduces the risk of the effect of thermal runaway spreading from defective batteries to unused ones. (Tukes 2019, 47.)

- **Instructions from the Finnish Defense Forces**
  - The Finnish Defense Forces do not have a separate guideline regarding the storage of lithium batteries.

- **Instructions from the battery manufacturer SAFT**
  - To ensure the best service life, store batteries in a cool, ventilated and dry place below 21°C. For lithium batteries, the best thing would be that there would be no temperature changes and in addition, moisture must be avoided. (SAFT 2023.)
  - Do not place near fire or heating devices and do not expose directly

to sunlight for long periods of time. High temperatures can reduce performance and/or battery life. (SAFT 2023.)
    - Normally, temperatures above 90°C can cause the battery to overheat or catch fire. (SAFT 2023.)
    - Sufficient space must be left between the walls and the batteries and nothing flammable must be near the batteries. (SAFT 2023.)

Regarding the storage of lithium batteries, it is noticeable that Tukes' instructions are general instructions and are not as precise as those of the battery manufacturer SAFT. It is understandable in itself, because Tukes gives instructions for storing lithium batteries in general, and SAFT's instructions focus on the lithium batteries of the KASI-system. The Finnish Defense Forces do not have a separate guideline for the storage of lithium batteries, so the storage section is entirely deficient in their case.

It is remarkable, however, that the Tukes instructions do not specify, for example, the conditions under which lithium batteries should be stored in more detail, for example the temperature limit values in general. It would be important to tell, for example, that lithium batteries must not be stored in too hot or cold places, because that may lead to damage to the batteries. It would be advisable for the Finnish Defense Forces to also have a written guideline regarding the storage of lithium batteries because working with lithium batteries requires constant caution.

4.3 Source information for handling and maintenance

- **Finnish Safety and Chemicals Agency Tukes**
    - Lithium batteries must be handled and maintained in accordance with the battery manufacturers' recommendations, because handling outside the manufacturer's recommended limits increases the resulting risks significantly. For example, lithium batteries can be damaged immediately or with a delay, but in practically all cases the risk of thermal runaway increases significantly. (Tukes 2019, 48.)

- The significantly increased risk of thermal escape also leads to an increased risk of large amounts of hydrogen fluoride being released into the space, and if you are not aware of this and enter the space without protection, there is also a significant risk of death. (Tukes 2019, 48.)
- Battery handling and maintenance must be concentrated in to the area reserved for it. The area must be dry and ventilated and there must be possibilities for extinguishing. In addition, the area should have the necessary protective equipment for personal protection. Examples of already existing facilities for processing and testing lithium batteries are, for example, hot work and ATEX facilities. (Tukes 2019, 49.)
- It is also important to prepare for the handling and maintenance of batteries, for example by creating a risk assessment. It would be good to include in the risk assessment what will burn if the battery catches fire. How do we act? How to evacuate? (Tukes 2019, 50.)

- **Instructions from the Finnish Defense Forces**
  - Each type of lithium cell or battery must demonstrate compliance with all test requirements specified in the 'Manual of Tests and Criteria.'" (Finnish Defense Forces 2020.)
  - Lithium cell and battery manufacturing must adhere to a quality system that includes:
    - Responsibilities related to the organizational structure and personnel for product design and quality. (Finnish Defense Forces 2020.)
    - Guidelines for inspections, testing, quality control, and quality assurance procedures. (Finnish Defense Forces 2020.)
    - Process control, including actions performed to detect and prevent internal short-circuits. (Finnish Defense Forces 2020.)

        - Inspection reports, certificates, testing and calibration data, and other quality-related documents. (Finnish Defense Forces 2020.)
        - Administrative assessments related to ensuring the effective operation of the quality system. (Finnish Defense Forces 2020.)
        - Methods for document control and updates. (Finnish Defense Forces 2020.)
        - Control of cells and batteries that do not conform to the tested type. (Finnish Defense Forces 2020.)
        - Employee training programs and qualification methods. (Finnish Defense Forces 2020.)
        - Methods ensuring the integrity of the final product. (Finnish Defense Forces 2020.)

- **Instructions from the battery manufacturer SAFT**
    - Connect the lithium batteries correctly. If connected incorrectly, they can cause short circuits. Do not either reverse the polarity of lithium batteries. (SAFT 2023.)
    - Do not mix different types or old and new lithium batteries together. Do not either expose to excessive mechanical stress. (SAFT 2023.)
    - Do not expose the lithium battery to water or condensation. Do not heat directly, do not solder or throw into fire. Such improper use may cause leakage or vaporized electrolyte vapors and may cause fire or explosion. (SAFT 2023.)
    - Remove batteries immediately if they emit an unusual odor, feel hot, change shape, or otherwise appear abnormal during use. In addition, it is important to remember to charge lithium batteries only with chargers intended for them. (SAFT 2023.)

Regarding the handling and maintenance of batteries, it can be seen that Tukes' instructions are extensive and focus on general standards related to where batteries should be handled and in what way. Tukes' instructions are excellent

and it is quite clear that they do not go into more detail about handling a specific battery type, as the instructions are made at a general level.

The guideline of the Finnish Defense Forces concerning the use and maintenance of lithium batteries is clearly a general guideline at the organizational level. The guideline primarily focuses on staff training and the written instructions required for these batteries. However, the practical instructions for handling the batteries themselves are very limited.

The instructions from the lithium battery manufacturer SAFT are completely focused on the use of the lithium batteries of the KASI system. The instructions show exactly how the batteries should be handled, but the instructions do not focus much on the environment where the batteries are handled and maintained. It would be important to focus on the environment, because lithium batteries cannot be handled in, for example, an easily flammable environment. In any case, SAFT's instructions are very precise and cover the proper handling of the lithium battery itself.

4.4 General observations on source differences

Table 2 below contains conclusions about the quality, timeliness, differences, and shortcomings of the sources.

	Finnish Safety and Chemicals Agency Tukes	Finnish Defence Forces	Battery manufacturer Saft
Timeliness	**Transport** The information was up to date	**Transport** The information was up to date	**Transport** The information was up to date
	Storage The information was up to date	**Storage** Needs supplementation	**Storage** The information was up to date
	Handling and maintenance The information was up to date	**Handling and maintenance** The information was up to date	**Handling and maintenance** The information was up to date
Quality	**Transport** High-quality	**Transport** Sufficient	**Transport** Sufficient
	Storage Needs supplementation	**Storage** Needs supplementation	**Storage** High-quality
	Handling and maintenance High-quality	**Handling and maintenance** Sufficient, but need additions at the practical level	**Handling and maintenance** Needs supplementation
Shortcomings	**Transport** No deficiencies	**Transport** No deficiencies	**Transport** No deficiencies
	Storage More information is needed about storage conditions	**Storage** A written guide is needed	**Storage** No deficiencies
	Handling and maintenance No deficiencies	**Handling and maintenance** Add more practical instructions for handling and maintenance of lithium batteries	**Handling and maintenance** More information is needed about handling and maintenance enviroment

Table 2 Summary of source differences

As shown in Table 2, the information from the sources regarding lithium batteries was up-to-date, and no incorrect or outdated information was found. The information regarding the transportation of lithium batteries was of high quality in every source, particularly from Tukes. However, both the Defense Forces and SAFT also provided entirely sufficient information on the topic.

Regarding storage, SAFT had comprehensively listed all the necessary details. However, Tukes' source would require updating because it lacks additional information regarding storage conditions. The Defense Forces need a written guideline entirely because it is missing.

Regarding handling and maintenance, Tukes' guidance was of high quality and included all the necessary information. The battery manufacturer SAFT's guidance would benefit from additional information regarding the environment in which lithium battery handling and maintenance activities should be conducted. In the Finnish Defense Forces' guideline, the focus is primarily on personnel training and the written instructions required for these batteries. However, the practical instructions for handling the batteries themselves are quite limited.

5 Recommendations for the use of KASI-system lithium batteries

In this section, there are recommendations for the proper transportation, storage, handling and maintenance of KASI-system lithium batteries. These recommendations are based on previous research.

5.1 Recommendations for transport

The transportation of KASI system lithium batteries falls under the regulation of hazardous materials transportation, in accordance with the VAK Act. More specifically, the transportation of KASI lithium batteries adheres to the ADR special regulation 188. The following recommendations pertain to the transportation of KASI lithium batteries:

Free Limit Regulation: When transporting lithium batteries, it is imperative to adhere to the 333-kilogram free limit regulation. If this weight limit is exceeded, the driver must obtain an ADR permit. It is important to note that regardless of the quantity of batteries being transported, an ADR-inspected vehicle is not mandatory.

Transportation Documents: When the quantity of lithium batteries is below 333 kilograms, a transportation document containing VAK information or a transportation document displaying the information of the transported material must be carried. Alongside these documents, safety instructions related to handling lithium batteries must also be provided.

Language Requirements: In international ADR transports, the language on the transportation document must be the official language of the country of departure. For instance, if the transportation originates from Finland, the document should be in Finnish.

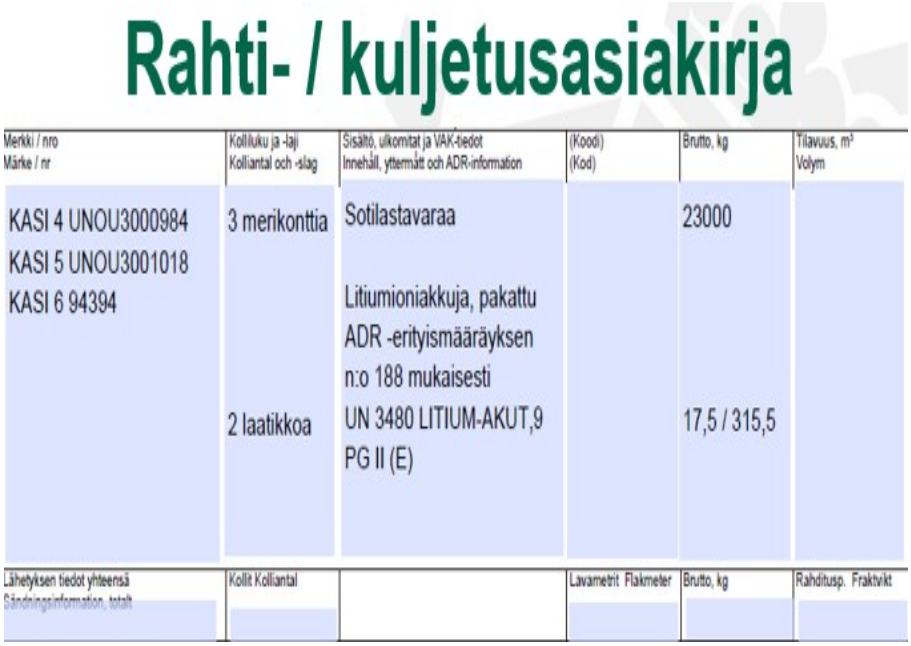
Packaging Materials: In the transportation of KASI system lithium batteries, ADR-approved plywood battery packaging must be utilized. In cases where the

equipment supplier's transport packaging is unavailable or when the number of batteries is too small to warrant the use of the aforementioned boxes, packaging suitable for the transportation of hazardous materials and compatible with the safe transportation of lithium batteries should be employed. In this scenario, the batteries should be packed in layers, with an insulating layer placed between them to prevent short-circuiting. Additionally, precautions should be taken to ensure that the batteries cannot short-circuit, such as placing them in Minigrip bags.

Class 9 and UN3480 Markings: For the temporary transportation of KASI system lithium-ion batteries, Class 9 markings, denoting a category in the United Nations classification of dangerous goods, and UN3480, a specific code in the UN classification indicating "Lithium Ion Batteries," should be used.

The following images, Figure 6 and Figure 7, depict the correct transportation box and waybill for KASI system lithium batteries.

Figure 6 Correctly labeled plywood transportation box for KASI-system lithium batteries



Rahti- / kuljetusasiakirja

Merkki / nro Märke / nr	Kolliluku ja -laji Kolliantal och -slag	Sisältö, ulkomitat ja VAK-tiedot Innehåll, yttermått och ADR-information	(Koodi) (Kod)	Brutto, kg	Tilavuus, m³ Volym
KASI 4 UNOU3000984 KASI 5 UNOU3001018 KASI 6 94394	3 merikonttia	Sotilastavaraa Litiumioniakkuja, pakattu ADR -erityismääräyksen n:o 188 mukaisesti		23000	
	2 laatikkoa	UN 3480 LITIUM-AKUT,9 PG II (E)		17,5 / 315,5	
Lähetyksen tiedot yhteensä Sändningsinformation, totalt	Kollit Kolliantal		Lavametrit Flakmeter	Brutto, kg	Rahdituspl. Fraktvikt

Figure 7 Proper transportation document for KASI-lithium batteries

5.2 Recommendations for storage

Proper storage of lithium batteries is crucial for ensuring their efficiency and safety. Below are recommendations for the storage of lithium batteries.

Lithium batteries should be stored in a dry and cool place. Maintaining a consistent temperature is essential, as temperature fluctuations can significantly reduce the battery's lifespan. Especially in Finland's varying weather conditions, where temperatures can change dramatically with the seasons, it is essential to carefully choose a storage location. One suitable option for storing lithium batteries could be an insulated container. However, during the summer, it is important to ensure that the container remains sufficiently cool and well-ventilated to prevent the temperature from exceeding safety limits. Overheating of lithium batteries can be dangerous, so adequate ventilation is necessary.

Lithium batteries can be stored either in a designated and restricted area specifically for battery storage, in another storage facility with a clearly marked-off section, or in their own dedicated space within another storage facility. Batteries can be stored as individual cells or as ready-to-use battery packs. It is

also crucial to ensure that the storage conditions are fire-safe. Damage or a short circuit in lithium batteries can lead to a fire, so the storage area should be equipped with appropriate fire extinguishing equipment and precautions, and there should be no flammable materials nearby.

Batteries should be kept in their original packaging, and they should not be mixed before use. This prevents potential damage or short circuits between the batteries.

Below, Figure 8 provides an example of the condition in which lithium batteries should be stored or charged.

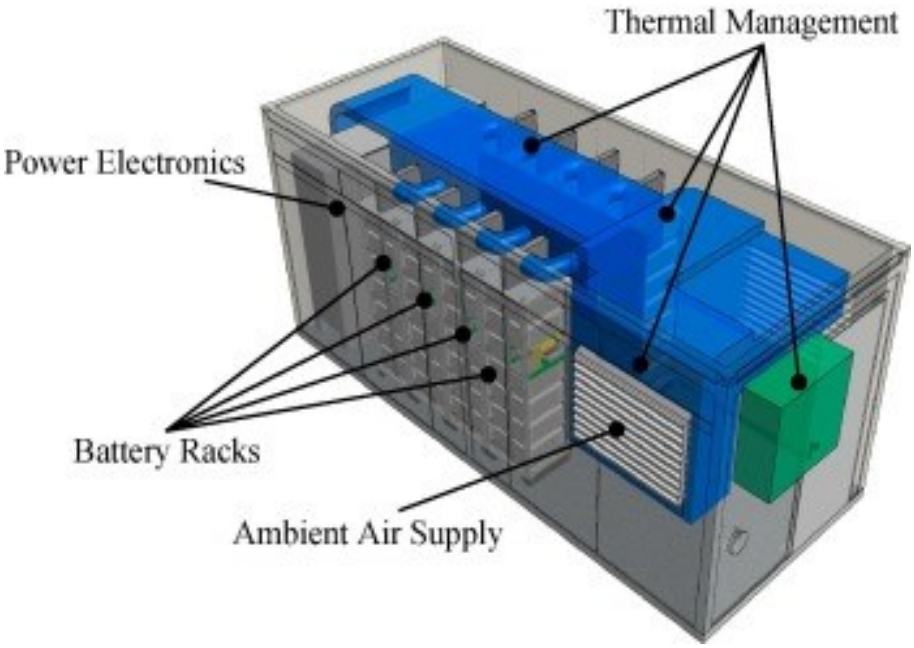


Figure 8 Proper storage container for lithium batteries

5.3 Recommendations for handling and maintenance

Safety is paramount when handling lithium batteries. Below are recommendations that help ensure the safe handling of lithium batteries:

Follow Manufacturer's Instructions: It is essential to strictly adhere to the manufacturer's instructions for handling and maintaining lithium batteries.

Deviating from these instructions significantly increases risks. Lithium batteries can become damaged, raising the risk of thermal runaway.

Risk of Thermal Runaway: Mishandling or damage to lithium batteries can lead to thermal runaway, a highly dangerous situation. In such cases, significant amounts of harmful hydrogen fluoride may be released, posing a risk of death without proper protection.

Secure Handling Area: Work with batteries in a designated, dry, well-ventilated area equipped with fire-fighting gear. Proper personal protective equipment, such as safety glasses and gloves, should be available. In some cases, specialized facilities like hot work or ATEX areas may be used for handling and testing lithium batteries.

Risk Assessment: It is advisable to conduct a risk assessment, considering what actions to take if a battery ignites, what materials might catch fire, and how to ensure safe and efficient procedures, including possible evacuation.

Correct Connections: Lithium batteries must be connected correctly to prevent the risk of short circuits. Reversing the polarity of terminals should also be avoided.

Avoid Mixing Types: Never mix different types of lithium batteries or combine new and old ones. Additionally, prevent subjecting batteries to excessive mechanical stress.

Avoid Moisture and Heat: Keep lithium batteries away from water, moisture, direct heat sources, soldering, or open flames. Improper use can lead to leakage or electrolyte vaporization, which may result in fire or explosions.

Monitor Unusual Symptoms: If a battery emits an unusual odor, feels hot, changes shape, or behaves abnormally during use, remove it from service immediately. Safety is always the top priority.

Use Proper Chargers: Charge lithium batteries only with chargers specifically designed for them. Using the wrong charger may pose safety hazards.

6 Final conclusions

In the thesis, the predefined criteria were met. The thesis extensively covers lithium batteries and related regulations, with a deep dive into the KASI system's lithium batteries. Various primary sources were compared to assess their currency and identified shortcomings. At the end of the thesis, a comprehensive guide for the use and maintenance of lithium batteries was created, which can be utilized in the future both within the company in Finland and by Saab AB in Sweden.

The outcome of the thesis was important for the company because there was no up-to-date database and guide for lithium batteries previously. However, this thesis will serve as such a resource in the future.

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