Related to the tasks to be completed by trained personnel, the training can be adopted to cover different scopes, ranging from for example basic training to advanced training. The training should be related to a specific design (for example high-voltage live tank circuit-breaker, medium-voltage switchgear, high-voltage switchgear, etc.) and different designs require different trainings to be certified.

In all cases, the training should be based on local regulations, operating instruction manuals of the electric power equipment, operating instruction manuals of the handling equipment, safety data sheets (SDS), instrument datasheets, international standards, and CIGRE brochures. In some countries certification of natural persons carrying out gas handling procedures for specific gases is mandatory. Release of C5-FK or C5-FK mixtures into the environment during manufacturing, operation, maintenance, and at end-of-life of the electric power equipment should be avoided. Local regulations can exist on this respect.

E.4.2 Training

Workers handling C5-FK or C5-FK mixtures should be familiar with safety, legal and environmental aspects, the properties of the gas, the gas handling tools and handling equipment, and procedures to assure the continuity of service.

The different aspects to be covered by a training are the following:

- safety and first aid (see Clause E.2), in particular:
  - local regulations, emergency plans and instructions in case of for example asphyxiation, internal arc fault;
  - safety equipment required for personal protection;
  - safety equipment required for working on open gas compartments in relation to the task;
  - safety equipment required for personal protection, working on open gas compartments in relation to the task, neutralising and handling of by-products;
- basic knowledge of relevant environmental issues;
- physical, chemical and insulating and switching characteristics of C5-FK mixtures;
- use of C5-FK mixtures in electric power equipment (insulation, switching);
- existence of local regulations and international standards in relation to the task;
- C5-FK mixtures handling, hazards and health characteristics;
- design of electric power equipment (properties and application/functionality);
- the operating instruction manuals given by the electric power equipment manufacturer in relation to the tasks;
- types of gas compartments filled with C5-FK mixtures;
- instruments and procedures for checking the quality of C5-FK mixtures;
- procedures of handling of C5-FK, O_2, CO_2, N_2, synthetic air and C5-FK mixtures:
  - topping-up of closed pressure systems;
  - air evacuation and C5-FK mixture filling and topping-up with C5-FK mixture;
  - recovery and reclaim of non-arced, normally and heavily arced C5-FK mixture; handling, neutralisation and removal of by-products, handling of safety equipment and tools which have been in contact with solid by-products;
- leak detection methods and repair techniques;
- storage and transportation of C5-FK, O_2, CO_2, N_2, synthetic air and C5-FK mixtures (see Clause E.5);
- handling equipment for C5-FK and C5-FK mixtures in relation to the tasks (see Clause E.6);
- procedures for entering the switchgear room in case of abnormal leakage and/or sudden release of C5-FK mixtures due to fire or internal arc fault (see E.2.7);

- transportation of the power electric equipment to the dismantling site, if applicable (see E.5.3);
- dismantling of electric power equipment and part sorting (see Clause 7);
- operation of tight drilling systems, if necessary (see 7.4).

E.4.3 Certification

Successful completion of training leads to in-house certification, where “in-house certification”, means a certificate of competence or other written confirmation issued by an employer to such of his own employees or external persons who have satisfactorily completed a course of training, relating to relevant work. Theoretical and practical examination sessions are performed to prove the skill and the ability gained. However, any certification required by local regulations takes priority over this document.

The following records should be retained:

- the training content;
- the date on which the training was completed.

Restrict the tasks to be performed (for example C5-FK mixture topping-up or recovery for a certain design) to personnel who have been certified for the respective skill levels and sustain a high level of expertise.

E.5 Storage and transportation

E.5.1 General

Storage and transportation of C5-FK and C5-FK mixtures, either in containers or in electric power equipment should always be carried out in accordance with local and international regulations.

An empty C5-FK container can still contain a residual amount of C5-FK. It should be stored and transported in the same way as a filled container.

E.5.2 Storage of containers filled with C5-FK or C5-FK mixtures

E.5.2.1 Storage of containers filled with C5-FK

Containers filled with C5-FK typically contain a liquid and a gaseous phase, at a maximum pressure depending on the container temperature. Up to temperatures of 46 °C the pressure in the container is below 200 kPa (see Figure E.2).

Containers should be handled carefully and stored in a cool, dry, well-ventilated area away from flammable or explosive material. They should be protected from direct sunlight, mounted clear of wet ground and secured to prevent falling over. Special valve protections should be adopted to avoid any potential damage on the valve itself. Containers should be clearly labelled to identify their contents. The storage containers should comply with local and international regulations and could be of the type used as for example a refrigerant recovery container with a dip tube. Container labelling should also comply with local and international regulations.

Table E.5 gives an overview of all possible storage methods on which a storage container can be based.

Table E.5 – Methods for storage of C5-FK

Method	Requirements	Features
Liquid	Pressure at room temperature (20 °C) < 100 kPa, up to 46 °C below 200 kPa	The cylinder should be equipped with a dip tube and a gas and a liquid valve. Recommendation: Containers should be painted according to local regulations.

Container types and labelling required for storage and transportation of C5-FK are shown in Table E.6.

Table E.6 – Examples of container types required for storage / transportation of C5-FK

Gas / fluid	Characteristic	Container type
Technical grade C5-FK	Liquid	For example, a refrigerant recovery container with a dip tube Recommendation: Containers should be painted according to local regulations.

E.5.2.2 Storage of containers filled with C5-FK mixtures

When storing C5-FK mixtures, the mixing ratio, the partial pressure of C5-FK and the minimum storage temperature of the container define the maximum total pressure to which this C5-FK mixture can be compressed without partial liquefaction of the C5-FK.

Containers should be handled carefully and stored in a cool, dry, well-ventilated area away from flammable or explosive material. They should be protected from direct sunlight, mounted clear of wet ground and secured to prevent falling over. Special valve protections should be adopted to avoid any potential damage on the valve itself. Containers should be clearly labelled to identify their contents, including mixing ratio and minimum storage temperature (before liquefaction of C5-FK).

Table E.7 gives an overview of all possible storage methods on which a storage container can be based.

Table E.7 – Methods for storage of C5-FK mixtures

Method	Requirements	Features
Gaseous	Typical pressures between 300 kPa and 1 500 kPa, depending on the mixing ratio, the C5-FK partial pressure and the minimum storage temperature.	As the quantity of the C5-FK mixture is limited due to the low pressure, this storage is not intended for storing large quantities. Main use might be topping-up of gas in case of a gas alarm to return to safe operating conditions.
Liquefied gas	Typical pressures between 1 000 kPa and 5 700 kPa, depending on mixing ratio, the C5-FK partial pressure and the heating temperature of the container.	At storage temperature the C5-FK in the C5-FK mixture is partly liquefied. Before taking the C5-FK mixture from the container and filling it in an electric power equipment, the gas container should be heated for a defined time to a defined temperature, to reach a homogeneous mixing ratio.
Liquefied gas	Typical pressures above 5 700 kPa at 20 °C and depending on the mixing ratio.	At storage temperature the C5-FK and the CO_2 in the C5-FK mixture are partially liquid. Before taking the C5-FK mixture from the container and filling it in an electric power equipment, the gas container should be heated for a defined time to a defined temperature above the critical temperature of CO_2, to reach a homogeneous mixing ratio.
NOTE The pressures refer to a temperature of 20 °C. The vapour pressure of CO_2 at 20 °C is 5 730 kPa.		

When samples of used C5-FK mixtures are stored for gas analysis off-site, the storage containers should comply with local and international regulations on pressurised containers. Container labelling should also comply with local and international regulations.

Table E.8 gives examples of container types required for storage and transportation of C5-FK mixtures. It is recommended to use transportable storage containers, wherever possible for practical reasons.

Table E.8 – Examples of container types required for storage / transportation of C5-FK mixtures

Fluid / gas	Characteristic	Container type
C5-FK mixtures	Liquefied gas	Suitable for a pressure of 7 000 kPa. Recommendation: Recommendation: Containers should be painted according to local regulations, e.g. EN 1089-3 [8].

E.5.3 Transportation of containers filled with C5-FK or C5-FK mixtures

E.5.3.1 Transportation of containers filled with C5-FK

International regulations for shipment of C5-FK containers are available for transportation by road (ADR), rail (RID), ship (IMDG code), and air (IATA – DGR). These are similar concerning UN numbering, classification, danger labelling, final classification, and transport documentation. However official languages differ as follows:

- ADR: German, French, English;
- RID: English;
- IMDG code: English;
- IATA – DGR: English.

The international regulations for shipment of C5-FK are summarised in Table E.9.

NOTE Information on UN numbering, classification, danger labelling, final classification and transport documentation is given in [20].

Table E.9 – International regulations for shipment of C5-FK

Fluid / gas	Characteristic	Class	Final classification	Transport document
Technical grade C5-FK	Liquid	not applicable	Not hazardous for transportation No UN number assigned	not applicable

E.5.3.2 Transportation of containers filled with C5-FK mixtures

International regulations for shipment of C5-FK mixtures containers are available for transportation by road (ADR), rail (RID), ship (IMDG code), and air (IATA – DGR). These are similar concerning UN numbering, classification, danger labelling, final classification, and transport documentation. However official languages differ as follows:

- ADR: German, French, English;
- RID: English;
- IMDG code: English;
- IATA – DGR: English.

The international regulations for shipment of C5-FK mixtures are summarised in Table E.10.

The UN numbering, classification, danger labelling, final classification and transport documentation for normally arced and/or heavily arced C5-FK mixtures can depend on the design and usage of the electric power equipment and should be defined in the safety data sheet of the electric power equipment manufacturer.

The classifications listed in Table E.10 are limited to C5-FK mixtures with C5-FK and O_2 concentrations not leading to an increased flammability. Details about maximum concentrations, maximum pressure and maximum temperature should be given in the safety data sheet of the electric power equipment manufacturer.

NOTE Information on UN numbering, classification, danger labelling, final classification and transport documentation is given in [20].

Table E.10 – International regulations for shipment of C5-FK mixtures

Fluid / gas	Characteristic	Class	Final classification [a, b]	Transport document [a]
Technical grade C5-FK mixture [c] and Non-arced C5-FK mixture [c]	Compressed gas	1A	UN 1956 COMPRESSED GAS N.O.S. 2.2	UN 1956 COMPRESSED GAS N.O.S. (fluoroketone and oxygen and/or nitrogen and/or carbon dioxide) 2.2
Technical grade C5-FK mixture [c] and Non-arced C5-FK mixture [c]	Liquefied gas	2A	UN 1058 LIQUEFIED GAS N.O.S. 2.2	UN 1058 LIQUEFIED GAS N.O.S. (fluoroketone and oxygen and/or nitrogen and/or carbon dioxide) 2.2
Normally arced C5-FK mixture [c, d]	Liquefied gas	2A	UN 3163 LIQUEFIED GAS N.O.S. 2.2	UN 3163 LIQUEFIED GAS N.O.S. (fluoroketone and oxygen and/or nitrogen and/or carbon dioxide) 2.2
Heavily arced C5-FK mixture [c, e]	Liquefied toxic and corrosive gas [f]	2TC	UN 3308 LIQUEFIED TOXIC AND CORROSIVE GAS N.O.S. 2.3 + 8	UN 3308 LIQUEFIED TOXIC AND CORROSIVE GAS N.O.S. (fluoroketone and oxygen and/or nitrogen and/or carbon dioxide with toxic and corrosive by-products) 2.3 + 8

[a] UN numbers are assigned by the Committee of Experts on the Transport of Dangerous Goods (TDG) and on the Globally Harmonized System of Classification and Labelling (GHS) of the Economic Commission for Europe of the United Nations.

[b] Final classification, including correct UN code and hazards identification numbers (e.g. H280) are listed in the safety data sheet and/or in the operating instruction manual of the electric power equipment manufacturer.

[c] C5-FK mixtures with C5-FK and O_2 concentrations not leading to an increased flammability.

[d] C5-FK mixtures that contain small amounts of by-products and have a LC50 value > 5 000 µl/l (ppmv).

[e] C5-FK mixtures that contain large amounts of by-products, typically after experiencing an internal arc, a failure to interrupt or a last number of short-circuit breaking operations and have a LC50 value < 5 000 µl/l (ppmv).

[f] According to UN regulations for transportation, a gas is classified “toxic” when its LC50 value < 5 000 µl/l (ppmv).

N.O.S.: “not otherwise specified”.

E.5.4 Storage and transportation of electrical power equipment containing C5-FK mixtures

Electric power equipment filled with C5-FK mixtures should be stored and transported according to local and international regulations.

International regulations for shipment are available for transportation by road (ADR), rail (RID), ship (IMDG code), and air (IATA – DGR). These are similar concerning UN numbering, classification, danger labelling, final classification, and transport documentation.

According to ADR, RID and IAT transportation codes the filling pressure should not exceed 200 kPa (relative) at 20 °C.

E.5.5 Responsibilities

The owner of the electric power equipment utilising C5-FK mixtures is responsible for the proper use, transportation and disposal of the electric power equipment and the C5-FK mixture.

E.6 Description of handling equipment

E.6.1 General

E.6.1.1 Overview

This subclause gives information about the handling equipment, which might be required for handling of C5-FK or C5-FK mixtures. Such handling equipment is required during development, testing, manufacturing, installation, service, repair and end-of-life treatment. Some of the handling equipment can also be used by the end-user of the electric power equipment.

The appropriate type and size of the handling equipment should be chosen according to the quantity of C5-FK and C5-FK mixture to be handled. Figure E.3 shows a basic functional scheme. The typical functions are as follows:

- evacuation of air from the gas compartment;
- preparation of C5-FK mixtures;
- filling of C5-FK mixtures in the gas compartment;
- recovery of C5-FK mixtures from the gas compartment;
- storage of C5-FK mixtures;
- removal of contaminants;
- flooding of the gas compartment with ambient air;
- container to container transfer.

Not all the listed handling equipment might be available and/or required, depending on the design of the electric power equipment. It is more a theoretical overview on the possible technical solutions.

The following handling equipment will be described below:

- vacuum pump;
- main and vacuum compressor;
- gas mixing and filling unit;
- gas filling unit;
- gas recovery unit;
- used gas storage and transportation devices;
- gas measurement devices;
- gas leakage detectors;
- gas leakage tester;
- gas sampling cylinders;

- alarm system detectors.

Some of the above-listed handling equipment might be combined for specific tasks.

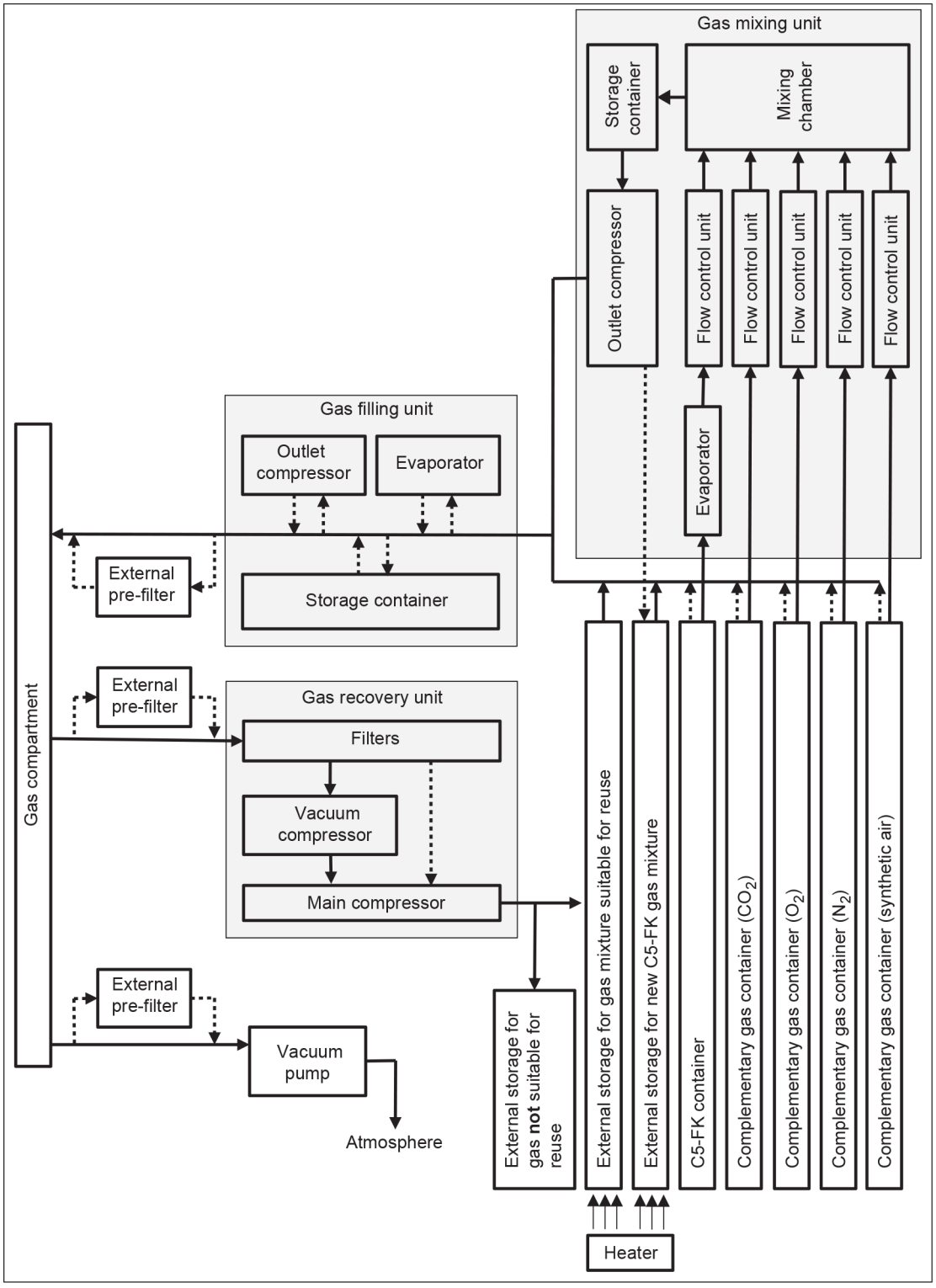

Figure E.3 – Schematic view of an example of a handling equipment for C5-FK mixture

E.6.1.2 Qualification of handling equipment

E.6.1.2.1 General

Before using any handling equipment, it should be ensured that the handling equipment can be used for the intended task (C5-FK or C5-FK mixture handling). This can be done by adequate tests at the handling equipment manufacturer itself or by the manufacturer of the electric power equipment that has proposed this handling equipment for the use with C5-FK or C5-FK mixtures.

Handling equipment for the same task but intended for another gas and not qualified for C5-FK mixtures, might be damaged, malfunction or give wrong readings and therefore might generate a risk to the operator or the handling equipment or the electric power equipment.

The qualification should cover the areas described in E.6.1.2.2 and E.6.1.2.3.

E.6.1.2.2 Prove that the handling equipment fulfils its function using C5-FK or C5-FK mixtures

This should be done by functional tests with C5-FK mixtures within the full gas concentration, pressure and temperature range for which the handling equipment will be used. Either the handling equipment has been especially designed for that use or it has been modified to operate with C5-FK mixture. In some cases, no modification might be required and standard handling equipment, originally designed for other gases, can be used, for example by calibration for the gas.

E.6.1.2.3 Test and verify that the handling equipment is compatible with C5-FK or C5-FK mixtures

All parts of the handling equipment in contact with C5-FK or C5-FK mixtures should be tested and certified by the manufacturer of the gas handling equipment to be compatible with C5-FK or C5-FK mixtures. It should be shown that the handling equipment is not damaged when it comes in contact with the gas or its by-products. For modified handling equipment it might be required, that materials in standard handling equipment are replaced for the use with C5-FK or C5-FK mixtures. In this case a clear differentiation between handling equipment variants that can be used with C5-FK or C5-FK mixtures and those that cannot be used should be done.

As the focus is on the impact of the gas on the handling equipment, care should be taken, that

- the technical functionality is not negatively influenced during the specified lifetime of the handling equipment or during the intervals between maintenance of the handling equipment;
- maintenance intervals are adjusted, if required.

Where applicable, flushing or cleaning procedures should be defined (for example to avoid long term contact with C5-FK mixtures or their by-products before the handling equipment is stored).

E.6.2 Filters

E.6.2.1 General

Filters are required to remove gaseous by-products, humidity and solid particles before storing C5-FK mixtures in a container, hence allowing for its reuse. Filters can be part of the handling equipment or external pre-filters. An external pre-filter might be required to remove particles, excessive levels of humidity and gaseous by-products, which are acidic compounds, and could damage the handling equipment or the gas storage container. The requirements of the external pre-filter are the same as those of the filters installed inside the handling equipment, but the pre-filtering capacity could be considerably higher.

Table E.11 shows typical filter types used as part of the handling equipment.

Table E.11 – Typical filter types

Filter type	Tasks	Major characteristics
Particle filter	Removes solid by-products and other particles.	Pore size lower than 1 µm.
Dry filter	Removes gaseous by-products and humidity.	Residual humidity lower than 100 µl/l (ppmv). Gaseous by-products retention ability. Particle retention ability.
Oil filter	Removes oil when required.	Special filter utilising active charcoal.

E.6.2.2 Filter types

E.6.2.2.1 Particle filter

To protect the handling equipment from damage, due to particles, it might be required to install particle filters. It is preferred that these filters are integral part of the handling equipment and are permanently installed on the inlet side. Source of particles might be for example metal particles from the production of the electric power equipment or generated during switching operations. Especially in heavily arced gas the generation of solid by-products might happen. Design, material and pore size of the filter should be defined by the handling equipment manufacturer. Special care should be taken on the selection of the material to avoid chemical reaction with C5-FK or adsorption of C5-FK.

E.6.2.2.2 Humidity and gaseous by-product filter (dry filter)

Appropriate filters can adsorb humidity and reactive gaseous by-products. Molecular sieves with a pore size smaller or equivalent to 0,5 nm (5 A) can be used. Bigger pore size leads to thermodynamic exothermal reactions, resulting in severe filter overheating, as the C5-FK might be absorbed.

E.6.2.2.3 Combined filter

Instead of separate particle filters and humidity and gaseous by-products filters also filters, which combine both filtering principles, can be installed.

E.6.2.2.4 Oil filter

An oil trap containing activated charcoal should be inserted in the C5-FK mixtures cycle if an oil lubricated machine is used or if an oil insulated electric component is included in the electric power equipment utilising C5-FK mixtures. The oil removal is achieved in several steps to avoid diffusion of the oil.

E.6.3 Vacuum pump

The vacuum pump is used to evacuate the gas compartment/container/sample cylinders from gases as air or other natural-origin gases which are permitted to be released to the atmosphere prior to filling with the C5-FK mixture.

The residual pressure at the inlet of the vacuum pump should be lower than 0,1 kPa. In order to speed up evacuation of gas compartments, the use of vacuum pumps with a residual pressure at the inlet lower than 0,01 kPa is recommended.

The vacuum pump is equipped with a vacuum pressure gauge. The resolution of the vacuum pressure gauge should be at least lower than 0,1 kPa (recommended value is lower than 0,01 kPa). Vacuum gauges independent of the gas type are generally recommended. Thermal vacuum sensors are dependent on the gas type and are not recommended.