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# Design guidelines for sodium loops

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## Summary

Using liquid sodium at high temperatures in test facilities requires defining rules specific to this technology to ensure that operations are safe and reliable. Such facilities can be operated under optimal safety conditions when a certain number of safety principles are adopted as early as the design phase. The purpose of this document is therefore to explain the safety rules to be incorporated by the designer during the definition of a project to build a facility implementing sodium at high temperature. These design rules are applicable to the various functions that the facility must provide under the best possible conditions of safety; for this reason, rules pertaining to construction or system operations are not covered in this document.

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# GLOSSARY

*Spark-plug leak detectors*: Set of one or two conducting electrodes used to detect sodium leaks by short-circuit. As sodium is conductive, it ensures there is contact between the electron and the ground.

*Bead-wire detection*: Leak detection for large components using a pair of bare electric wires insulated by ceramic beads in which sodium can flow. The sodium ensures there is contact between two conductors, thus leaks can be detected.

*Thermal shock*: A thermal shock occurs when the contact of components with different temperatures causes damage to the materials.

*Economiser*:This device is a compact Na/Na heat exchanger It is used to cool the sodium flowing into the cold trap and to reheat the outgoing Na.

SGHX: Sodium Gas Heat Exchanger.

SG: Steam Generator.

*Plugging indicator* (PI): This device is used to determine the Na saturation temperature and thus determine the quantity of impurities in the Na.

*ISIR:* In-Service Inspection & Repair.

*Na*: the chemical symbol for sodium. It is used as an abbreviation.

*NADYNE:* French acronym for dynamic sodium.

*NAIMMO:* French acronym for immobile sodium.

*NaK*: this refers to sodium potassium alloy. It is used as an abbreviation.

*NAPEM:* French acronym for sodium qualification of an electromagnetic pump.

*NSET:* French acronym for new thermal test station.

*EM pump:* Electromagnetic pump.

*Cold trap*: A device designed to trap impurities dissolved in the liquid sodium by means of crystallisation.

*Priming chamber*:This tank is used to prime the pump used to fill the sodium system. It is filled with sodium from the storage tanks and is positioned above the level of the filling pump.

*SWR:* Sodium-water reactions.

*SAC:* French abbreviation for additional safety shutdown system.

*SEPIA:* French abbreviation for passive sentinel for negative reactivity insertion.

*STALACMITES:* French acronym for washing station for components and mock-ups immersed in sodium during tests.

*TC:* Thermocouple.

*TUSHT:* French name of a high-temperature ultrasonic transducer.

*VISUS:* Visualisation in sodium using ultrasounds.

*Retention area in the sodium system*: Area in the system likely to promote the accumulation of sodium after draining.

CHEOPS: Site with high temperature sodium loops for Sodium components qualification.

*Device: used to qualify small-sized components, e.g. measuring instruments.*

*NATAN: German acronym for Natrium Test ANlage ( engl. Sodium test facility).*

*DRESDYN: German acronym for DREsden Sodium facility for DYNamo and thermohydraulic studies.*

*I&C Instrumentation and Control.*

Attention

This report has been written on the basis of document Nos. [1] and [2].

# 0 PREAMBLE

The recommendations in this document take into account CEA feedback on safety issues related to the design of sodium facilities; they do not under any circumstances replace the regulations in force applicable to each subject discussed.

KIT added experiences of historical and actual facility designs within KASOLA family and analysis of non-nuclear accidents in high temperature sodium facilities (CSP).

The HZDR contributes to this document with many years of experience gained at the NATAN experimental facility.

IPUL added experience gained at operation of various test stands – DN 40, DN60, DN100, DN 125 and AMPERE.

# 1 PURPOSE

Using liquid sodium at high temperatures in test facilities requires defining rules specific to this technology to ensure that operations are safe and reliable.

Such facilities can be operated under optimal safety conditions when a certain number of safety principles are adopted as early as the design phase.

The purpose of this document is therefore to explain the safety rules to be incorporated by the designer during the definition of a project to build a facility implementing sodium at high temperature. These design rules are applicable to the various functions that the facility must provide under the best possible conditions of safety; for this reason, rules pertaining to construction or system operations are not covered in this document.

# 2 DEFINITIONS

## 2.1 Facility containing sodium

This refers to a facility which comprises pipes and devices containing sodium - flowing or not - and operating at a high temperature, thus requiring the implementation of technologies adapted to sodium-based facilities.

For the sake of clarity, certain sub-systems of such a facility are described below:

- The sodium system, including:
    - Pipes for sodium.
    - Devices and components connected by these pipes.
- The volumes (tanks, containers) containing sodium, such as:

  - Storage tank(s).
  - Containers (pots and vessels) containing the equipment to be tested and the sodium used as the medium.
  - Interface tanks (expansion volume: sodium/cover gas).

## 2.2 Components

These refer to the parts of a system implementing a technology specific to sodium environments, e.g. pumps, cold traps, heat exchangers. The term "device" is used to qualify small-sized components, e.g. measuring instruments.

## 2.3 Functions

The presence of liquid sodium at high temperatures in the pipes and components, the circulation of this sodium, and its filtering are just a few of the states or events that require a certain number of functions that the facility must be able to perform.

## 2.4 Basic functions

These functions are required to ensure that a system containing sodium can operate correctly; they exist in most facilities.

The main functions are:

- Operation
- Storage
- Transitions
  - Filling and draining
  - Preheating and heating
- Filtering
- Maintenance
- Decommissioning
- Rapid shutdown in case of accident (full draining of the system)

In KASOLA different stages of facility operation are specified including the transitions as can be seen in Figure 2.1.

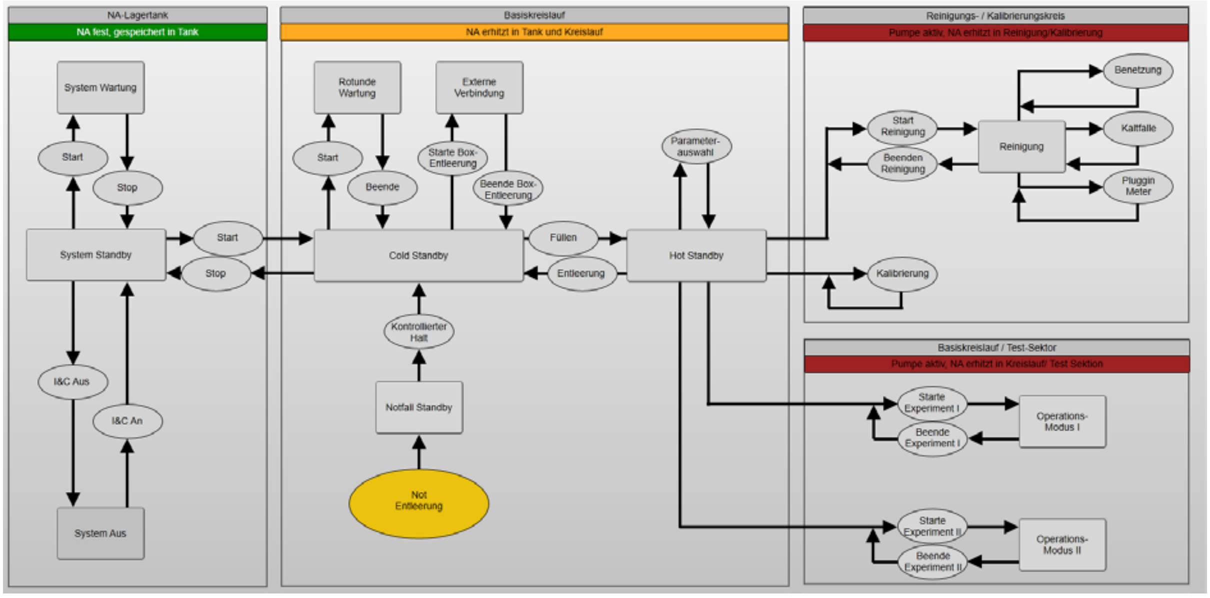

Figure 2.1 Schematics of KASOLA facility states and transitions for manual and automatic operations

## 2.5 Risk analysis

It is recommended to remain consistent with the other sodium facilities managed by the CEA, thus, an organized systemic risk assessment method (MOSAR) should be applied during the design of any new sodium systems. The risk assessment method should be in accordance to the valid national rules.

Risk analysis also includes provisions against seismic threads.

## 2.6 Facility safety level definition

The nature of these premises and devices is determined in accordance with the instructions of the facility's category: the amount of liquid-metal coolant contained therein, the heat carrier's activity, as well as, to some extent, the maximum temperature accepted for the loop [14], [15], [16], [17].

The main factors determining the scale of potential danger in the maintenance of alkaline metal systems are radioactivity, the amount and aggregate state of alkali metal.
Facilities are divided into three categories:
Category 1 - Facilities with liquid radioactive alkali metals are not volatile from volume;
Category 2 - Facilities with a volume of liquid non-radioactive alkali metal more than 0.5m$^3$;
Category 3 - Facilities with a volume of liquid non-radioactive alkali metal from 0.01 to 0.5m$^3$.
Premises with auxiliary production include:
- a room for the decommissioning of alkali metals;
- a storage area for waste.

The room for the decommissioning of alkali metals is intended for:
- cleaning of the equipment contaminated with alkali metal;
- decommissioning of technological waste of alkali metals.

# 3 RECOMMENDATIONS PER COMPONENT

## 3.1 Storage

This concerns the management of the sodium supplies. One or several containers - called storage tanks - must be available in order to hold the facility's entire supply of sodium if necessary.

The storage tanks always contain two fluids:

- Hot or cold sodium.
- Inert gas (generally argon or nitrogen) providing the gas cover.

The pipe components (for the sodium or NaK and argon) right up to the isolation valves related to these tanks are considered an integral part of these tanks.

### 3.1.1 Design rules

#### *3.1.1.1 Location*

The storage tank must be located at the lowest point on the system. It is recommended that this tank be placed in a pit equipped with:

- Steel retention tray equipped with a sodium leak detection system and a coverage to allow for reduced access of gases.
- Suitable detection of anoxia and emergency ventilation system to reduce the risk of anoxia owing to the use of argon in the facility in case of sodium fire.
- Ventilation system to eliminate the argon due to leakage in the facility or a high performance oxygen detection system with acoustic and optical alarm signalising a low oxygen content.

#### *3.1.1.2 Pressure issues*

An isolated tank is subject to significant pressure variations; the pressure can sometimes greatly exceed the working pressure. The following parameters are involved in designing a tank:

- The maximum working pressure, taking into account the pressure used for exceptional transfers
- Maximum working temperature
- Filling factor, k, defined as follows:

$$k = \frac{Maximum\ sodium\ volume}{Total\ volume\ of\ the\ storage\ tank}$$

It is also important to assess the maximum permissible pressure likely to be reached in the event of the following cumulated incidents (details in Section 3.8.1):

- Overpressure due to an error or a gas intake defect
- Heating incident.

There should be two safety valves calibrated to the maximum permissible pressure with an alarm if the threshold is reached. Alternatively, a single safety valve with the needed performance level could be installed.

#### 3.1.1.3 *Temperature issues*

Considering the safety role of the storage tanks (emergency sodium draining), they must be able to withstand a thermal shock that corresponds to the maximum temperature difference between the sodium system and the storage tanks during draining. For the large facility tanks (CHEOPS), it will be necessary to:

- Keep sufficient sodium inside the storage tank at low temperature
- Install a mixing device to avoid stratification in the sodium layers
- Incorporate the hydraulic properties of the mixing device into the design.

#### 3.1.1.4 *Sodium quantities and tank volumes*

The quantity of sodium to be stored must be calculated by adding up:

- The useful volume of sodium at the preheating temperature. This represents the volume of the system filled to its highest nominal level with a safety margin, in compliance with the requirements in the specifications ref.[10], [11], [12], [13].
- The volume of hot sodium to remain in the tanks to limit thermal shocks during draining and to leave any sodium deposits at the bottom of these tanks.

Once the total quantity of sodium has been calculated, the tank volumes can be calculated for this sodium at the maximum working temperature, taking into account the filling factor. This factor is used to compensate for expansion phenomena during melting and during the temperature ramp-up and to allow for sufficient sodium remaining in the storage tank when the test facility is completely filled.

#### 3.1.1.5 *Connection pipes*

The connection pipes must necessarily be placed in the top part of the tank. It is prohibited to connect pipes in the bottom part of the tank. Any manways must be preferably located on the sealing flange. Removable flanges with welded lip seals will be used, at least in high temperature regions.

The sodium loop can be connected to the sodium tank with a combined immersed filling and draining pipe or separate pipes.

If separate fill and drain pipes are used, the drain pipes must never be immersed. A tube immersed in the sodium will be used to fill the system. Drain pipes must be able to withstand thermal shocks; the drain pipe section must be sufficiently short to eliminate the risk of freezing through the flange of the manway.

The tank must be equipped with a vent line. This line must be designed to drain the sodium quickly.

The draining pipe has to be connected by a fast acting valve to the expansion tank for fast gas exchange.

A tube immersed in the sodium will be used to fill the system.

The tubes on the tank that are not connected to a system (e.g. used for its own drainage) must be plugged with fixed unremovable devices or welded.

#### 3.1.1.6 *Inspection equipment*

The tanks must be equipped with devices to measure and check the minimum and maximum sodium levels, the temperature and the pressure; the latter two must be equipped with threshold alarms. Two diverse systems are recommended.

### 3.1.2 Other containers

Containers that serve similar purposes to the storage tanks must also comply with the recommendations given in Sections 3.1.1.2 (pressure issues), 3.1.1.3 (temperature issues), and 3.1.1.6 (inspection equipment).

## 3.2 Filling

This function involves transferring the liquid sodium from the storage tank into the rest of the facility's system. This requires a certain system layout and the necessary means to transfer the fluid into the system.

For safety reasons, fast draining must be possible as it may be required during such filling operations. Therefore, all the necessary measures must be taken to enable such draining at any moment, regardless of the filling method used.

### 3.2.1 Filling process

As the pump is located above the storage tanks (to make it drainable), it must be primed. A priming chamber should be placed just above the pump.

The priming chamber can be filled in several manners:

- Initial filling using a pump immersed in the storage tanks
- Filling during the system's operating phases, when draining a test volume.
- Emergency filling by over-pressurising the gas cover in the storage tank in the case of failure of the immersed pump.

In the latter case, all measures must be taken to avoid pressurising the entire system, so as to comply with the maximum working pressure and to avoid transforming "conventional" equipment into pressure equipment.

The sodium system design must cover all the possible filling methods based on the same pressure and temperature rules as those for connecting volumes.

At KASOLA, which has a total height of app. 12 m the filling process is done using evacuated base loop and a slight overpressure in the storage tank.

Filling process can be done using filing either evacuated loop or pressurised loop, but pressurised loop situation is more preferable when there is a small distance between lowest and highest points of the loop (in case of horizontal loop).

Before the filling the system should be heated up at the same time evacuating the gas system of the device to minimize the oxidation of sodium.

The temperature of the sodium depends on the possibility to heat up the loops components. If there are any potential cold parts which cannot be heated up above sodium melting temperature, filed sodium temperature increase should be considered to avoid solidification during filling. In any case 250°C temperature should not be exceeded.

### 3.2.2 General design rules

The filling operation must be carried out at a relatively low temperature: the recommended value is 150°C for technical reasons (sodium purity) and safety requirements (to limit the consequences of a leak).

Regardless of the filling method used, the sodium must not flow through the siphon area on the filling route to avoid trapping any gas which might prejudice the interpretation of the system's state. When this is not possible, a purge valve must be installed on the siphoning parts.

The filling level must be checked by redundant and reliable measures. Measures are: conductive or inductive level probes, time of flight methods, radar methods or thermocouples.

The filling at IPUL loops usually is being done at slight overpressure at the loop. In case there are no purge valves or there are components where trapped gas pockets may occur, filling process is being performed under vacuum.

## 3.3 Draining

Draining consists in transferring all the liquid sodium from the facility into the storage tank.

This can be a routine action associated with normal operation, facility maintenance or a test modification, but it must be possible to carry it out in an emergency.

The general safety principles are therefore:

- Draining must be possible at any moment.
- Draining must be complete (excepting in the filtering unit, cold trap).
- Draining must occur by gravity.
- Safety draining must be 100% reliable.
- The drain process must be completed within a reasonable time (1-2 min), it depends on the size of the loop and at which level the completed draining will be defined (To be pre-calculated by system codes…).

### 3.3.1 Construction rules

The construction rules below must be taken into account:

- The type of drain valves, their location and their method of actuation must be chosen carefully (see Section 3.3.2 below).
- The drain line and equalizing line (needed for draining) must be permanently preheated; the storage tank must be kept at a sufficient temperature to limit the amplitude and the effect of thermal chocks.
- The lowest point of the facility must be the storage tank. The lines should have a slope of at least 5%, and the flow sections must have a suitable diameter to allow for fast drainage. The duration of this drainage operation must be determined by a risk and safety assessment.
- Drainage in the case of an incident requires the implementation of measures that will prevent damaging the components by thermal shock.
- Argon must be able to flow freely between the storage tanks and the top parts of the facility in the equalising lines.

### 3.3.2 Drain valves

These valves must be robust and provide a large flow section, while remaining leak tight in a closed position. Solidified-joint valves should be used where possible.

The type of the valve has to be selected so that it is open without actuation (fail safe)

#### *3.3.2.1 Types of valve control*

Controls must be automatic and made redundant by a manual control. Manual control must include mechanical extensions and must be installed at the limit of the system in a leak-protected area.

#### *3.3.2.2 Valve locations*

Drainage areas should not be subjected to the sodium system pressure whenever possible by installing nozzles in low-pressure areas.

Drain valves should be positioned as close as possible to these nozzles, which should be located at the lowest point on the system. They should be installed on a section of vertical piping if possible.

They must be preheated under the same conditions as the drain lines (see Section 3.5 on preheating).

Any measures that can be implemented to prevent the accumulation of impurities in known weak spots (cold spots, settling, etc.) should be implemented.

### 3.3.3 Controlling drainage

A certain number of devices must be installed to:

- measure the sodium levels in the top parts of the facility (expansion tank) and in the storage tanks,
- measure the temperature.

A non-invasive flow measurement device should also be installed on the drain line, if other reliable measures give not sufficient information about the draining.

## 3.4 Isolation and connection

These requirements concern the system's devices used to partially or completely isolate the system, or those components representing a risk of leakage such as flanges or seals.

Long-term experiences gained at HZDR using the sodium loop NATAN and at IPUL (Riga dynamo experiment) show that a hazard-free application of flanges and valves is possible in a temperature range up to 350°C.

Drain valves are the subject of specific measures; accordingly, they are discussed in Section 3.3 on drainage.

### 3.4.1 Valves

Generally speaking, all valves should remain accessible. If this is not possible, valves must be controlled by remote means.

Valves should be positioned so they can be easily removed if necessary.

All valves to be operated in the case of an emergency must be visibly identified and the following instructions must be clearly visible:

- Open,
- Close.

Argon inlet and outlet valves must be placed outside the system's perimeter though still in close proximity.

All sensitive parts of the valves have to be heated.

### 3.4.2 Flanges, seals and connections

Removable parts (flanges and connections) should be kept to a strict minimum in high temperature loops, choosing welds whenever possible. When removable parts are foreseen, they must be designed carefully since they represent strong constraints, sensitive to shocks and thermal cycles.

Flanges equipped with seals should only be used in low temperature sodium loops up to 350°C when required due to technical reasons. The following must thus be provided:

- Leak detection at flange connections or below
- Metal seals or metal covered seals (e.g. stainless steel covered graphite)
- Removable insulation for regular inspection
- Special care should be taken at the choice of sodium compatible seal materials and orientation of valves.

### 3.4.3 Leak prevention

Mechanical locking devices preventing the complete removal of equipment (detection plug or instrumentation) must be provided. Openings left by the removal of any equipment must be systematically equipped with captive plugs fixed by a chain.

Leak detection devices (wire-bead detectors or detection plugs, see recommendations on designing sodium systems) must be placed on adequate locations on all pipes and devices. Specific leak detection means must systematically be installed in locations where components are regularly removed, such as flanges and certain pipe sections.

## 3.5 Trace-heating

Trace-heating consists in ramping up the temperature of the facility so it can be filled with sodium, while limiting thermal shocks and keeping temperatures in the operational range for sodium.

For the implementation of a facility containing frozen sodium, it must be possible to successively heat up sections of the system, starting with the free levels to avoid melting in a section surrounded by two areas where the sodium is still solid.

There are several types of preheating:

- Heating electrical cables
- Inductive heating
- Gas in a double jacket (HX).

Without assuming a technical solution, this document only discusses electrical preheating and gas heating in case of sodium-gas HX.

### 3.5.1 Operating conditions

The maximum permissible temperature on the outer surface of the insulation must not exceed the limit imposed by regulations (maximum hand contact temperature).

The insulation must be protected at least by one metal sheath.

The drain lines must be preheated to a temperature comparable to that of the facility and it’s test section: they should be heated so that any thermal shocks resulting from fast drainage remain compatible with the objective of reliability for these lines (see Section 3.3 - Drainage).

When high preheating power levels are required for large volumes (significant mass of sodium to melt), a safety system must be installed to prevent reaching an excessively high temperature in the event of temperature control failure (safety temperature control system separated from the heating control system).

Generally speaking, the temperature calculated for the facility is higher than the equilibrium temperature reached during preheating. This design temperature should be determined in the safety assessment.

Three separate temperature sensors should be used for regulated preheating:

- One for temperature control.

- One for temperature monitoring to trigger an alarm if the limit is reached.
- One back-up sensor is recommended.

The temperatures of the preheated pipes must be monitored by sensors installed along the pipe sections.

The location should be optimized depending on the electric heating spatial distribution

### 3.5.2 Instrumentation and control

It must be possible to control the operating state of the preheating equipment on all lines. This operating state must be indicated on a control board that informs the operators on the effective operation of the preheating cables. The safety-important lines contributing to the drainage function (drain and equalising lines) should be equipped with monitoring systems and alarms.

It is important to fast and precisely identify the facility state.

## 3.6 Cleaning

This consists in reducing the level of impurities in the liquid sodium by trapping them.

This is achieved by circulating the sodium in a cold trap for which the temperature is adjusted.

It is controlled by means of a plugging indicator, with the plugging temperature indicating the degree of purity.

The filtering device must be considered as an integral part of the sodium system.

### 3.6.1 Cleaning

Filtering itself does not raise any safety requirements.

Therefore, all the general safety rules applicable to systems containing liquid sodium (excluding cold traps which cannot be drained) must be followed, with an important additional requirement: the configuration must be such that operations can be carried out safely on the devices, in particular for the replacement of cold traps.

There are some limits of the impurities (t.b.d.) to be reached before operation at high temperature sodium loops.

### 3.6.2 Filtering

In the fill line, a particle filter is installed to protect the base loop from metallic particles from the storage tank and the loop. Since draining takes place in a separate line, corrosion and erosion particles are kept inside the storage tank. The filter is backflooded during draining.

## 3.7 Circulation of sodium

This section provides the rules that ensure the normal circulation of liquid sodium in the different parts of the system in safe conditions.

The filling and draining operations are discussed in Sections 3.2 and 3.3.

The devices concerned by these operations are: the pipes, their connection to the volumes, the pumps, the I&C system, and the related alarms.

The design of the systems must take into account any accidental operating disturbances. It should also take into account the different foreseeable configurations.

### 3.7.1 System pipes and components

The following rules must be applied:

- The pipes must have a slope of at least 5%; a minimum of 3% is permitted exceptionally on sections of limited length when hot. Long drainage lines should have an inclination of ~4°.

- Handling devices must not be placed in areas that are difficult to access from which an operator could not easily exit in the case of an incident.
- Handling devices should be positioned on the periphery of the system. They must be accessible via platforms.
- Openings on pipes must be avoided.
- Dip tubes and vents descending into a tank should be identified.
- The problems of thermal expansion of pipelines for circuits with alkali metals should be considered more strictly than for most industrial pipelines, since they are characterized by high operating temperatures, and high thermal expansion coefficients of the structural materials used. For example, austenitic stainless steels have an expansion factor of 40% higher than the carbon steel.

### 3.7.2 Pumps

Pumps are used for filling a system (electromagnetic pump) or for circulating sodium in a closed circuit (mechanical or electromagnetic pump).

If a volume containing a cover gas under normal operating conditions is subjected to the resulting dynamic pressure, the legislation governing devices subjected to gas pressure must therefore be followed (see Section 3.8 on the gas cover function).

A volume located downstream of a pump must be designed and equipped considering the pump's maximum pressure.

The operation of the pump necessarily means that the correct temperature can be maintained.

Inlet duct of the pump should be designed with a proper care to ensure low hydraulic resistance, allowing to avoid cavitation. If the design of the facility does not allow to create enough height of liquid metal column at pumps inlet, additional gas pressure should be added to avoid cavitation if such process occurs.

When creating mechanical pumps for liquid metals, specific tasks arise, mainly related to the choice of materials, the use of seals that practically exclude metal leaksor using bearings that operate in the pumped medium, with the need to drain the metal from the pump at the end of work.

It should also be possible to seal of cavity of the pump entering the circuit tightly ensuring vacuuming before filling the metal. Mechanical pumps are developed and used successfully on liquid metal circuits, cooling systems of nuclear reactors with a capacity from several $m^3/h$ to 3000 $m^3/h$, operating temperature up to 600°C and efficiency in the range of 70-90%.

Their specificity is mainly in the performance of the drive and the organization of the shaft seal. The most characteristic of these are pumps with a suction shaft and seals on this shaft, rotated by a conventional electric motor; pumps driven with a built an electric motor; pumps with a gas seal, in which the motor is far away from the impeller and sealed a cap, cooled by water, and others.

The high electrical conductivity of liquid metal allowed the development of pumps in which the pumped liquid acts as a rotors for conventional machines. The head in such pumps is created by electromagnetic forces. The use of electromagnetic pumps (EM pumps) is attractive because of the ability to obtain hermetically sealed systems. EM pumps can be designed in variety of types and configurations. Detailed analysis of all types to obtain the best selection for each application would be a prodigious task. Each of the types of pumps is adapted to a certain field of operation; many of the pumps have one or more characteristics unacceptable for needed application and are eliminated from further consideration.

There are two ways in which the current can be applied. Either an external constant current is applied to the sides of the conduit at right angle to a constant magnetic field. This magnetic field is also applied from outside to conduit. In this case, the EM pump is usually referred to as a conduction EM pump. It is a simple pump however the main disadvantage is the very high current must be transported to the wall and thereby creates both Ohmic resistance and constitutes a fire hazard. For this reason, conductive EM pump is not retained.

The other possibility for EM pumps is one in which the magnetic field is varied in time as a travelling sine-wave, thereby inducing a current at right angle to the magnetic field in the electrically conductive fluid (Maxwell equations). In this case the EM pump is known as an induction EM pump. Induction EM pump alternating field can be created using electrical inductor or moving magnet system.

In terms of efficiency an induction EM pump ranks quite low. Efficiency ranges from a few percent up to 40% (depending on conductivity of liquid metal) at most in an optimized configuration, although larger pumps tend to favor greater efficiency.

EM pumps have important advantages in in comparison with mechanical pumps:

- Absence of dynamic condensation and complete tightness;

- Absence of wear by friction of driven elements of a design;

- Minimum vibration and noise.

### 3.7.3 Instrumentation related to sodium circulation

Each system must be equipped with monitoring instrumentation to provide the following information at least:

- Sodium leakage.
- Minimum and maximum levels.
- Over-/ undertemperature.
- Cold point on the drain line.
- Flow rate threshold.
- Pressure threshold.

This information will be used to trigger alarms or automatic actions, e.g. shutdown of pumping or heating. In the case where the operator is required to intervene, the thresholds for alarms and for automatic actions should be timed correctly to allow for corrective action if necessary.

The alarms for each system should be transferred through to an overall control board specific to the building.

This list is not comprehensive and must be validated by a risk and safety assessment.

### 3.7.4 Proximity between a sodium system and a water system

#### *3.7.4.1 Pipes and components of systems containing water*

This section does not cover steam generators.

Pipes containing water must be placed in different vertical planes to those of pipes containing sodium or better in different compartment. Air humidity has to be controlled. Condensation on the outside of these pipes must be eliminated by using a light layer of insulation.

If water is used as the coolant without an intermediate fluid, there must be:

- Two metal walls providing a double leak tight barrier.
- Fast evacuation of the HX for water and sodium.
- A retention volume larger than the total possible leak.

- Circulation of the water in a closed circuit (with a make-up water system isolated by two valves).
- Troughs under the water pipes.

If an intermediate fluid (e.g. thermal fluid compatible with sodium) is interposed between sodium and water, its pressure must always be greater than that of sodium and water.

#### *3.7.4.2 Instrumentation related to the presence of water*

The following must be provided:

- Means of detecting water leaks and intermediate fluid leaks where necessary, as well as means for measuring the free level.
- Gas pressurization of the systems and monitoring/ adjustment of this pressure level.

#### *3.7.4.3 Sodium system design*

In the case of the heat exchanger thermal test station, the heat exchange tubes of a steam generator mock-up separate the sodium system from the water system. As these tubes are single-wall pipes, the sodium system must be designed taking into account sodium-water interactions due to the total and instantaneous failure of all the heat exchange tubes.

The consequences of these interactions and the correct design of the system faced with such an event must be validated; some information for the preliminary design of the system is provided in ref. [9]. Heat exchangers can be designed to avoid direct contact of the sodium to water facing wall by using intermediate cooling agents.

### 3.7.5 Pressure shocks and hydraulic events

Some components require specific analysis of the sodium flow under dynamic conditions to confirm their structural strength.

Cavity-type accessories in contact with the sodium flow (thermal wells, closed pockets) must be designed so that their resonance frequency does not coincide with that of the eddy created.

In the case hydraulic tests prove necessary for some components of the system, the design phase (study) must be taken into consideration.

## 3.8 Gas cover and gas systems

The top sections of the volumes, above the free surface of the sodium, must be filled with an inert gas (such as argon, nitrogen or helium) to form the gas cover; the pressure applied should be marginally higher than the atmospheric pressure (around 100 mbar) and can increased to a much higher level for disconnecting the loop of the gas supply.

These gas plenums are connected to each other and to the storage tank via an equalising line. There are other connections for injecting more gas or for venting all or part of the system.

Hysteresis-type regulation is preferred to minimise gas consumption.

### 3.8.1 Design overpressure or negative pressure

The difficulties associated with establishing pressure in a storage tank are described in Section 3.1.

A specific pressure is normally stipulated in the regulations for all vessel types. If the working pressure is higher than this stipulated pressure, safety measures must be installed.

If the working pressure of the vessel is less than the stipulated pressure, it is possible to limit the use of such valves and still ensure intrinsic safety. The design must therefore take account of the possibility of overpressure and its main causes (see below).

1. Overpressure caused by a pump (including the electromagnetic pump in the filtering station): It is possible that some pipes may become blocked (by impurities or ice or because of closed valve(s)). Conversely, a valve may leak and cause suction in a volume that is normally isolated.
2. Heating incident. The heating controller may become locked in the "heat" position when a volume is isolated. The initial sodium level is the normal maximum level. The initial temperature is the preheating temperature. The initial pressure is equal to the pressure that can normally be set given the normal setting of the intake pressure-reducing valve.
3. Overpressure due to an error or a gas intake defect: It is accepted in this case that the master pressure-reducing valve for the distribution system is safe, but that the facility's dedicated pressure-reducing valve is defective. This presumes that the pressure-reducing valve for the distribution system is lead-sealed (safety seal) and that it is backed up by an overpressure alarm.

Wherever overpressure cannot be tolerated intrinsically, safety valves or diaphragms must be provided. The design pressure for the vessels or system is therefore lower than the set pressure of the diaphragms or safety valves.

As a minimum requirement, the facility must be able to withstand the negative pressure caused by the following:

1. A controlled draining operation when the equalising line is blocked.
2. Cooling of the sodium after draining at maximum temperature without regulating the pressure.
3. Initial cleaning of the facility inner surfaces and removing of remaining air due to evacuation if designed for the facility.

### 3.8.2 Gas system design

#### *3.8.2.1 Equalising line*

The equalising line connecting the storage tank to the volumes plays a role in the safety of the system as this largely depends on limiting accidental overpressure or negative pressure.

There are two potential designs for the equalising lines:

- Hot legs: the line is treated as a sodium line and has the same "hot leg" safety features as a drainage pipe. It must be capable of being washed by hot sodium. An equalizing line should not include a siphon.
- Cold legs: the line is made of non-insulated ordinary steel. The connections on the storage tank and vessels are made through sodium vapor filters.

The "hot leg" design is preferred if the total argon flow rates are high (with significant and frequent variations in level).

The valve(s) used to shut off the line must be capable of being set to "open" at the start of the filling operation. The use of bellows valves is preferred to prevent air from entering the line.

The instrumentation (see Section 3.8.2.6) must provide an easy means of checking that the gas is flowing freely in the equalizing line.

#### *3.8.2.2 Overflow line*

This is the line used to return any excess sodium back to the storage tanks. There are two different scenarios here:

- Sodium pots operating without continuous intake of sodium: in this case, the equalizing line can provide the overflow line function.
- Pots with continuous sodium intake: in this case, the overflow line must be separate from the equalizing line since this has to regulate the gas pressure.

#### *3.8.2.3 Gas intake*

The gas supply must make as much use as possible of the buildings' existing distribution systems, except in very specific cases subject to licensing. A reliable (e.g. lead-sealed) master pressure-reducing valve with an adequate performance level must be used for this distribution system. The distributed pressure must be limited by a pressure-reducing valve and a safety valve calibrated and lead-sealed for every use. The number of different categories of pressure-reducing valves used must be kept to the minimum possible.

If a higher cover gas pressure than the pressure of the distribution system is required, cylinders will be used (subject to licensing). Compliance with gas storage legislation must be ensured. Cylinders must be stored in an outdoor storage area wherever possible but must not, under any circumstances, be stored directly under a system.

Pressure control devices give alarm if gas stack is not sufficiently filled.

#### *3.8.2.4 Vents*

The vent line must be able to withstand a higher flow rate than the argon intake.

Bends and complicated runs must be avoided.

Vents must be used in the cyclones or discharge pots to prevent any particles from being discharged from the system. Discharge from the vents will be released outside the building.

Exhaust lines of the vacuum system of installations of Category 1 should be withdrawn to special ventilation.
Exhaust lines of the vacuum system of units Categories 2-3 should be withdrawn, if there are toxic substances in the vacuum cavities, in special ventilation or through filter elements. Vacuum equipment, gas - vacuum armature and devices are recommended, as a rule, to be placed outside the enclosure of installations.
It is recommended to divide gas-vacuum systems of Category 1 installations from gas-vacuum systems of installations of other categories.

#### *3.8.2.5 Safety valves and diaphragms*

The following recommendations must be taken into account when installing safety valves or diaphragms:

- Hydraulic safety valves are preferred to mechanical safety valves or diaphragms.
- Safety valves must flow towards correctly equipped vent lines (with seal pot or cyclone).
- Safety valves must be protected by a sodium vapour trap which is separate from the vapour trap on the normal vent.
- No other valves must be placed either upstream or downstream on the safety valve vent line.
- Under no circumstances should safety valves or diaphragms allow air ingress into the system in the event of negative pressure.
- An overpressure alarm must be provided for every safety valve or diaphragm installed. This alarm must be set below the working pressure for the discharge device.

- A safety valve may be installed if any potential scenarios could lead to a backflow of sodium to the safety valve. If this backflow cannot be totally eliminated, it will be necessary to install a diaphragm on a discharge line to a storage tank.

#### *3.8.2.6 Instrumentation*

Every free-level tank is equipped with a pressure-reducing valve protected by a vapour trap.

The alarm pressure sensors are installed downstream of the vapour traps.

### 3.8.3 Case of isolated covers with sodium-induced gas pressure

This section does not apply to storage tanks. Refer to Section 3.1 for information on storage.

A certain number of systems include vessels which have to operate with an isolated gas cover and overpressure. The main safety issue here is not that this overpressure exists, as it can be quite low, but that any unintended venting could cause a sodium overflow since it is the sodium which induces the gas pressure.

Such "isolated" covers have to be designed to be fully isolated during operation, i.e. to ensure that no connection can be made to the gas line during operation.

All seals need to be sodium-type seals.

# 4 GENERAL LAYOUT ARRANGEMENTS

The information below complements that given in the specification, reference document [8].

## 4.1 Server and workstations

A system’s operational safety relies to a large extent on the measures adopted in terms of the overall layout of the system and its auxiliary components, taking account of the constraints imposed by the existing environment.

The preliminary design studies, which allow the functional diagrams and operating mode (nature and frequency of operations) to be drawn up, will provide a clear overview of the operations to be carried out on the facility and will therefore help to design a safe, functional layout.

The various workstations will be organized in accordance with employment regulations and will be subject to an analysis of the human and organizational factors.

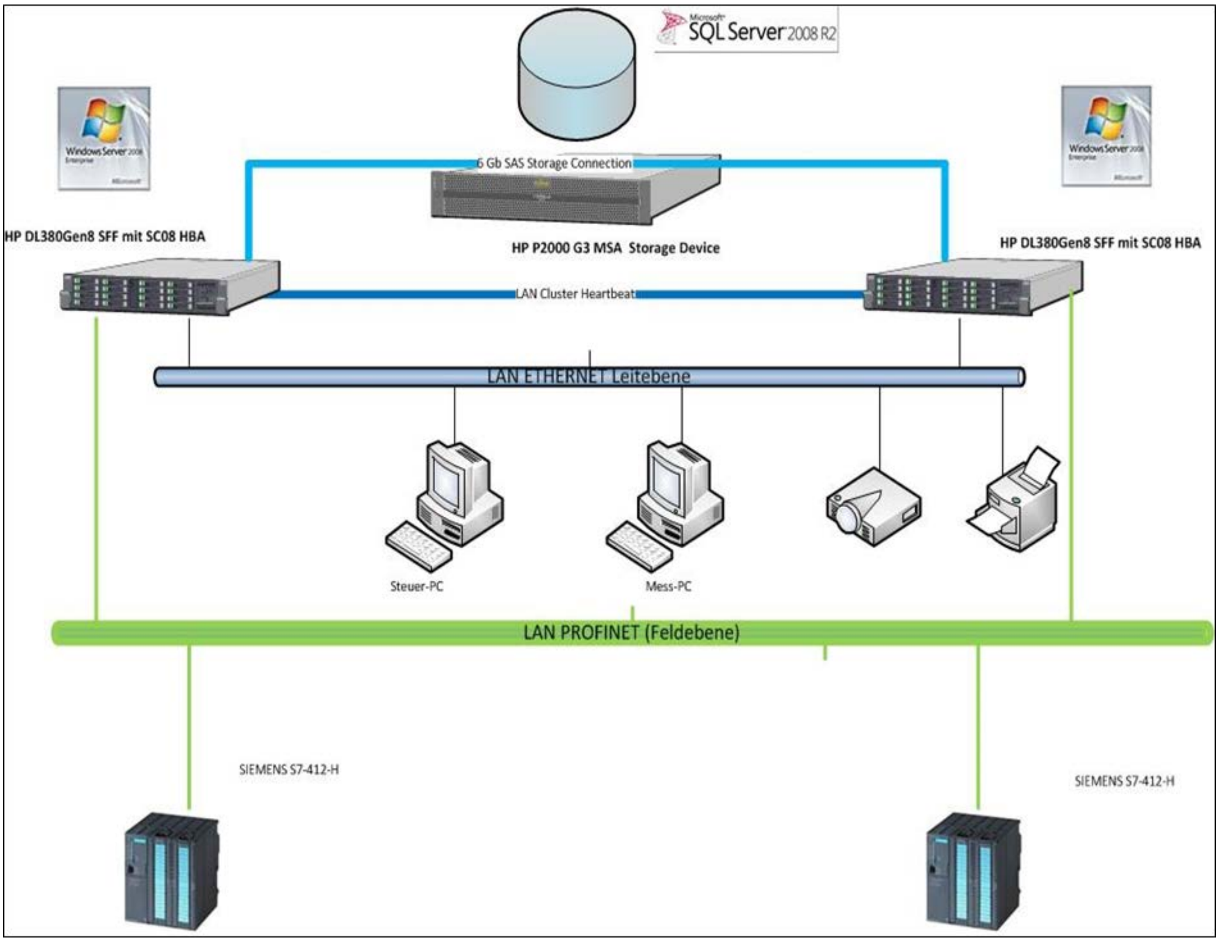

Figure 4.1 KASOLA safety relevant guidance and control structure with two independent PLCs

### 4.1.1 Control room

The design of the control room must take account of the need to accommodate several operators with different roles:

- Operations and monitoring personnel.
- Experimenters.

Provision must therefore be made for two dedicated stations to cover each of these specialist roles.

#### *4.1.1.1 Operations and monitoring station*

This station is generally located in front of the I&C monitoring station. It is reasonable to assume that this station will need to accommodate several operators simultaneously during working hours.

The area reserved for this station must be sufficient to allow personnel to move freely after the I&C station and a board (for preparing and conducting experiments) have been installed. The board must be included on the layout plan.

This area must provide the operator facing the racks with an overview of the whole system during all operating phases (instrumented mimic panel, video surveillance, plus any equipment deemed necessary during the safety assessment).

This area must be clear of the actual system itself. If necessary, provision must be made for a protective metal screen and canopy (to protect personnel from sodium splashes and falling objects depending on the environment).

This area leads is recommended at ground level in two opposite directions to two wide clearance zones on level zero or, if necessary, to working platforms in large facilities.

This area should not be confused with a passageway and even less so with a materials transfer area.

#### *4.1.1.2 Experimentation station*

This station adjoins the operations and monitoring station. A means must be provided for feeding back the results of the experiments conducted (all useful data will be presented in the interface memo, reference document [4]).

The area reserved for this station must be sufficient to allow personnel to move freely after the data feedback station and a table (for preparing and conducting experiments) have been installed. The board must be included on the layout plan.

This area should not be confused with a passageway and even less so with a materials transfer area.

### 4.1.2 System control station

This station comprises the operating devices such as the hand wheels for the argon and sodium valves in particular. Except in exceptional circumstances, these devices need to be activated by an operator to change state (filling, draining, pressure adjustment, venting, operating a sodium pressure sensor, etc.).

Given that all the functions required for operating and securing the system will be accessible from the control room, the permanent presence of an operator at this station should never be necessary. Only brief operations are envisaged.

These stations should not be located within a system.

It must be possible to access these stations from two opposite directions. They will preferably be accessible on the ground floor, otherwise at least one access must be via a stairway and the second can be via a ladder.

### 4.1.3 Operating station for opening the system

It is sometimes necessary to open the system to be able to remove certain components.

The system is drained but may not be entirely cold.

The corresponding work areas must be designed to facilitate the work of operators as far as possible, bearing in mind they will be wearing protective clothing.

The conditions for accessing these areas are the same as those described in the section above.

The area must be large enough to be able to lay out the necessary tools and equipment.

### 4.1.4 Emergency Operating station

In case of failure of all IT stations the basic control system has a special human interface (tab-screen) which allows to control the facility and return to safe state (emergency drain,…)

## 4.2 Solid steel or open mesh platforms

For large facilities, solid steel is usually used for platforms provided that there is an adequate means of smoke extraction should a sodium fire break out below the platform.

In practical terms, if a sodium leak is likely to occur above a platform, this should be made from solid steel as a minimum requirement in all areas where workstations (see Section 4.1), passageways, trunk ways, control racks and more generally the facility's safety-related equipment are located below the platform.

This layout must be compatible with the number of compartments required in the event of sodium fire.

Solid steel platforms reduce by surface spreading the risk of spray fire.

## 4.3 Partitioning

All or part of a facility can be equipped with protective metal partitions. These can be installed:

- to protect the station used to secure the system in an emergency,
- to keep the work areas or passageways separate from a device considered to be particularly fragile or hazardous,
- to limit the production of aerosols during a fire following a sodium leak.

These protective partitions must not impede the movement of personnel in any way, especially not emergency tracks and exits.

This form of local shielding is not to be confused with the full or partial closure of a system in a vessel (sealed or otherwise). This completely enclosed configuration can only be used in those sections of the system where the characteristics of a sodium leak require the installation of a splash board to help contain the spread of sodium. However, it should be noted that this configuration does involve a strict operating constraint, i.e. entry into the vessel is absolutely forbidden when there is sodium in the loop.

This configuration can therefore only be envisaged for very specific constraints associated with the loop and the environment. It goes without saying in this case that all operator controls and workstations must be located outside the vessel enclosure (see section 5.3.2).

# 5 BUILDING LAYOUT

In addition to the general safety rules applicable to all buildings housing conventional industrial activities, there are very specific rules governing premises where liquid sodium is handled, regardless of whether or not the sodium is radioactive.

The following rules only apply to non-irradiated sodium used in test facilities.

## 5.1 Building construction

Compliance with regulations for environmentally-regulated facilities is required.

These are some of the most important points:

- Consider the resistance of metal frameworks (for both the sodium hall and the facilities) in the event of a conventional fire and a sodium fire.
- Design roofs so that they prevent any risk of rainwater.

- The overall seismic withstand will need to be validated.
- A hot air heating system will be preferred to a hot water system.

## 5.2 General building layout

The project must make a clear distinction between all the different areas:

- A hall housing the sodium systems and storage tanks. This is the only part of the building where sodium-related hazards exist.
- An instrumentation and control room with a direct exit to the outside of the building is recommended.
- Offices, labs and miscellaneous rooms for personnel (changing rooms, toilets, rooms for the cleaning staff) separated from the sodium hall by a corridor exiting directly outside and allowing the safe passage of personnel protected from smoke in the event of an evacuation. The offices and labs will have no direct access to the hall.
- Storage rooms for gases and flammable products which must be kept outside the hall with no direct access from the hall.
- If provision is made for workshops, these will be adjacent to the hall and will lead off into an assembly area for large components which must be kept unobstructed.
- Storage of alkali metals in standard factory containers and special containers. Alkali metals in a standard factory container must be stored in an alkali metal warehouse.
- Preparation of alkali metals for melting. (Opening of containers, cleaning of ingots of alkali metals from preservative grease and slags, cutting ingots, washing and loading ingots into melting tanks, sealing melting tanks). These operations can be performed in a specially equipped room located in the warehouse building with alkali metals or a building with liquid metal plants.
- Melting of alkali metals in sealed containers. Melting of alkali metals can be carried out in a specially equipped for this purpose room in the building of liquid metal plants, as well as in premises with liquid metal plants.
- Storage of equipment with alkali metals, as well as the storage of alkali metals in a standard factory container, presents a fire hazard. The dismantled equipment is stored in a special room of the building for decommissioning and cleaning site.

## 5.3 Layout inside the hall

### 5.3.1 Distribution and fluid discharge systems

The water supply will only be used in the sodium hall for technical use requirements on the systems. A master shut-off valve will be located in the control room.

### 5.3.2 Location of facilities

There must be a very clear and simple subdivision between the test facilities themselves and the areas reserved for equipment and the movement of personnel and materials.

The distance between two systems must be sufficient to prevent any interaction in the event of an accident.

Areas which must not be obstructed will be marked out on the floor.

The floor will be covered with an appropriate material capable of containing sodium in the event of a leak. In areas designated as hazardous, all concrete surfaces will be clad in steel to prevent any interaction with the concrete.

In areas located below systems, extinguishing trays will be arranged in such a way as to limit the production of aerosols as far as possible in the event of a pool-type sodium fire. To keep these to a minimum, collectors could be installed to contain and channel any sodium leaks. A study will be conducted to optimise the surface area required in relation to the volume of the extinguishing trays.

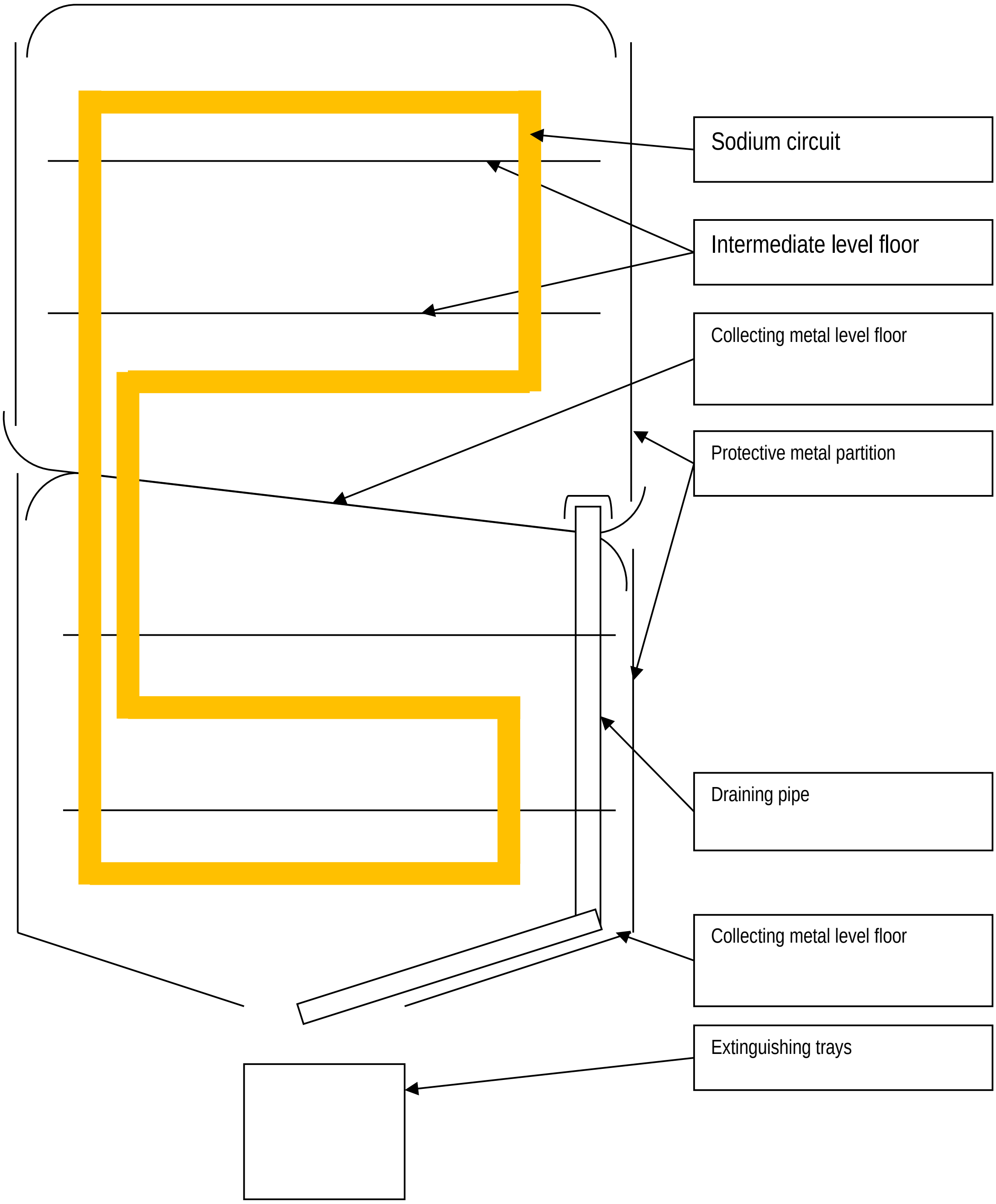

Figure 5.1 Example of compartmentalisation

The pits will also be laid out according to requirements, particularly in terms of housing the storage tanks.

### 5.3.3 Emergency exits

Compliant with regulations.

### 5.3.4 Emergency lighting

Compliant with regulations.

### 5.3.5 Ventilation

In the event of a sodium fire, it is imperative that any releases into the environment are via the dedicated waste outlets defined during the hazard study. One of the main roles of these outlets is to limit the overpressure applied to the building in such a situation.

These waste outlets could be used in the event of a conventional fire to ventilate the building.

All other measures provided to combat conventional fires or aid ventilation must not compromise the hazard study in any way.

Exhaust ventilation of premises, in which the installation of Categories 1-3 and auxiliary equipment is located, must be separated from the ventilation devices of other premises. Ventilation units in premises where the production processes are accompanied by the release of hydrogen (for example, facilities for the destruction of alkali metals) must be carried out in an explosion-proof installation with a multiplicity of air exchange by calculation, but not less than 10 per hour. Fans of exhaust systems must be installed in separate chambers; the fire resistance limit of the enclosing structures should be at least 1 hour. It is prohibited to enter in to the chambers from premises with alkaline metals. Exhaust ventilation systems servicing premises with installations of Categories 1-2 must have back-up ventilation units automatically activated when the main unit is stopped. Switching on and off the supply and exhaust ventilation of industrial premises with the installation of Category 2-3 should be outdoors. Supply - exhaust ventilation of industrial premises should be arranged in such a way that the possibility of air entering from one room to another is excluded.

## 5.4 Alarm equipment

### 5.4.1 Smoke detectors

Global detection systems must be provided in addition to the local sodium leak detection systems installed on the system itself (see section 9). This requirement can be covered by a conventional fire alarm system.

The operating principle of these devices and the design and implementation of a leak detection system are described in the memo, reference document [3].

### 5.4.2 Flood detectors

These will be provided at ground level and especially in the pits.

### 5.4.3 Alarms linked to these detectors

The alarms associated with these various detection systems can be either visual or audible.

Visual alarms will be grouped on a mimic panel to be able to locate an accident immediately.

## 5.5 Prevention and emergency response measures

An assessment will be made to identify the most appropriate locations for the various prevention and emergency response measures required (essentially overalls in the case of prevention measures and protective clothing and fire-fighting and first aid equipment in the case of emergency response measures).

## 5.6 Connections

These can be either wired (via telephone line, intercom, emergency buttons, etc.) or via radio link. Approved equipment will be used.

At the very minimum the facility will include an emergency warning system which will be controlled from the control room (if there is one).

# 6 EDUCATION AND TRAINING

Not directly connected to the design and construction of the facility, the designer, engineers and other staff have to be introduced to the needs and the peculiarities of the fluid used. Maintenance is only allowed under drained facility and ambient temperature. Safety instructions on yearly basis are necessary as well as training on emergency reactions.

# 7 LIST OF REFERENCE DOCUMENTS

[1] Technical report STRS / VAL / 76-29 – Recommandation concernant la sécurité pour la conception des installations d’essais sodium.

[2] Technical report STRS / VAL / 78-64 – Recommandation de sécurité pour la conception des installations en sodium.

[3] Technical report NT-2012-012 - Recommandations de conception des circuits sodium.

[4] Technical report NT 0212-015 - Note d’interfaces des maquettes et composants ASTRID.

[5] Technical report NT 2012-014 - Spécifications de fabrication et de montage des composants des circuits sodium.

[6] W. Hering, A. Jianu, M. Lux, KASOLA Anlagenbeschreibung und Sicherheitsvorkehrungen, INR-Bericht 1/13, Bericht NUKLEAR 3454, Jan 2013

[7] A. Onea, W. Hering, C. Homann, A. Jianu, M. Lux, S. Scherrer and R. Stieglitz, Optimization of the KASOLA high Temperature Liquid Metal Loop, The 15th International Topical Meeting on Nuclear Reactor Thermal hydraulics (NURETH-15), Pisa, Italy, May 12-15, 2013

[8] Technical report ST 2012-002 CHEOPS CDC INSTALLATIONS CHEOPS – réf. : 100 TECNA PJU CDC 12000003 – CEA/DEN/CAD/DPIE/DIR/CHEOPS/DO 2 du 13/02/12

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