25

European Working Group "Hot Laboratories and Remote Handling"
October 21-23, 1998 - Windscale - United Kingdom

New requirements for HEPA filters for ventilation networks in Hot Laboratories, especially against fire hazard - Assessment of their efficiency by specialized test houses

Gilbert BRUHL - CEA/DSNQ/MSN/France (1)

Abstract

HEPA filters constitute an important safety component of the ventilation systems in nuclear facilities, because of their behaviour to limit the spread of radioactive contamination into the near environment, during normal and abnormal operating conditions.

In the event of an accidental situation, especially in case of fire, these equipment ensure effectively, in conjunction with the walls of the building, the last barrier of prevention against the spread of the radioactive contamination outside of the facility.

So, in order to guarantee the permanency of their efficiency during the whole duration of the most plausible fire, the degree of resistance of this kind of equipment should be adapted to the following associated operating conditions which will occur during an accidental situation: high level of temperature, over pressure, clogging due to the fumes and hot aerosols transported by the extracted air, toxic atmosphere, ...

For that purpose, many companies and especially CEA (France) have contributed in the recent past to the development of a new type of HEPA filters which is able to resist to a high increasing of temperature and to a set of other environmental conditions, associated to a fire event in nuclear installations.

The present communication intends to summerize the studies realized in France by the different organization in charge of these questions (safety authorities, end users, manufacturers, certification bodies, ...). The presentation will cover the following items:

- inventory of the environmental conditions associated to a fire hazard in nuclear installations,
- design of a new type of HEPA filters able to fulfil the corresponding requirements,
- definition of an assessment program for that category of safety equipment,
- qualification of several types of HEPA filters by the IPSN Centre of Qualification of Nuclear Equipment.

---

(1) CEA/Direction de la Sûreté et de la Qualité/Mission Sûreté Nucléaire - CEA Saclay - F 91191 Gif-Sur-Yvette

1 - DEFINITIONS

◆ Filters

Devices which removes specific particulate contaminants (liquids or solids) from atmosphere passing through it. A filter is constituted by a **filtering medium**, generally made of a porous or fibrous material (i.e. glass fibber **paper**) fastened in a **frame** or casing. The filter is mounted in a leaktight manner in its casing or frame, during the manufacturing process, using a **lute.**

◆ Filtering efficiency (or scrubbing coefficient)

The behaviour or efficiency of a filter to retain particulate contaminants is defined by the scrubbing coefficient, in mass, of the filtering element. This coefficient is equal to the ratio of the mass concentration of incident particles on the mass concentration of emergent particles.

For the purpose of the present communication other definitions apply [1]. The first is called *efficiency factor* which is defined as the reversed value of the efficiency [efficiency factor = 1/efficiency].and the second, called *penetration factor*, defines the ratio of the number of emergent particles on the number of incident particles [penetration factor = 1-efficiency].

These coefficients, measured on a test bench for each unit filter, at its nominal flow rate, must be as the minimun:

- 5 000 for the test with soda fluorescein (uranine), according to NF 44-011 (efficiency 99,98 % - penetration 0,02 %),
- 10 000 for the test with sodium chloride (NaCl), according to EUROVENT document 464 (efficiency 99,99 % - penetration 0,01%).

◆ HEPA and ULPA filters

HEPA *(High Efficiency Particulate Air filter)* and ULPA *(Ultra Low Penetration Particulate Air Filter)* are classified according to their filtration performances. Different national and european standards, as well as relevant trade association standards such as EUROVENT give several classification of these kind of filters, according to the test aerosol used. We can mentioned:

- soda fluorescein : NF X 44-011
- monodispersed DOP (dioctylphtalate) of 0,4 µm : US MIL STD 282
- NaCl (sodium chloride) of 0,35 µm : NF X 44-013
- paraffin oil : DIN 24185

A recent european implementation program in a standardization field has lead to the following classification of HEPA and ULPA filters according to their filtration performances [2].

Filter Group	Filter Class	Efficiency (%)	Penetration (%)
H	10	85	15
H	11	95	5
H	12	99,5	0,5
H (1)	13	99,95	0,05
H (1)	14	99,995	0,005
H	15	99,999 5	0,000 5
U	16	99,999 95	0,000 05
U	17	99,999 995	0,000 005

(1) Domain of nuclear industrie

◆ **Last filtering stage**

The last filtering stage is the ultimo filtration device before release to the environment via the track.

● **Mechanical resistance**

The mechanical resistance is the value (in pascal) at which the rupture of the glass fibber paper occurs, consecutively to an increasing of the air flow rate.

2 - CONDITION OF USE OF HEPA FILTERS

HEPA filters are used in ventilation networks equipping nuclear installations [3] and in some cases in process files of nuclear incinerators [4]. For these different purposes, the following categories are considered:

• **normal operating conditions**:
- low level of irradiation
- temperature lower than 70 °C (alarm level of some fire detectors),
- atmospheric pressure,
- extraction of dry air.

• **degraded operating conditions**:
- extract air may contain vapours and gaseous,
- extract air may contain solid or liquid particles,
- possibility of over pressures,
- air flow rates could vary in a large range,
- increase of temperature possible, in case of fire.

For each of these configurations, a set of requirements and corresponding representative qualification tests have be defined in order to verify if the filter are able to fulfil or not the required functions. Three classes of HEPA filters have so be defined:

- filters for only normal operating conditions, below 70°C (at normal atmospheric pressure);
- filters for qualified operating conditions, until 120 °C;
- filters for qualified operating conditions, until 200 °C.

In the event of an accidental situation, for example after a fire, it is admitted that the HEPA filters located at the last filtration level before release to the environment, may be in operation, respectively until 120°C (200°C), during an estimated time of 2 hours (same requirements as all the components located at the same extraction network, and especially the fire dumpers) [5].

3 - MAIN DESIGN REQUIREMENTS

• **Filtering medium**

The filtering media should be free of any connections. The only gluing materials accepted are on one hand the lute, which ensures the leaktightness between the filtering medium and the frame and on other hand the gluing of separation lines on the medium when this last technology is used. In this case, the material used for filtering medium shall be fire resistant.

The separation lines (metallic or fibber glass wire) should resist to the degraded operating conditions defined here above.

- **Geometric dimensions and air flow rates**

In order to reduce the number of models of HEPA filters in use in the ventilation systems of hot cells facilities, the external dimensions have been standardized and limited to 4 models, according to the possible air flow rates passing through these filters. The following table gives the characteristics of these four categories of HEPA filters.

Model	Length	Width	Depth	Nominal air flow rate
1	610 mm	610 mm	292 mm	3 400 $m^3.h^{-1}$
2	610 mm	305 mm	292 mm	1 500 $m^3.h^{-1}$
3	600 mm	325 mm	202 mm	1 250 $m^3.h^{-1}$
4	600 mm	65 mm	202 mm	100 $m^3.h^{-1}$

- **Sealing system**

The function of the sealing system (O ring seal or flat seal) is to ensure the leaktightness between the metallic casing which constitute a fixed part of the ventilation network and the removable HEPA filtering devices. The sealing system shall be able to be compressed by the mechanical lever equipping the casing. Leaktightness should be ensured by a mechanical strength of about 4,5 daN/cm.

- **Nominal pressure drop**

The nominal pressure drop of a new HEPA filter shall be lower than 300 Pa. For information, the maximal pressure drop level of a clogged filter, before its replacement is about 1 000 Pa.

- **Scrubbing coefficient**

The scrubbing coefficient, measured in the normal operating condition (normal temperature and atmospheric pressure), at the nominal air flow rate, should be higher than 5 000.

- **Mechanical resistance, at 20 °C**

The mechanical resistance of filters corresponds to the maximum value of the pressure drop for which a filter is able to maintain its filtering efficiency. Beyond this value, the pressure drop decrease and the corresponding filtration efficiency to.

For filters available for normal operating conditions, a mechanical resistance test of the filters, at 20 °C, will be achieved. This mechanical resistance of the filter, at 20 °C, should be higher than 4 000 Pa. In normal condition of use, the filters can be in operation until the maximal clogging value is equivalent to a pressure drop of 1 000 Pa (at the nominal air flow rate).

For filters designed to operate in degraded conditions, the mechanical resistance will be continuously measured during the cycles of increasing and decreasing of temperature as defined here after.

- **Transport behaviour**

Due to the fact that the filter could be degraded during the transport, its resistance to vibration must be implemented in the same position as during the transport. For this purpose, the filter, contained in its transport packaging, is placed on a vibration table and submitted to a sinusoidal acceleration at a frequency of 3,3 Hz during 30 minutes.

After the test, the scrubbing coefficient, measured at the nominal air flow rate in the normal condition of use, should be higher than 5 000.

- **Static thermal resistance**

The static thermal resistance is related to the behaviour of the filter material to resist to high temperatures, but does not give a good representation of the capability of the filter to resist to a high temperature continuous flow rate.

The first criteria can be improved by placing the filter in a climatic cabinet, without blowing hot air, and maintain a level of hot temperature as specified here after, during 24 hours. After coming back to normal temperature, the following parameters should be measured again:

- mechanical resistance by increasing of air flow rate (indicative measurement),
- scrubbing coefficient.

The value of the scrubbing coefficient measured at normal temperature, with soda fluorescein aerosol (5 000) should not be modified when the filter is placed into a climatic cabinet at the following conditions:

- at 120 °C during 24 hours, for a filter qualified for operating conditions, until 120 °C,
- at 200 °C during 24 hours, for a filter qualified for operating conditions, until 200 °C.

- **Resistance to water vapour**

It will not be proceeded to a water vapour resistance test. A water immersion test will be preferred.

After having immersed completely a new filter in water during 2 hours, it will be verified that the characteristics of mechanical resistance at normal temperature by air flow rate increasing (higher than 2 000 Pa) and the value of the scrubbing coefficient measured at normal temperature, with soda fluorescein aerosol (5 000) will not be changed during this test.

- **Fire behaviour**

The fire behaviour of the material used for the construction of the filter shall be improved. There are no requirements for filters used only in normal operating conditions.

For filters used in hot temperature conditions (120 °C or 200 °C), the glass fibber paper should be classified M1 (1) and the frame M0 (1). The lute should correspond to the following classes:

- M3 for filters used until 120 °C
- M1 for filters used until 200 °C

The designation of the classes MO, M1, M2, M3, M4 and M5 corresponds to the following definitions given in a french standard which characterizes the reaction of the material submitted to a fire:

M0 is equivalent to a non burnable material
M1 is equivalent to a non flammable material
M2 is equivalent to very difficult flammable material
M3 is equivalent to a medium flammable material
M4 is equivalent to a easily flammable material
M5 is equivalent to a very easily flammable material

- **Dynamic thermal resistance**

The dynamic thermal resistance will permit to verify the behaviour of the filter to resist to a hot stream which can occur during a fire. Filters used only in normal conditions will not be submitted to the following test.

The guaranteed value of the scrubbing coefficient shall in any circumstances never been lower than 5 000 when measured with an NaCl aerosol of median mass diameter of 0,08 µm and when the filter is submitted to a hot air flow rate according to the following sequence:

The filter is submitted during 5 minutes to a hot air flow rate:

- at a temperature of 200 °C and with a pressure drop of 2 000 Pa for filters used until 120 °C,
- at a temperature of 300 °C and with a pressure drop of 2 000 Pa for filters used until 200 °C.

The filter is then submitted during 2 hours to a hot air flow rate:

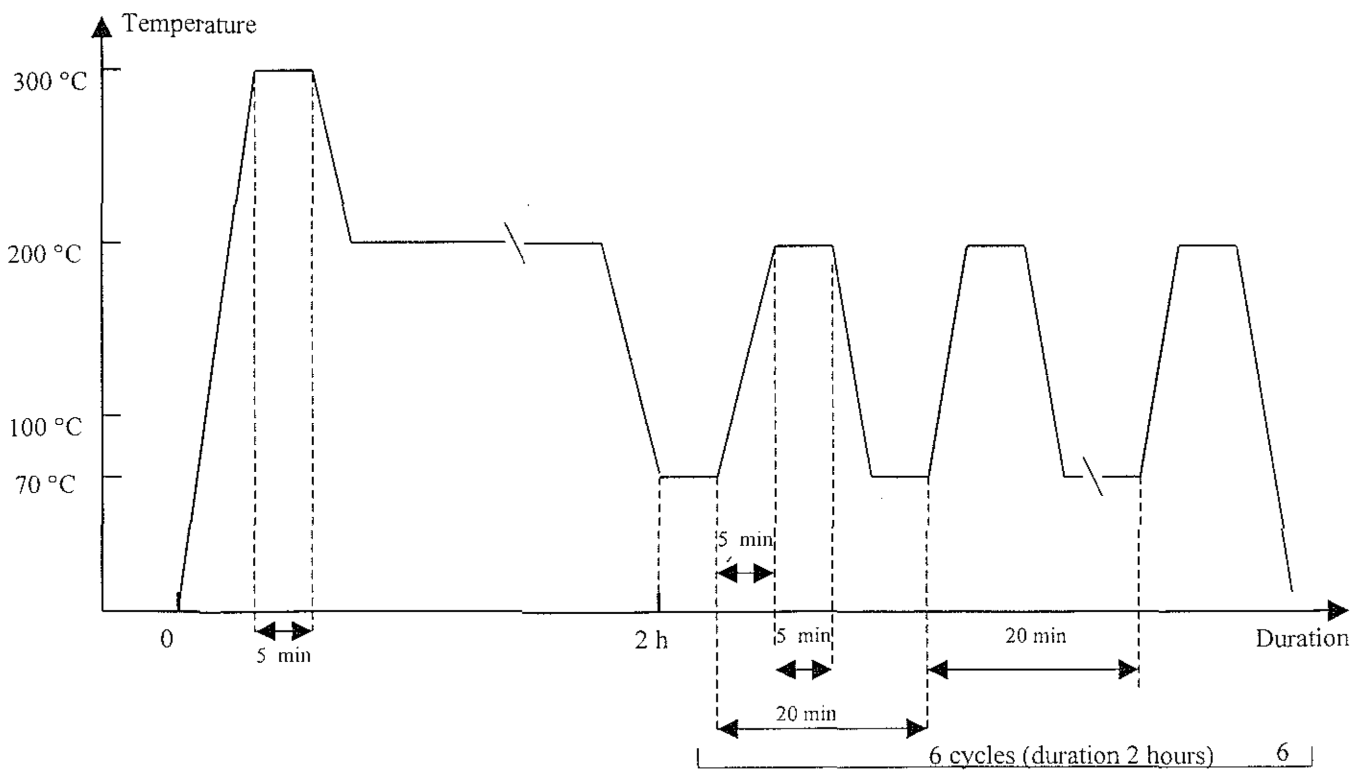
- at a temperature of 120 °C and with a pressure drop of 2 000 Pa for filters used until 120 °C,
- at a temperature of 200 °C and with a pressure drop of 2 000 Pa for filters used until 200 °C.

The filter is then submitted to 6 cycles of 20 minutes, including each one:

- a « high » plateau
  - at a temperature of 120 °C and a pressure drop of 2 000 Pa for filters used until 120 °C;
  - at a temperature of 200 °C and a pressure drop of 2 000 Pa for filters used until 200 °C;
- a « low » plateau at a temperature of 70 °C; the pressure drop can be free and adapted to the test equipment.

These variations of temperature are simulating the functioning of the ventilation network during a fire: closing of the extraction line when the temperature downstream the last HEPA filtration level is over the dimensioning limit of the filter (respectively 120 °C and 200 °C) and the re-opening of the extraction line when the temperature has decreased approximately to around 70 °C.

The « low » and « high » plateau should have a duration approximately equivalent.



Simoun-loop
a high temp. test loop / Saclay

4 - TESTS METHODS AND DETERMINATION OF THE PERFORMANCE LEVELS

In the present paper, only the most important qualification tests will be described. The verification of the geometrical dimensions, the compliance of the sealing system with the requirements, the vibration test, the water immersion test, etc... will not described in detail.

- **Nominal pressure drop and mechanical resistance measurement**

The filter is placed in a ventilation network. The test consists of passing through the filter a proper air flow, with a constant velocity. The pressure drop is the difference between the inlet and the outlet pressure.

The test apparatus includes:

a) a ventilation network which *comprises:*

- a casing receiving the filter to control,
- a ventilator able to insure the required air flow, equipped with a measurement and an adjustment device,
- an imput HEPA filter.

b) a differential pressure manometer, *able to indicate a* decapascal

The test consist to measure the pressure drop of the casing without any filter and the whole pressure drop of the casing equipped with the HEPA filter. The result is given in pascal, and corresponds to the difference between the values obtained with and without the presence of the filter.

The determination of the mechanical resistance is carried out by increasing of the air flow rate passing through the filter until the rupture of the materials, that corresponds to the discontinuity of the pressure drop and the decreasing of the filtering efficiency.

- ***Assessment of the filtration efficiency/scrubbing coefficient***

The test consist to add a soda fluorescein aerosol to the air flow rate passing through the filter assembly and to collect the incident and the emergent amount of aerosols, via calibrated HEPA filters placed upstreams and downstreams the filter under control. The aerosols retained by each of these collection filters should be extracted and their quantity measured by a fluorescence technique.

The test equipment is shown on the following figure.

It comprises a:

a) a ventilation network including :

- an imput HEPA filter,
- an air conditioning and treatment station, able to maintain the humidity of the imput air at a rate of 80 % of relative humidity,
- a ventilator able to insure the required air flow, equipped with a measurement and an adjustment device,
- a casing able to receive the filter under control,
- an aerosol homogenization equipment,
- two probes for taking the aerosol samples.

b) an aerosol generator

c) two aerosol sampling lines

d) **a measurement device (fluorimeter)**
e) **accessory materials**

- **Pre-clogging - Dynamic thermal resistance test**

The method consist to install the filter assembly in a temperature test loop and to submit it to a heated air flow, in the range of 0 °C to 300 °C, at the nominal flow rate. The scrubbing coefficient and the pressure drop (mechanical resistance) of the filter are measured in continuous. The test aerosols are uranine (soda fluorescein) until 150 °C and NaCl (sodium chloride) above.

The test equipment comprises:

a) **an aeraulic test loop**, able to maintain an air flow rate through the filter until 4 000 $m^3.h^{-1}$ at 400 °C,
c) **two aerosol generators** (sodium chloride and uranine),
d) **a set of measurement devices** such as pressure manometers, flowrate meters, temperature sensors, flame photometers (for NaCl concentration measurement), etc.

The principle of pressure drop measurement on pre-clogged filter is applied.

• **Pre-clogging**

The filter is pre-clogged with sub micro particles of sodium chloride used for the measurement of the scrubbing coefficient at high temperature, in order that the filter presents, at their nominal levels of temperature (120 °C or 200 °C respectively), a pressure drop of 2 000 Pa at their nominal air flow rates. When the filter is pre-clogged, the dynamic thermal resistance test can start.

• **Simulation of the flash-over**

The pressure drop of the filter is maintained at 2 .000 Pa. The temperature of the inlet air flow is rapidly increased to the maximal temperature Tmax:

Tmax = 200 ° C (for filters qualified for operating conditions until 120°C)
Tmax = 300 ° C (for filters qualified for operating conditions until 200°C)

• **Functioning at qualified temperature**

The temperature is then reduced to the qualification temperature, and the air flow rate adjusted in order to keep constant the pressure drop at 2 000 Pa (± 10 %):

T = 120 °C for filters qualified for operating conditions until 120°C)
T = 200 °C for filters qualified for operating conditions until 200°C)

This plateau is maintained during 2 hours. The scrubbing coefficient is measured in continuous (NaCl test).

• **Simulation of opening and closing of the extraction line**

At minimum 6 cycles of reduction and increasing of temperature, between the two following levels of temperature are performed: the high plateau defined as the qualified temperature and the low plateau considered as equivalent to 70 °C.

The duration of the total cycle is 20 minutes. The duration of the high temperature and the low temperature phases are approximately equivalent.

4 - CONCLUSION

The necessity of guarantee the permanency of the efficiency of the last level of filtration of the extraction line of ventilation systems in Hot Laboratories in degraded or accidental situation e.g. during a fire has lead to the development of a new concept of HEPA filters.

The main difference with the previous generation of HEPA filters is the compliance with a **dynamic thermal resistance** (that means the resistance to a foreseen pressure drop corresponding to a pre-clogging of the filter) instead of the compliance with a **static thermal resistance** alone, for which the previous categories of filters were qualified.

These new requirements can be transposed to nuclear incinerator applications, for which the necessity of resistance against hot temperatures and in a dynamic way is also required, especially in the process files.

In order to comply with this new demand, many manufacturers have been asked to developed a series of new generations of HEPA filters. This task of research and development has been achieved with the help of several users from CEA and the IPSN Qualification Centre of Nuclear Equipment, which has delivered at this moment more than 12 certifications [6].

At the present stage, we can concluded that most of the european manufacturers are now able to propose an alternative solution for HEPA filters equipping ventilation systems in nuclear facilities.

4 - REFERENCES

[1] ISO/DIS 11933-4 :"Components for containment enclosures - Part 4 -Ventilation and gas cleaning systems such as filters, traps, safety and regulation valves, control and protection devices".

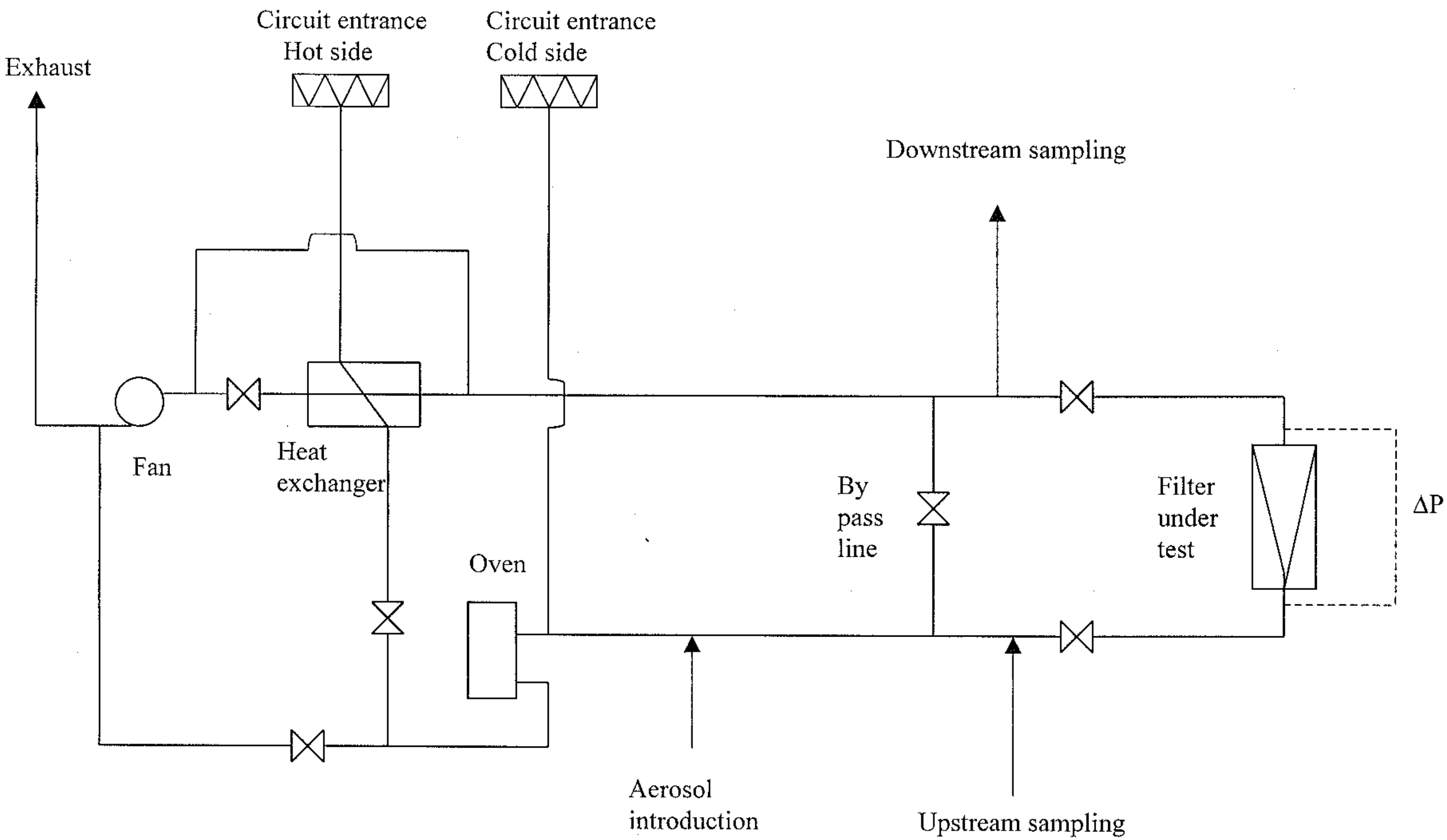
[2] Performance Testing of HEPA Filters: Progress Toward an European Standard Procedure, J. Dyment (AWE plc, UK), 24th DOE/NRC Nuclear Air Cleaning and Treatment Conference, 1995.

[3] French requirements for HEPA filters equipping the last level of filtration of ventilation networks in nuclear installations, IPSN Report CTHEN n°93-030, Cl. ROUSSEL, G. BRUHL et al., France, 1993.

[4] French requirements for HEPA filters equipping the process lines in nuclear incinerators, IPSN Report CTHEN n°96-116, D. VIGLA, G. BRUHL et al., France.

[5] Draft ISO Standard :"Criteria for the Design and the Operation of Ventilation Systems in Nuclear Facilities, G. BRUHL, R. ALNET, France, April 1998.

[6] IPSN Qualification Centres For Nuclear Safety Equipments - Their contribution to the safety of nuclear facilities and protection of workers and environment. G. BRUHL, M. CHEMTOB, A. LORIDAN, CEA/IPSN, France, 34th plenary meeting of the European Workind Group "Hot Laboratories and Remote Handling", MOL, June, 14 and 15, 1994, Belgium.



SIMOUN : A high temperature test loop