SPHINX:
AN INNOVATIVE SOLUTION FOR ENVIRONMENTAL PROTECTION IN CASE OF FIRE

D. BOIS ; T. DELAFORGE; M. NEUMANN; M. LADURELLE(*)
CEA, DEN, DPIE
CEA Cadarache, F- 13108 St Paul lez Durance - FRANCE

ABSTRACT

Among the most likely risks existing in nuclear facilities, one of the greatest in terms of consequences is probably fire. In an extreme situation, in which the response means could not extinguish a fire in a room containing hazardous materials, current practices consist in isolating it by means of specially-designed equipment dividing the area into compartments that will prevent it from spreading.
In this situation, the effects of pressure caused by the temperature variations may nevertheless degrade the containment barriers designed to protect the environment. To take this risk into account, which has become a statutory obligation in the field of nuclear facility management, the CEA has developed an innovative hydraulic valve called "SPHINX".
In this paper, we shall present the principle governing this device and ongoing actions involving its development and qualification.

1. Context

1.1 Fire issues in nuclear facilities

One of the major risks in nuclear facilities is fire. Safety analyses carried out have enabled us to identify its potential sources and to define the most effective means of the prevention, surveillance and limitation of its consequences. Despite this system of in-depth defence, the hazard cannot be ruled out entirely and in this case, material containment has to remain a priority both in terms of occupational health and environmental protection.

The containment actually consists of a system equipped with dual features: one is static and the other, dynamic:
- The static system relies on the installation of partitions in all the rooms of the facility.
The fire hazard analysis has led us to classify these rooms as “fire compartments” (made up of artificial walls, doors and fire dampers installed within the air supply and exhaust system) and the “containment zones” include the “fire compartments”.

- The dynamic system essentially relies on the ventilation that guarantees a cascade of negative pressures of the less contaminated zones towards the more contaminated zones.

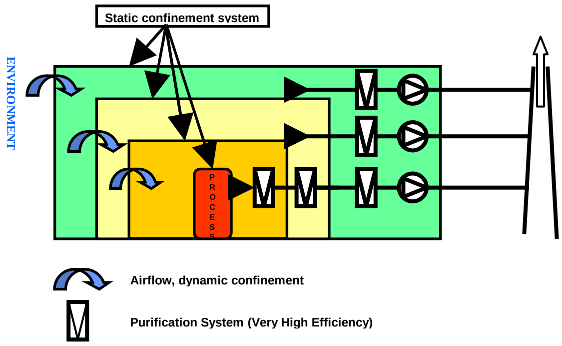

Fig 1: Basic principles of static and dynamic confinement in a nuclear facility

(*) : dominique.bois@cea.fr; thierry.delaforge@cea.fr; marie-francoise@cea.fr

In case of a fire, the basic ventilation controls ensure:

- Closure of the fire damper supplying air. This control, which is automatically triggered as soon as the fire-detection alarm goes off in a specific room (see Figure 2), enables us to eliminate any air supply to the fire. It is also accompanied by a sudden drop in the ambient pressure because the extraction ventilation system remains in operation. A rise in pressure once again occurs according to the clogging of the filters.

- If the fire continues to spread, temperature detection in the exhaust duct (see Figure 3) triggers the closure of the corresponding fire damper and thus isolates the room.

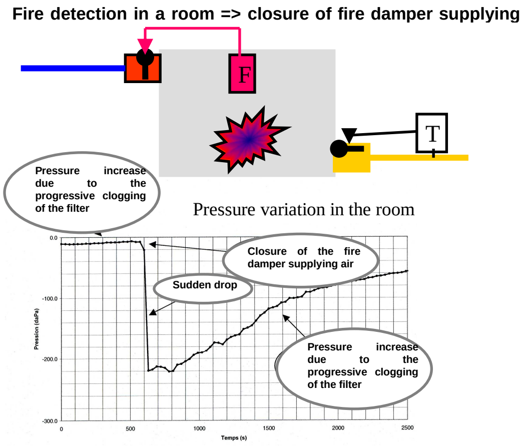

Figure 2: Automatic interlocking when fire is detected in a room

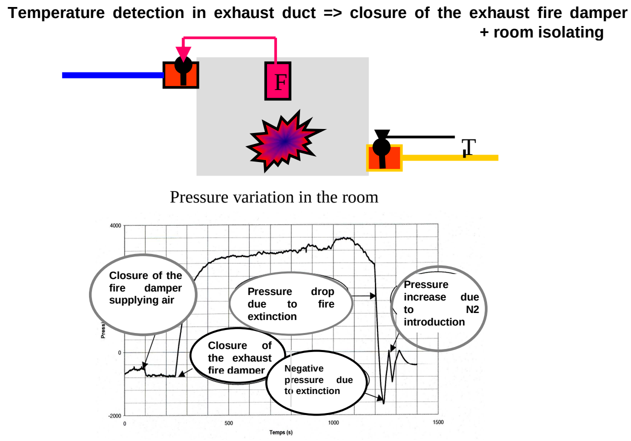

Fig 3: Automatic fire interlocking when fire is detected in a duct

If the fire is not extinguished (by itself due to a lack of combustion agent or thanks to the response of the specialized fire-fighting teams), we then witness a rise in pressure in the fire compartment. It should be recalled that at this time, the doors and the valves whose mechanical strength and containment is guaranteed up to a pressure of 2000 P become the most vulnerable components.

When a fire goes out for lack of combustion agent the thermal exchanges are such that through the contraction of the gases, we witness a spectacular pressure drop in the room (see Figure 3). The compartmentation components, already rendered quite fragile by the rise in pressure and in temperature during the fire, sustain renewed stress.

1.2 Regulations and standards

From a French regulatory standpoint, the ministerial order of 31/12/1999 and that of 26/09/2007 demand that the ventilation systems in all licensed nuclear facilities be designed so that they:

- do not contribute to the propagation of the fire
- limit the dispersal of radioactive materials, toxic, inflammable, corrosive or explosive within the facility as well as uncontrolled releases into the environment,
- limit the possibility of the formation of an explosive atmosphere

The recent standards (ISO/NF 17873 ventilation of laboratories and factories and ISO26802 for reactors) go even farther since their objective is to “limit the pressure effects produced by a fire in order to guarantee the integrity of the fire compartment by relieving pressure through use of the appropriate devices”.

2. SPHINX

In order to take into account the problems inherent to ventilation operation in case of a fire while meeting the growing demands in regulations, a CEA team has perfected an innovative device called, SPHINX (Fire Hydraulic Valve), which was the object of a patent (see [1]). This device is designed to limit the effects of pressure on the facility at the start of a fire and at the time of its extinction.

2.1 Basic operating principle

The principle implemented here is to transfer the gases in the fire compartment towards the adjacent containment zone by bubbling through a filtering media in a hydraulic siphon whose water level determines the triggering threshold. This enables us not only to make sure that the fire will not spread due to the combustion gases but also allows us to cool the smoke and to trap part of the released aerosols. This device therefore acts as a valve that can move the overpressure in the fire compartment towards the containment zone and thereby enable us to preserve the static containment components (doors and fire damper in particular)

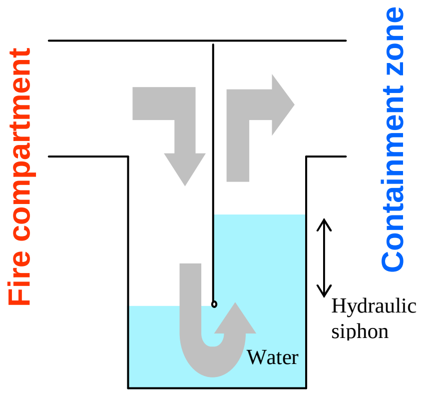

Figure 4 : Operation of SPHINX as a fire develops (high overpressure)

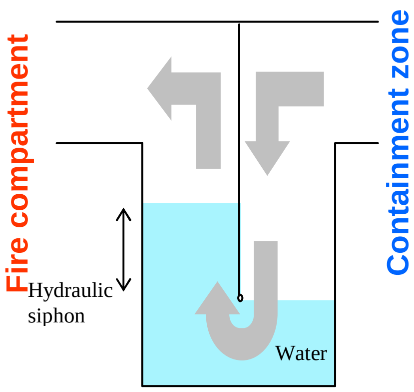

Figure 5 : Operation of SPHINX at the time of the fire extinction (high negative pressure)

This system is also reversible since it allows us to take into account the high negative pressure (see Figure 3) that accompanies fire extinction. Thus, in this case, it is the air, coming from the containment zone that will bubble in the hydraulic seal before being admitted into the fire compartment.

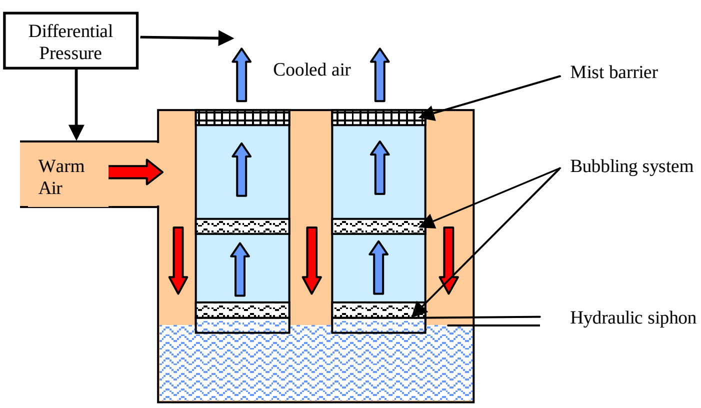

Figure 6 : Principle of operation

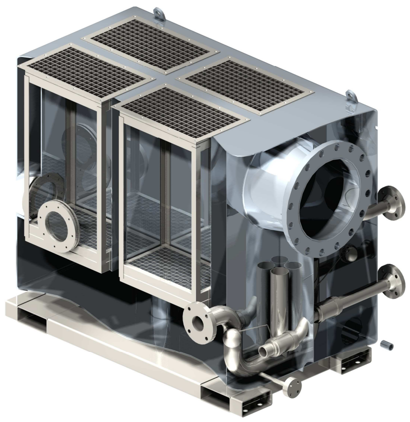

Figure 7 : 3D view of the design

2.2 Principle of installation

The valve is installed directly at the edge of the fire compartment in the containment zone. It must be connected to a water system in order to feed the vessel including the liquid seal and the effluent network (either suspect or active effluents according to the risk involved) to remove the excess water.

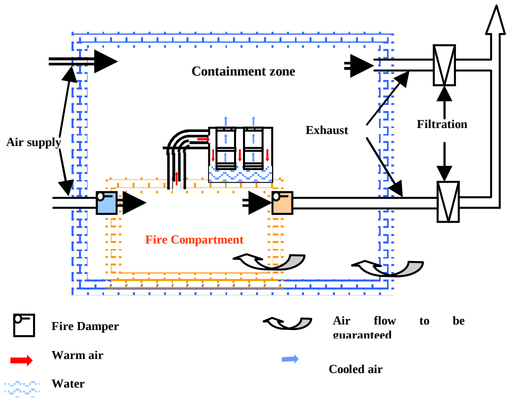

Figure 8 : Schematic diagram of the SPHINX installation

2.3 Advantages of the system

One of the advantages of the system is that it provides an effective means to limiting the consequences of pressure rise in the fire compartments. It is also reversible because its bubbling system operates both during the pressure rise as the fire develops, but also during the negative pressure resulting from the extinction. Furthermore, it is passive for it operates independently, without any switch or energy, which is essential from the safety standpoint.

3. Results and prospects in 2009

The performance of the device have been tested and characterized on aeraulic loops.
These tests have enabled us, in particular, to demonstrate the limitation of the pressure at less than 2000 Pa for a release flow of 10'000 m3/h , a cooling of the combustion gases at 250°C at water temperature (about 25°C) and a trapp ing comparable to that of a high efficiency filter. Given the good results of the tests and following an agreement issued by the French Nuclear Safety Authority, SPHINX was hooked up, in 2009, to a licensed nuclear facility in operation (PEGASE; BNF n° 22).

Furthermore, the thermo-aeraulic qualification tests carried out at different temperatures simulating combustion gases must be undertaken by the end of the year under the direction of an officially approved laboratory.

In closing it should be mentioned that industrial development studies have been carried out because this device, developed initially for the nuclear industry also meets the need existing in other industries dealing with dangerous materials (i.e. the chemical and petro-chemical industries) or at a high value added (the pharmaceutical industry, in particular). This valve may also be useful in fire compartments containing no dangerous materials (for example, the electrical areas) but that are nevertheless equipped with an automatic extinction using gas or water mists, something which intensifies the depression phenomena at extinction.

Once the product has been qualified and the market demand targeted, the CEA team has drawn up both legal and commercial contracts that could lead to a licensing agreement with a partner capable of manufacturing and distributing the product, our objective being to develop a product that could be commercialized by the end of 2010.

4. References

[1] CEA Patent n° FR 2 879 471: « Device designed to mitigate the ultimate consequences of an uncontrolled mass fire in a leaktight vessel containing hazardous materials ».