Boiler explosion in a district heating boiler plant

30 March, 1994

Courbevoie - [Hauts-de-Seine] France

Explosion
Boiler plant
Natural gas
Guillotine valve
Organisation
Human factor
Internal and external victims
Property damage

THE INSTALLATIONS IN QUESTION

The site:

The boiler plant is located in a residential and light industrial zone being built as part of a master-planned development approximately 1 km from the "*Grande Arche* " monument in the *La Défense* district. A single-family dwelling and a small 3-story apartment building lie at the site's immediate periphery (a distance of 50 m). Extending out to a 200-m radius, the land use contains: a 5-story office building where some 400 employees work, an 80-person residence hall, and many homes and small company offices set up in conventional buildings, hangars and temporary quarters.

The plant involved is the main one supplying the *La Défense* district (within the Hauts-de-Seine department) with both heat and air conditioning. The network supplies 2.2 million m² of office space (for 110,000 employees) and approximately 30,000 local residents.

The facility:

The boiler plant, initially commissioned in 1967, operates according to the principle of cogeneration, producing hot water, ice water and electricity. At the time of the accident, 5 boilers were operating:

- ✓ 2 coal-fired boilers installed as part of the original plant; and
- ✓ 2 coal/natural gas hybrid boilers and another natural gas-fired boiler, added subsequently.

The last capacity increase had taken place during 1987. A 6th boiler, natural gas-fired, was being assembled at the time of the accident, bringing the total installed power to 499.7 MW.

The installation also comprised 7 Freon-based refrigerating units with a total power of 132 MW and 14 PCB/PCT type transformers for a total quantity of onsite products reaching 22.45 tons. The three largest transformers (15.7 tons of dielectric products) had been installed in retention basins.

The new boiler authorization procedure had been turned to account to establish a new set of technical guidelines to regulate all facilities (by Prefecture decree dated October 21, 1993). As regards gas supply network safety, a special prescription calls for an efficient identification system applicable to all installed cut-off devices.

The installations are housed together inside a metal building in the shape of a truncated pyramid with a 4,000 m² footprint and 30 m in height, spanning 9 stories (two below ground level) and entirely covered by a clipped slate roof. Two electrofilters and a 100-m high chimney had been set up immediately adjacent. The boilers were installed on a concrete slab at ground level, and underneath runs the piping networks and coal conveyor belts.

The boiler plant was supplied with pulverized coal by means of rail service. Gas was fed to the plant from an underground pipeline (at 15 bar). A pressure regulator station, refitted in 1993 and located at the site boundary, served to lower pressure to 4.5 bar. This regulator station was also equipped with two relief valves operating in parallel, protected by automatic bypass valves and controlled by a calculator using pressure and flow rate information collected both upstream and downstream of the station. These valves would close in the event of a pressure drop upstream and a rapid or excessive variation in the pressure or flow rate being delivered. According to this operating mode, the calculator compares the measured instantaneous values with integrated average values during the one-hour elapsed period. In the case of an emergency that goes undetected by the calculator (slow leak, moderate flow leak), it is not possible to trigger the automatic bypass valves, neither by remote control nor even locally. The only cut-off valve available is manually-operated, activated using a special turning key.

An underground pipe with a 300-mm diameter conveys the gas directly to the boiler plant basement where each boiler supply tap can be isolated by a manual valve. For the tap supplying hybrid boiler HP4, this valve was backed up by a so-called "guillotine valve" (a sort of sliding gate) actionable manually and solely in the absence of pressure. This set-up allows avoiding routing gas to a boiler that is not in a state to accommodate gas inflow.

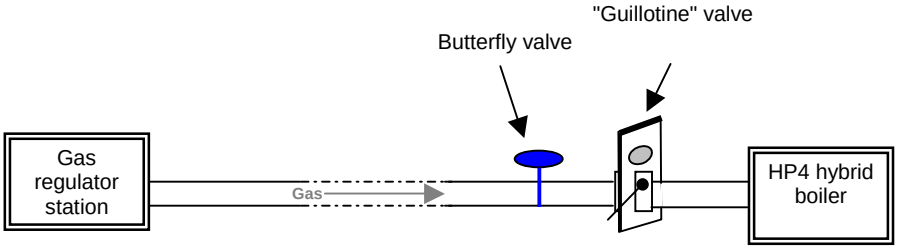


Diagram of the HP4 boiler gas supply process

The only automatic cut-off devices are the gas burner supply valves that automatically close upon detecting the absence of a flame.

The plant employs a staff of 90, and this number rises from time to time due to the onsite presence of employees from outside companies. Operations and maintenance functions are clearly laid out in a set of formal guidelines updated on a regular basis. The organization includes a department specifically assigned responsibility for plant safety under the supervision of an executive level engineer.

The last incident prior to the accident recorded in this boiler plant was an electrical fire, with only minor consequences, that broke out in 1989.

THE ACCIDENT, ITS BEHAVIOUR, EFFECTS AND CONSEQUENCES

The accident:

On March 30, 1994 at 1:30 am, a violent explosion rocked the boiler plant and could be heard tens of kilometres away.

In its May 5, 2004 ruling, the Versailles Appellate Court detailed the set of circumstances surrounding the accident.

At the time of the incident, 5 employees were present inside the facility: a shift supervisor, an assistant supervisor, an electrician and 2 boiler operators. A gas boiler and a coal-fired boiler were running. The shift supervisor was on duty in one of the control rooms located on level 4 of the facility, equipped with an assistance and monitoring system.

The day prior to the accident, the maintenance team, which alone was qualified to do so, prepared the hybrid boiler for operation with gas.

The team on duty then attempted to start up the boiler, but was unable to properly adjust the draft fan and the two blower fans. The message was left with the night shift, which also tried to start the boiler. Upon each attempt to activate the fans, the boiler switched into safety position. In recognizing that the two gas inflow manometers were reading zero pressure, the supervisor deduced that the problem stemmed from the boiler gas supply line. After inspecting the drawings, he requested one of the two operators on duty to open both cut-off valves a quarter turn. Despite this step, the two manometers still indicated zero pressure.

In the absence of the maintenance team, the supervisor then requested the first boiler operator, with whom he had never worked before and after receiving the operator's assurance of his level of competence, to open the guillotine valve and afterwards the butterfly valve in order to feed gas into the hybrid boiler. Opening the butterfly valve caused a major gas leak. The operator responsible was knocked over yet still managed to leave the premises. The supervisor then ordered his assistant along with the electrician to stop the gas-fired boiler and close the gas inflow to the plant's supply regulator station, located 110 m outside the building. Unable to find the network shutdown key in the control room, the two men were unable to perform this operation. In hearing the gas continue to spread, the supervisor requested the second boiler operator to shut down the coal-fired boiler and, wearing a respirator mask and carrying an electric lamp, made his way to the level of the gas leak to close both valves. A thick cloud of fog created by the leak enveloped the room. The supervisor was nonetheless able to close the butterfly valve, but the explosion occurred before he could reach the valve.

Alerted by the sound of the explosion, fire fighters arrived on the scene just a few minutes later. A fire broke out in a prefabricated 400-m² office building and presented a risk of propagation to the adjoining home. The "red plan" (emergency response for large numbers of victims) was immediately activated. Some fifty vehicles and 200 fire fighters, dispatched from 12 fire stations, were called to the site and extinguished the various combustion sources with relative ease. Gas supply technicians made their way to the facility 2 hours after and successfully closed the gas supply valve.

Several tens of law enforcement officers were assigned to the premises to control looting. Guards were posted (within a half-hour following the explosion) to prevent stealing from the shops whose windows had been blown out.

The consequences:

✓ The human toll was particularly heavy: the second boiler operator was killed in the basement, both the shift supervisor and first operator sustained serious injuries. The other two staff members, despite enduring major shock, walked away unscathed. The destruction of a single-family home located at the periphery of the site, 50 m from the building, hurt a 6 year-old girl to a point where she died 4 days later as a direct result of these injuries.

Within the vicinity of the site, a total of 59 individuals were hurt, 2 of whom were listed in critical condition. Another 250 were evacuated from their homes and moved to a nearby sports facility for shelter before being temporarily housed elsewhere.

In addition, heating was temporarily cut off to some 140,000 users and employees. As a result of having to shut down air conditioning production, the operations of large-scale computing systems (including those used by private firms and public administrations) were highly disturbed.

✓ The explosion devastated the boiler plant: three boilers destroyed, the other boilers and auxiliary equipment quite seriously damaged, the offices and control room collapsed. Most of the slate covering the building was propelled to the ground and debris from both wall sheeting and thermal insulation was projected up to 200 m beyond the site boundary. The electrofilters were heavily damaged. The transformers and cold zone did not sustain any major loss. The Freon supply was cut in order to lower the risk of discharge.

Property damage spanned a 3 to 5 km² zone and was very extensive: a hundred or so buildings, including the *Grande Arche de la Défense* landmark, and many vehicles. Some 600 people were temporarily laid off. Window panes shattered within a radius of 2 km around the plant. Judging from property loss claims, the effects from the explosion seem to have followed a North-North-East course with pressure surges capable of reaching 140 and 50 mbar at distances of 100 m and 500 m, respectively. A total of 1,051 property claims were filed subsequent to the accident, half of them for broken glass.

32 floors of the *Grande Arche* building were damaged, and 3,500 employees with a single public agency were released for a half day or full day.

The measurements recorded by university seismographs in the region made it possible to estimate that the amount of energy dissipated into the ground was the equivalent of detonating 50 kg of TNT. On the other hand, the airwave generated was evaluated on the order of a few tons of TNT.

✓ In all, the cost of property damage amounted to 83.2 million Euros: € 57.6 million internally, and € 25.6 million externally. Operating losses were evaluated at € 52.4 million.

According to results from the investigation, 3,750 Nm^3 of gas would have been released until the time the technicians arrived on site to cut supply, i.e. a half-hour after the explosion.

European scale of industrial accidents:

By applying the rating rules of the 18 parameters of the scale made official in February 1994 by the Committee of Competent Authorities of the Member States which oversees the application of the 'SEVESO' directive, the accident can be characterised by the following 4 indices, based on the information available.

The parameters that comprise these indices and the corresponding rating method are available at the following address: http://www.aria.ecologie.gouv.fr.

Given the distances over which the explosion was felt (broken glass up to 2 km away), the "Dangerous Materials Released" parameter was rated at 3 (TNT equivalent of roughly a few tons). The 3,750 Nm³ of gas spread out prior to arrival of the gas specialists to cut supply corresponds to a level 3 for the Q1 parameter relative to hazardous materials released.

The value of 6 assigned to the human and social consequences corresponds to the 600 individuals temporarily placed out of work, due to damaged company premises (parameter H6); level 5 is reached for the sixty or so injuries (parameter H4). The death of the young girl living in the home destroyed by the explosion corresponds to a level 4 for parameter H3.

The economic index is rated at 6 as a result of the costs related to external property damage, amounting to € 25.6 million (parameter €17).

Lastly, this accident did not produce any known environmental impact.

ORIGIN, CAUSES AND CIRCUMSTANCES OF THE ACCIDENT

The operation of hybrid boilers running on gas or coal engenders risks relative to the two types of fuels. The accident might have resulted from an explosion of gas and coal dust, as the behaviour of coal dust could have been responsible for the violent effects observed. Given the magnitude of network pressure along with the leak cross-section, as represented by the partial opening of the valve, it is possible that the gas jet power was sufficient to disperse coal dust particles far and wide throughout the installation.

The high gas leak rate would have also contributed to the opacity of the local atmosphere, which prevented the operator from successfully closing the manual valve.

The valve that initially caused the leak was located in a zone that sustained relatively minor damage, which suggests that:

- ✓ Concentration of the air-gas cloud within this zone remained far outside the explosibility range due to the extremely high gas content in the mix immediately adjacent to the leak.
- ✓ The coal-fired boiler in service at the time of the accident was one of the hot spots capable of triggering the explosion.

Moreover, the question of whether the manometers were in good working order needs to be raised. They had been inspected on January 19, 1994 with no anomaly detected. Nonetheless, the investigation report indicated that their condition might have been deteriorated by a pressure surge prior to the accident. Furthermore, pressure readings recorded on a manograph at the gas regulator station could not be found following the explosion.

Below are the organizational and human errors cited by the investigators:

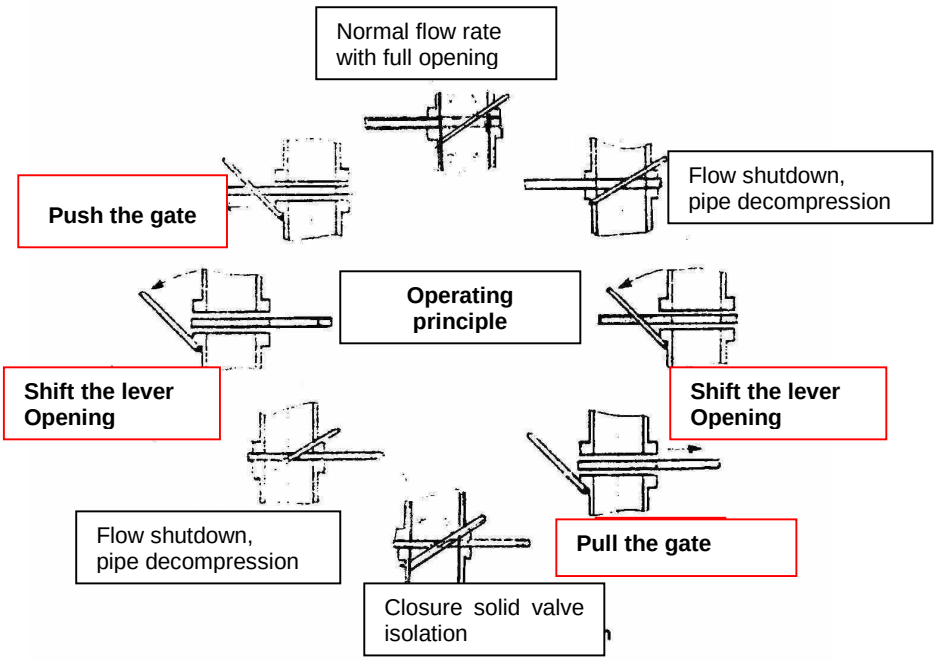
- ✓ The decisions and actions undertaken by the shift supervisor, which can only be performed by competent maintenance personnel. The supervisor should have contacted the on-call engineer before proceeding with any of these manipulations. Though such an initiative could have averted the explosion, handling the gas regulator station valves was prohibited and, in emergencies, plant operators are instructed to request assistance from gas technicians.
- ✓ The valve was not designed to be handled under pressure; it had been installed in order to reinforce the butterfly valve seal for which it served as a backup and only for bleeding the line; it thus should have been closed before pressurizing the gas pipes.
- ✓ The butterfly valve would have been manipulated by the first boiler operator without first verifying the valve, which had remained in the intermediate position, where it is no longer airtight due to slightly-spaced flanges, thereby allowing for gas to pass inside the pipe towards the outside.

To move the valve from the open to closed position, a lever needs to be engaged in order to spread the flanges by approximately 4 mm, which enables manually displacing the support ring into the desired position (see diagram below,

with the handling steps framed in red). Opening the butterfly valve allowed for gas inflow at the level of the valve, which became locked in this position due to the pressure effect, and the leak continued until the circuit was closed at the level of the regulator station.

Valve in the intermediate position shortly after the explosion

Valve in the closed position



Operating principle for the guillotine valve
Source: Supplier

- ✓ Personnel had not been trained in handling both the guillotine and butterfly valves.

No gas leak and explosion scenario had been discussed during the site hazard study, and the risks related to coal dust had not been raised either. The interactions, domino effects or eventual synergistic effects between a gas-related accident and the presence of pulverized coal inside the facilities had thus not been analyzed.

Moreover, the handbook of general safety guidelines, drawn up by the facility operator, had no chapter specifically devoted to "gas installations".

ACTIONS TAKEN

A Prefecture-level decree, containing emergency measures proposed by hazardous installations inspectors, required the operator to introduce installation safety features, destroy and eliminate all waste generated, and prohibit resuming operations without first submitting a new and complete authorization application.

Once the accident had been controlled, specialized firms were contracted to remove the rubble and other damaged machinery located outside that constituted a hazard for people working on site. Barricades were also set up to enclose the plant boundary.

An investigation was launched during which time access to the damaged installations was placed under strict judicial control. A judicial inquiry was initiated on April 1st, 1994 to examine the charges of involuntary manslaughter and injuries as well as involuntary destruction of third-party property due to the effect of an explosion on the part of the boiler plant operating company as the primary responsible party, and company executives, the shift supervisor, his driver and the gas supplier as the secondary party. On May 5, 2004, the Versailles Appellate Court magistrate ruled that the case had no grounds for prosecution.

Two fuel oil/gas hybrid boilers with a total power of 19.55 MW and a fuel oil deposit of less than 100 m^3 were installed temporarily on the site in order to continue producing heat for the zone's priority service users. Over the longer term, the heating power station has been replaced by a new 214 MW, fuel oil-powered boiler plant.

Measures have been adopted by the administration to respond to eventual concerns expressed by neighbours of similar installations because of this accident.

LESSONS LEARNT

The risks of gas leak and explosion in the installation were not given the attention they deserved. The installation security analysis was too shoddy to yield an identification of realistic means and measures of prevention to be implemented. The following systems or equipment would enable avoiding this type of accident or, at least, minimizing the consequences:

- ✓ Fast-acting cut-off devices, controllable both locally and remotely (from the control room) installed on each boiler supply tap, in order to isolate them during an emergency situation within satisfactory time limits and without necessarily having to rely upon local operator manipulation.
- ✓ An atmospheric gas detection system for the plant closing automatically the valves and with a local alarm and relay transmitted into the control room. A moderate leak, even one too small to trigger the gas regulator station safety features, could have been properly detected.
- ✓ Local and remote control (activated from the control room) of a positive safety, emergency cut-off system located right where the gas pipe enters the building, in order to halt all inflows into the site in the case of a leak on the general network.
- ✓ If need be, a supplemental motorized sectional valve on the general installation supply network, located outside the unit yet immediately adjacent to the building, for use in particular by internal and external emergency personnel.
- ✓ A device to physically immobilize the mechanism handling this type of guillotine valve, for the purpose of prohibiting use by unauthorized personnel.
- ✓ Additional regulator stations equipped with remote-controlled, positive safety features, assigned to each boiler and placed outside, yet immediately adjacent to, the building. It is actually preferable to distribute gas inside industrial premises at the lowest possible pressure that still guarantees installation operations. This additional measure enables: detecting individual abnormal flow rates that go unnoticed by the overall control station, limiting the quantities of gas released in the event of a leak, and ensuring both a general and individual, remote-controlled emergency isolation for each boiler.

From an organisational standpoint, several measures may be adopted to mitigate this risk:

- ✓ The valves introduced must be adapted to the product, and all valve use constraints must be taken into consideration (e.g. risks incurred with a guillotine valve should it be mistakenly handled under pressure).
- ✓ The risk of coal dust explosion, domino effects and synergistic effects to be feared between a leak and/or a gas deflagration on the one hand, and airborne inflammable pulverized coal dust on the other, must be taken into account alongside the appropriate measures, with special emphasis on cleaning coal dust in plant premises.
- ✓ The operations teams must be made aware of the specificity and operating risks related to the maintenance function alone, in order to ensure that the teams do not step beyond the bounds of this critical safety guideline even if they are extremely knowledgeable about the installation.

- ✓ The booklet of general safety recommendations, drafted by the operating company, must contain a chapter devoted to "gas installations".
- ✓ The measurement instruments typically used to provide vital indications of installation operations must be verified on a regular basis.
- ✓ The boiler plant teams must be given the possibility to activate in the control room an emergency shutdown of the system or a means to halt gas inflow into the plant via the regulator station. This possibility must be made available within the scope of a set of strictly-defined procedures between the plant operating company and the gas distributor.
- ✓ The operations that require heightened vigilance and tighter safety measures, such as boiler startup in the event a malfunction has been detected, must be carried out following an adequate analysis conducted by personnel with the right qualifications and in the right numbers (e.g. avoiding a reduced night shift crew).
- ✓ The choice to locate such installations necessitates incorporating risks related to potential accident scenarios, and in particular the intensity of possible effects on individuals likely to be exposed in the vicinity.