Gas Boilers
Accidentology feedback
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The Courbevoie thermal power station accident dated 30 March 1994 (ARIA 5132) has left a deep scar on the minds of the people due to the seriousness of the consequences and the extent of damage in a highly urbanised zone. Accidents in exclusively gas or mixed combustion facilities involve power stations, low-power boilers or facilities that supply steam, hot or superheated water required for a process. Unlike heavy oil boilers, the risk lies in the gravity of the effects resulting from an explosion.

The sample from the ARIA database comprises 121 accidents, that occurred in France between 15/06/1972 and 05/02/2007, can be divided as follows:

- 41 accidents involving gas boilers rooms and boilers (natural gas, coke oven gases, LPG, etc.).
- 80 accidents involving gas boilers rooms and boilers where the fuel is not known or is not gas operated but whose feedback can be applied to gas operated facilities.

In addition, 37 accidents of the same type that occurred abroad between February 1973 to July 2007 were also listed due to their peculiarity, seriousness or the lessons learnt.

Process type facilities (industrial furnaces), recovery boilers (refuse incineration plants), combustion turbines and engines are excluded from the sample. Accidents solely involving fuel storage sites have not been included as well.

**Activities included in the sample study:**

<table>
<thead>
<tr>
<th>NAF (Official French Nomenclature of activities) code</th>
<th>No.</th>
<th>%</th>
<th>NAF code</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 - Agriculture, hunting and related activities</td>
<td>1</td>
<td>0.85</td>
<td>35 - Production and distribution of electricity, gas, steam and air conditioning</td>
<td>34</td>
<td>29</td>
</tr>
<tr>
<td>10 - Food industry</td>
<td>9</td>
<td>7.7</td>
<td>38 - Collection, treatment and disposal of waste, recovery</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>11 - Beverage industry</td>
<td>1</td>
<td>0.85</td>
<td>42 - Civil engineering</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>13 - Textile industry</td>
<td>1</td>
<td>0.85</td>
<td>43 - Specialized construction works</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>16 - Wood and wood item manufacturing industry</td>
<td>3</td>
<td>2.6</td>
<td>45 - Automobile and motor cycle trade and repair</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>17 - Paper and cardboard industry</td>
<td>2</td>
<td>1.7</td>
<td>46 - Wholesale trade except automobile and motor cycle</td>
<td>3</td>
<td>2.6</td>
</tr>
<tr>
<td>18 - Publishing, printing, copying</td>
<td>1</td>
<td>0.85</td>
<td>47 - Retail trade automobile and motor cycle</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>19 - Coking, refining industry</td>
<td>2</td>
<td>1.7</td>
<td>49 - Land and pipeline transport</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>20 - Chemical industry</td>
<td>11</td>
<td>9.4</td>
<td>56 - Restaurant</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>21 - Pharmaceutical industry</td>
<td>1</td>
<td>0.85</td>
<td>64 - Financial service activities, except insurance and pension funds</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>22 - Rubber and plastic industry</td>
<td>2</td>
<td>1.7</td>
<td>74 - Other professional, scientific and technical activities</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>23 - Manufacturing of other non-metallic mineral products</td>
<td>5</td>
<td>4.3</td>
<td>84 - Public administration and defense, compulsory social security</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>24 - Metallurgy</td>
<td>1</td>
<td>0.85</td>
<td>85 - Education</td>
<td>9</td>
<td>7.7</td>
</tr>
<tr>
<td>25 - Manufacturing of metal products, except machinery and equipment</td>
<td>8</td>
<td>6.8</td>
<td>86 - Health and social services</td>
<td>5</td>
<td>4.3</td>
</tr>
<tr>
<td>29 - Automobile industry</td>
<td>1</td>
<td>0.85</td>
<td>93 - Recreation, cultural and sporting activities</td>
<td>3</td>
<td>2.6</td>
</tr>
<tr>
<td>30 - Production of other transport equipment</td>
<td>1</td>
<td>0.85</td>
<td>96 - Other personal services</td>
<td>1</td>
<td>0.85</td>
</tr>
<tr>
<td>31 - Production of furniture</td>
<td>1</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33 - Repair and installation of machinery and equipment</td>
<td>1</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of accidents whose NAF code is known | 117 | 100 |

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1 A brief summary of accidents whose ARIA number has been put in bold in the text has been included at the end of the document. The full list of the summaries of 158 accidents used for this study is available in french at www.aria.developpement-durable.gouv.fr, in the “Analysis and feedback” section.

2 Collection of information started on 1 January 1992 ever since the ARIA database has been set up. However, a few accidents prior to this date could be listed depending upon the information available.
Gas boiler accidentology is marked by a high proportion of explosions and fires. In fact, the specific ignition characteristics of gas fuels and their ability to spread in service shafts and other piping \(\text{(ARIA 25923, 32777)}\) create an explosive atmosphere in rather confined environments.

The fault in majority of the cases lies in the cooling system (29%) and fuel supply (26.5%) the main reason behind the release of dangerous materials and explosions.

Five malfunctions recorded in the fuel supply resulted in an explosion in the boiler room due to the air / gas mixture within the explosivity limits (ARIA 3212, 6323, 6343, 6347, 28389).

The “Miscellaneous” accidents correspond to five near-accidents (ARIA 5063, 6552, 7768, 20085, 30425) and the flooding of a boiler subsequent to the steep rise in the level of water body (ARIA 19230).

### Typology and equipment behind the 121 accidents:

<table>
<thead>
<tr>
<th>Typology [not mutually exclusive]</th>
<th>Fuel supply</th>
<th>Combustion chamber</th>
<th>Heat transfer fluid systems and related equipment</th>
<th>Flue system</th>
<th>Electrical equipment</th>
<th>Utilities/heat distribution network</th>
<th>Miscellaneous</th>
<th>Not known</th>
<th>Total number of accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosions</td>
<td>12</td>
<td>3</td>
<td>11</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>14</td>
<td>43</td>
</tr>
<tr>
<td>Fires</td>
<td>6</td>
<td>-</td>
<td>6</td>
<td>1</td>
<td>8</td>
<td>-</td>
<td>4</td>
<td>14</td>
<td>39</td>
</tr>
<tr>
<td>Release of dangerous materials outside adapted containers</td>
<td>15</td>
<td>-</td>
<td>12</td>
<td>3</td>
<td>1</td>
<td>11</td>
<td>5</td>
<td>16</td>
<td>63</td>
</tr>
<tr>
<td>Bursting / Abrupt breakage of equipment</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>Other types</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>Total number of accidents</td>
<td>22</td>
<td>3</td>
<td>24</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>9</td>
<td>38</td>
<td>121</td>
</tr>
<tr>
<td>Proportion as compared to accidents where the faulty part of the facility is known</td>
<td>26.5%</td>
<td>3.5%</td>
<td>29%</td>
<td>6%</td>
<td>9.5%</td>
<td>14.5%</td>
<td>11%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
High pressures in confined environments create favourable conditions for the release of significant quantities of mechanical energy. The cases studied show that the accidents may be accompanied by effects of high external overpressure and projection of debris over large distances (several hundred meters).

Nine accidents result in 17 victims: 15 technicians, 1 fireman, and 1 inhabitant (ARIA 164, 5132, 6082, 6538, 16316, 17103, 18195, 19223, 25754).

The recorded disasters have social (technical unemployment, evacuation, etc.) or environmental repercussions, and result in damage to residences and facilities, and spill over of products in purification networks and facilities.

Due to the characteristics of fuels, gas boiler accidents pollute the natural environment to a relatively lesser extent. The environmental consequences most often include surface water pollution (10 cases) and harm to plants and animals (4 cases) by products used for the “secondary” operations. These cases have been included in the fifth part of this document.

### Recorded consequences of 121 events:

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Number of accidents</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human consequences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal</td>
<td>9</td>
<td>7%</td>
</tr>
<tr>
<td>Serious injury</td>
<td>14</td>
<td>11.5%</td>
</tr>
<tr>
<td>Evacuation of inhabitants</td>
<td>15</td>
<td>12%</td>
</tr>
<tr>
<td>Environmental consequences</td>
<td>14</td>
<td>11.5%</td>
</tr>
<tr>
<td>External material damage</td>
<td>10</td>
<td>8%</td>
</tr>
</tbody>
</table>
Several accidents are subsequent to loss of air-tightness before the boiler at the valves and branch connections of the gas fuel supply pipes: obsolete leaking joint (ARIA 6560), defective (ARIA 17103, 24680) or broken (ARIA 25923) pipe fittings, etc. Moreover, movable joints and cut-off elements must be handled with rigour and in compliance with the operating guidelines specific to each valve type: two accidents have been recorded following inappropriate handing of the sliding gate valve (or follower ring valves) that opens the pipe to the outside (ARIA 5132, 6133). After a maintenance operation on a boiler, a technical caused a significant gas leak by opening the gas supply without blocking the flange or carrying out an air-tightness test with compressed air or nitrogen (ARIA 31337). On boilers fuelled with LPG stored in tanks, vaporizers are sometimes another source of leakage (ARIA 11158).

The rupture of supply pipes causes massive quantities of flammable gas to leak. There are several causes for instance an error in handling a power lift truck moving wooden pallets piled up before a pipe (ARIA 4472).

The leaks are responsible for explosions (six out of 12 recorded leaks in the gas pipe on site lead to an explosion), fires (five cases on 12 recorded of which three are subsequent to explosions) and result in casualties and significant material damage. The ignition sources may directly be the boiler, an electrical connection or operations involving hot spots, etc.

The explosion of the Courbevoie boiler, subsequent to a significant leak in the valve on the supply pipe of the boiler causing the death of two people tragically illustrates this scenario (ARIA 5132).

In the case of mixed gas / carbon boilers, the concomitant risk of ignition of natural gas and carbon dust really needs to be taken into account during risk analysis. In case of a gas leak on a boiler supply pipe, the explosion of carbon particles suspended in air by the high flow of the leak is likely to increase the intensity of the explosion (ARIA 5132).

Abroad

In 1987 in the United States, lightning struck an urban natural gas boiler and punctured a valve at the burner gas inlet (ARIA 6541).
The accident concentration of gas inside the combustion chamber can result in conditions conducive to explosion. Such accidents generally occur when the boiler is restarted or commissioned. Several scenarios could lead to such a situation:

- leaving the gas supply open following an error in procedure (ARIA 164), malfunctioning of the regulator compressor valve (ARIA 6323), solenoid valve (ARIA 3212) or even any fault in the piping itself (ARIA 6343)
- very low pressure of the gas in the injectors (ARIA 6347)
- blow-off of flame (ARIA 28389, 32175)
- error in understanding, deactivating safety measures (ARIA 6343, 28349)
- pre-ventilation defect before restarting the boiler (ARIA 6538).

Surveillance and safety equipment have led to several accidents or collateral accidents, they must be managed with great rigour. Without having the required information to analyse faults, the workers often force the boiler to start causing the gas accumulated in the firebox to explode (ARIA 6323). In Dunkerque, the breakdown of the flame control camera did not allow to detect that the flame was extinguished (ARIA 28389). In Lyon, a technician, unable to establish the reasons of the emergency shutdown of a burner due to the breakdown of regulatory control devices, restarts the boiler causing the gas in the firebox to explode (ARIA 6343).
In 2000 in Zambia, a pipe clogged with rust caused heat to accumulate in the boiler leading to a serious fire that destroyed the refinery (ARIA 19434).

In 1994 in Germany, the rupture of a superheated steam pipe at 550°C during adjustment resulted in six deaths and one injury among staff in an urban boiler. Nine days before the accident, an inspection body had proceeded to re-testing the part of the circuit involved at a pressure lower than the working pressure and the report was forged (ARIA 5954).

Several cases of explosions, destruction or fires inside the boilers recorded in the sample study are due to the abrupt vaporisation of the heat transfer fluid in its circuit following:

- crack or rupture of the piping (coils, tubes, etc.) with or without failure of the safety device (ARIA 1015, 1465, 8055, 8725, 16806, 19079);
- pollution of heat transfer fluid (ARIA 6338, 7768, 25754).

In Le Havre, the presence of hydrocarbons in the feed water of a new boiler caused the temperature of the metal piping to increase beyond the calculated values used in the test. The new boiler used to pre-heat a fuel oil tank, exploded at the end of the tests and was projected about 10m backward, killing one employee and injuring 17 others (ARIA 25754).

Leakage or spill over of heat transfer fluids outside the boiler pollutes the surroundings or the rain water sewer system. There could be several reasons: maintenance operations such as draining the heat transfer fluid circuit (ARIA 7592), act of vandalism (ARIA 15805), partial rupture of a draining header of a primary circuit (ARIA 25832) or a spill over of excessively hot water into a river leading to a high incidence of death of aquatic fauna (ARIA 2780).

The integrity of the heat transfer fluid circuit and its supply must be ensured and the characteristics of the heat transfer fluid monitored that may deteriorate due to accidental mixing (ARIA 29808) or following several heating cycles.

The natural environment is also affected by accidental release of maintenance products used in circuits (cleaners, etching agents, antiscalant) (ARIA 25894, 28569, 28911).

The opening of safety valves of the steam system following a steam surge (ARIA 31242) or a mechanical malfunctioning of the valve (ARIA 30953) sometimes results in severe noise annoyance for the surrounding environment.

Moreover, hot water and steam distributing pipes rupture onsite (ARIA 316, 6339, 19223, 30899) or outside (ARIA 18195, 19943, 20961, 25402, 26159, 31063) due to several reasons: land subsidence, obsolescence of pipes, mechanical and thermal constraints (high pressures and temperatures) and faults due to inappropriate operating practices. Even though these accidents do not result in casualties, they lead to evacuation of the general public and cut-off of heat and hot water supply.

Lastly, pipes transporting hot heat transfer fluids are a source of ignition for flammable products or fuel upon contact. Thus in a power station, lubricating oil dripping from a defective solder ignited upon contact with a pipe transporting superheated steam and resulted in a fire (ARIA 8726).

Abroad

In 2000 in Zambia, a pipe clogged with rust caused heat to accumulate in the boiler leading to a serious fire that destroyed the refinery (ARIA 19434).

In 1994 in Germany, the rupture of a superheated steam pipe at 550°C during adjustment resulted in six deaths and one injury among staff in an urban boiler. Nine days before the accident, an inspection body had proceeded to re-testing the part of the circuit involved at a pressure lower than the working pressure and the report was forged (ARIA 5954).
V . EVENTS NOT INVOLVING GAS FUELS

b / Other accident scenarios

The emission of fumes rich in carbon monoxide generated by a poor combustion in the boiler (ARIA 2670, 7789, 16794, 19508, 21885, 25932, 26019, 29006), and further compounded for instance by a defective chimney (ARIA 26872) have led to poisoning of both operators and public. The poor draught of a chimney could lead to the accumulation of gas and the explosion of the boiler (ARIA 6348, 22980). The ignition of a thermally insulated metal lining by hot fumes must also be noted (ARIA 24021).

If the boilers are not defective, they are at times responsible for igniting a flammable cloud coming from an external source: propane leak from a tanker truck (ARIA 6610) or natural gas following an accidental extraction of a pipe by workers digging a hole (ARIA 31468, 32777), emission of solvent vapours from a tank being cleaned (ARIA 8052), etc.

In numerous industrial sites, the boilers are also involved in accidents caused due to other facilities or equipment of the site: electrical faults (ARIA 4933, 16466, 18204, 24845, 27370, 28565, 31492) resulting in fires, and pollution of water bodies by an accidentally drained foam compounds (ARIA 32801). These facilities are also exposed to natural phenomena such as ground movement (ARIA 5063, 10785) and floods (ARIA 19230).

Abroad

In 1980 in the United States a boiler in a boiler room that was shutdown urgently following an instrumentation failure exploded on restarting undoubtedly due to insufficient drain and pre-scavenging (ARIA 6535).

In 2000 in the United States, a leak in a propane tank of a soft drink bottling plant causing the gas cloud to explode upon contact with a boiler resulting in a BLEVE of the tank (ARIA 18967).

In 1994 in Pakistan, a short circuit in a power station triggered a fire in the underground cable network in generation units leading to the emergency shutdown of a 210 MW generating unit and other major damage (ARIA 5539).

In 1994 in Germany, a lubricating oil leak in a mechanical gear box of a gas turbine caused it to explode resulting in four deaths and six injuries including two serious injuries involving the staff of the power plant and a subcontracting company (ARIA 5958).
Commissioning, maintenance, overhaul, tests and restart operations require special attention. 31.5% of accidents (37 accidents) take place during these operations while they correspond to lower time proportions in the service life of the facilities. This high proportion just shows how crucial these transitory phases are and must not be considered as just routine operations. It is symptomatic that eight out of nine accidents resulting in victims and 24 explosions and bursting of equipment take place in these circumstances.

It must also be noted that the accidents take place when there is less staff: at night, lunchtime, and bank holidays (ARIA 6645, 8055, 12686, 16806, 19257, 22980, etc.). The safety devices must be functional and in proper working order especially to monitor the level of heat transfer fluid and initiate the emergency shutdown of the facility subsequent to a fault. This recommendation is even more applicable for boilers operated without technicians.

Circumstances and defective equipment:

<table>
<thead>
<tr>
<th>Circumstances</th>
<th>Fuel supply</th>
<th>Combustion chamber</th>
<th>Heat transfer fluid system and related equipment</th>
<th>Flow circuit</th>
<th>Electrical equipment</th>
<th>Distribution of utilities (steam, heat, etc.)</th>
<th>Miscellaneous</th>
<th>Not known</th>
<th>Total number of accidents</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance / overhaul / test in progress</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>19</td>
<td>15.5 %</td>
</tr>
<tr>
<td>Boiler restart / change</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>14</td>
<td>11.5 %</td>
</tr>
<tr>
<td>Commissioning</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>3.5 %</td>
</tr>
<tr>
<td>Abandoned facility</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1 %</td>
</tr>
<tr>
<td>General operations / unspecified circumstances</td>
<td>10</td>
<td>1</td>
<td>15</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>30</td>
<td>83</td>
<td>68.5 %</td>
</tr>
<tr>
<td>Total number of accidents</td>
<td>22</td>
<td>3</td>
<td>24</td>
<td>5</td>
<td>8</td>
<td>12</td>
<td>9</td>
<td>38</td>
<td>121</td>
<td>100 %</td>
</tr>
</tbody>
</table>

Proportion with respect to accidents whose defective facility is known: 26.5 %, 3.5 %, 29 %, 6 %, 9.5 %, 14.5 %, 11 %.
Without going into cases of malice (ARIA 15805), the analysis of accidents shows that the initial causes rarely originate from purely technical aspects. Insufficient risk analysis, organisational failure, change management, insufficient or poorly adapted training, absence or non-compliance with guidelines, poor maintenance, inspection or vigilance are often the real reasons.

19 out of 37 accidents during the operational and transitory phases (51 %) are due to clearly identified human or organisational failures. Accidents occur because technicians failed to follow the distribution of tasks and responsibilities (ARIA 5132), they received inappropriate operating guidelines (ARIA 6133), ignored warning messages or did not comply with the operating procedures and the safety rules (ARIA 164, 5132, 6343, 6538, 31337). In the absence of information required to analyse these faults, the technicians sometimes force the boiler to start (ARIA 6323, 28349). Lack of training, routine, taking risks less seriously is rather likely in several cases. Taking the feedback into account could have avoided some accident sequences from taking place (ARIA 6133, 5132).

Manufacturing defects (ARIA 25754), problems in settings and handling errors (ARIA 7592, 7768, 23421, 23893, 28569, 32801) during maintenance (ARIA 6347, 17103, 32175), possibly due to lack of monitoring and inspection have also been reported.

Apart from operating procedures, the technicians must be informed on the risks related to the products handled (ARIA 25894).

Nine other accidents clearly involve organisational and human factors in normal operating period: 3 result from basic errors (ARIA 4472, 16371, 32777) probably due to ergonomic, training or inspection problems and five from poor maintenance (ARIA 6338, 6560, 11158, 19508, 25923) or monitoring (ARIA 6645).
Accidentology has illustrated numerous examples of accidents related to an overall organisational failure and poor or unsuitable operating conditions. Currently, safety management in industrial facilities is governed by a set of well-established principles:

- Organisation of duties and responsibilities of staff including subcontractors
- Regular and adapted training of staff
- Identification and assessment of accident risks
- Total control of processes by guidelines and procedures enabling operations under the best possible safety conditions in both steady and transient state
- Work management, analysis of risk beforehand upon receipt of project including consultation with all involved players, accreditation of the players and organisation and supervision of project
- Use of organisational measures to manage change in facilities
- Feedback management within the same group and more generally within the same line of work
- Inspection of discrepancies observed between the overall organisation of the working of the facility and practices followed
- Involvement of the management in safety management.
Operation of facilities

- Increasing the awareness of operating teams on the specific risks related to maintenance operations so that the safety guidelines are not violated despite an excellent knowledge of the facilities.
- Updating knowledge levels and ensuring strict compliance with guidelines especially in rigorous procedures.
- Exercising extreme rigour in operation, maintenance and implementation of transient phases to ensure optimal safety of the facility.
- Ensuring availability of precise and updated guidelines at all times.
- Special training of technicians to handle unusual circumstances such as contingencies and transitory phases: action to be taken for the emergency shutdown of units, performance of additional manual operations that are added to an existing procedure or an automatism.
- Regular inspections using procedures and methods adapted of the tightness of devices under pressure (flanges, joints, valves, reducing piece, etc.), measuring instruments and safety devices.
- For gas / carbon mixed facilities, cleaning of carbon dust and clear separation of zone with high risk of gas accumulation and zones with high risk of dispersion and ignition of carbon dust.

Design and manufacture of equipment

- Location of such facilities taking into account the risks underlying the various possible accident scenarios and especially the extent of impact on persons in the surroundings likely to be exposed.
- Boiler design taking into account high pressures that could be attained in special conditions as well as related activities.
- Optimal assembly quality in the start guarantees lasting tightness of the facilities.
- Location, position and choice of appropriate cut-off and control elements: they must be adapted to the product and operations during which they will be used and remote controlled to guarantee optimal conditions to operate, test, inspect, ensure maintenance.
- Choice of control devices that allows as far as possible to view the position of the elements (open, closed, etc.) as well as nature of the fluid in question.
- Use of gas detection devices controlled by local visual and/or sound alarm systems carried over to the control room, ensuring the safety of the facility (cutting-off fuel supply, and switching off electricity to ATEX non-compliant equipment).
- Setting up locking or immobilising system on sensitive controls likely to be activated inadvertently or intentionally (to shorten a procedure for instance): implementing appropriate procedures to avoid sudden unlocking of these devices (by getting the key from the appropriate department supervisor, etc.).
- Taking into account the regulation automatisms of the ventilation conditions (air/gas control) of all operating phases including exceptional operating conditions such as reduced output or transfer phase from start up to full output.
In a chemical plant, a 17.7x5.5x 18 m, 696 plate electrostatic dust removal filter of a 116 MW carbon boiler exploded. The accident occurred when the boiler was restarted after being shut down for 15 days for maintenance. The explosion took place due to the accumulation of 440 m³ of gas in the boiler following the gas supply of a back-up burner (300 m³/h) left open for 1 hour and 20 minutes before the accident and another 1 hour and 30 minutes after. One manual valve and two automatic check valves were left open (no visual inspection, check valves unautomated with compressed air fine control, warning messages ignored). The explosion resulted in one death and eight injured among the technicians. The shattering of glass and projection of material were observed as far as 250 m. Material damage was assessed at 20 MF.

A 1962 boiler producing 100 t/h of steam at 82 bar and 475°C exploded three days after it was restarted after being shut down for 3 months for maintenance. The result was a yield broke 23 tubes out of 470 (A37 steel, 63 to 76 mm in diameter and 4 to 5 mm in thickness) at least 20 m from the upper and lower water tanks. The screen was opened and moved. Tube debris and refractory aggregates were projected at a distance of 100 m, causing mild injuries to one operator. The accident may have occurred due to an acid deposit (metallic sulfates) in the heterojunction causing several corroded tubes (2 mm) to burst at the same time. The perforation of either of the tubes may have subsequently caused them to erode. The cost of repair was assessed at 15 MF.

An explosion occurred at 1.30 am in a residential boiler (500 MW, 6,000 m²). The energy dissipated in the ground is estimated to be equivalent to 50 kg of TNT. The boiler room commissioned in 1987 comprises five boilers (2 carbon boilers, 2 carbon/gas mixed boilers and 1 gas boiler). During the previous shift, several attempts to restart the mixed boiler proved unsuccessful. Since the boiler would not restart and the gas inlet manometer indicated zero pressure, the right shift supervisor instructed the opening of the two valves by a quarter turn from the sectioning of the gas inlet on the main circuit. The pressure reading was still zero so he asked the boiler operator to open the guillotine valve and then a butterfly valve to supply the mixed boiler with gas. This led to a major gas leak. A gas boiler was urgently shutdown and the explosion occurred when two operators were just about to cut off supply to the gas pressure regulator station at 110 m from the building. One of the five employees was killed. A 10 year old girl living 50 m from the plant dies four days later after sustaining injuries. 59 other inhabitants were also injured. The facility was destroyed. The neighbouring districts suffered significant damage. 500 people were laid off temporarily and 250 inhabitants relocated. While waiting for their connection to adjacent networks, 140,000 users and 2.2 Mm² of offices were left without gas for 3 days before being restarted the morning. A possible cause of the accident could have been an inappropriate operation involving the accidental filling of the heating unit with cold water triggering a sudden evaporation upon contact with the heating tube whose temperature was already high. An expert report dating back to 1995 stated that a partial draining of the fire tube could have led to damage from an energy perspective. This report however does not confirm that the draining was the real cause.

A gas leak caused an explosion and started fire in a propane boiler of a printing press (500 people). Two employees sustained burns, including one who sustained second degree burns and was transported to the military hospital in CLAMART by a helicopter. One employee was unwell due to the fumes released. The leak results from the rupture of a propane supply pipe that passes through the far end of the equipment room near the quick cut-off and control element regulated from the outside by a palm button. An error in operating the power lift truck to move the wooden pellets piled up in front of the pipe may be the cause of the leak. The boiler was supplied by a 35,000 kg tank of liquefied propane.

In a prepared meat products plant, a firetube boiler with a steam production capacity of 117 t/h exploded. It had a capacity of 2,790 l, a heating surface of 27 m² and a gas pressure of 1 atm. It was set up in 1979 to supply five industrial pressure cookers and was rated at 10 bars. A hissing sound was heard at the relief valves just before the explosion that destroyed the building scattering the debris in an area of 200 m². Three employees died (a body was found at 250 m with the front face of the boiler), three other injured including one in serious condition. The body of the boiler (31) was projected 150 m to the north, the fire tube and the hot water tank at 200 m to the south. The boiler was stopped and drained for maintenance (relief valve, drain valve) three days before was restarted the morning. A possible cause of this accident could have been an inappropriate operation involving the accidental filling of the heating unit with cold water triggering a sudden evaporation upon contact with the heating tube whose temperature was already high. An expert report dating back to 1995 stated that a partial draining of the fire tube could have led to damage from an energy perspective. This report however does not confirm that the draining was the real cause.
In a steam generation plant, there were problems in starting the boiler. The operator repeated the start-up procedure, but failed to proceed industriously, the reason for the breakdown could not be established. The technician nevertheless triggered the automatic restart sequence that was followed by an explosion 30 seconds later soon after the start of the pre-sweeping out operation (injection of air into the furnace). The investigation revealed the presence of foreign bodies (metal particles and carbon deposits) inside the gas filter and gas supply valve of the boiler, a mark on the disc of the 1st valve (leak?), significant loss of load on the air vent (22 m long, 12 square elbows). These faults have seemingly allowed gas to leak into the generator for 30 min following the emergency shutdown of the boiler. The attempt to restart the boiler with an air injection in the furnace helped reach the upper explosive limit and caused the explosion in the combustion chamber.

An explosion took place in the smoke flue of a 2.5 MW gas boiler installed in the boiler room of a hospital. The accident resulted in significant material damage on the boiler (access doors and covers ripped out, masonry destroyed, joints and chimney interiors blown away). Two theories had been propounded as to the origin of the accident: malfunctioning of the burner cycle or more likely poor combustion and smoke evacuation conditions. The flue shape (large horizontal volume) and the presence of unfavourable weather conditions (storm) may have contributed to the accumulation of CO, with ignition of the other boiler connected to the same flue. Inspecting the gas solenoid valve helps ensure its air tightness.

In a 250 MW thermal power station, 13,000 litres of lubricating oil caught fire upon contact with a pipeline transporting superheated steam. The smoke covered the control room. A flash was produced with the oil vapours accumulated below the roof that caused considerable damages. The high pressure oil caused vibrations during the pumping of the inlet valves of the turbine driven feed pump. These vibrations were transmitted to the copper low pressure tubes (diameter 22 cm) carrying lubricating oil. The rupture of a solder was the main reason behind the accident. The oil stream projected droplets that caught fire at the various local hot spots of the pipe resulting in an upward oriented vertical blowpipe flame fueled at 250 to 300 l/min for 45 min, operating time of the pump. The repairs lasted for over a month. The damage was assessed at 10 MF. Corrective measures were implemented during operations to avoid another accident.

A gas boiler exploded in a facility manufacturing concrete elements for construction. After having detected the smell of gas the previous day, the operator called upon the services of a boiler maintenance company that had sealed a small leak at the gas heating device on the morning of the accident. Since the smell persisted, the operator subsequently had a gas supply company intervene urgently. The explosion occurred before the gas company arrived. The company’s heating system was damaged resulting in an internal operational loss. The operator planned to set up gas detectors along with an automatic cut-off valve in the boiler room. The natural gas supplier was also consulted for direct connection to the natural gas network instead of a gas tank to supply the boiler.
ACCIDENTS

ARIA 15805 - 29/05/1999 - 51 - REIMS
30.20 - Construction of locomotives and other railway equipment running on rails
On the site of an abandoned plant, an act of vandalism or theft led to the spillage of several hundred litres of cooling fluid contained in an un-drained boiler. The liquid flowed into an internal gutter of the boiler room and then reached the public way through a pipe running through the wall of the premises. The sanitation department recovered around 500 litres of liquid in a rain water network. A list of abandoned products and waste material was drawn up for disposal.

ARIA 16316 - 09/01/1985 - 94 - CHAMPIGNY-SUR-MARNE
47.52 - Hardware, paints and glass in wholesale specialty shops
There was no major environmental impact. The clinker production was stopped but not the production of cement as the plant could operate on the existing clinker stock while awaiting the necessary repair operations.

ARIA 16371 - 17/09/1999 - 79 - AIRVAULT
23.51 - Cement production
In a cement works, a fire broke out in a boiler room releasing huge quantities of smoke. Two boilers (1 electric and 1 gas) that could not be operated at the same time were used to warm-up a highly viscous fuel. When the gas boiler was operating, the electric boiler was switched on leading to the overheating of the residual cooling fluid. There was no major environmental impact. The clinker production was stopped but not the production of cement as the plant could operate on the existing clinker stock while awaiting the necessary repair operations.

ARIA 16466 - 14/09/1999 - 54 - MONT-SAINT-MARTIN
42.11 - Construction of roads and highways
A fire broke out in the thermal fluid boiler of a road material hot pre-coating facility. The firemen brought the fire under control within 1 hour and 30 minutes and watered the nearby far tanks out of precaution. The cooling fluid used in the facility spilled into the buffer tank meant for the purpose. A short circuit in the electrical cabinet was the cause of the accident. An expert analysis was carried out on the boiler before re-commissioning.

ARIA 17103 - 05/04/1997 - 57 - SARREGUEMINES
46.74 - Plumbing and heating hardware and supplies wholesale shop
An explosion occurred in a building when the gas network and boilers were being installed. The bodies of three persons were found below the wreckage. In the judicial investigation that followed, two experts highlighted faults at the joints between the gas columns and boilers. The owner was given a six month suspended sentence and fined 50,000 F (judgement dated 06/12/99).

ARIA 18195 - 07/07/2000 - 75 - PARIS
35.30 - Production and distribution of steam and conditioned air
A high pressure heating pipeline running below a pavement ruptured when the pavement collapsed following violent storms. Steam leak occurred and the pipeline exploded an hour later during operations being carried out by the staff of the heating company along with firemen and policemen. The explosion resulted in a 10m x 4m crater, projected several people, smashed glass panes and damaged vehicles in the proximity. Two firemen were seriously injured of whom one died shortly after. 21 other people also sustained injuries. Rescue services arrived in great numbers (150 firemen from 19 fire stations, dog squads, etc.). A danger area was demarcated and a neighbouring day-care centre was evacuated.

ARIA 19223 - 15/11/2000 - 75 - PARIS
35.30 - Production and distribution of steam and conditioned air
While re-commissioning a steam pipeline (1800°C and 22 bar) running through an underground tunnel, an explosion caused steam to be released. The workers undertaking repair operations at this phase were trapped in the tunnel by the steam and temperature flow. The workers in the technical tunnel (~ 25 m) were killed on the spot (3 persons), as well as the ones at 10 m below ground level; eight out of nine other workers in other zones or at the upper level (3 m below ground level) sustained severe burns. The team was carrying out a delicate operation of increasing pressure on a 4.5 km section along with tests on the line. The operator presented the overall procedure as standard. Investigations were carried out to determine the causes of the accident.

ARIA 22980 - 36/07/2002 - 43 - JULLIANGES
16.10 - Wood saving and planing
A central heating wood-fed boiler exploded in a sawmill after six employees left for their lunch break. The children playing in the vicinity sounded the alert after the accident occurred. The stones comprising the boiler chimney were projected nearby. The rabble was recovered as far as 150 m according to the press. Vehicles parked nearby were damaged. An electric line was damaged and the technical department had to be called in to restore electricity supply in the neighbourhood. The sawmill used a central heating boiler that produced hot water (no steam) between 80 and 90°C to heat the wood drying building. High temperature conditions (40 to 50°C) are required to prepare the wood before transferring it to the oven. The sawmill recycles the wooden chips and sawdust used as fuel for the boiler. Following the explosion, the on-site operations could not be resumed due to the extent of damage. According to the operator, the explosion occurred due to gas accumulation in the furnace due to poor draught. The manufacturer modified the supply to the boiler to cut-off in the event of a fault. A problem on the boiler exhaust valve is also suspected (leak and rapid evaporation of water in the furnace). An inspection of the exhaust valve has been added to the periodical maintenance operations. Site reconstruction operations were to last between six to eight months.
Fifty litres of sodium hydroxide (NaOH) leaked from the supply of a boiler demineralisation unit of a flue production plant. The damaged network that empties into the SORGUE river. The rise in the pH led to the precipitation of calcium carbonate creating a major whitish turbidity in the river that disappeared in an hour. Following this accident, the company has planned to refloor and leakproof the unit, a new auxiliary boiler in a power station (10 t of steam/h) exploded. This auxiliary boiler was meant to supplement the supply of steam required to heat heavy storage fuels and to cool the burners of segment 3. This corrugated tube boiler has a 3 pass design. The combustion gases are transported to the back of the boiler and then brought to the front through internal smoke ducts before being transferred to the chimney at the back via the upper ducts. The boiler was supposed to operate as a buffer on the network along with another boiler of the same type (stopped on the day of the accident) and a steam transformer producing bleed steam for turbo-alternator units. The accident took place at the end of the boiler start-up tests that were monitored by a technician from the product manufacturing company and two technicians of the boiler room. One of the ends of the corrugated tube got detached from the condenser tube plate creating a breach at the rear end of the boiler. The water in the boiler, under the action of the immediate vapourisation of the high pressure steam (about 13 bars), escaped through this breach hurling the boiler backwards by a few dozen meters causing it to lodge into the slag-remover of a 350 MW boiler. The vapour escaping from the boiler passed through the fuel shifting bay, destroyed the walls of the mechanical workshop and while vapourising partially at atmospheric pressure occupied significant volume causing burns to the staff in the workshop. One person died and 17 were injured in the explosion, they were all inside the mechanical workshop. Even though the boiler specifications were not in accordance with some calculation codes, they did however comply with the ISO code and the NFE 32.104 French standard. The supply water contained hydrocarbons heavier than water at the operating temperature of the boiler. They were deposited on the firetube resulting in a switch over to film vapourisation. This consequently brought about an increase in the metal temperature beyond the maximum temperature guaranteed in the specifications of the steel used. In fact there were chances of the vapour circuit being polluted by the fuel oil during heating; the vapour condensates may have been recovered in tanks supplied to the boiler. Since the actual operating conditions at the time of the explosion were not known with full certainty, the presence of fuel oil in the supply water and specifications not compliant with calculation codes caused the accident to take place.
An explosion followed by a start of fire occurred in the boiler room of a particle board manufacturing company subject to authorisation. Prior to the explosion, the press coupled with the boiler has already stopped and been restarted on several occasions. Just before 5.00 pm, the boiler 2 control room operator noticed that the entire facility had stopped operating and a “white smoke/vapours” was released at the cooling oil pump. He immediately warned the area manager by telephone. A few seconds later, there was an explosion followed by a start of fire in the oil drain tank sector connected to the boilers primary circuit. Boiler room 2 was evacuated. The automatic foam sprinkler system brought the fire under control. The firemen on site assisted by external rescue teams put out the flames. 15 minutes later in the secondary furnaces and marked out a danger area of 300m around the building whose sides were on the verge of collapsing. To avoid the fire fighting water from polluting, the operated isolated the rain water collection tank from the water body where it emptied. The technician in the boiler control room who was under a state of shock was hospitalised. The siding sheets were ripped out during the explosion, two electrical cabinets and facilities related to the drain tanks were damaged by the flames. Even though the main frame of the building was not damaged, the operator feared that the explosion might have weakened the end restraints of the sides. The inspector of classified facilities recommended the prefect to issue the operator an official notice ordering the update of the site contingency plan. Ten days before the accident, a start of fire had already broken out on the press of the plant (n° ARIA 29729). According to the expert analysis, water in the primary circuit of the boiler degraded the physico-chemical characteristics of the cooling fluid. The sudden overflowing of the hot oil into the drain tanks triggered foaming upon contact with the water in the tanks resulting in an overpressure in one of the tanks and opening of its rupture disc. The cloud that was vaporised exploded on contact with a hot surface.

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The summaries of the accidents presented in this document are available in french at:

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