Analysis of pressure equipments related accidents

February 2016
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The present analysis has been conducted using a selection of 247 events that took place in France and were adequately detailed in the ARIA database. The period analysed spans the 5 years from 1st Jan 2010 through 31st Dec 2014. The actual number of events occurring during this time frame is likely to be higher, with any difference being explained by the fact that:

- the information on accidents stems mainly from the DREAL Environmental Agencies or the press;
- BARPI’s offices are not systematically informed of all events occurring in facilities like refineries or nuclear power plants featuring an internal Recognised Inspection Service;
- the accuracy of information communicated by a pressure equipment inspector or a Classified Facilities inspector tends to vary as each specialist views the accident through the lens of their own regulatory reference.

In acknowledging these provisos, the data that follows merely represents trends regarding the events recorded in the ARIA base over the 5-year study period.

1. Scope of this study

Given the large number of accidents involving pressure equipment in the ARIA base, the following criteria have been applied in order to calibrate the study sample in favor of events of sufficient interest to generate experience feedback. The method employed thus consists of excluding events relative to:

- household use of gas (gas bottles, gas distribution network);
- rail or road traffic accidents (derailment of rail tanker cars or pressurised gas lorry tanker skidding off the road);
- exploding equipment during a fire event (e.g. gas bottles engulfed in a blaze).

The distribution of these events (lower number on the chart) per year is as follows:

![Annual distribution chart]

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1 Effective application date of the BSEI No. 09-242 Circular, promulgated on 31st December 2009.
2. Activities covered

Pressure equipment is present everywhere in our daily lives, e.g. extinguishers, LPG tanks, oxygen bottles. To clarify and simplify this analysis, the events studied have been sorted into 3 categories according to whether they took place in:

- industry;
- a plant featuring a Recognised Inspection Service (SIR).

An "other" category has been created to combine events occurring:

- at individuals’ homes or in office buildings (refrigerated unit for air conditioning systems);
- on worksites, excluding industrial sites;
- in Buildings open to the Public, such as hospitals, middle schools and high schools;
- in unknown places or when no specific information is provided (e.g. abandoned gas bottles);
- at military installations.

On the basis of this classification, we obtain the following distribution:

![Pie chart showing distribution of events by category.](chart)

Autre = Other   Industrie = Industry   SIR = Recognised Inspection Service

The primary industrial sectors involved are:

![Bar chart showing number of events by sector.](chart)

Number of events by sector of activity [Distri HC = Distribution of hydrocarbons: service stations or LPG filling stations, Trait. eau = Water treatment, Other Ind. = Other industries, food includes food processing, Alimentaire = Food processing, Métallurgie = Metallurgy, Raffinage = Refining, Papéterie = Paper mills]
3. Targeted equipment

a) Regulatory system

At the regulatory level, pressure devices may fall under pressure equipment (ESP) regulations, or else regulations applicable to transportable pressure equipment (ESPT). The ranking of events by regulatory system makes it possible to highlight the predominance of pressure equipment within the sample:

The under-representation of ESP can be explained by the removal of events tied to the household use of gas. Many LPG bottles (which fall under the ESPT classification) are the cause of fatal accidents each year (refer to the summary of accident study data on household use of gas). The ESP found in the sample are mainly bottles containing various industrial gases (hydrogen, acetylene, chlorine in water treatment plants or swimming pools).

b) Distribution by type of equipment

In order to simplify this equipment analysis and adhere to the equipment categories listed in the regulations, the various devices have been classed in 7 categories, namely:

- containers, comprising tanks, spheres and other storage receptacles;
- gas bottles;
- refrigerated units;
- exchangers;
- steam generators or boilers;
- autoclaves;
- a plant's pipe network.

[réservoirs=tanks, bouteilles=bottles, groupe foid=refrigeration unit, chaudières=pipes boilers, échangeurs= exchangers]
The distribution in the number of accidents may be adjusted depending on the particular industrial sector and the type of activity in order to expose specific accident patterns:

<table>
<thead>
<tr>
<th>Industry</th>
<th>Pipes</th>
<th>Tanks</th>
<th>Refrigeration</th>
<th>Steam generator</th>
<th>Exchangers</th>
<th>Bottles</th>
<th>Autoclave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeronautics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Agriculture</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Food processing</td>
<td>1</td>
<td>3</td>
<td><strong>35</strong></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrocarbon distribution</td>
<td>6</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Energy (excluding nuclear)</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail distribution</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper mills</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refining</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Steelmaking / Boilermaking</td>
<td>8</td>
<td>5</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Water treatment</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>13</strong></td>
</tr>
<tr>
<td>Chemicals</td>
<td>14</td>
<td>7</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Automobile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other industries</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Nuclear</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We can therefore observe that:

- The food processing industry is more frequently prone to problems of leaking refrigerant on refrigeration installations. These leaks may prove to be hazardous depending on the nature of the refrigerant (ammonia). Installations of this type are also addressed in exemptions to conventional regulations when subjected to specific construction-related constraints (formerly listed in the DMTP directive or special technical clauses).
- Extensive discharging occurs around LPG cisterns during the distribution of hydrocarbons (service stations), especially due to inadequate clamping torque at the flanges interlocking the joints.
- Water treatment centres (municipal drinking water purification plants, swimming pools) are particularly concerned by leak-related issues on chlorine bottles.
- Lastly, many leaks are formed on pipes running through chemical plants.
c) General characteristics

1. Pressure

<table>
<thead>
<tr>
<th>Type of equipment</th>
<th>No. of events in which the internal pressure of the equipment is known</th>
<th>Average pressure (in bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>autoclave</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>bottles</td>
<td>6</td>
<td>110</td>
</tr>
<tr>
<td>exchangers</td>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>steam generator</td>
<td>4</td>
<td>49</td>
</tr>
<tr>
<td>refrigeration unit</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>tanks</td>
<td>12</td>
<td>58</td>
</tr>
<tr>
<td>piping systems</td>
<td>21</td>
<td>42</td>
</tr>
</tbody>
</table>

2. Volume

<table>
<thead>
<tr>
<th>Type of equipment</th>
<th>No. of events with known volume</th>
<th>Average volume (in litres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bottles</td>
<td>11</td>
<td>34</td>
</tr>
<tr>
<td>tanks</td>
<td>27</td>
<td>14500</td>
</tr>
</tbody>
</table>

Average bottle volume: 34 litres

Average tank volume: 14500 litres

3. Nominal dimension of pipes

<table>
<thead>
<tr>
<th>Type of equipment</th>
<th>No. of events in which the ND is known</th>
<th>Average ND</th>
</tr>
</thead>
<tbody>
<tr>
<td>pipes</td>
<td>6</td>
<td>240</td>
</tr>
</tbody>
</table>

The Nominal Dimensions (denoted ND) are units of measurement used for pipe components. The nominal dimension is expressed in terms of mm and corresponds to the pipe’s internal clear width.
4. Year of construction and age of equipment

The catalogued accidents encompass recent (less than 10 years in service) or new equipment as well as older installations.

The average age of equipment listed in these summaries is 20 years, while the median is 18.

Obsolescence of installations was only explicitly mentioned as the accident cause on a single database summary (ARIA 42650).

5. Fluids involved

The main fluids contained in the equipment studied are:

- various chemical products in gaseous form (e.g. acetylene, hydrogen, chlorine, nitrogen, oxygen)
- LPG
- refrigerant gases in refrigeration installations
- steam
- or quite simply compressed air.

An "unknown" products category was created in order to catalogue those cases in which identifying the fluid proved complicated or could not be communicated to BARPI.
The equipment classification vs. fluid contained within is as follows:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Air</th>
<th>LPG</th>
<th>Unknown</th>
<th>Chemical Products</th>
<th>Refrigerants</th>
<th>Steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>autoclave</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>bottles</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td></td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>exchangers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>steam generator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>refrigerating unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>52</td>
</tr>
<tr>
<td>tanks</td>
<td>3</td>
<td>41</td>
<td>2</td>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>pipes</td>
<td>4</td>
<td>8</td>
<td>5</td>
<td></td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

Number of events vs. particular fluid and equipment
6. Accessories

Accessories constitute the source of leaks, notably in cases involving:

- relief valve malfunctions;
- poor seals in the vicinity of valves;
- poor clamping torque around flange joints;
- problems with network taps;
- flap gate malfunctions;
- burst rupture disc during the operations phase.

The studied events are thus broken down as follows when the accessory is known:

![Bar chart showing leakage sources]

- Relief valve: 24
- Valve: 23
- Flange/joint: 16
- Tap: 5
- Flap gate: 3
- Rupture disk: 2
4. Accident typology

The primary hazardous phenomena identified in the accidents studied are indicated in the following table:

<table>
<thead>
<tr>
<th>Hazardous phenomena</th>
<th>No. of events</th>
<th>% (on the basis of the 247 events)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosion</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Ignited leak</td>
<td>16</td>
<td>6</td>
</tr>
<tr>
<td>Spraying of accessories due to the effect of pressure</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Discharge of hazardous or polluting substances</td>
<td>197</td>
<td>80</td>
</tr>
</tbody>
</table>

Discharges of hazardous or polluting substances, combined with the ignition or explosion of an inflammable gas (should the gas be placed in contact with a heat source), account for the main hazardous phenomena encountered.

Cases of hazardous or polluting substance discharges pertain to:

- opening of relief valves on LPG storage facilities;
- leaks in the vicinity of flanges or flange joints;
- taps placed on the equipment (damage due to shocks, corrosion);
- leaks in the vicinity of equipment instrumentation (pressure switches, manometers);
- discharges in the vicinity of valves or draining/bleeding devices.

These leaks ignited in 6% of all cases, as determined based on the gas contained in the equipment, which in most cases involved bottles of acetylene.

The explosions recorded were associated with:

- bursting of either acetylene gas or LPG bottles;
- broken equipment (piping: ARIA 41142, 42479, 44448, air conditioning unit: ARIA 41289, autoclave: ARIA 40935).
Two fatal cases (ARIA 41954 and 44156) were included in the study sample. As a common feature, they both occurred during the pneumatic testing of pressure devices.

Personal injuries were associated with 50 events. Different types of injuries were recorded; they entailed:

➢ individuals either intoxicated or taken ill due to gases escaping from storage containers;
➢ technicians in shock after an explosion;
➢ physical injuries (including tinnitus, shocks created by spraying of components, especially during pneumatic or hydraulic testing).

If they are conducted under improper conditions, pneumatic or hydraulic tests (ARIA 44156) are often the cause of injuries (see the ARIA flash on pressure equipment tests published in August 2013).

Installation of a safety perimeter often takes the form of:

➢ placing the plant's facilities where the accident occurred in a secure operating mode;
➢ activating the internal emergency plan for Seveso-rated establishments;
➢ evacuating neighbours or companies adjacent to the site;
➢ suspending road or rail traffic, as required.

Property damage also comprises degradation to the plant's internal machinery (burst pipelines) as well as damage caused by third parties (broken window panes on neighbours' dwellings in ARIA 42421). Operating losses due to an accident can amount to several million euros (ARIA 44683).

Environmental consequences are reflected by surface water or atmospheric pollution (flaring of process residue generating black smoke: ARIA 43489).

While some events have not given rise to environmental or human consequences, the industries involved still had to issue press releases in order to reassure the neighbouring population (ARIA 42910).
6. Causes

a) Initial causes (disturbances)

Such causes naturally consist of equipment malfunctions, as manifested by leaks or broken machinery. Cases of leaks or breaks are, in over 10% of all events catalogued, due to either corrosion phenomena (31 cases recorded) or material fatigue problems (ARIA 38751, 39526, 44430). Such disturbances become magnified when the equipment is older (ARIA 42897). Let’s recall that in the study produced by BARPI in 2014 on corrosion-related accidents, the zones indicated in the following diagram had been identified as particularly accident prone. The observations reported during this previous study have in fact been adapted to the special case of pressure equipment.

Anomalies raising doubts over equipment design are sometimes mentioned in the accident summaries (ARIA 43587).

Beyond physical defects, human deficiencies are the cause of a number of accidents:

➢ works carried out on equipment that has not been adequately depressurised, while also failing to consult the appropriate technical documentation beforehand (ARIA 42946);
➢ damage to a plant’s piping network caused by a forklift driver (ARIA 44142, 44448);
➢ insufficient bolt clamping, resulting in leaks in the vicinity of flange joints (ARIA 44911, problems on LPG tanks: ARIA 45310, 45352, 45476);
➢ incorrect set pressure applied to relief valves (ARIA 45670).
Process control flaws are also the source of runaway reactions and are noticed by pressure surges or exothermic reactions (ARIA 40328). Such flaws are sometimes related to the overfilling of storage containers (LPG: ARIA 44381) or to improper equipment settings (excess fuel: ARIA 43695). One case of reagent flowing back into the circuit during execution of an industrial process also triggered a pressure surge (ARIA 45637).

b) Deep-rooted causes

Several types of causes are responsible for disturbances or serve as the primary reasons for accidents. In most cases, they pertain to the organisational aspect of running a site or to technical considerations in installation design.

Among the organisational problems encountered, let's note the absence of:

- monitoring during pressure equipment operations, plus failure to perform the inspections stipulated in regulations (ARIA 39526, 43587, 46114). During an event, the device involved had been stripped of its regulatory marking (EC marking: ARIA 41289).  
  Remark: The lack of operational monitoring may be applicable to equipment that has not been pressurised but, in the event of malfunction, still generates problems on the pressurised networks (e.g. problem with a compressor motor belt that led to a pressure surge in a refrigeration installation: ARIA 44610).

- training of technicians to cope with risks related to pressure equipment and installation operations (bleed valve left open: ARIA 42629 / lack of technician training and failure to update instructions: ARIA 42798 / failure to verify whether circuits had remained pressurised: ARIA 43587 / problem during repair work performed on wind turbine accumulators: ARIA 44150 / absence of instructions displayed on how to use pressure devices: ARIA 43587);

- scheduling of equipment maintenance operations (ARIA 42798) or repair work (fouling of a boiler's heating tubes: ARIA 42907 / neglect of maintenance of bottle fittings on a water chlorination facility: ARIA 43434 / block valve covered with ice on a refrigerated circuit: ARIA 45008);  
  Remark: Accidents, at times deadly and quite often causing injuries, have occurred during inadequately prepared pneumatic or hydraulic tests. By and large, they result from poor practices (trial conducted without a gas expansion valve: ARIA 45293);

- traceability of zones that have undergone stopgap repairs (temporary clogging: ARIA 44848);

- risk analysis as a component of installation operations (difference between manual and automatic installation controls: ARIA 43695);

- subcontractor supervision (equipment inspection, especially prior to service restart, transmission of instructions regarding bolt clamping torque: ARIA 44911 / verification of relief valve set pressure: ARIA 45670);

Technical problems encountered in installation design include:

- layout of utility lines within the unit (accessibility for performing equipment inspections and maintenance, number of pipes running in heat-insulated racks: ARIA 42835 / external corrosion caused by a leak on the steam line of a circuit lying just above: ARIA 45765)
- the absence of support brackets for a plant's pipes (ARIA 42897)
- poor choice of pressure sensors or level gauges (ARIA 42864)
- no analytical input on dilatation-related phenomena with respect to fluid temperature (ARIA 42897)
- failure to install gas detectors (ARIA 45750, 46582).

Beyond these causes specific to pressure equipment defects, let's also keep in mind that technicians must be able to respond under efficient conditions in the event of a leak. Some testimonials point to the inadequacy of operating protocols when faced with a gaseous discharge (difficulties accessing iced-over block valves, inappropriate protective gear: ARIA 45008).
Pressure equipment is just as hazardous while operating as when idle, especially when performing works, maintenance or repairs. For this reason, the measures adopted by facility operators pertain to both operations and overhauls (e.g. downtime, preparation for periodic certification renewals).

7. Measures adopted subsequent to accidents

a) Measures relative to pressure equipment operations

The primary provisions enacted just after an accident are as follows:

- revision of equipment use procedures (ARIA 43587, 43728);
- posting of safety instructions (ARIA 43587);
- personnel training devoted to pressure-related risks (ARIA 43587);
- regular cleaning of devices in order to avoid fouling (ARIA 43587);
- update of plans and contracts specific to equipment maintenance (ARIA 43587, 45008, 45199), modifications and facilities for streamlining maintenance activities (ARIA 44150);
- standardisation of the marking protocol for all pipes on-site (ARIA 44448);
- installation of a system to continuously record pressure readings (ARIA 45061);
- changes to the scheduling of programmable controllers that supervise the safety chains (ARIA 45637), with the pressure control systems also being recalibrated and better adjusted to detect pressure surges;
- improved access to and from installations (ARIA 42835);
- machine vibration controls in order to limit fatigue phenomena (ARIA 38751);
- modification of equipment start-up procedures in the aim of reducing stresses (fatigue phenomenon: ARIA 39526) and control over hot and cold clamping of joints (ARIA 39816).

Moreover, subsequent to an accident, the following measures are often applied:

- revision of equipment inspection plans carried out by the Recognised Inspection Service (increased inspection frequency: ARIA 44683);
- control of all equipment similar to the one that gave rise to the accident (ARIA 44829);
- limitation of tank filling rates, especially during periods of intense heat (ARIA 45632), or scheduling of special operating practices during extreme cold spells (ARIA 41945);
- inspection of the threading on all components (ARIA 46047).

In addition to measures relative to equipment operations and maintenance, more fundamental modifications are found to affect the technologies introduced into industrial processes, in particular involving refrigerant fluids (change in ammonia refrigerant for a chloro-fluoro liquid: ARIA 41479).

b) Measures specific to pressure equipment during idle periods

Post-accident measures adopted by facility operators are also intended to better supervise the ensuing phases of works carried out on the equipment:

- Drafting a set of specifications dedicated to the works (ARIA 42835);
- Visual inspection while installing heat insulation (ARIA 42835).
TECHNOLOGICAL ACCIDENTS ONLINE

Safety and transparency are two legitimate requirements of our society. Therefore, since June 2001, the website www.aria.developpement-durable.gouv.fr hosted by the French Ministry of Environment, Energy and the Sea has been offering to both professionals and the general public lessons drawn from analyses of technological accidents. The main sections of the website are available in both French and English.

Under the general sections, the interested user can, for example, inquire for the governmental action programmes, access large excerpts of the ARIA database, discover the presentation of the European scale of industrial accidents, become familiar with the "dangerous substances index" used to complete the "communication on the spot" in case of accident or incident.

The accident description, which serves as the raw input for any method of feedback, represents a significant share of the site's resources: when known, event sequencing, consequences, origins, circumstances, proven or presumed causes, actions taken and lessons learnt are compiled.

Over 250 detailed and illustrated technical reports present accidents selected for their particular interest. Numerous analyses, sorted by technical topic or activities, are also available. The section dedicated to technical recommendations develops various topics: fine chemistry, pyrotechnics, surface treatment, silos, tyre depots, hot work permits, waste treatment, material handling, etc. A multicriteria search engine enables getting information about accidents occurring in France or abroad.

The website www.aria.developpement-durable.gouv.fr is continually growing. Currently, more than 47 000 accidents are online, and new theme-based analyses will be regularly added.

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

www.aria.developpement-durable.gouv.fr

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