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Non-destructive testing — Acoustic emission testing (AT) — Leak detection by means of acoustic emission

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Foreword

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This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 9, *Acoustic emission testing,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 138, *Non-destructive testing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 18081:2016), which has been technically revised.

The main changes are as follows:

— Figure 1 has been improved;

— term “AT equipment” has been replaced by “AE instrument” in the whole document;

— term “system” has been replaced by “instrument” in the whole document;

— Figure 2 showing an adjustable air jet has been added;

— Formula (1) has been corrected;

— Table 2 “Leakage grading and the influence of leak flow dynamic on AE activity“ has been added;

— editorial corrections throughout the document.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Non-destructive testing — Acoustic emission testing (AT) — Leak detection by means of acoustic emission

1 Scope

This document specifies the general principles required for leak detection by acoustic emission testing (AT). It is addressed to the application of the methodology on structures and components, where a leak flow as a result of pressure differences appears and generates acoustic emission (AE).

It describes phenomena of the AE generation and influence of the nature of fluids, shape of the gap, wave propagation and environment.

The different application techniques, instrumentation and presentation of AE results are discussed. Also included are guidelines for the preparation of application documents which describe specific requirements for the application of the acoustic emission testing.

Annex A gives procedures for some leak-testing applications.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

ISO 12716, *Non-destructive testing — Acoustic emission inspection — Vocabulary*

ISO/TS 18173, *Non-destructive testing — General terms and definitions*

EN 1330-1, *Non-destructive testing — Terminology — Part 1: General terms*

EN 1330-2, *Non-destructive testing — Terminology — Part 2: Terms common to the non-destructive testing methods*

EN 1330-9, *Non-destructive testing — Terminology — Part 9: Terms used in acoustic emission testing*

EN 13477-1, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 1: Equipment description*

EN 13477-2, *Non-destructive testing — Acoustic emission — Equipment characterisation — Part 2: Verification of operating characteristics*

EN 13554, *Non-destructive testing — Acoustic emission testing — General principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12716, ISO/TS 18173, EN 1330-1, EN 1330-2 and EN 1330-9 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

NOTE The definitions of leak, leakage rate, leak tightness are those defined in ISO 20484.

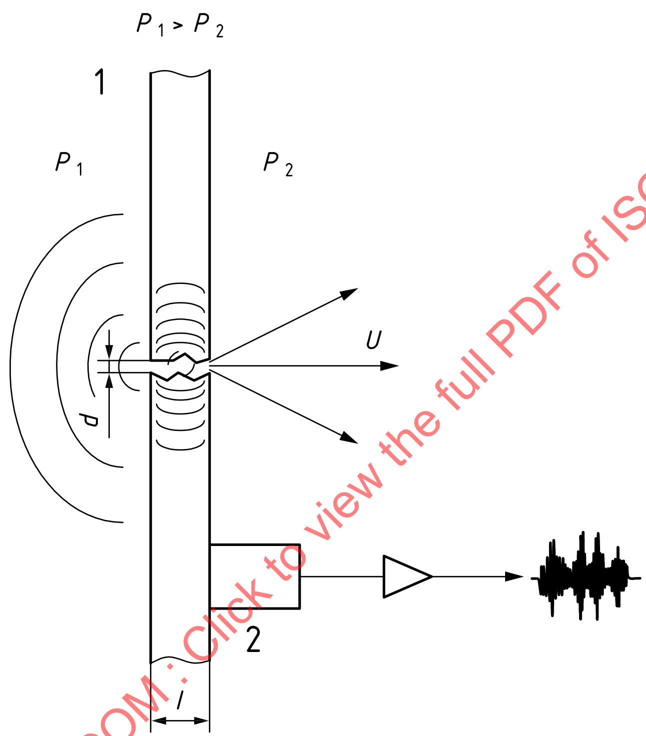
4 Qualification of test personnel

It is assumed that acoustic emission testing is performed by qualified and capable personnel. In order to prove this qualification, it is recommended to certify the personnel in accordance with ISO 9712.

5 Principle of acoustic emission testing

5.1 The acoustic emission phenomenon

See Figure 1.



Key

1 fluid

2 AE sensor

P_1 pressure on side of fluid

P_2 pressure on side of sensor

d main dimension of leak orifice

l wall thickness

U leaking fluid

Figure 1 — Schematic principle of acoustic emission and its detection

The continuous acoustic emission in the case of a leak, in a frequency range, looks like an apparent increase in background noise, depending on pressure.

5.2 Influence of different media and different phases

The detectability of the leak depends on the fluid type and its physical properties. These will contribute to the dynamic behaviour of the leak flow (laminar, turbulent) (see Table 1).

Table 1 — Influence of the different parameters on the AE activity

Sub-clause	Parameter	Higher activity	Lower activity
5.2	Test media	gas	liquid
		two phase	
	Viscosity	low	high
	Type of flow	turbulent	laminar
	Fluid velocity	high	low
5.3	Pressure difference	high	low
5.4	Shape of leak	crack like	hole
	Length of leak path	long	short
	Surface of leak path	rough	smooth

In contrast to turbulent flow, the laminar flow in general does not produce detectable acoustic emission signals.

Acoustic emission in conjunction with a leakage is generated by the following:

— turbulent flow of the escaping gas or liquid;

— fluid friction in the leak path;

— cavitations, during two-phase flow (gas coming out of solution) through a leaking orifice;

— the pressure surge generated when a leakage flow starts or stops;

— backwash of particles against the surface of equipment being monitored;

— gaseous or liquid jet (verification source);

— pulsating bubbles;

— explosion of bubbles;

— shock-bubbles on the walls;

— vaporization of the liquid (flashing).

The frequency content of cavitation may comprise from several kHz to several MHz.

Cavitation results in a burst emission whose energy is at least one order of magnitude higher than that caused by turbulence.

The relative content in gas or air strongly influences the early stage of cavitation.

The acoustic waves generated by leaks can propagate by the walls of the structure as well as through any fluids inside.

Acoustic waves are generated by vibration at ultrasonic frequencies of the molecules of the fluid. The vibrations are produced by turbulence and occur in the transition between a laminar and a turbulent flow within the leak path and as these molecules escape from an orifice.

The acoustic waves produced by the above-mentioned factors are used for leak detection and location.

5.3 Influence of pressure differences

The pressure difference is the primary factor affecting leak rate. However, the presence of leak paths can depend on a threshold value of fluid temperature or pressure.

Pressure-dependent leaks and temperature-dependent leaks have been observed, but in extremely limited number.

Pressure-dependent or temperature-dependent leaks denote a condition where no leakage exists until a threshold pressure or temperature is reached. At this point, the leakage appears suddenly and can be detectable.

When the pressure or temperature is reversed, the leakage follows the prescribed course to the critical point at which leakage drops to zero.

Temperature and pressure are not normally applied in the course of leak testing for the purpose of locating such leaks. Instead, they are used to force existing discontinuities to open, so as to start or increase the leakage rate to point of detection.

An example of this effect is the reversible leakages at seals below the service temperature and/or service pressure.

Sound waves emitted by a leak will normally have a characteristic frequency spectrum depending on the pressure difference and shape of the leak path.

Therefore, the detectability of the leak depends on the frequency response of the sensor and this shall be taken into account when selecting the instrumentation.

5.4 Influence of geometry of the leak path

The AE intensity from a natural complex leak path (e.g. pinhole corrosion, fatigue or stress corrosion cracks) is generally greater than that produced by leakage from an artificial source, such as a drilled hole used for verification.

The main parameters defining the complexity are the cross section, length and surface roughness of the leak path.

5.5 Influence of wave propagation

Acoustic emission signals are the response of a sensor to sound waves generated in solid media. These waves are similar to the elastic waves propagated in gasses and fluids but are more complex because solid media are also capable of transmit shear force.

Waves that encounter a change in media in which they are propagating may change directions or reflect. In additions to reflection, the interface causes the waves to diverge from its original line of flight or refract in the second medium. Also, the mode of the wave can be changed in the reflection and/or refraction process.

Incident waves upon an interface between two media will reflect or refract such that directions of the incident, reflected and refracted waves all lie in the same plane. This plane is defined by the line along which the incident wave is propagating and the normal to the interface.

The following factors are important to acoustic emission testing:

a) wave propagation has the most significant influence on the form of the detected signals;

b) wave velocity is key to computed source location;

c) wave attenuation governs the maximum sensor spacing that is acceptable for effective detection.

The wave propagation influences the received waveform in the following ways:

d) reflections, refractions and mode conversions on the way from source to sensor result in many different propagation paths of different lengths;

e) multiple propagation paths on the way from source to sensor, even in the absence of reflecting boundaries, can be caused by the structure itself, for example, spiral paths on a cylinder;

f) separation of different wave components (different modes, different frequencies) travelling at different velocities;

g) wave attenuation (volumetric dispersion, absorption, as well as attenuation due to the effects given in 5.5 d) and 5.5 f)).

The wave attenuation is influenced by liquids inside a structure or pipe, which will assist in the propagation of acoustic waves, while liquids (inside and outside) have a tendency to reduce the detectability of the acoustic waves.

This effect will depend on the ratio of the acoustic impedances of the different materials.

The sound wave inside will be used normally for the detection of AE sources over long distances because of the low sound attenuation of most liquids.

6 Applications

Acoustic emission testing (AT) provides many possibilities to detect leaks from pressurized and atmospheric equipment in industry and research fields.

AT is used in following areas:

a) pressure vessels;

b) pipe and piping systems;

c) above ground storage tanks;

d) underground storage tanks;

e) boiler drums;

f) boiler tubes;

g) autoclaves;

h) heat exchangers;

i) containments;

j) valves;

k) safety valves;

l) pumps;

m) vacuum systems.

7 Testing equipment

7.1 General requirements

The testing equipment (hard and software) shall be in accordance with the requirements of EN 13477-1 and EN 13477-2.

7.2 Sensors

7.2.1 Typical frequency ranges (band widths)

The optimum frequency range for leak detection depends very much on the application, the fluid type, pressure difference at the leak, the leak rate, and the sensor to source distance and more.

For example, the optimum frequency range for tank floor leak detection of atmospheric tanks is around 20 kHz to 80 kHz, because the source to sensor distance can be large and at these frequencies the attenuation is low.

The preferred frequency range for high pressure piping leak detection may go up to 500 kHz for optimum signal-to-noise ratio in presence of background noise.

Leak detection at pipes for low pressure (e.g. water supply) is typically performed at frequencies down to 5 kHz.

a) Usually, a sensor shall be in direct contact to a test object.

b) Then a coupling agent shall be used between the sensor and the test object for optimum and stable wave transfer.

c) Durability, consistency and chemical composition of the couplant shall comply with the duration of the monitoring, the temperature range and the corrosion resistance of the test object.

7.2.2 Mounting technique

The mounting method is influenced by the duration of the monitoring.

For a temporary installation on a ferromagnetic test object, a magnetic holder may be the preferred mounting tool.

For permanent installations, sensors may be fastened by metallic clamps or bonded to the test object using a suitable adhering coupling.

7.2.3 Temperature range, wave guide

The operating temperature range of the AE sensor shall meet the surface temperature conditions of the test object, otherwise waveguides shall be used between sensor and test object.

7.2.4 Intrinsic safety

If the sensor is to be installed in a potentially explosive atmosphere, the sensor shall be intrinsically safe and ATEX Directive 2014/34/EU (Equipment) and 1999/92/EC (Workplace) can apply for the classified hazard at the location where it is to be used. See also EN 60079-0, EN 60079-11 and EN 60079-14 for explosion-proof installations.

7.2.5 Immersed sensors

a) If the sensor is to be immersed in a liquid, the sensor's IP-code (defined in EN 60529) shall be specified to at least IP68.

b) Sensors and other immersed accessories shall be tight for the maximum possible pressure of the liquid.

7.2.6 Integral electronics (amplifier, RMS converter, ASL converter, band pass)

Passive sensors and sensors with an integrated pre-amplifier of suitable bandwidth are available.

Sensors with built-in electronics are less susceptible to electromagnetic disturbances, due to the elimination of a sensor-to-pre-amplifier cable.

These sensors are usually a little larger in size and weight and have a more limited temperature range due to internal electronics, e.g. 80 °C.

Sensors may also include a signal-to-RMS converter, a signal-to-ASL converter and/or a limit-comparator with digital output.

7.3 Portable and non-portable AE instruments

An instrument for leak detection by acoustic emission designed for portable use contains usually one or a few channels.

The choice of a portable AT instrument is generally based on several factors, such as cost, size of the device, test duration, environmental conditions (e.g. hazardous areas), and availability of external power.

Portable AE instruments are used for on-site leak testing of limited areas.

Non-portable instruments are used for testing of large structures or for permanent in-service monitoring of leaks in critical applications.

7.4 Single and multi-channel AT instruments

7.4.1 Single-channel instruments

Single-channel instruments are mainly used for a point-by-point search strategy, the sensor being moved to areas of interest over the structure.

These instruments typically acquire and store RMS, ASL, signal amplitude and signal waveform data for determination of time and frequency features.

7.4.2 Multi-channel instruments

Multi-channel instruments are mainly used for large structures where the sensor positions are fixed and one of the location procedures in 9.3 may be applied.

Also, permanently installed instruments for continuous remote in-service monitoring, for leak detection in the piping network of nuclear plants, are often used with multi-channel configurations.

7.5 Determination of features (RMS, ASL vs. hit or continuous AE vs. burst AE)

Simple instruments determine continuously as a function over time the ASL (the arithmetic average of the logarithm of the rectified AE signal over a specified period of time) and/or RMS (the square root of the average of squared AE signal over a specified period of time) and/or average of the maximum value of the signal amplitude within a specified period of time, and display the results.

On some of the instruments the resulting functions over time can be shown for each channel numerically or graphically and be compared against static or computed alarm levels so alarm conditions may automatically trigger an alarm.

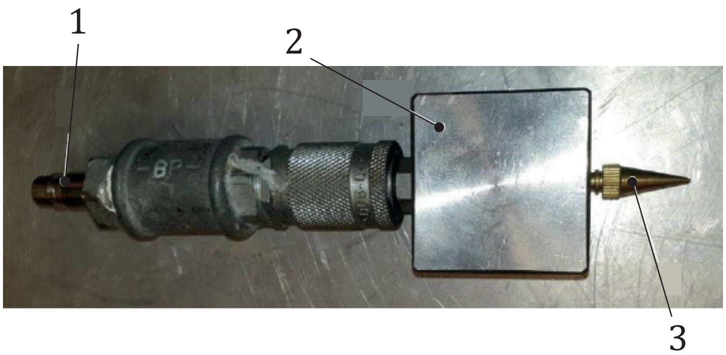
More sophisticated instruments can also acquire and store waveform data for determination of time differences by Δt-measurement or by cross-correlation method.

7.6 System verification using artificial leak noise sources

An artificial leak noise source shall be used for system verification. Figure 2 shows an example.

A setup using an air jet or a test block/pipe with a drilled hole passing a controlled flow of gas or liquid may be used to determine the dependency of stimulation signal amplitude versus stimulated flow of gas or liquid and signal amplitude measured at a certain distance from emitter.

A well reproducible artificial leak noise source, like a passive sensor stimulated by an electrical signal, such as white noise or a sinusoidal signal of a certain frequency from a function generator, may be used for periodic system verification.



Key

1 coupling for compressed air

2 metallic block

3 nozzle with adjustable air jet

Figure 2 — Adjustable air jet

8 Test procedure for leak detection

8.1 Mounting of sensors

a) For aboveground structures, surface-mounted AE sensors with fixed positions shall be attached with direct contact to the test object or via acoustic waveguides.

b) For leak testing of underground pressure equipment utilities such as waveguides (e.g. on vessels) or pigs (e.g. in pipelines) may be applied.

c) The mounting technique and coupling materials shall be selected dependent on temperature and duration of measurement (see 7.6).

d) The quality of sensor coupling may be enhanced by special shoes that conform to the diameter/curvature of the test object.

e) With leak detection pigs for buried pipelines, the AT sensors shall be mounted on the pig and measurements are usually made during the pig run (see A.2).

f) The corresponding position of the pig shall be determined on the basis of an encoder and/or acoustic markers positioned on the outside of the pipe.

g) The sensors shall be positioned so as to ensure leak location based on appropriate location procedure (see Clause 9) and to achieve the required location accuracy.

h) Their positions on the structure shall be taken into consideration welds, changes of shape that affect flow characteristics, shadowing effects of nozzles and ancillary attachments.

i) Prior to testing, wave propagation and attenuation measurements, using a Hsu-Nielsen source or artificial leak noise sources (see 7.2), shall be performed on the test object in order to determine the effective wave velocity and to calculate the maximum allowed sensor distance needed for leak detection with specified sensitivity.

The maximum sensor spacing for detection and location of leaks is influenced by many factors, such as surface covering by coating, cladding or insulation, background noise level, pressure on the test object, type of fluid, type of leak.

8.2 Additional features to be determined

In its simplest form leak detection will comprise measurement of the RMS/ASL at each defined sensor position as a function of time for estimation of approximate location of the source.

In addition, pressure is measured as a function of time and the occurrence of a change in RMS/ASL, can be correlated to a change of pressure.

It is recommended that the RMS/ASL is determined as a function of increasing or decreasing pressure for verification purposes.

For more complex situations or improved diagnosis, other features may be determined, such as the following:

a) crest factor;

b) arrival time;

c) maximum value of signal amplitude;

d) signal waveform;

e) frequency spectrum;

f) related external parameters, e.g. pipe or valve temperature, pressure difference at the valve.

8.3 Background noise

8.3.1 General

The background noise is usually a combination of environmental and process noise.

8.3.2 Environmental noise

Sometimes it is unavoidable that environmental noise, even airborne noise, is picked up in addition to the sound of interest. This can be noise from e.g. weather conditions, road traffic, rail, airplanes or birds.

In such cases, it can be helpful to add a sensor (guard) to monitor the airborne noise (waterborne in subsea environment) to identify and disregard the environmental noise.

8.3.3 Process noise

Process noise will be created from the in-service conditions of the tested structure, e.g. product flow noise.

The influence of the process noise may be reduced by

— choosing an appropriate test period,

— isolating from the noise sources, and

— using more sophisticated analysis methods, filtering, pattern recognition.

8.4 Data acquisition

Data acquisition in its simplest form involves point measurements of one variable (e.g. RMS, ASL, or signal amplitude) in a search mode to detect and locate a leak.

a) Whenever the equipment allows, the results of all measurements as well as the test parameters shall be stored.

b) When more advanced equipment is used, the necessary signal parameters shall be acquired and recorded continuously or periodically.

c) The duration of the acquisition shall be chosen taking into account the values and fluctuation of the background noise.

9 Location procedures

9.1 General

The AE signals caused by a fluid leak are usually continuously superposed by transients reflecting the nature of the fluid dynamics, leak path, structural response and wave propagation path in the containment structure.

Attention shall be paid to attenuation (e.g. by coatings, wrappings, insulations) of acoustic waves and possible multiple wave paths (metallic wall or liquid fluid) between source and sensor location to get reliable results.

Various strategies for leak location have been developed.

In general, none of the strategies yields highly accurate location, but for industrial applications even an approximate location can be very economic.

9.2 Single-sensor location based on AE wave attenuation

This strategy uses the attenuation of the AE waves in the containment structure. Close to the source the signal levels will be higher than further away from the source. The position of the leak is assigned to the measurement position with the highest signal level, e.g. RMS, ASL or average of the maximum value of the signal amplitude.

Often a single-sensor hand-held device is used to make the tests at different positions on a structure. In this case tests shall be performed over a longer time span or repeatedly per position in order to identify possible fluctuations in the AE signals that can affect localization.

A variant of the above is the technique of "acoustic field mapping" where point-by-point tests are made following a grid pattern.

A further application of this technique is the difference method with a two-point access and the leak in between.

a) The calculation shall be performed using the difference of signal levels at the access points A and B.

b) If the difference is zero, the source shall be on half distance between A and B.

c) At a linear structure with access points A and B, the source location X_S shall be calculated using Formula (1):

$$X_S = 0{,}5\ (X_A + X_B) + \frac{0{,}5\ (U_B - U_A)}{\alpha} \quad (1)$$

where

X_S is the X-location of source;

X_A is the X-location of access point A;

X_B is the X-location of access point B and is larger than X_A;

U_A is the signal level at access point A in dB_{AE};

U_B is the signal level at access point B in dB_{AE};

α is the attenuation coefficient in dB/m, is larger than 0 and shall either be known or determined by experiment by a third access point at a known distance from points A or B.

d) α shall either be known or determined by experiment at a third access point at a known distance from A and B.

9.3 Multi-sensor location based on Δ*t* values (linear, planar)

9.3.1 Threshold level and peak level timing technique

With this strategy, the attenuation curve is known and several sensors in a location scheme are used to locate the source from Δt values.

Because the signals are more or less continuous in nature, this technique relies on the presence of superimposed transients on the signals. The arrival times are measured using threshold levels and/or burst signal amplitudes.

The result of the threshold level technique may be improved by adjusting the threshold per channel based on the amplitude distribution or the known wave attenuation.

An example of the use of this technique, the planar location on an above-ground storage tank floor, is given in A.4.

9.3.2 Cross-correlation technique

Correlation commonly refers to a broad class of statistical relationships involving dependence. Cross-correlation is a measure of similarity of two waveforms as a function of a time-lag applied to one of them. Although, it is commonly used in order to search for a shorter duration pattern within a long duration signal, it can be used for other linear measurements. It also has applications in pattern recognition.

In the field of AT, cross-correlation has been used to find the time-frequency-pattern of a burst in a continuous waveform record.

The time-lag shall be determined between two channels and used for location calculation.

The cross-correlation is defined as:

$$(f \times g)(t) = \int_{-\infty}^{\infty} f^{*}(\tau) \times g(t+\tau)\,\mathrm{d}\tau \qquad (2)$$

where f^* denotes the complex conjugate of f.

Similarly, for discrete functions, the cross-correlation is defined as:

$$(f * g)[n] = \sum_{m=-\infty}^{\infty} f^{*}[m] \times g[n+m] \qquad (3)$$

The cross-correlation is similar in nature to the convolution of two functions.

In an auto-correlation, which is the cross-correlation of a signal with itself, there will always be a peak at a lag of zero unless the signal is a trivial zero signal. Therefore, it can be used to dig out a signal from high background noise.

As an example, consider two real functions $f(x)$ and $g(x)$ differing only by an unknown shift along the X-axis. One can use the cross-correlation to find how much the function g shall be shifted along the X-axis to make it identical to the function $f(x)$. The formula essentially slides the $g(x)$-function along the X-axis, calculating the integral of their product at each position. When the functions match, the value of $(f \times g)$ is maximized.

For the application in sense of leak detection, the cross-correlation is useful for determining the time lag between two signals coming from the same source propagating along a pipe across a sensor array. After calculating the cross-correlation between the two signals, the maximum of the cross-correlation function indicates the point in time where the signals are best aligned. The time lag between the two signals is determined by the argument of the maximum (arg max) of the cross-correlation as:

$$\tau_{\mathrm{lag}} = \arg\max_t \left[(f \times g)(t) \right] \tag{4}$$

By this technique, the wave packet detected from two or more sensors are cross correlated in order to determine the time difference between the received signals at the different sensors, resulting from the different wave propagation paths.

Once the time differences are known the normal Δt location algorithms can be used.

In case the previously described techniques give a location result with insufficient accuracy, combining techniques may improve the accuracy.

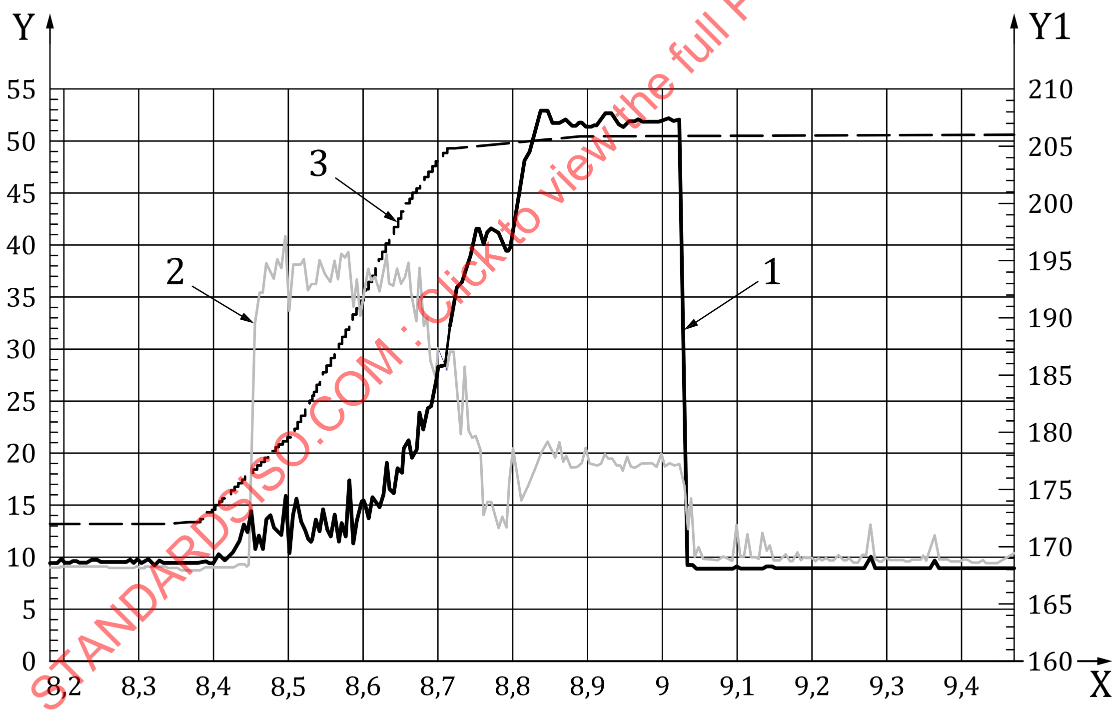
Examples are given in A.2 and A.4.

10 Data presentation

10.1 Numerical data presentation (level meter)

In its simplest form this is a presentation of RMS or ASL and may also include the peak signal level.

10.2 Parametric dependent function



Key

X local time, in h

Y RMS status, in $\mathrm{dB_{AE}}$

Y1 absolute pressure, in bar

1 RMS curve related to an AE channel placed closed to an untight valve, which resulted in a confirmed water leakage

2 RMS curve related to an AE channel placed in an area where no leak is present

3 absolute pressure curve

Figure 3 — Example for RMS and pressure vs. time

An example is shown in Figure 3.

The RMS increases regularly during the pressure ramp and does not return to a normal level when the final pressure hold is reached.

When the leaky valve was identified, the tap was tightened and the RMS level on all channels returned to initial values.

10.3 Frequency spectrum

a) The sensing frequency range shall be matched to the application.

b) The collected signals shall include leak and background noise.

c) Spectrum analysis of the signals may provide, e.g. an improved signal-to-noise ratio using analogue/digital filtering or wavelet analysis.

d) Feature or time-based filtering or pattern recognition software and waveform streaming analysis may be used to distinguish the AE signals caused by leakages from the background noise.

11 Data interpretation

11.1 Leak validation

11.1.1 On-site (during test) and off-site (post analysis)

a) For spot tests with portable one-channel systems, leak indications shall be verified by tests around the estimated leak location, e.g. for valves upstream and downstream. By this, noise from outside can be recognized and distinguished from relevant signals.

b) For other applications, the validation of a leak may be performed by monitoring the ASL, RMS as well as average of the maximum of the signal amplitude during pressure increase.

c) Also, location graphs may show the suspected position. By evaluation of other AE features (e.g. duration, counts, rise time), the localization process can be improved and located noise sources can be easily distinguished from the real leak source.

Further analysis after the acquisition, by filtering out noise signals, gives a more clarified view of the located leak.

11.1.2 Correlation with pressure

Higher pressure difference through a leaking orifice increases the ASL, RMS and average of the maximum of the signal amplitude of the produced AE signals. The acquired ASL, RMS and average of the maximum of signal amplitude will be increased only above a certain minimum differential pressure level.

For burst emission application, there is also a pressure limit, which shall be exceeded before the AE signals can be detected. This pressure limit depends on the size of the orifice, the viscosity of the test fluid and the distance of the AE sensors from the orifice.

11.1.3 Rejection of false indications

The AE sensor shall be placed as close as possible to the likely leak, and the object shall be tested on minimum and maximum pressure, in order to further analysis and compare the recorded signals.

During pre-test it is advisable, if possible, on minimum pressure differences (minimum pressure), to record the background noise to identify potential noise sources (possible external noise), that can be further rejected during analysis.

If noise appears during AE acquisition, due to persistent external noise, multi-channel systems can identify it by means of the location process.

Noise caused by sand or soil hitting the revealed part of a buried pipeline, or drops (condensation) falling from a tank roof on the product surface, or operating noise next to a leaking valve, can show false indications that are located in the same way as a leak.

11.2 Leakage rate estimation

For valve testing, a rough estimation of the leakage rate may be made on the basis of a database or by analysis of level (to base level during pre-test) of ASL, RMS and average of the maximum value of signal amplitudes in correlation with the pressure decrease.

The main parameters influencing the results are type and size of the valve, fluid type and pressure difference.

After detection of a leak in large structures, the leakage rate can be potentially estimated from the pressure decrease per minute. Direct estimation of leakage rate from just the AE signals can be difficult and usually requires extensive experimentation and development of an appropriate database.

Another estimation can be based on the comparison with the leakage rate measured from a calibrated standard leak.

11.3 Demand for follow-up actions

a) The client is responsible for any follow-up actions.

b) The leak rate estimation and its grading as well as the subsequent recommended action, for the identified and located leak, shall be defined in the test procedure.

c) According to the test results and their interpretation, further tests may be useful. In this case, other test methods apart from acoustic emission test shall also be considered.

When a potential leak has been located, other techniques like optical ones can give further information.

For typical grading categories for the detected leak see Table 2.

Table 2 — Leakage grading and the influence of leak flow dynamic on AE activity

AE activity	Definition	Further actions
Low activity	No leak or leak is uncritical	No further action is necessary
Medium activity	Potentially critical	First check if the leak is repairable, and when a leak is not repairable but uncritical in its current state, then it shall be monitored whether its size increases with time or not; when the leak is repairable, it shall be repaired when possible, and after repair a retest is necessary
High activity	Critical	Critical leaks always shall be repaired when possible and after repair a retest is necessary

d) The retest shall be done according to the original test procedure (see Clause 12).

e) It shall include all sectors of the structure, which were affected by the repair works.

f) When a structure is not repairable, the client shall decide on any other action.

12 Quality management documents

12.1 Test procedure

The written test procedure shall consider all aspects of preliminary information, preliminary preparation, on-site preparations, test performance including data acquisition, data presentation, test report requirements and subsequent operations according to EN 13554, if appropriate.

12.2 Test instruction

The AE test organization shall provide a written test instruction. The test instruction shall be prepared in accordance with ISO 9712 and EN 13554.

The test instruction shall include but not necessarily be restricted to the following:

a) explicit indication of the purpose of the test and limitations if any;

b) a description of the test object, including geometry and dimensions, materials, design and operating parameters;

c) the application documents;

d) qualification/certification of the test personnel;

e) type of surface preparation;

f) type of acoustic coupling used;

g) type of AE instruments used with the main characteristics;

h) the test software used;

i) sensor type, frequency range and manufacturer;

j) number of sensors required and the sensor arrangement;

k) method of sensor attachment;

l) signal level measurement method to be used;

m) the verification intervals for the AE instrument, the AE sensors and description of verification procedures;

n) description of in-situ verification;

o) description of test performance;

p) maximum level of background noise and the minimum required sensitivity of AE sensors;

q) procedure for determination of the attenuation coefficient;

r) recorded data and recording method;

s) online presentation of data

t) description of data analysis and location procedure to be used;

u) post analysis process.

13 Test documentation and reporting

13.1 Test documentation

The test documentation shall contain at least the following information:

a) identification of the site and the client;

b) identification of the test object;

c) reference to relevant procedural documents including the aims and objectives of the test;

d) description of the testing equipment;

e) site operational conditions;

f) level of background noise;

g) results of on-site verification of sensor sensitivity;

h) pressure difference;

i) type of analysis carried out;

j) any deviation from the procedure;

k) interpretation/evaluation of data;

l) test result;

m) place, date and time of the test;

n) name, qualifications and signature of the test operator.

13.2 Test report

a) Normally two reports will be produced:

   1) an on-site preliminary report, which shall contain the positions of the AE leak sources and their preliminary significance;

   2) a final test report which shall contain the results of the post-test analysis and provide the traceability to the test documentation.

b) The final test report shall at least include the following:

   1) the International Standard used (including its year of publication);

   2) date of the test and place of the test site;

   3) name(s) of test operator(s);

   4) the method used;

   5) testing equipment description including AE instrumentation and AE sensors;

   6) description of the test object;

   7) number of sensors and locations;

   8) test detection threshold;

   9) fluid product and pressure difference;

10) maps of the structure showing the AE leak sources identified during the test;

11) characterization of the AE leak sources;

12) the testing result(s);

13) any deviations from the procedure;

14) any unusual features observed.

Annex A
(informative)

Example applications of leak detection

A.1 Performance test of steam traps

A.1.1 Steam traps

The purpose of a steam trap installation is to remove condensate from the system in order to ensure an efficient use of energy and to avoid steam hammering. Leaky or blocked valves inside the steam trap lead to decreased operating safety and to increased costs of energy. In order to detect damaged steam traps at an early stage, a frequent testing is necessary.

Usually, multiple steam traps are installed in a plant. The conditions are often hazardous as steam traps can heat up to 800 °C and operate in explosive areas. Accordingly, a short testing time is expected while ensuring reliable and easily documentable results.

A.1.2 Test equipment

a) For a fast and reliable testing of steam traps a mobile test kit consisting of a single-channel ultrasonic test device, a heat resistant structure-borne ultrasonic probe and a temperature sensor shall be used.

b) In order to achieve optimal results, the device shall operate with a frequency of typically around 40 kHz.

c) The test device shall be designed to down-mix ultrasound into the audible frequency range and to output acoustic signals, as well as ASL or RMS values.

d) The use of headphones is recommended in testing environments with distracting ambient noise.

e) To ensure a reliable data documentation at every test location, an integrated data logger shall be used.

A.1.3 Testing personnel

a) The testing personnel to inspect steam traps shall be qualified according to ISO 9712.

b) The handling of the test equipment is intuitive. Hence, a basic qualification is sufficient for supervisory and testing personnel. However, as the exact testing procedures vary amongst the several types and manufacturers of steam traps the testing personnel shall pass a special training.

A.1.4 Test procedure

Manufacturers of steam traps usually recommend their individual testing procedure.

a) Additionally, the operating plant shall issue a special test instruction adapted on the conditions on-site.

b) Before the actual testing is carried out it is recommended to equip each steam trap with a label (ID) and specific measuring points.

c) The operating pressure shall be known.

d) The temperature values are collected by putting the temperature sensor on the specific test points which depend on the type of steam trap and are usually recommended by the respective manufacturer.

e) For determining the ultrasound level, the probe for structure-borne ultrasound shall be placed vertically with constant, slight pressure on the defined test points which again vary amongst the different types and manufacturers of steam traps.

f) The recording of the ultrasound level should cover at least one complete closing and opening cycle of the valve inside the steam trap.

g) If required, potential ambient noises can be detected at a part of the piping system next to the tested steam trap.

h) After the test, the following data shall be documented:

   1) trap ID;

   2) location;

   3) test date;

   4) manufacturer;

   5) type;

   6) operating pressure;

   7) temperature values;

   8) ultrasound level.

i) Typically, such tests are performed periodically on a monthly or annual basis. The frequency of periodic testing crucially depends on the trap size, the operating pressure and the position in the system.

j) For an evaluation of data in comparative and long-time tests it the sensors shall be placed on the same position of the steam trap to test always under the same conditions.

k) Only steam traps of the same type may be compared with each other, then unbiased results can be ensured.

l) For a correct performance test, the steam system shall have its usual operating temperature.

m) The test may only be carried out during operation.

n) Ambient noises may influence the value of ultrasound. If possible, ultrasound emitting components and devices shall be turned off during the test.

o) Moreover, it is important to follow the safety instructions issued by the manufacturer of the ultrasonic testing device and the steam trap shall be observed.

A.1.5 Interpretation of test results

Steam traps operate on a number of different principles which show distinctive characteristics. Consequently, test results shall be interpreted according to the specific guidelines which are provided by the respective steam trap manufacturer.

The values of pressure and temperature correlate. Accordingly, the determined temperature values and the operating pressure can indicate whether the valve inside the trap is blocked or correctly removes condensate from the system. If one of these values is specified, the other one shall be determined by using Table A.1.

Table A.1 — Correlation between pressure and temperature

Differential pressure, in bar	0	1	2	3	4	5	6	8	10	13	16
Boiling temperature, in °C	100	120	133	144	151	159	165	175	184	194	204
Differential pressure, in bar	20	24	28	32	40	50	60	80	100	120	150
Boiling temperature, in °C	214	223	231	238	250	264	275	294	310	323	341

Further information about the condition of the steam trap can be attained by comparing the determined ultrasound level with a specific steam trap type and manufacturer dependent limit value.

The valve is closed and steam-tight, if the determined ultrasound level remains stable below the limit value. If the steam trap operates in the intermittent mode, the ultrasound level fluctuates between a minimum and a maximum. In this case, the valve inside the steam trap opens and closes correctly. If the ultrasound level remains permanently above a certain limit value, the valve is most likely leaky and not working correctly.

A.1.6 Documentation

Collected test values and interpretations shall be transferred to a local database in order to ensure a reliable long-term comparison of test results and an efficient condition monitoring.

A.2 Leak detection on pipelines

A.2.1 Determination of wave attenuation

The sensitivity of leak detection on pipelines is determined mainly by the wave attenuation at the sensing frequency. For above-ground pipelines, the problem can be solved easily by the application of more sensors, but also this can become expensive. On the other hand, the wave attenuation can be useful for the location of leaks on the pipeline. This can be done by a search methodology, where the operator moves the sensor(s) to different positions on the pipeline or uses two or more sensors fixed to the pipe. In this case, the attenuation curve is used to calculate the location of the leak. The maximum distances between sensors will depend on the accessibility, the required sensitivity and the type of process/test fluid. It will generally be not more than 200 m for liquids. Most pipelines are buried which limits the application of this methodology due to the restricted access.

A.2.2 Cross-correlation

In addition to the application of sensors for leak detection and location based on sound attenuation, the cross-correlation method offers the potential for more practical sensor distances, up to 500 m, and sometimes 800 m to 1 000 m if accelerometers or hydrophones can be used inside the pipe. However, the working distance can be reduced to 100 m to 200 m depending on the pipe material, pipe diameter and required sensitivity.

a) A minimum of two sensors shall be applied to the pipeline.

b) The particular sound velocity and wave attenuation shall be measured (Figure A.1).

c) In the case of buried pipelines, the normal frequency range for cross-correlation leak detection and location shall be between 100 Hz and 5 kHz.

d) After configuring the software for the pipe material, length and diameter, the basic measurement is performed.

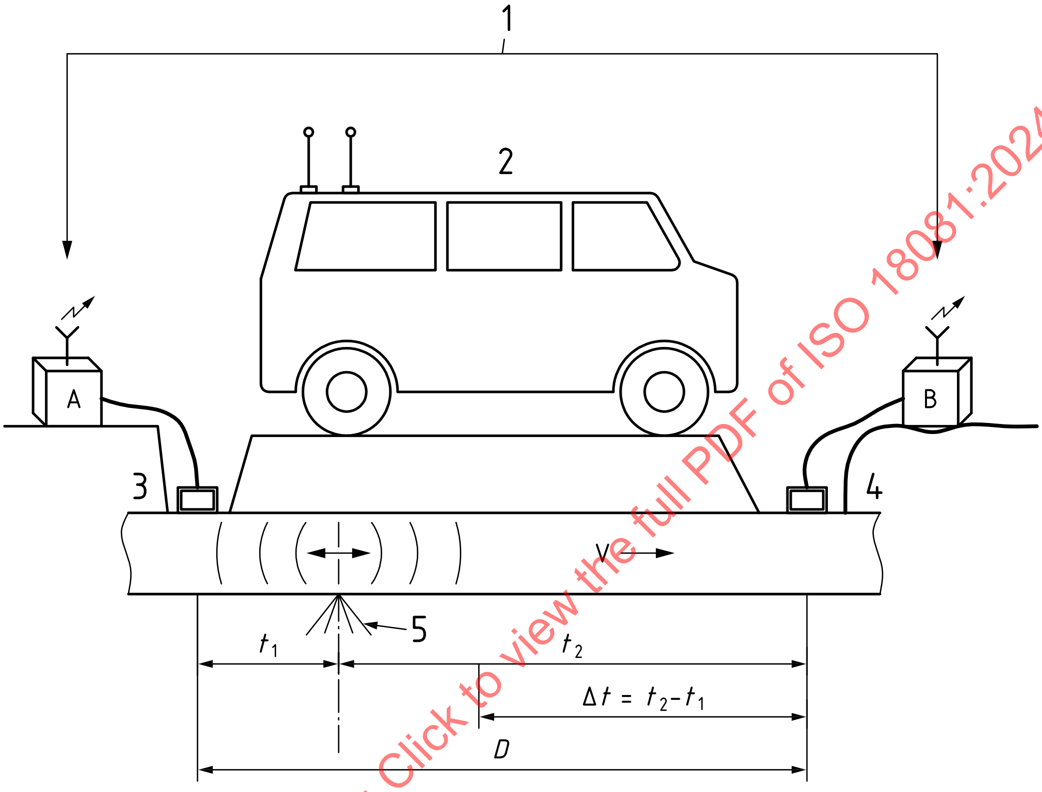
    1) First, the background noise spectrum shall be considered together with possible background noise source indications.

2) The pipeline shall then be pressurized up to a specified pressure hold (often the service pressure of the pipeline) and the measurement starts.

e) After measuring the coherence spectrum and applying the resulting filter criteria, the test results shall be evaluated.

f) According the position of leaks and their probability shall be reported.

g) If a leak-like indication occurs, a plot of the coherence spectrum and the cross-correlation function, including the cross-correlation factor shall be produced.



Key

1 amplifier and transmitter modules
2 reveiver antennas
3 sensor A
4 sensor B
5 leaking fluid
A data acquisition system for sensor A
B data acquisition system for sensor B
t_1 distance between sensor A and leak
t_2 distance between sensor B and leak
D distance bewteen the sensors A and B
V direction of flow

Figure A.1 — Test set up for cross-correlation

A.2.3 Pigging

When the pipeline is pig-able, with transmitter and receiver traps for pigs, leaks can be detected using a leak detection pig. This overcomes the problem of wave attenuation between the source (leak) and sensor. The pig consists of a receiving sensor, data processing and storage unit and power supply (see Figure A.2). This is conveyed through the pipeline by the process fluid during normal service. The quality of the pig, the transport medium and the transmission velocity determine the sensitivity (lowest detectable leak rate of the pig-system), down to 5 L/h under optimal conditions. The leak detection pig may be equipped with an odometer wheel for an exact location of the leak within the pipeline.

A typical pig run comprises, the application of markers in support of the location system, transmission of the pig from the transmission trap within the normal transport medium, withdrawal of the pig from the receiver trap, reading and cleaning the data storage unit and evaluation of the data according the presence of a leak and its location.

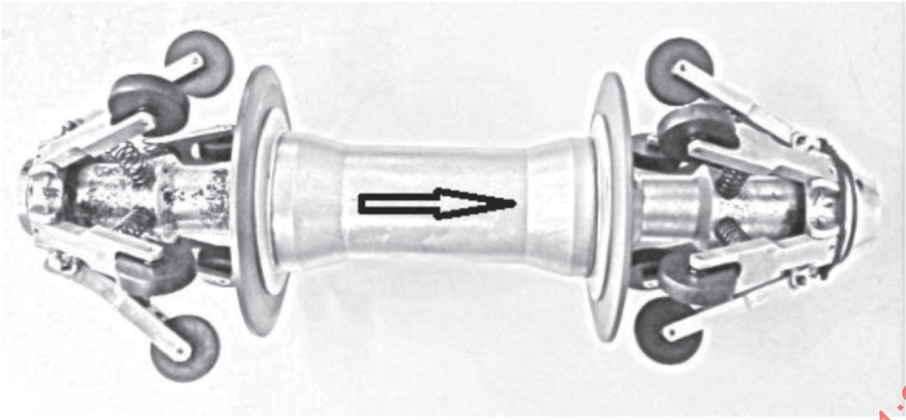


Figure A.2 — Sketch of a pig

A.3 Leak detection during hydrotest of nuclear power plant primary loops

A.3.1 General

The proof test of pressurized water reactors (PWR) in French nuclear power plant primary loops is performed according to pressure vessels regulation. The hydrotest includes pressurization to a final hold at 207 bar with a hold at 172 bar, called reference hold. The proof test is satisfactory if the primary loop withstands the final hold pressure without leakage and without permanent strain.

That means that the water tightness of many different welds shall be checked.

Due to the high number of welds (about 450), the difficulty to reach the locations of the welds and the high radiation level, these tests cannot be achieved visually.

Acoustic emission testing has been chosen to overcome the difficulties encountered by visual testing.

Three parts of the primary circuit are mainly defined to be monitored:

a) the vessel head instrumentation welds;

b) the bottom-mounted instrumentation welds;

c) the pressurizer heater sleeves.

A.3.2 Technique

The technique is based on the influence of three main factors:

a) evolution of acoustic emission with leakage rate;

b) comparison of AE signal level and the background noise;

c) attenuation of AE signal in the different parts of the pressure equipment (components and welds).

The influence of these factors has been studied in different laboratory and on-site tests.

Specific mock-up loops with artificial defects have been used to determine the correlation between leakage characteristics and the acoustic emission signature.

On-site measurements have been performed in order to measure the background noise under various operating conditions and so, estimate the minimum detectable leakage rate according to the operating conditions.

The realization of attenuation measurements in the different parts of the circuit enabled to take into account the influence of AE signal loss due to the propagation conditions.

All these preliminary steps have allowed to determine the influent parameters related to the instrumentation and the implementation of the method and subsequently the guaranteed level of sensitivity (worst-case approach) was calculated.

A.3.3 Primary loop hydrotest monitoring

A.3.3.1 Sensors positions

The resonant sensors used shall be placed in three areas of the primary loop as shown on Figure A.3.

Depending on the area, three to six sensors are necessary to guarantee the NDT performance (detection sensitivity and coverage).

A.3.3.2 AE monitoring

The AE monitoring shall be performed during the last steps of the pressurization sequence, from the first reference hold at 172 bar to the hydrotest final pressure hold at 207 bar, and going back to a second hold at 172 bars.

A.3.3.3 Real-time data analysis

a) Acoustic emission signals shall be recorded permanently in real-time.

b) The main criteria shall be based on the analysis of the evolution of RMS signal during holds.

c) The RMS evolution between holds is not formally analysed, but a qualitative approach shall be used (see 10.2).

d) A potential leak shall be assumed during the final hold whenever the RMS signal rises consistently above a specified threshold level. This threshold shall be determined during the penultimate reference hold according to the measurement of the background noise level (which depends on the local specific primary loop configuration).

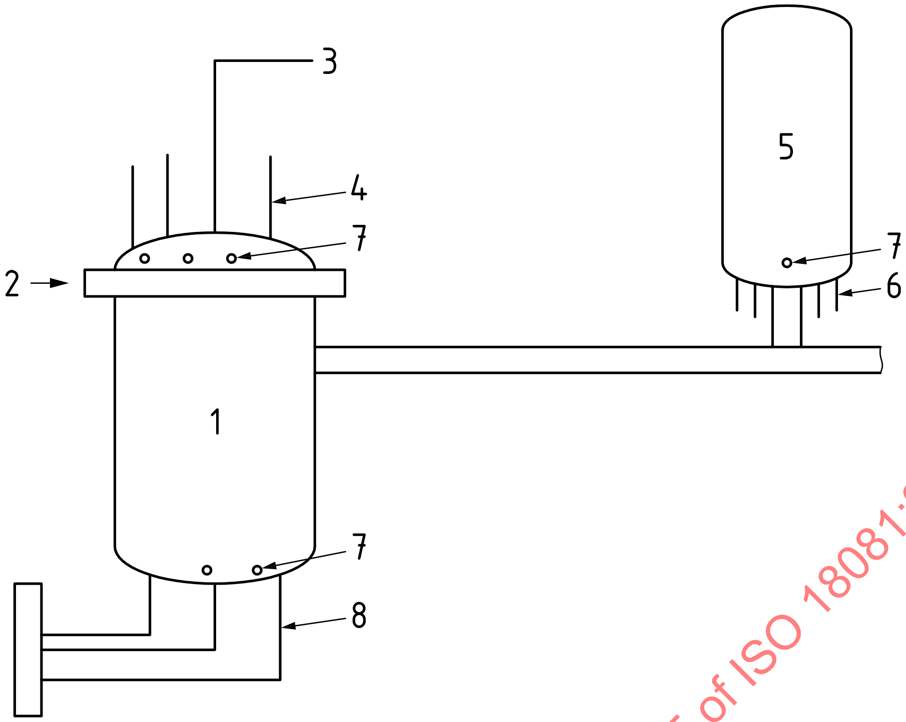
e) The efficiency of the method shall be ensured through a series of in-service operating conditions (e.g. reproducible coupling, sensitivity checks).

A.3.4 Qualification and main results

This methodology has been used since the 1980s. It has been qualified according the French nuclear regulator requirements in 2006.

The methodology is periodically reviewed to reflect changes in the acoustic emission instrumentation and feedback from field testing.

One of the main results showing the performances of this methodology is the detection of a crack in an instrumentation nozzle weld (vessel head) of a French PWR in the 1990s.



Key

1	vessel	5	pressuriser
2	vessel head	6	PZR Heater sleeves
3	vent pipe	7	qualified acoustic emission sensors
4	instrumentation nozzle	8	bottom-mounted instrumentation nozzle

Figure A.3 — Position of AE sensors on the primary circuit of nuclear power plant

A.4 Leak testing on tank floors

A.4.1 General

Leak detection on flat-bottomed storage tanks for liquid stock products is applied since the early 1980s mainly in chemical and petrochemical industry. All testing techniques exploit that turbulent flow of liquid is a source of acoustic emission. The primary effect can be accompanied by secondary effects. Amongst others such secondary effects are impact of solid particles at the outside of the bottom plates (e.g. sand foundation) due to leakage flow or on-going corrosion process due to corrosive environment in the area of bottom plate penetration.

Achieving turbulent flow in case of the presence of a leak is therefore a basic requirement. It is known that high viscous products turn from laminar flow to turbulent flow only at high differential pressure. Experience based knowledge gained since first tests showed that 40 centistokes is the limit for kinematic viscosity under testing conditions given usually at tanks with tank shell height not higher than 20 m. If tank design and density of product allows installation of water bottom then leak testing may be performed as well.

A penetration of the tank floor does not lead necessarily to loss of product. Leakage paths can be blocked, by sludge or sediments, and thus are out of scope for detection with testing techniques based on acoustic emission. An active leak is characterized by the presence of turbulent flow and detection of such kind of leak is considered in the following.