A verified protection factor above the minimum requirements resulting from the approval standards for respiratory protection devices permits the reliable deployment of self-contained respiratory protection devices at extremely high H₂S concentrations.
Working on oil fields containing acidic gases, e.g. in Mexico, North and South America\(^1\) and the Middle East (Saudi Arabia, Emirate of Dubai etc.), harbours exceptionally high risks for personnel: including serious health damage or even death by asphyxiation. The oil of these highly sulphurous wells, which are therefore called acidic, contains very high concentrations of hydrogen sulphide (H\(_2\)S) which can cause a contamination of the ambient air of up to 450,000 ppm (ppm = parts per million) and more during incidents or accidents. H\(_2\)S may cause immediate death already at concentrations of 1,000 ppm in the inhaled air.

To ensure that oil field workers are also adequately protected in the case of extraordinary H\(_2\)S concentrations, they must have self-contained respiratory protection devices with a correspondingly high protection factor available. Health and safety organisations, such as NIOSH, OSHA and CEN\(^2\), publish standards for respiratory protection devices in order to define minimum requirements in the form of protection factors. However, for extreme situations, such as work on oil fields containing acidic gas, no defined safety standards exist. In these cases the companies must carry out their own analysis, taking into account the expected maximum levels, in order to select a suitable respiratory protection device. As a minimum, the respective applicable regional occupational exposure limits must be taken into account (see table: Regional occupational exposure limits).

### LIMITS OF RISK MINIMISATION

During the risk assessment, all substitution options and all technical and organisational measures for risk minimisation must be exhausted. However, if the risks cannot be reduced to a reasonable minimum in spite of all efforts, employees must be provided with suitable personal (respiratory) protective equipment.

### The protection factor as a relevant criterion when selecting a suitable respiratory protection device

When selecting suitable respiratory protection devices, the Assigned Protection Factor (APF) of the respective device type is useful. This protection factor describes the ratio of the concentration of a contaminant / hazardous substance in the ambient atmosphere

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1. [http://www.petroleum.co.uk/sweet-vs-sour; accessed: 02.04.2015](http://www.petroleum.co.uk/sweet-vs-sour; accessed: 02.04.2015)
2. NIOSH—National Institute for Occupational Safety and Health (NIOSH)/USA, OSHA—Occupational Health & Safety Administration, CEN—Comité Européen de Normalisation
and the contamination in the face piece of the respiratory protection device during use. The higher the protection factor, the fewer hazardous substances reach the respiratory pathways of the device wearer. The required protection factor for a respiratory protection device is specified in the respective approval standard. For self-contained breathing apparatus and full-face masks, for example, an APF of 2,000 is required; for devices with positive pressure function an APF of 10,000 will be necessary to obtain certification in accordance with e.g. DIN EN 137.

Internationally, two protection factor systems are in use for practical applications: the Assigned Protection Factor (APF) in accordance with European guidelines (EN) and the APF in accordance with American guidelines (OSHA). The European version describes the realistic protection achieved or exceeded by 95% of users. The American APF describes the protection level achieved by a respiratory protection device of this category without taking anthropometry (different head and face shapes) into account. Both APF are determined using the so-called Total Inward Leakage (TIL) test.

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<table>
<thead>
<tr>
<th>Authority/ Country</th>
<th>Description</th>
<th>Time-weighted average (TWA)</th>
<th>Short-term exposure limit (STEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIOSH</td>
<td>REL</td>
<td>10 ppm TWA</td>
<td>15 ppm STEL</td>
</tr>
<tr>
<td>OSHA</td>
<td>PEL</td>
<td>20 ppm Ceiling</td>
<td>50 ppm for 10 min</td>
</tr>
<tr>
<td>ACGIH</td>
<td>TLV</td>
<td>10 ppm TWA</td>
<td>15 ppm STEL</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>WEL</td>
<td>5 ppm TWA</td>
<td>10 ppm STEL</td>
</tr>
<tr>
<td>Canada</td>
<td>OEL</td>
<td>10 ppm TWA</td>
<td>15 ppm</td>
</tr>
<tr>
<td>Australia</td>
<td>OEL</td>
<td>10 ppm TWA</td>
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</tr>
<tr>
<td>Germany</td>
<td>BGR</td>
<td>5 ppm</td>
<td>15 ppm</td>
</tr>
<tr>
<td>South Africa</td>
<td>OEL</td>
<td>10 ppm TWA</td>
<td>15 ppm STEL</td>
</tr>
<tr>
<td>Brazil</td>
<td>OEL</td>
<td>8 ppm (max 48 hrs/wk.)</td>
<td></td>
</tr>
</tbody>
</table>

REL: Recommended Exposure Limit is a level that NIOSH believes would be protective of worker safety and health over a working lifetime
STEL: Short-Term Exposure Limit is the acceptable average exposure over a short period of time, usually 15 minutes
TWA: Time-Weighted Average is the average exposure over a specified period of time, usually a nominal eight to ten hours depending on national regulations
TLV: Threshold Limit Value is a level to which it is believed a worker can be exposed day after day for a working lifetime without adverse health effects
WEL: Workplace Exposure Limit is an upper limit in the UK on the acceptable concentration of a hazardous substance in workplace air for a particular material or class of materials
OEL: Occupational Exposure Limit is an upper limit in Australia on the acceptable concentration of a hazardous substance in workplace air for a particular material or class of materials
AGW: Arbeitsplatzgrenzwert is an upper limit in Germany on the acceptable concentration of a hazardous substance in workplace air for a particular material or class of materials
PEL: Permissible Exposure Limit is a legal limit in the United States for exposure of an employee to a chemical substance or physical agent

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CAUTION: Under extreme conditions explosions may be expected from a concentration of 40,000 ppm H₂S. Therefore, the respiratory protection device must be certified for use in explosive environments. Whether a device meets these requirements is confirmed by the ATEX classification³⁴.

Total Inward Leakage (TIL) test
For the TIL test according to EN 136 (full-face masks) and EN 137 (SCBA⁵ units), several persons don the respiratory protection devices to be tested during a certification test. The test persons are in a chamber which is flooded with the simulation gas sulphur hexafluoride (SF₆) at a defined concentration. Here

⁴ Most Draeger respiratory protective devices are approved for ATEX Zone 0.
⁵ SCBA–Self Containing Breathing Apparatus
too, the measured results determine the ratio of the hazardous substance contamination outside and inside of the respiratory protection mask.

The minimum requirement defined by the standard with regard to the leakage value (TIL) of this device class is <0.05%. A respiratory protection mask with a TIL of ≤0.05% according to EN 136 guarantees an APF of 2,000:

$$\frac{100\%}{0.05\% \text{ (TIL)}} = 2.000 \text{ (APF)}.$$ 

This value can be significantly improved using a positive pressure lung demand valve. This is because when a positive pressure is generated in the mask, the leakage value will be markedly lower. The respiratory protection device thus achieves an APF of up to 10,000.

**Test procedures under realistic conditions**

Both protection factors (APF EN and APF US) are based on general assumptions derived from the respective standard or guideline. These provide the basic simulation scenarios for the leakage tests. However, extreme workplace conditions, such as those occurring in the oil and gas industries, were not taken into account when defining the test procedures for APFs.

In this case, individual tests must be carried out to ensure that persons who are potentially at risk will be adequately protected. To this end, test procedures are used which relate to the workplace-specific ambient conditions. These are called Workplace Protection Factor (WPF) or Simulated Workplace Protection Factor (SWPF) tests. Here, measurements are taken during the actual activity and being exposed to the real ambient hazardous substances or the activity and hazardous substances are simulated using suitable means.

**SWPF test procedure using particles**

SWPF tests with particles as simulation medium are only suited to test the protection offered by respiratory protection devices against particles. An example is the test by the Dutch institute ProQares. Here, the tight fit of the full-face mask is tested with the aid of nebulised aerosols as simulated hazardous substance. In the past, these test results were also used to select suitable respiratory protection devices for high H₂S concentrations. However, because gases behave differently from particles, this procedure does not permit unqualified conclusions regarding the protection against hazardous gaseous substances.

**SWPF TESTS VS. WPF TESTS**

SWPF and WPF tests provide information about the tight fit of respiratory protection devices during use. In WPF tests the measurements are taken under real conditions with actual hazardous substances. On the one hand, it is of course important to select the most meaningful realistic method possible. On the other hand an ethical question arises: Is it acceptable for a test person to be exposed to this potentially lethal and at least potentially harmful environment? SWPF tests, on the other hand, are only reliable if the typical workplace conditions are simulated with attention to detail (e.g. by using gaseous or particulate hazardous substances).

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6 http://www.proqares.com/; accessed: 02/04/2015
SWPF tests with gaseous simulation media

Dräger does not consider a test, which is conducted exclusively with particles in the form of aerosols, sufficient to describe the protective effects against gaseous hazardous substances. A TIL test in accordance with the tests of DIN EN 136/137 and incorporating the 5%/95% percentile distribution of the head shapes (in accordance with the future ISO RPD standard) can provide the best possible and safest demonstration of the actual protection against gaseous hazardous substances. By using the test gas SF₆, which behaves similar to H₂S, the SWPF test simulates in particular the gaseous hazards on acidic oil fields as realistic as possible. This is also supported by the highly different test results of an SWPF test with aerosols and an SWPF test with SF₆.

SWPF tests with SF₆ confirm that SCBA by Dräger ensure much higher protection factors than required in the corresponding standards. This verification was provided by the Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversiche rung (IFA, German health and safety institute commissioned to carry out testing for the German Statutory Accident Insurers DGUV). Two Dräger full-face masks (Dräger Panorama Nova® and FPS® 7000) were tested in positive pressure mode. Both masks achieved leakage values which for a percentile distribution of 95% of device wearers guarantee an SWPF of 90,000 and for 5% an SWPF of 20,000. Thanks to these above-average results they are specifically suited for the use with SCBA and Escape SCBA in the oil and gas industries where they are already being successfully used.

NEW ISO RPD PUT FOCUS ON THE USER

The new ISO RPD will in future replace all existing standards for respiratory protection devices across the EU as well as in other countries (USA, Australia, India, Brazil, Japan etc.) or complement them. It is related to complete respiratory protection devices (excluding technical interface mask to LDV/filter) and takes in particular the requirements of the device user concerning handling, fit and protection class into account. The first publication of the new ISO RPD standard has been planned for 2018 (based on information as of: April 2015).

3-D scans of 3,000 heads are the basis to reconstruct five typical head shapes that represent 5 to 95 % of all humans:

- small S
- short–wide SW
- medium M
- long–narrow LN
- large L

7 http://www.dguv.de/ifa/Pr%C3%BChung-Zertifizierung/index.jsp; accessed: 02/04/2015
Comparison of SWPF simulation media: SF₆ vs. aerosols

<table>
<thead>
<tr>
<th>PHYSICAL PROPERTIES</th>
<th>HAZARDOUS SUBSTANCE</th>
<th>TEST SUBSTANCE 1</th>
<th>TEST SUBSTANCE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designation</td>
<td>H₂S</td>
<td>SF₆</td>
<td>Aerosols</td>
</tr>
<tr>
<td>Grain size/molar mass</td>
<td>34.08 g·mol⁻¹</td>
<td>146.05 g·mol⁻¹</td>
<td>0.5 nm–10 μm</td>
</tr>
<tr>
<td>State of aggregation</td>
<td>gaseous</td>
<td>gaseous</td>
<td>solid or liquid airborne particles in a gas</td>
</tr>
<tr>
<td>Weight</td>
<td>heavier than air</td>
<td>heavier than air</td>
<td>heavier than air</td>
</tr>
</tbody>
</table>

Summary

When selecting the best suited respiratory protection devices, the maximum permissible and the actually expected contamination at the concrete workplace must be determined during risk assessments on site and compared to the protection factor of the respiratory protection device. Only on the basis of these two parameters, the suitability of the devices for this workplace use can be confirmed.

Using tests which are carried out with gas instead of particles and whose results exceed the standard requirements, Dräger addresses the specific actual mission scenarios within the oil and gas industries. Furthermore, the successful SF₆ tests demonstrate that the tested Dräger respiratory protection devices provide safe protection during high risk missions on acidic oil fields.

Hans Cray, Global Business Manager, Segment Oil & Gas,
is responsible for the strategic portfolio management of the ‘Personal Protective Equipment’ product range of Dräger Safety. He is an expert in the development of application-oriented safety concepts for the oil and gas industries. Cray defines H₂S respiratory protection devices across different products, e.g. for escape, cleaning and inspection scenarios.

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