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Risk Assessment Data Directory

Report No. 434 – 1
March 2010

Process release frequencies

International Association of Oil & Gas Producers

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Abbreviations:

ANSI	**American National Standards Institute**
API	**American Petroleum Institute**
DNV	**Det Norske Veritas**
ESD	**Emergency Shutdown**
HC	**Hydrocarbon**
HCRD	**Hydrocarbon Release Database**
HSE	**(UK) Health and Safety Executive**
LNG	**Liquefied Natural gas**
OREDA	**Offshore Reliability Data**
OSHA	**Occupational Safety and Health Administration**
PSM	**Process Safety Management**
QRA	**Quantitative Risk Assessment (sometimes Analysis)**
UKCS	**United Kingdom Continental Shelf**

1.0 Scope and Definitions

1.1 Equipment

This datasheet presents (Section 2.0) frequencies of releases from the following process equipment types. They are intended to be applied to process equipment on the topsides of offshore installations and on onshore facilities handling hydrocarbons but are not restricted to releases of hydrocarbons.

1. Steel process pipes
2. Flanges
3. Manual valves
4. Actuated valves
5. Instrument connections
6. Process (pressure) vessels
7. Pumps: Centrifugal
8. Pumps: Reciprocating
9. Compressors: Centrifugal
10. Compressors: Reciprocating
11. Heat exchangers: Shell & Tube, shell side HC
12. Heat exchangers: Shell & Tube, tube side HC
13. Heat exchangers: Plate
14. Heat exchangers: Air-cooled
15. Filters
16. Pig traps (launchers/receivers)

OREDA [1] gives frequencies of releases from subsea equipment. If these are used, it should be noted that these are based on only a small number of incidents (a total of 13 from several different components) and so are subject to considerable statistical uncertainty. It is suggested that use of onshore/topsides failure frequencies, i.e. the frequencies for the corresponding equipment types from nos. 1 to 16 above, is preferable.

The precise definition of each equipment type is given with the data in Section 2.0.

Besides the equipment defined in the above list, the equipment types listed in Table 1.1 are also covered by the data given in Section 2.0.

Table 1.1 Other Equipment Types Covered

Equipment Type	See Datasheet or Section No.	Equipment Type	See Datasheet or Section No.
Absorbers	6	Grayloc flanges	Section 3.5.5
Clamp connections	2	Knock-out drums	6
Columns	6	Pipe connections	2
Distillation columns	6	Process reactors	6
ESD valves	4	Reactors	6
Fin-fan coolers	14	Scrubbers	6
Fittings (small-bore)	5	Separators	6
Gaskets	Section 3.5.5	Small-bore fittings	5

1.2 Release types

According to analysis of historic process release frequency data [2], releases can be split into three different types:

- **Full releases**: consistent with flow through the defined hole, beginning at the normal operating pressure, and continuing until controlled by emergency shut-down and blowdown (if present and operable) or inventory exhaustion. This scenario is invariably modelled in any QRA.
- **Limited releases**: cases where the pressure is not zero but the quantity released is much less than from a full release. This may be because the release is isolated locally by human intervention (e.g. closing an inadvertently opened valve), or by a restriction in the flow from the system inventory (e.g. releases of fluid accumulated between pump shaft seals). This scenario may be modelled, depending on the detail of the QRA, but the consequences should reflect the limited release quantities.
- **Zero pressure releases**: cases where pressure inside the leaking equipment is virtually zero (0.01 barg or less). This may be because the equipment has a normal operating pressure of zero (e.g. open drains), or because the equipment has been depressurised for maintenance. This scenario is typically excluded from QRA, and is included mainly for consistency with the original HSE data (see Sections 3.3, 4.0).

Therefore, the release frequencies are tabulated for each of these release types, as well as the overall frequencies for all release types taken together being tabulated[1].

2.0 Summary of Recommended Data

A datasheet is given below for each of the equipment types listed in Section 1.1. The definitions given of the equipment types are consistent with those used by the UK HSE.

[1] Note that these overall frequencies are not the sum of the frequencies for each release type; they are calculated by a separate mathematical function, as described in Section 4.1.2, fitted to the release data.

Equipment Type: (1) Steel process pipes

Definition:

Offshore: Includes pipes located on topsides (between well and riser) and subsea (between well and pipeline).
Onshore: Includes pipes within process units, but not inter-unit pipes or cross-country pipelines.
The scope includes welds but excludes all valves, flanges, and instruments.

(a) All piping release frequencies (per metre year) by pipe diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	9.0E-05	4.1E-05	3.7E-05	3.6E-05	3.6E-05	3.6E-05
3 to 10	3.8E-05	1.7E-05	1.6E-05	1.5E-05	1.5E-05	1.5E-05
10 to 50	2.7E-05	7.4E-06	6.7E-06	6.5E-06	6.5E-06	6.5E-06
50 to 150	0.0E+00	7.6E-06	1.4E-06	1.4E-06	1.4E-06	1.4E-06
>150	0.0E+00	0.0E+00	5.9E-06	5.9E-06	5.9E-06	5.9E-06
TOTAL	1.5E-04	7.4E-05	6.7E-05	6.5E-05	6.5E-05	6.5E-05

(b) Full piping release frequencies (per metre year) by pipe diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	5.5E-05	2.6E-05	2.3E-05	2.3E-05	2.3E-05	2.3E-05
3 to 10	1.8E-05	8.5E-06	7.6E-06	7.5E-06	7.4E-06	7.4E-06
10 to 50	7.0E-06	2.7E-06	2.4E-06	2.4E-06	2.4E-06	2.3E-06
50 to 150	0.0E+00	6.0E-07	3.7E-07	3.6E-07	3.6E-07	3.6E-07
>150	0.0E+00	0.0E+00	1.7E-07	1.7E-07	1.6E-07	1.6E-07
TOTAL	8.0E-05	3.8E-05	3.4E-05	3.3E-05	3.3E-05	3.3E-05

(c) Limited piping release frequencies (per metre year) by pipe diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	3.1E-05	9.9E-06	8.1E-06	7.8E-06	7.7E-06	7.6E-06
3 to 10	1.5E-05	4.9E-06	4.0E-06	3.8E-06	3.8E-06	3.7E-06
10 to 50	1.3E-05	2.5E-06	2.0E-06	1.9E-06	1.9E-06	1.9E-06
50 to 150	0.0E+00	3.2E-06	5.2E-07	5.0E-07	4.9E-07	4.9E-07
>150	0.0E+00	0.0E+00	2.4E-06	2.4E-06	2.4E-06	2.4E-06
TOTAL	5.9E-05	2.0E-05	1.7E-05	1.6E-05	1.6E-05	1.6E-05

(d) Zero pressure piping release frequencies (per metre year) by pipe diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	3.7E-06	3.2E-06	3.1E-06	3.1E-06	3.1E-06	3.1E-06
3 to 10	2.7E-06	2.3E-06	2.3E-06	2.3E-06	2.3E-06	2.3E-06
10 to 50	6.0E-06	1.9E-06	1.8E-06	1.8E-06	1.8E-06	1.8E-06
50 to 150	0.0E+00	3.4E-06	7.7E-07	7.6E-07	7.6E-07	7.6E-07
>150	0.0E+00	0.0E+00	2.6E-06	2.6E-06	2.6E-06	2.6E-06
TOTAL	1.24E-05	1.07E-05	1.06E-05	1.05E-05	1.05E-05	1.05E-05

Equipment Type: (2) Flanges

Definition:

The following frequencies refer to a flanged joint, comprising two flange faces, a gasket (where fitted), and two welds to the pipe. Flange types include ring type joint, spiral wound, clamp (Grayloc) and hammer union (Chicksan).

(a) All flange release frequencies (per flanged joint year) by flange diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	4.4E-05	6.5E-05	9.6E-05	1.2E-04	1.5E-04	2.1E-04
3 to 10	1.8E-05	2.6E-05	3.9E-05	5.1E-05	6.2E-05	8.5E-05
10 to 50	1.5E-05	1.1E-05	1.6E-05	2.1E-05	2.5E-05	3.4E-05
50 to 150	0.0E+00	8.5E-06	3.2E-06	4.1E-06	5.1E-06	6.9E-06
>150	0.0E+00	0.0E+00	7.0E-06	7.6E-06	8.2E-06	9.3E-06
TOTAL	7.6E-05	1.1E-04	1.6E-04	2.1E-04	2.5E-04	3.4E-04

(b) Full flange release frequencies (per flanged joint year) by flange diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	2.6E-05	3.7E-05	5.9E-05	8.3E-05	1.1E-04	1.7E-04
3 to 10	7.6E-06	1.1E-05	1.7E-05	2.4E-05	3.2E-05	4.9E-05
10 to 50	4.0E-06	3.0E-06	4.7E-06	6.6E-06	8.8E-06	1.4E-05
50 to 150	0.0E+00	2.0E-06	6.1E-07	8.7E-07	1.1E-06	1.8E-06
>150	0.0E+00	0.0E+00	1.7E-06	1.8E-06	1.9E-06	2.2E-06
TOTAL	3.8E-05	5.3E-05	8.3E-05	1.2E-04	1.5E-04	2.4E-04

(c) Limited flange release frequencies (per flanged joint year) by flange diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	1.5E-05	2.3E-05	3.1E-05	3.8E-05	4.4E-05	5.4E-05
3 to 10	7.9E-06	1.2E-05	1.6E-05	2.0E-05	2.3E-05	2.8E-05
10 to 50	8.6E-06	6.4E-06	8.7E-06	1.1E-05	1.2E-05	1.5E-05
50 to 150	0.0E+00	5.4E-06	2.4E-06	2.9E-06	3.4E-06	4.1E-06
>150	0.0E+00	0.0E+00	4.3E-06	4.8E-06	5.2E-06	5.9E-06
TOTAL	3.2E-05	4.7E-05	6.2E-05	7.5E-05	8.7E-05	1.1E-04

(d) Zero pressure flange release frequencies (per flanged joint year) by flange diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	1.5E-06	1.7E-06	2.6E-06	4.2E-06	6.7E-06	1.4E-05
3 to 10	1.1E-06	1.2E-06	1.9E-06	3.1E-06	4.9E-06	1.1E-05
10 to 50	2.0E-06	1.0E-06	1.5E-06	2.5E-06	4.0E-06	8.6E-06
50 to 150	0.0E+00	1.3E-06	6.4E-07	1.1E-06	1.7E-06	3.6E-06
>150	0.0E+00	0.0E+00	1.4E-06	2.2E-06	3.5E-06	7.6E-06
TOTAL	4.6E-06	5.3E-06	7.9E-06	1.3E-05	2.1E-05	4.5E-05

Equipment Type: (3) Manual valves

Definition:

Includes all types of manual valves (block, bleed, check and choke); valve types gate, ball, plug, globe, needle and butterfly. The scope includes the valve body, stem and packer, but excludes flanges, controls and instrumentation.

(a) All manual valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	4.4E-05	6.6E-05	8.4E-05	9.8E-05	1.1E-04	1.3E-04
3 to 10	2.3E-05	3.4E-05	4.3E-05	5.0E-05	5.6E-05	6.4E-05
10 to 50	2.1E-05	1.8E-05	2.3E-05	2.7E-05	3.0E-05	3.4E-05
50 to 150	0.0E+00	1.1E-05	6.3E-06	7.3E-06	8.0E-06	9.3E-06
>150	0.0E+00	0.0E+00	7.8E-06	8.7E-06	9.5E-06	1.1E-05
TOTAL	8.8E-05	1.3E-04	1.7E-04	1.9E-04	2.1E-04	2.4E-04

(b) Full manual valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	2.0E-05	3.1E-05	4.3E-05	5.3E-05	6.2E-05	7.8E-05
3 to 10	7.7E-06	1.2E-05	1.7E-05	2.1E-05	2.4E-05	3.0E-05
10 to 50	4.9E-06	4.7E-06	6.5E-06	8.0E-06	9.4E-06	1.2E-05
50 to 150	0.0E+00	2.4E-06	1.2E-06	1.5E-06	1.8E-06	2.2E-06
>150	0.0E+00	0.0E+00	1.7E-06	1.9E-06	2.1E-06	2.3E-06
TOTAL	3.2E-05	5.0E-05	6.9E-05	8.5E-05	1.0E-04	1.2E-04

(c) Limited manual valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	2.4E-05	2.7E-05	3.2E-05	3.7E-05	4.3E-05	5.4E-05
3 to 10	1.4E-05	1.5E-05	1.8E-05	2.1E-05	2.5E-05	3.1E-05
10 to 50	1.4E-05	9.5E-06	1.1E-05	1.3E-05	1.5E-05	1.9E-05
50 to 150	0.0E+00	6.4E-06	3.5E-06	4.1E-06	4.7E-06	6.0E-06
>150	0.0E+00	0.0E+00	4.1E-06	4.8E-06	5.5E-06	7.0E-06
TOTAL	5.1E-05	5.8E-05	6.9E-05	8.1E-05	9.3E-05	1.2E-04

(d) Zero pressure manual valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	3.6E-07	7.1E-07	1.1E-06	1.4E-06	1.7E-06	2.2E-06
3 to 10	3.5E-07	6.9E-07	1.1E-06	1.4E-06	1.7E-06	2.1E-06
10 to 50	2.4E-06	7.8E-07	1.2E-06	1.6E-06	1.9E-06	2.4E-06
50 to 150	0.0E+00	4.0E-06	7.1E-07	9.2E-07	1.1E-06	1.4E-06
>150	0.0E+00	0.0E+00	5.4E-06	7.0E-06	8.5E-06	1.1E-05
TOTAL	3.1E-06	6.2E-06	9.5E-06	1.2E-05	1.5E-05	1.9E-05

Equipment Type: (4) Actuated valves

Definition:

Includes all types of actuated valves (block, blowdown, choke, control, ESDV and relief), but not actuated pipeline valves (pipeline ESDV and SSIV). Valve types include gate, ball, plug, globe and needle. The scope includes the valve body, stem and packer, but excludes flanges, controls and instrumentation.

(a) All actuated valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	4.2E-04	3.6E-04	3.3E-04	3.1E-04	3.0E-04	2.8E-04
3 to 10	1.8E-04	1.5E-04	1.4E-04	1.3E-04	1.3E-04	1.2E-04
10 to 50	1.1E-04	6.6E-05	6.0E-05	5.6E-05	5.4E-05	5.0E-05
50 to 150	0.0E+00	3.3E-05	1.3E-05	1.2E-05	1.1E-05	1.1E-05
>150	0.0E+00	0.0E+00	1.8E-05	1.8E-05	1.8E-05	1.7E-05
TOTAL	7.1E-04	6.2E-04	5.6E-04	5.3E-04	5.0E-04	4.7E-04

(b) Full actuated valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	2.4E-04	2.2E-04	2.1E-04	2.0E-04	2.0E-04	1.9E-04
3 to 10	7.3E-05	6.6E-05	6.3E-05	6.0E-05	5.9E-05	5.6E-05
10 to 50	3.0E-05	1.9E-05	1.8E-05	1.7E-05	1.7E-05	1.6E-05
50 to 150	0.0E+00	8.6E-06	2.4E-06	2.3E-06	2.2E-06	2.2E-06
>150	0.0E+00	0.0E+00	6.0E-06	5.9E-06	5.9E-06	5.9E-06
TOTAL	3.5E-04	3.2E-04	3.0E-04	2.9E-04	2.8E-04	2.7E-04

(c) Limited actuated valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	1.7E-04	1.3E-04	1.1E-04	9.7E-05	8.9E-05	7.7E-05
3 to 10	8.8E-05	6.9E-05	5.7E-05	5.1E-05	4.7E-05	4.1E-05
10 to 50	7.8E-05	3.8E-05	3.2E-05	2.8E-05	2.6E-05	2.3E-05
50 to 150	0.0E+00	2.3E-05	9.0E-06	8.0E-06	7.3E-06	6.4E-06
>150	0.0E+00	0.0E+00	1.1E-05	9.8E-06	9.2E-06	8.3E-06
TOTAL	3.3E-04	2.6E-04	2.2E-04	1.9E-04	1.8E-04	1.6E-04

(d) Zero pressure actuated valve release frequencies (per valve year) by valve diameter

HOLE DIA RANGE (mm)	2" DIA (50 mm)	6" DIA (150 mm)	12" DIA (300 mm)	18" DIA (450 mm)	24" DIA (600 mm)	36" DIA (900 mm)
1 to 3	1.1E-05	1.8E-05	2.5E-05	3.0E-05	3.4E-05	4.1E-05
3 to 10	7.8E-06	1.3E-05	1.7E-05	2.1E-05	2.3E-05	2.8E-05
10 to 50	1.3E-05	9.6E-06	1.3E-05	1.6E-05	1.8E-05	2.2E-05
50 to 150	0.0E+00	1.1E-05	5.2E-06	6.2E-06	7.1E-06	8.5E-06
>150	0.0E+00	0.0E+00	9.3E-06	1.1E-05	1.3E-05	1.5E-05
TOTAL	3.2E-05	5.1E-05	6.9E-05	8.3E-05	9.5E-05	1.1E-04

Equipment Type: (5) Instrument connections

Definition:

Includes small-bore connections for flow, pressure and temperature sensing. The scope includes the instrument itself plus up to 2 instrument valves, 4 flanges, 1 fitting and associated small-bore piping, usually 25 mm diameter or less.

Instrument connection release frequencies (per instrument year; sizes 10 to 50 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	3.5E-04	1.8E-04	1.6E-04	8.8E-06
3 to 10	1.5E-04	6.8E-05	7.4E-05	5.5E-06
10 to 50	6.5E-05	2.5E-05	3.6E-05	3.8E-06
TOTAL	5.7E-04	2.8E-04	2.7E-04	1.8E-05

Equipment Type: (6) Process (pressure) vessels

Definition:

Offshore: Includes all types of pressure vessel (horizontal/vertical absorber, knock-out drum, reboiler, scrubber, separator and stabiliser), but not the HCRD category "other", which are mainly hydrocyclones.
Onshore: Includes process vessels and columns, but not storage vessels.
The scope includes the vessel itself and any nozzles or inspection openings, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Pressure vessel release frequencies (per vessel year; connections 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	9.6E-04	3.9E-04	3.5E-04	1.8E-04
3 to 10	5.6E-04	2.0E-04	2.0E-04	1.4E-04
10 to 50	3.5E-04	1.0E-04	1.2E-04	1.2E-04
>50	2.8E-04	5.1E-05	7.9E-05	1.8E-04
TOTAL	2.2E-03	7.4E-04	7.4E-04	6.3E-04

Pressure vessel release frequencies (per vessel year; connections >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	9.6E-04	3.9E-04	3.5E-04	1.8E-04
3 to 10	5.6E-04	2.0E-04	2.0E-04	1.4E-04
10 to 50	3.5E-04	1.0E-04	1.2E-04	1.2E-04
50 to 150	1.1E-04	2.7E-05	3.7E-05	5.5E-05
>150	1.7E-04	2.4E-05	4.2E-05	1.4E-04
TOTAL	2.2E-03	7.4E-04	7.4E-04	6.3E-04

Equipment Type: (7) Pumps: Centrifugal

Definition:

Centrifugal pumps including single-seal and double-seal types*. The scope includes the pump itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

*** Analysis has shown that there is no statistical difference between single- and double-seal types for releases in the size range considered.**

Centrifugal pump release frequencies (per pump year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	5.1E-03	3.4E-03	1.3E-03	2.4E-04
3 to 10	1.8E-03	1.0E-03	5.6E-04	1.4E-04
10 to 50	5.9E-04	2.9E-04	2.4E-04	9.4E-05
>50	1.4E-04	5.4E-05	8.3E-05	7.2E-05
TOTAL	7.6E-03	4.8E-03	2.2E-03	5.5E-04

Centrifugal pump release frequencies (per pump year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	5.1E-03	3.4E-03	1.3E-03	2.4E-04
3 to 10	1.8E-03	1.0E-03	5.6E-04	1.4E-04
10 to 50	5.9E-04	2.9E-04	2.4E-04	9.4E-05
50 to 150	9.7E-05	3.9E-05	5.0E-05	3.1E-05
>150	4.8E-05	1.5E-05	3.3E-05	4.1E-05
TOTAL	7.6E-03	4.8E-03	2.2E-03	5.5E-04

Equipment Type: (8) Pumps: Reciprocating

Definition:

Reciprocating pumps including single-seal and double-seal types*. The scope includes the pump itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

*** Analysis has shown that there is no statistical difference between single- and double-seal types for releases in the size range considered.**

Reciprocating pump release frequencies (per pump year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	3.3E-03	2.1E-03	8.9E-04	0.0E+00
3 to 10	1.9E-03	1.2E-03	6.2E-04	0.0E+00
10 to 50	1.2E-03	7.4E-04	4.7E-04	0.0E+00
>50	8.0E-04	5.0E-04	5.3E-04	0.0E+00
TOTAL	7.2E-03	4.5E-03	2.5E-03	0.0E+00

Reciprocating pump release frequencies (per pump year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	3.3E-03	2.1E-03	8.9E-04	0.0E+00
3 to 10	1.9E-03	1.2E-03	6.2E-04	0.0E+00
10 to 50	1.2E-03	7.4E-04	4.7E-04	0.0E+00
50 to 150	3.7E-04	2.3E-04	1.9E-04	0.0E+00
>150	4.3E-04	2.7E-04	3.4E-04	0.0E+00
TOTAL	7.2E-03	4.5E-03	2.5E-03	0.0E+00

Equipment Type: (9) Compressors: Centrifugal

Definition:

The scope includes the compressor itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Centrifugal compressor release frequencies (per compressor year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	6.7E-03	3.4E-03	2.9E-03	3.7E-04
3 to 10	2.6E-03	6.8E-04	1.4E-03	2.4E-04
10 to 50	1.0E-03	1.3E-04	7.4E-04	1.8E-04
>50	3.0E-04	1.3E-05	3.5E-04	1.8E-04
TOTAL	1.1E-02	4.2E-03	5.5E-03	9.6E-04

Centrifugal compressor release frequencies (per compressor year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	6.7E-03	3.4E-03	2.9E-03	3.7E-04
3 to 10	2.6E-03	6.8E-04	1.4E-03	2.4E-04
10 to 50	1.0E-03	1.3E-04	7.4E-04	1.8E-04
50 to 150	1.9E-04	1.0E-05	1.9E-04	6.7E-05
>150	1.1E-04	2.5E-06	1.6E-04	1.1E-04
TOTAL	1.1E-02	4.2E-03	5.5E-03	9.6E-04

Equipment Type: (10) Compressors: Reciprocating

Definition:

The scope includes the compressor itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Reciprocating compressor release frequencies (per compressor year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	4.5E-02	2.4E-02	1.9E-02	0.0E+00
3 to 10	1.7E-02	8.0E-03	9.4E-03	0.0E+00
10 to 50	6.7E-03	2.6E-03	4.7E-03	0.0E+00
>50	2.0E-03	8.8E-04	2.2E-03	0.0E+00
TOTAL	7.1E-02	3.6E-02	3.6E-02	0.0E+00

Reciprocating compressor release frequencies (per compressor year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	4.5E-02	2.4E-02	1.9E-02	0.0E+00
3 to 10	1.7E-02	8.0E-03	9.4E-03	0.0E+00
10 to 50	6.7E-03	2.6E-03	4.7E-03	0.0E+00
50 to 150	1.3E-03	4.0E-04	1.2E-03	0.0E+00
>150	7.3E-04	4.8E-04	1.0E-03	0.0E+00
TOTAL	7.1E-02	3.6E-02	3.6E-02	0.0E+00

Equipment Type: (11) Heat exchangers: Shell & Tube, shell side HC

Definition:

Shell & tube type heat exchangers with hydrocarbon in the shell side. The scope includes the heat exchanger itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Heat exchanger release frequencies (per heat exchanger year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	2.2E-03	1.2E-03	1.2E-03	0.0E+00
3 to 10	1.1E-03	4.1E-04	7.3E-04	0.0E+00
10 to 50	5.6E-04	1.4E-04	4.9E-04	0.0E+00
>50	2.6E-04	3.6E-05	4.0E-04	0.0E+00
TOTAL	4.1E-03	1.8E-03	2.8E-03	0.0E+00

Heat exchanger release frequencies (per heat exchanger year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	2.2E-03	1.2E-03	1.2E-03	0.0E+00
3 to 10	1.1E-03	4.1E-04	7.3E-04	0.0E+00
10 to 50	5.6E-04	1.4E-04	4.9E-04	0.0E+00
50 to 150	1.4E-04	2.4E-05	1.7E-04	0.0E+00
>150	1.2E-04	1.2E-05	2.3E-04	0.0E+00
TOTAL	4.1E-03	1.8E-03	2.8E-03	0.0E+00

Equipment Type: (12) Heat exchangers: Shell & Tube, tube side HC

Definition:

Shell & tube type heat exchangers with hydrocarbon in the tube side. The scope includes the heat exchanger itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Heat exchanger release frequencies (per heat exchanger year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	2.0E-03	8.2E-04	7.9E-04	1.8E-04
3 to 10	8.8E-04	3.8E-04	4.3E-04	7.7E-05
10 to 50	4.0E-04	1.8E-04	2.5E-04	3.4E-05
>50	2.0E-04	7.6E-05	1.9E-04	1.3E-05
TOTAL	3.4E-03	1.5E-03	1.7E-03	3.0E-04

Heat exchanger release frequencies (per heat exchanger year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	2.0E-03	8.2E-04	7.9E-04	1.8E-04
3 to 10	8.8E-04	3.8E-04	4.3E-04	7.7E-05
10 to 50	4.0E-04	1.8E-04	2.5E-04	3.4E-05
50 to 150	9.1E-05	4.3E-05	7.4E-05	7.7E-06
>150	1.1E-04	3.3E-05	1.2E-04	5.4E-06
TOTAL	3.4E-03	1.5E-03	1.7E-03	3.0E-04

Equipment Type: (13) Heat exchangers: Plate

Definition:

The scope includes the heat exchanger itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Heat exchanger release frequencies (per heat exchanger year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	5.1E-03	3.9E-03	2.7E-03	0.0E+00
3 to 10	2.8E-03	2.0E-03	1.3E-03	0.0E+00
10 to 50	1.6E-03	1.1E-03	6.7E-04	0.0E+00
>50	9.9E-04	6.3E-04	3.2E-04	0.0E+00
TOTAL	1.0E-02	7.3E-03	5.0E-03	0.0E+00

Heat exchanger release frequencies (per heat exchanger year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	5.1E-03	3.9E-03	2.7E-03	0.0E+00
3 to 10	2.8E-03	2.0E-03	1.3E-03	0.0E+00
10 to 50	1.6E-03	1.1E-03	6.7E-04	0.0E+00
50 to 150	4.8E-04	3.2E-04	1.7E-04	0.0E+00
>150	5.1E-04	3.1E-04	1.5E-04	0.0E+00
TOTAL	1.0E-02	7.3E-03	5.0E-03	0.0E+00

Equipment Type: (14) Heat exchangers: Air-cooled

Definition:

Often referred to as fin-fan coolers but in principle includes all air-cooled type heat exchangers. The scope includes the heat exchanger itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Heat exchanger release frequencies (per heat exchanger year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	1.0E-03	1.0E-03	0.0E+00	0.0E+00
3 to 10	4.9E-04	4.9E-04	0.0E+00	0.0E+00
10 to 50	2.4E-04	2.4E-04	0.0E+00	0.0E+00
>50	1.1E-04	1.1E-04	0.0E+00	0.0E+00
TOTAL	1.0E-03	1.0E-03	0.0E+00	0.0E+00

Heat exchanger release frequencies (per heat exchanger year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	1.0E-03	1.0E-03	0.0E+00	0.0E+00
3 to 10	4.9E-04	4.9E-04	0.0E+00	0.0E+00
10 to 50	2.4E-04	2.4E-04	0.0E+00	0.0E+00
50 to 150	6.0E-05	6.0E-05	0.0E+00	0.0E+00
>150	4.9E-05	4.9E-05	0.0E+00	0.0E+00
TOTAL	1.0E-03	1.0E-03	0.0E+00	0.0E+00

Equipment Type: (15) Filters

Definition:

The scope includes the filter body itself and any nozzles or inspection openings, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Filter release frequencies (per filter year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	2.0E-03	1.3E-03	5.1E-04	1.3E-04
3 to 10	1.0E-03	5.1E-04	3.3E-04	9.3E-05
10 to 50	5.2E-04	1.9E-04	2.3E-04	7.7E-05
>50	2.6E-04	5.5E-05	2.1E-04	1.0E-04
TOTAL	3.8E-03	2.1E-03	1.3E-03	4.0E-04

Filter release frequencies (per filter year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	2.0E-03	1.3E-03	5.1E-04	1.3E-04
3 to 10	1.0E-03	5.1E-04	3.3E-04	9.3E-05
10 to 50	5.2E-04	1.9E-04	2.3E-04	7.7E-05
50 to 150	1.4E-04	3.5E-05	8.4E-05	3.3E-05
>150	1.2E-04	2.0E-05	1.3E-04	7.2E-05
TOTAL	3.8E-03	2.1E-03	1.3E-03	4.0E-04

Equipment Type: (16) Pig traps

Definition:

Includes pig launchers and pig receivers. The scope includes the pig trap itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is also excluded.

Pig trap release frequencies (per pig trap year; inlets 50 to 150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	3.2E-03	2.3E-03	7.4E-04	2.7E-04
3 to 10	1.9E-03	7.2E-04	5.6E-04	2.3E-04
10 to 50	1.2E-03	2.2E-04	4.8E-04	2.3E-04
>50	8.3E-04	4.7E-05	7.1E-04	5.2E-04
TOTAL	7.0E-03	3.3E-03	2.5E-03	1.3E-03

Pig trap release frequencies (per pig trap year; inlets >150 mm diameter)

HOLE DIA RANGE (mm)	ALL RELEASES	FULL RELEASES	LIMITED RELEASES	ZERO PRESSURE RELEASES
1 to 3	3.2E-03	2.3E-03	7.4E-04	2.7E-04
3 to 10	1.9E-03	7.2E-04	5.6E-04	2.3E-04
10 to 50	1.2E-03	2.2E-04	4.8E-04	2.3E-04
50 to 150	3.7E-04	3.3E-05	2.1E-04	1.1E-04
>150	4.6E-04	1.4E-05	5.0E-04	4.1E-04
TOTAL	7.0E-03	3.3E-03	2.5E-03	1.3E-03

3.0 Guidance on use of data

3.1 General validity

The data presented in Section 2.0 can be used for process equipment on the topsides of offshore installations and for onshore facilities handling hydrocarbons[2], and could also be used as appropriate for subsea completions.

DNV [3] have compared failure rate data for LNG facilities with the data presented in Section 2.0. The comparison indicates that LNG failure frequencies may be around 40% to 65% of those given here. However, this has not been verified and the data for LNG installations is relatively sparse. We therefore recommend use of the same frequencies for LNG installations as given in Section 2.0. A 50% reduction could be considered as a sensitivity but decisions based on this would need to be fully justified.

The release frequencies given in Section 2.0 are valid for holes of diameter (d) from 1 mm to the diameter of the equipment (D). Frequencies of smaller holes may be estimated by extrapolation of the frequencies to smaller hole sizes, but this is beyond the range of the HSE data (see Section 4.0). The data are not sufficient to determine the frequencies of larger holes (e.g. long splits or guillotine breaks allowing flow from both sides) and this can only be addressed using engineering judgment.

The release frequencies are valid for equipment diameters (D) within the normal range of offshore equipment. This is not precisely defined in the available equipment population data. Using judgment based on the trends of the estimated diameter dependence and the average diameters of the available data groups, the following ranges of validity are suggested:

- Pipes: 20 to 1000 mm
- Flanges: 10 to 1000 mm
- Manual valves: 10 to 1000 mm
- Actuated valves: 10 to 1000 mm
- Instruments: 10 to 100 mm
- Pig traps: 100 to 1000 mm
- All other equipment: 40 to 400 mm

With lesser confidence, the datasheets in Section 2.0 can be used to estimate frequencies over larger ranges, but they should be subject to sensitivity testing. These functions have been checked for mathematical consistency over a range of equipment diameters from 10 to 1000 mm. The frequencies are not recommended for equipment outside this range.

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[2] The justification for using offshore data for onshore facilities is two-fold. First, no public domain dataset for onshore facilities is available that is comparable to HCRD, considering both the equipment population and completeness of recording releases. Second, although offshore facilities operate in a more challenging (e.g. more corrosive) environment, this is compensated for in the design, inspection and maintenance. Hence there is no apparent reason why onshore and offshore release frequencies should differ significantly. However, some environmental factors are considered in Section 3.5. The standard of the safety management system is also believed to have a major influence on release frequencies, regardless of operating environment, as also discussed in Section 3.5.

3.2 Uncertainties

The sources of uncertainties in the estimated release frequencies are discussed in Section 4.1.3.

The uncertainty in the release frequencies presented in Section 2.0 tends to be greatest for large hole sizes, for equipment sizes far from the centres of the ranges of validity given in Section 3.1, and for equipment types where fewer releases have been recorded (see Section 4.1.1).

No quantitative representations of the uncertainty in the release frequency results have yet been derived. Based on the sensitivity test that have been conducted and on previous analyses of the same dataset, the uncertainly in the results may be a factor or 3 (higher or lower) for frequencies of holes in the region of 1 mm diameter, rising to a factor of 10 (higher or lower) for frequencies of holes in the region of 100 mm diameter. A simple sensitivity test would therefore be to use the frequencies for All releases in place of the Full release frequencies.

3.3 Definition of release types

The three release frequency types defined in Section 1.0, and for which frequencies are given separately in Section 2.0, are described in further detail in the following sub-sections.

3.3.1 Full releases

This scenario is intended to be consistent with QRA models that assume a release through the defined hole, beginning at the normal operating pressure, until controlled by ESD and blowdown, with a small probability of ESD/blowdown failure. Full releases are defined as cases where the outflow is greater than or broadly comparable with that predicted for a release at the operating pressure (since the normal pressure is unknown in HCRD) controlled by the quickest credible ESD (within 1 minute) and blowdown (nominally a 30 mm orifice[3]). This is subdivided as follows:

- **ESD isolated releases, presumed to be controlled by ESD and blowdown of the leaking system.**
- **Late isolated releases, presumed to be cases where there is no effective ESD of the leaking system, resulting in a greater outflow.**

Typical use in the QRA:

These events should always be included in quantified risk assessments. They have the potential of developing into serious events endangering personnel and critical safety functions.

These releases represent approximately 31% of all releases in the HSE HCRD for 1992-2006.

[3] The actual orifice diameter should be used in QRA modelling, or preferably the orifice diameter that gives blowdown to a specified pressure in the actual time

3.3.2 Limited releases

This scenario includes all other pressurised releases. They are defined as cases where the equipment is under pressure (over 0.01 barg) but the outflow is less than from a release at the operating pressure controlled by the quickest credible ESD (within 1 minute) and blowdown (through an orifice nominally of 30 mm diameter). This may be because the release is isolated locally by human intervention (e.g. closing an inadvertently opened valve), or by a restriction in the flow from the system inventory (e.g. releases of fluid accumulated between pump shaft seals).

Typical use in the QRA:

a) *Coarse QRAs*. **Limited Releases should normally be included in the risk analysis, and treated as Full Releases with regards to the consequence modelling. This is a conservative approach, which normally is in line with the nature of Coarse QRA.**
b) *Detailed QRAs*. **Limited Releases could be considered for their expected (realistic) consequences. These events may be of concern for personnel risk, but it is less likely that they develop into any major concern for other safety functions, such as structural integrity, evacuation means, escalation, etc. Any consequence calculations should reflect that these events involve limited release volumes. If the consequences are not specifically assessed, the approach of** *a)* **above apply also for detailed QRAs.**

There are two possible approaches to modelling these releases, depending on whether the limitation is on the duration (through prompt local isolation) or the flow (through a restriction). In the first case (limited duration), flow is likely to be at the same release rate as for a full release but reduced to a short duration (e.g. 30 seconds). In the second case, the release rate will be much lower than for the corresponding full release and the quantity released also smaller. In this case an approach previously suggested [4] has been to model the flow rate as 8% of the full release rate and the duration as 6% of the full release duration.

These releases represent approximately 59% of all releases in the HSE HCRD for 1992-2006.

3.3.3 Zero pressure releases

This scenario includes all releases where the pressure inside the releasing equipment is virtually zero (0.01 barg or less). This may be because the equipment has a normal operating pressure of zero (e.g. open drains), or because the equipment has been depressurised for maintenance.

Typical use in the QRA (but not limited to this example):

These are events that typically are excluded from QRA assessments. Most likely there are no serious consequences and if so, the contribution to the overall risk level is considered insignificant. These events are mainly included for consistency with the original HSE data.

The event is likely to result in release of a small quantity of hydrocarbon. This could be taken as the inventory of the system hydrocarbon full at atmospheric pressure.

These releases represent approximately 10% of all releases in the HSE HCRD for 1992-2006.

3.4 Consequence modelling for the largest release size

Where the data tables in Section 2.0 show “>50 mm” or “>150 mm” for the largest hole diameter range, the consequences of the release should be modelled using the size of the actual pipe/valve/flange or the largest connection to other equipment types.

3.5 Modification of frequencies for factors specific to plant conditions

3.5.1 General considerations

The frequencies tabulated in Section 2.0 are generic frequencies for installations designed and operating to "typical" European / North American standards. A large number of possible factors may suggest that these generic frequencies ought to be modified to make them specific to the local conditions. These factors include the physical characteristics of the equipment, the operating conditions, and characteristics of the management system in place. Factors related to the physical characteristics and operating conditions could include:

- Design code
- Material of construction
- Fluid inside equipment
- Operating pressure
- Operating temperature
- Operating environment
- Cold or hot weather
- Equipment age
- Seismic activity
- Integrity status
- Process continuity
- Stress cycling
- Welds
- Radiography

Many of these are addressed in Section 8.3 of API 581 1st ed. [14], discussed in Section 3.5.2. Some more specific factors relating to inter-unit piping and flanges are presented in Sections 3.5.3 (piping) and 3.5.5 (flanges). The influence of safety management, well recognized as influencing release rates, is discussed in Section 3.5.3.

3.5.2 API 581 Approach

3.5.2.1 1st Edition

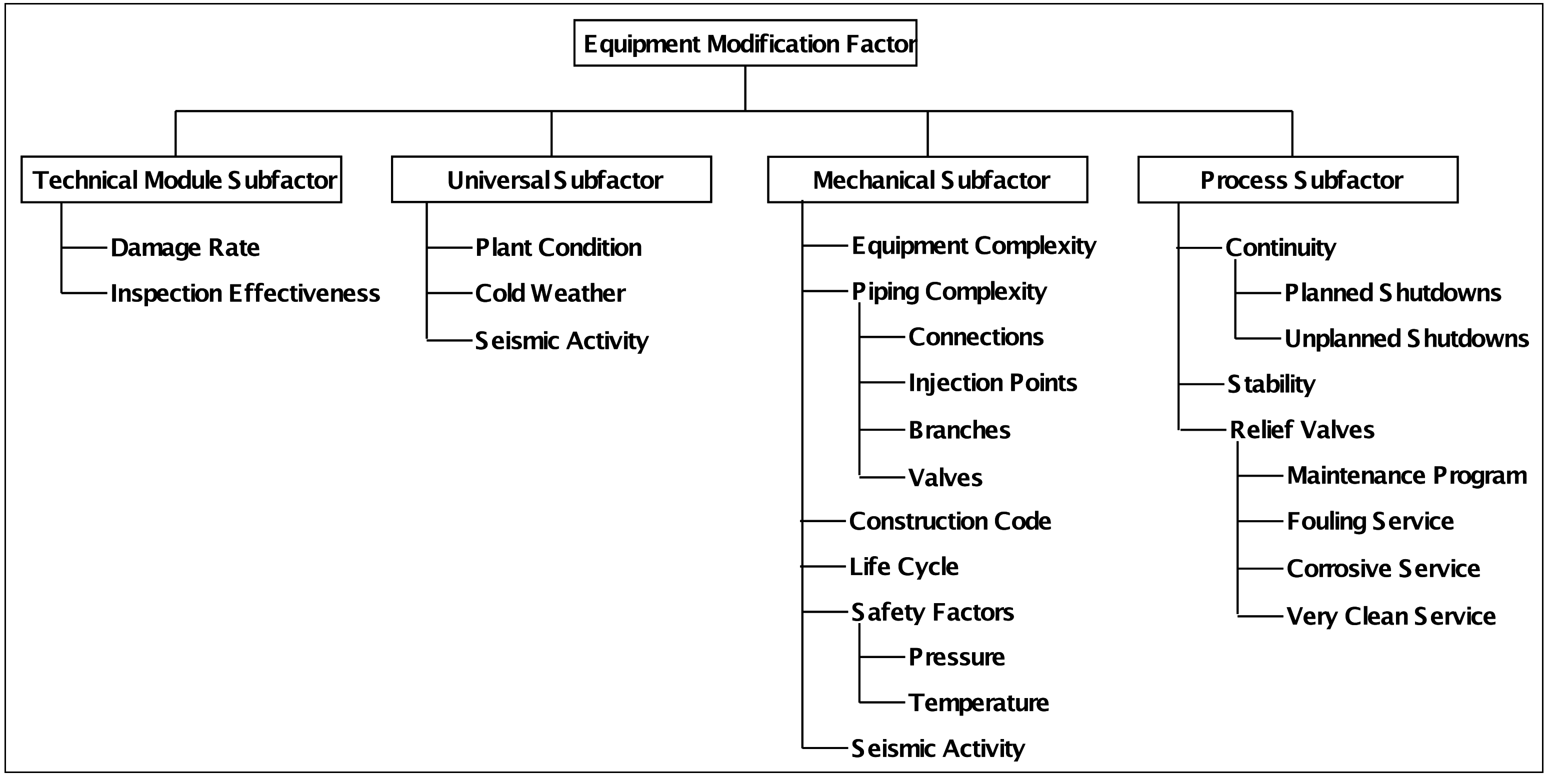
An equipment modification factor is developed for each equipment item, based on the specific environment in which the item operates. This factor is composed of four subfactors illustrated in Figure 3.1. These subfactors are summarised as follows:

- The **Technical Module Subfactor** is the systematic method used to assess the effect of specific failure mechanisms on the likelihood of failure. The module evaluates:
  1. The deterioration rate of the equipment item's material of construction (i.e. corrosion), resulting from its operating environment.
  2. The effectiveness of the facility's inspection programme to identify and monitor the operative damage mechanisms prior to failure.
- The **Universal Subfactor** covers conditions that equally affect all equipment items in the facility: plant condition, cold weather operation, and seismic activity.
- The **Mechanical Subfactor** addresses conditions related primarily to the design and fabrication of the equipment item.
- Conditions that are most influenced by the process and how the facility is operated are included in the **Process Subfactor**.

The API 581 document provides full details of how the four factors can be evaluated individually and combined to obtain the overall equipment modification factor for each equipment item. This can then be applied to the generic frequencies given in Section 2.0[4].

[4] However, it should be noted that Section 8.2 of API 581 includes generic leak frequencies for many of the equipment types covered in this Datasheet. The factors are presumably intended to be used with those frequencies, although there is nothing to suggest that this is obligatory. Hence the equipment modification factor approach set out in API 581 is considered suitable for more detailed analysis based on the generic frequencies presented in this datasheet.

Figure 3.1 Overview of Equipment Modification Factor (from API 581 1st ed.)



3.5.2.2 Possible Changes for 2nd Edition

The 2nd edition is currently out for consultation with interested parties so its final content is not fixed. However, some of the proposed changes affect the approach summarised in Section 3.5.2.1 as follows:

- **Parts of the universal and mechanical subfactors will be removed.**
- **The entirety of the process subfactor will be removed.**
- **Additional factors will be introduced to address very specific issues:**
  - **Thinning**
  - **Component lining damage**
  - **Stress corrosion cracking**
  - **External corrosion**
  - **Brittle fracture**
  - **Embrittlement**
  - **Piping mechanical fatigue**

Users of the API 581 1st edition approach are recommended to apprise themselves of changes in the 2nd edition, which will be finalised subsequent to the issue of this datasheet.

3.5.3 Safety Management

The quality of operation, inspection, maintenance etc is a critical influence on release frequencies, as illustrated by the Flixborough accident (Section 2.4). The selected pipe release frequencies reflect safety management in UK offshore installations during 1992-2006, which is believed to be a good modern standard. The release frequencies at plants with lesser standards may be much higher.

In order to reflect the standard of safety management at an individual plant, it is possible to quantify this using a safety management audit, and convert the audit score into an overall management factor (MF), by which all the generic failure frequencies can be multiplied. Due to lack of experience with this technique, the relationship between the audit scores and management factors is highly speculative. Several such techniques have been used, of which the most recent studies [11][12] suggest that MF values should lie between 0.1 and 10.0 (i.e. from 10 times better than average to 10 times worse than average)[5].

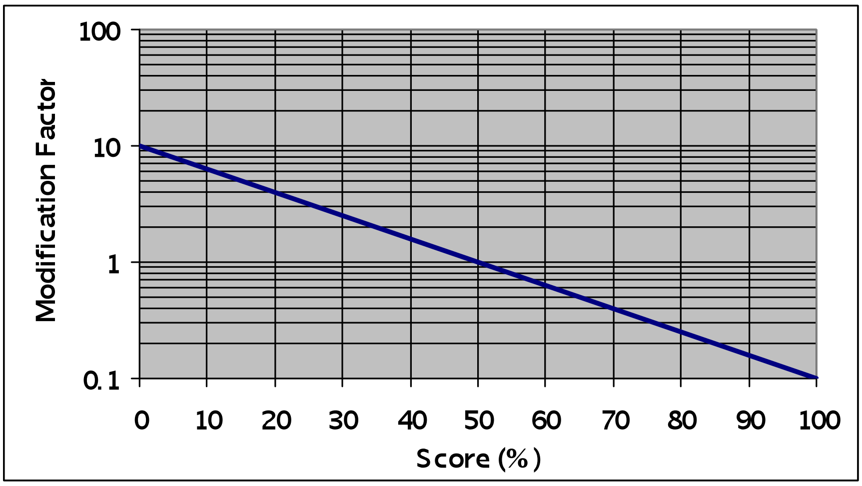
API 581 [14] provides a management systems evaluation audit scheme, summarised in Section 8.4 and set out in full in a workbook forming Appendix III. The subject areas, from the OSHA PSM standard [14], are:

- **Leadership and administration**
- **Process safety information**
- **Process hazard analysis**
- **Management of change**
- **Operating procedures**
- **Safe work practices**
- **Training**
- **Mechanical integrity**
- **Pre-startup safety review**
- **Emergency response**
- **Incident investigation**
- **Contractors**
- **Audits**

[5] Although it has been suggested [13] that the degradation in plant condition that occurred at Bhopal as a result of safety management deficiencies led to the risk of a major accident increasing by a factor of 1000.

The audit comprises 101 questions, and the answers are scored to obtain a percentage. This is converted to a management factor that applies to the whole unit or facility studied. The conversion is based on assuming, first, that an "average" US petrochemical plant would score 50%, giving a management factor of 1 (i.e. generic frequencies, which are multiplied by this factor, are unchanged). A "perfect" score of 100% would yield an order of magnitude reduction in total unit risk, i.e. a factor of 0.1. A score of 0% would result in an order of magnitude increase in total unit risk, i.e. a factor of 10. Figure 3.2 shows the resulting conversion graph.

Figure 3.2 Frequency Moification Factor vs. Management System Evaluation (API 581)



Note that the scoring is stated to be against an "average US petrochemical plant". Since the frequencies presented in Section 2.0 are based on offshore UKCS data, it should *not* be assumed that safety management in that environment is comparable with that on an average US petrochemical plant. However, no comparative study and corresponding conversion system has been developed for offshore UK, hence use of this system requires some care and guidance is beyond the scope of this datasheet.

3.5.4 Inter-unit piping

The frequencies given in datasheet 1 for steel piping are, for onshore installations, intended to be applied within process units. For piping linking process units (inter-unit pipe) and piping to/from storage or loading facilities (transfer pipe), the following release frequency modification factors can be applied:

- **Inter-unit pipe: 0.9**
- **Transfer pipe: 0.8**

These have been derived from detailed analysis of the causes of piping failure [5] and application to this analysis of judgemental modifications to account for the differences in inter-unit and transfer pipes [6].

3.5.5 Flanges

Studies [7], [8] of the effect of flange type on flange failure frequency developed modification factors to the frequencies presented on datasheet 2. These functions should be applied when performing detailed risk analyses where the flange types are known, alternatively as decision input to design when flange types are to be decided. The flange types considered are:

- **ANSI Ring Joint**
- **ANSI Raised faced**
- **Compact flange**
- **Grayloc flange.**

The release frequency for each flange type is based on the release frequency for flange from HCRD data. HCRD data for flanges include ring joint, spiral wound, Grayloc and hammer union, but the contribution from each type can not be identified from the flange frequency. The ANSI Ring Joint, at this time the most common flange type, is assumed to be represented by the HCRD data for flanges.

Because different flanges will have different failure modes, and thereby both different release frequencies and different distribution of release frequencies, dependent on hole size or release rate, the release frequency for the different flange types will be adjusted relative to the release frequency for ANSI Ring Joint flanges. The resulting modification factors are set out in Table 3.1.

Table 3.1 Release Frequency Modifications for Different Flange Types

Flange type	Hole diameter range (mm)	Modification
ANSI Ring Joint	1-3	None
	3-10	None
	10-50	None
	50-150	None
	>150	None
ANSI Raised Face	1-3	10% of total flange release frequency
	3-10	10% of total flange release frequency
	10-50	30% of total flange release frequency
	50-150	30% of total flange release frequency
	>150	20% of total flange release frequency
Compact	1-3	× 0.062
	3-10	× 0.062
	10-50	× 0.062
	50-150	× 0.991
	>150	× 0.991
Grayloc	1-3	× 0.064
	3-10	× 0.064
	10-50	× 0.064
	50-150	× 1.020
	>150	× 1.020

4.0 Review of data sources

4.1 Basis of data presented

The release frequencies for the main process equipment items presented in Section 2.0 are based on an analysis of the HSE hydrocarbon release database (HCRD) for 1992-2006 [9], according to a methodology described in [4]. An overview of this methodology is given in Section 4.1.2.

The HSE hydrocarbon release database (HCRD) has become the standard source of release frequencies for offshore QRA and provides a large, high-quality collection of release experience, now available on-line. All offshore releases of hydrocarbons are required to be reported to the HSE Offshore Safety Division (OSD) as dangerous occurrences under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 (RIDDOR), which became effective offshore on 1 April 1996. The Hydrocarbon Releases (HCR) system contains detailed voluntary information on offshore hydrocarbon release incidents supplementary to that provided under RIDDOR (and previous offshore legislation that applied prior to April 1996). The database contains reports of 3824 releases dating from 1 October 1992 to 31 March 2006, of which 2551 relate to the equipment types addressed in this datasheet.

The database is considered to be "high-quality" on a combination of two features:

- The equipment population is believed to be highly accurate
- The incident population is believed to be reasonably complete, and not to suffer so much from the under-reporting of small incidents that often occurs

Hence it has been selected in preference to other data sources discussed in Section 4.2.

4.1.1 Summary of release statistics

Table 4.1 summarises the number of releases and exposure (population) for each equipment type represented in the HSE HCRD.

Table 4.1 Summary of Release Statistics for HSE HCRD 1992-2006

Equipment type	All Releases	Releases excluding < 1 mm	Exposure
1. Steel process pipes	700	646	5,958,814 pipe metre years
2. Flanges	327	298	3,368,520 flange joint years
3. Manual valves	175	154	1,498,038 valve years
4. Actuated valves	264	221	329,562 valve years
5. Instrument connections	528	442	749,786 instrument years
6. Process (pressure) vessels	42	37	17,494 vessel years
7. Pumps: Centrifugal	126	110	14,564 pump years
8. Pumps: Reciprocating	21	19	2,652 pump years
9. Compressors: Centrifugal	40	33	3,110 compressor years
10. Compressors: Reciprocating	43	36	507 compressor years
11. Heat exchangers: Shell & Tube, shell side	18	14	3,398 exchanger years
12. Heat exchangers: Shell & Tube, tube side	26	21	6,165 exchanger years
13. Heat exchangers: Plate	31	30	2,865 exchanger years
14. Heat exchangers: Air-cooled	5	2	1,069 exchanger years
15. Filters	48	47	12,495 filter years
16. Pig traps	29	28	3,994 pig trap years

4.1.2 Methodology for obtaining release frequencies

The method of obtaining release frequencies from HCRD consists of three main steps:

- Grouping data for different types and sizes of equipment, where there is insufficient experience to show significant differences between them.
- Fitting analytical frequency functions to the data, in order to obtain a smooth variation of release frequency varying with equipment type and hole size. For some equipment types the influence of equipment size can also be inferred.
- Splitting the release frequencies into the different release scenarios described above (Sections 1.0, 3.3).

The release size distribution is represented by an analytical frequency function [2], which ensures non-zero release frequencies for all holes sizes between 1 mm and the diameter of the inlet pipe. In the case where the frequency depends on the equipment size (Steel process pipes, Flanges, Manual valves), the function is of the general form:

$$F(d) = C(1 + aD^n)d^m + F_{rup}$$

where:	$F(d)$	**= frequency per year of releases exceeding size** d **(mm)**
	D	**= equipment diameter**
	F_{rup}	**= rupture frequency per year**
	C,a,m,n	**= constants specific to the equipment type and release scenario**

In the case where the frequency does not depend on the equipment size the function is of the simpler general form:

$$F(d) = Cd^m + F_{rup}$$

where the symbols have the same meanings as above.

The function can then be used to calculate the frequency of a release in any size range (such as the ranges used in Section 2.0) d_1 **to** d_2 **as** $F(d_1) – F(d_2)$**.**

The rupture frequency F_{rup} **and constants** C,a,m,n **referred to above are derived by a combination of mathematical curve fitting and expert judgment.**

4.1.3 Uncertainties in release frequencies

Uncertainties in the estimated release frequencies arise from three main sources:

- **Incorrect information in HCRD about the releases that have occurred. This included the possibility of under-reporting of small releases, errors in measuring the hole diameter or estimating the quantity released etc. Although the data in HCRD appears to be of unusually high quality, the possibility of bias or error is recognized.**
- **Inappropriate categorisation of the releases into the different scenarios.**
- **Inappropriate representation of the release frequency distributions by the fitted release frequency distributions. This results in part from the small datasets, but also from the simplifications inherent in the chosen functions, and their use to extrapolate frequencies in areas where no releases have yet been recorded.**

Sensitivity tests have been carried out [4] on the release frequency functions. The sensitivity tests indicated that the results are sensitive to:

- **The choice of isolation and blowdown times.**
- **The accuracy of the recorded release quantities.**
- **The treatment of cases where the inventory is not recorded.**

4.1.4 Comparison with experience

A comparison has been made between historical release frequencies for a North Sea platform and the corresponding frequencies predicted by the model described in the preceding sub-sections. The results are set out in Table 4.2.

Table 4.2 Comparison of Predicted Release Frequencies with Historical Experience for One North Sea Platform

Data Source	Release Category	Release Rate (kg/s)	Gas Release Frequency (/year)			
			Full Releases	Limited Releases	Zero Pressure Releases	TOTAL
Historical data	Small	0 – 1	N/A	N/A	N/A	1.3×10^{-1}
	Medium	1 – 10	N/A	N/A	N/A	0
	Large	> 10	N/A	N/A	N/A	0
	TOTAL	All	N/A	N/A	N/A	1.3×10^{-1}
HCRD (see Note below)	Small	0 – 1	6.0×10^{-2}	3.3×10^{-2}	5.1×10^{-3}	1.4×10^{-1}
	Medium	1 – 10	2.4×10^{-2}	5.6×10^{-2}	0	8.0×10^{-2}
	Large	> 10	6.0×10^{-3}	3.8×10^{-2}	0	4.4×10^{-2}
	TOTAL	All	9.1×10^{-2}	1.4×10^{-1}	3.4×10^{-2}	2.7×10^{-1}

Note: Frequencies as predicted by model described in the preceding sub-sections, based on HCRD data up to 2003.

From the comparison in Table 4.2, the following observations and conclusions were made:

- Compared to the original risk analysis frequencies, based on data from a 1995 analysis, the new total release frequencies estimated based on the HRCD data are reduced significantly, by about 84%.
- Compared to the adjusted risk analysis frequencies, the new total release estimated based on the HRCD data are reduced significantly, by about 71%.
- Compared to the historical release frequencies, the new total and full release frequencies estimated based on the HRCD data are within a factor of about 2 (noting that the platform concerned had only one recorded release during the period of operation considered, introducing uncertainty into the estimate of the true historical rate).

4.1.5 Conclusions

Others have also analysed the HCRD and obtained different functional forms for the release frequencies. However, the release scenarios identified in Section 1.0 provide:

- A plausible representation of the different circumstances in which releases have been found to occur;
- A model that ensures the frequencies of "full" releases (typically modelled in all QRAs) are not over-estimated;
- A model that, overall, is consistent with experience.

On this basis, the data tabulated in Section 2.0 are presented as the best available analysis of the best available data.

4.2 Other data sources

A large number of other data sources and analyses of process release frequencies were analysed previously. These are listed in Section 6.2 (not all of these address all the equipment types for which frequencies are given in Section 2.0).

5.0 Recommended data sources for further information

For further information, the data sources used to develop the release frequencies presented in Section 2.0 and discussed in Sections 3.0 and 4.0 should be consulted. These references are shown in bold in Section 6.1.

6.0 References

6.1 References for Sections 2.0 to 4.0

The principal references are shown in bold; the others were used to provide supplementary information.

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