Appendix A
Latin Hypercube Sampling Program

This appendix presents the user manual for the FORTRAN computer program LHSAP. The input data file "SAMPLING.INP" is prepared. The sampling results are stored in the output data file "SAMPLING.OUT." To confirm the accuracy of the probability density distribution, the sampling data are also stored in the "DISTRIBUTION.OUT" file.

In this program, a total of 15 types of probability density function (PDF) are considered. They are defined in Table A.1. For a Gamma function defined in Eq. (2.19), the closest other type of PDF may approximately be used for sampling.

The input data variables used in the LHSAP program are defined as follows:

(1) IV is the number of parameters affecting the event.
(2) IS is the number of event scenarios to be selected.
(3) LHSOPT is the Latin hypercube option. If LHSOPT = 1, both the scenario sampling and density distribution data are provided. If LHSOPT = 0, then only the scenario sampling is provided.

In (4) to (9) below, variables are iteratively defined for each of the parameters affecting the event, with IV defined in (1).

(4) IFU is the number of functional components when the PDF is composed of multiple discrete components.
(5) IFTYPE is the type of PDF, as defined in Table A.1.
(6) NC is the number of coefficients.
(7) CSTART is the smallest value of the distribution range.
(8) CEND is the largest value of the distribution range.
(9) Ci are the coefficients of the corresponding PDF defined in Table A.1.

The format of the SAMPLING.INP file is provided below.

```
JOB TITLE
<Blank>
NUMBER OF PARAMETERS AFFECTING THE EVENT
```

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Table A.1 Types of PDFs considered in the LHSAP program

Type	Function	Equations	Type	Function	Equations	Type	Function	Equations
1	Constant	(2.4)	6	Trigonometrical sine	(2.9)	11	Normal	(2.14)
2	Linear	(2.5)	7	Trigonometrical cosine	(2.10)	12	Weibull	(2.15)
3	2nd polynomial	(2.6)	8	Trigonometrical tangent	(2.11)	13	Lognormal	(2.16)
4	3rd polynomial	(2.7)	9	Exponential	(2.12)	14	Logistic	(2.17)
5	4th polynomial	(2.8)	10	Natural logarithm	(2.13)	15	Log-logistic	(2.18)

```
IV
NUMBER OF EVENT SCENARIOS
IS
DEFINITION OF PROBABILITY DENSITY FUNCTIONS
<Blank>
PARAMETER #1
NUMBER OF FUNCTIONAL COMPONENTS
IFU
TYPE OF PDF, NO. OF COEFFICIENTS, START, END AND COEFFICIENTS
IFTYPE,NC
CSTART,CEND,C1,C2…
<Blank>
PARAMETER #2
NUMBER OF FUNCTIONAL COMPONENTS
IFU
TYPE OF PDF, NO. OF COEFFICIENTS, START, END AND COEFFICIENTS
IFTYPE,NC
CSTART,CEND,C1,C2…
<Blank>
PARAMETER #3
NUMBER OF FUNCTIONAL COMPONENTS
IFU
TYPE OF PDF, NO. OF COEFFICIENTS, START, END AND COEFFICIENTS
IFTYPE,NC
CSTART,CEND,C1,C2…
<Blank>
…..
```

Consider an applied example in which three parameters affect an event and 50 event scenarios are to be selected. The PDFs are defined as follows:

Parameter #1 with a linear function with three functional components:

$$f(x) = \begin{cases} -12x + 4.0 & (0.0 \leq x \leq 0.3) \\ 0.4 & (0.3 < x \leq 0.9) \\ x^2 - 3x + 2.29 & (0.9 < x \leq 1.0) \end{cases} \tag{A.1}$$

Parameter #2 with a normal function with one functional component:

$$f(x) = \frac{1}{\sqrt{2\pi} C_2} \exp\left[\frac{-(x - C_1)}{2C_2^2}\right] \quad (0.0 \leq x \leq 10), C_1 = 45.5, C_2 = 15.7 \tag{A.2}$$

Parameter #3 with a two-parameter Weibull function with one functional component:

$$f(x) = \frac{C_2}{C_1}\left(\frac{x}{C_1}\right)^{C_2-1} e^{-\left(\frac{x}{C_1}\right)^{C_2}} \quad (0.0 \le x \le 5.0), C_1 = 1.87, C_2 = 0.078 \tag{A.3}$$

In this case, the input data file SAMPLING.INP is defined as follows:

```
APPLIED EXAMPLE OF EVENT SAMPLING


NUMBER OF PARAMETERS AFFECTING THE EVENT
3
NUMBER OF EVENT SCENARIOS
50
DEFINITION OF PROBABILITY DENSITY FUNCTIONS


PARAMETER #1
NUMBER OF FUNCTIONAL COMPONENTS
3
TYPE OF PDF, NO. OF COEFFICIENTS, START, END AND COEFFICIENTS
2,2,0.0,0.3,-12.0,4.0
1,1,0.3,0.9,0.4
3,3,0.9,1.0,1.0,-3.0,2.29


PARAMETER #2
NUMBER OF FUNCTIONAL COMPONENTS
1
TYPE OF PDF, NO. OF COEFFICIENTS, START, END AND COEFFICIENTS
11,2
0.0,10.0,45.5,15.7


PARAMETER #3
NUMBER OF FUNCTIONAL COMPONENTS
1
TYPE OF PDF, NO. OF COEFFICIENTS, START, END AND COEFFICIENTS
12,2
0.0,5.0,1.87,0.078
```

Appendix B
Passive Fire Protection Materials

Passive fire protection (PFP) schemes are applied in structures and infrastructures to mitigate the increase in their temperatures during fires. In fire engineering, PFP behavior in fires is modelled using temperature-dependent thermal conductivity and specific heat to highlight the thermal effects of PFP.

The types of insulation in the most commonly used fireproofing materials in the petroleum industry can be categorized as active and inactive insulation. Active insulation undergoes chemical and physical changes when exposed to fire, whereas inactive insulation does not. A typical material categorized as providing active insulation is epoxy. A typical material categorized as providing inactive insulation is cement. PFP materials are sorted into epoxies, cements, and panels. The main performance criteria of these materials are provided in Table B.1.

Epoxy-type PFP materials provide active insulation either by intumescence or sublimation. They are generally available in multiple-part mixtures for spray application. However, they can be purchased in prefabricated panels that can be bolted in place. Epoxy-type PFP is shown in Fig. B.1. Its features are shown in Table B.2. Epoxy-type PFP is widely used offshore for structural members, external

Table B.1 Main performance criteria of PFP materials

Criteria	Epoxies	Cements	Panels
Insulation behavior	Active	Inactive	Inactive
Durability	Good	Fair	Poor
Explosion resistance	Good	Poor	Fair
Fire performance	Good	Good	Poor to fair
Reaction in a fire	Toxic gas	Safe	Safe
Installation requirement	Average	Average	Easy
Cost	Very high	Moderate	Low to moderate
Applicability	Wide range	Wide range	Partitions

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Fig. B.1 Epoxy-type PFP

Table B.2 Features of epoxy-type PFP

Advantages	Disadvantages
• Superior performance to hydrocarbon fires and jet fires • Superior resistance to explosions, environments, and chemicals, good mechanical strength, and elasticity modules against steel expansion • Good adherence and normally no maintenance requirement, does not require top coating or anti-corrosion paints, and corrosion free • Lightweight and can be easily applied to complex shapes	• Release of possibly toxic smoke by chemical reaction • Minimum temperature requirement of 200–300 °C for high efficiency • Intumescent coatings can be sensitive to exposure to chemicals, temperature variations, and UV waves • Expensive, specially subliming material, and application by qualified specialists required

Fig. B.2 Cementitious-type PFP

Table B.3 Features of cementitious-type PFP

Advantages	Disadvantages
• Incombustible, and therefore quite stable under fire conditions and does not emit toxic smoke when exposed to fire • Easy to repair, cheap material, and can be easily applied to complex shapes	• May cause corrosion of the steelworks to which it is attached • Poor blast resistance, weak resistance to mechanical, chemical, and climate aggression, and top coat necessary • Weight, mesh is imperative

decks and roofs, underside decks, equipment enclosures, pipe work, and risers. However, it is prohibited inside buildings or enclosed areas where personnel may be present and need to stay or pass through in a fire situation.

Cementitious-type PFP materials provide inactive insulation. They are generally mixed as slurry and spray-applied. They can also be purchased in prefabricated panels that can be bolted in place. Cementitious-type PFP is widely used onshore and applied onto structural members (inside modules), evacuation escape rescue equipment and enclosures, pressure vessels, and supports. However, cementitious-type PFP is not acceptable for offshore use. Cementitious-type PFP is shown in Fig. B.2. Its features are shown in Table B.3.

Prefabricated panels are generally made of ceramic or mineral fibers and are supported by a rigid steel or cement slab. They can use other PFP materials, such as epoxies, cements, or composites. Prefabricated panels are protected from cellulosic fires outside of restricted areas, internal enclosures for equipment, buildings, and enclosures in dry climates. Their features are shown in Table B.4.

As gypsum board is a porous material, heat transfer through gypsum is a combination of all three modes: conduction through a solid and convection and radiation through pores. Therefore, the effective thermal conductivity of gypsum should include these effects. This effective thermal conductivity can be affected by many factors, such as temperature, density, moisture content, and the porosity of the material. Assuming gypsum is made of a solid substrate and uniformly distributed spherical pores, its effective thermal conductivity can be demonstrated in three parts: (1) constant thermal conductivity up to 95 °C before water evaporation, equal to that at ambient temperature; (2) linear decrease in conductivity to 0.1 W/(m °C)

Table B.4 Features of prefabricated panels

Advantages	Disadvantages
• Good resistance to blasts and chemicals and normally maintenance free • Light weight, can be easily removed, and inexpensive	• Incompatible with direct exposure to hydrocarbon fires • Fibers decompose when exposed to fire, especially with organic binders, and fiberglass melts and drips under fire conditions at approximately 300 °C • Moisture absorption induces corrosion on the steelworks to which they are attached

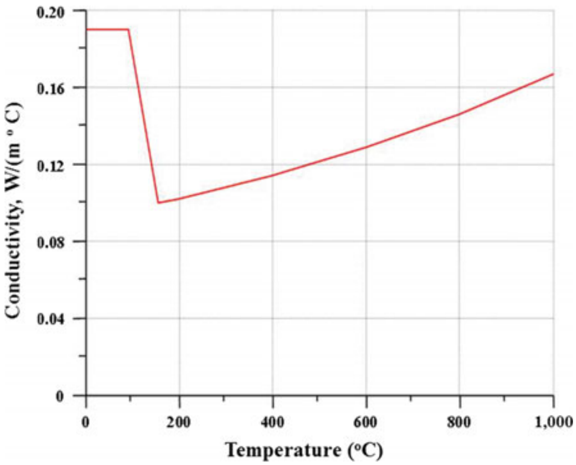

Fig. B.3 Temperature-dependent thermal conductivity of gypsum board

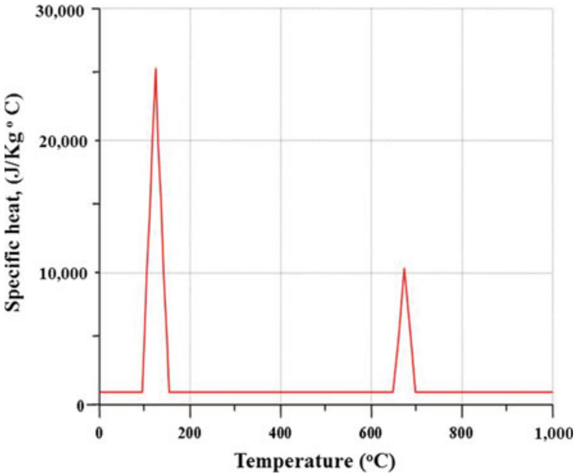

Fig. B.4 Temperature-dependent specific heat of gypsum board

at 155 °C; and (3) nonlinear increase in thermal conductivity based on the density and porosity of the material. The thermal properties of gypsum board are shown in Figs. B.3 and B.4.

Appendix C
SI Units

C.1—SI Unit Prefixes

Exa (E) = 10^{18}	Deci (d) = 10^{-1}
Peta (P) = 10^{15}	Centi (c) = 10^{-2}
Tera (T) = 10^{12}	Milli (m) = 10^{-3}
Giga (G) = 10^{9}	Micro (μ) = 10^{-6}
Mega (M) = 10^{6}	Nano (n) = 10^{-9}
Kilo (k) = 10^{3}	Pico (p) = 10^{-12}
Hecto (h) = 10^{2}	Femto (f) = 10^{-15}
Deca (da) = 10	Atto (a) = 10^{-18}

Conversion Factors

Quantity	SI unit	Other unit	Inverse factor
Length	1 m = 1000 mm	3.28084 feet (ft)	1 ft = 0.3048 m
	1 cm = 10 mm	0.393701 inch (in)	1 inch = 2.54 cm
	1 km = 1000 m	0.539957 nautical mile (nm)	1 nm = 1.852 km
		0.621371 mile	1 mile = 1.609344 km
Area	1 m^2	10.7639 ft^2	1 ft^2 = 0.09290304 m^2
	1 mm^2	0.00155 in^2	1 in^2 = 645.16 mm^2

(continued)

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(continued)

Quantity	SI unit	Other unit	Inverse factor
Volume	1 m^3 1000 cm^3 = 1 L	35.3147 ft^3 0.219969 gal (UK) 0.264172 gal (US) 1 bushel (UK) = 8 gal (UK)	1 ft^3 = 0.0283168 m^3 1 gal (UK) = 4.54609 L 1 gal (US) = 3.78541 L 1 gal (UK) = 0.125 bushel (UK)
		1 barrel (US) = 42 gal (US)	1 gal (US) = 0.02381 barrel (US)
Mass	1 kg	2.20462 lb (lb)	1 lb = 0.45359237 kg
	1 mg	0.0154323 grain (gr)	1 gr = 64.79891 mg
	1 g	0.035274 oz (oz)	1 oz = 28.3495 g
	1 tonne	0.984204 long tonne (LT) (UK) 1.10231 short tonne (ST) (US)	1 LT = 1.01605 tonne 1 ST = 0.907185 tonne
Velocity, speed	1 m/s = 3.6 km/h	3.28084 ft/s	1 ft/s = 0.3048 m/s
		2.23694 mile/h	1 mile/h = 0.44704 m/s
		1.94384 knot (kt) (meter system)	1 kt (meter system) = 0.514444 m/s
		1.94260 knot (kt) (yard–pound system)	1 kt (Yard-Pound system) = 0.514773 m/s
Speed-length ratio	$1\,\frac{\mathrm{m/s}}{\sqrt{m}}$	0.31933 Froude no. $(V/\sqrt{Lg})$	1 Froude no = 3.13156 $\frac{\mathrm{m/s}}{\sqrt{m}}$
		1.94384 $\frac{\mathrm{kt}}{\sqrt{m}}$	$1\,\frac{\mathrm{kt}}{\sqrt{m}} = 0.51444\,\frac{\mathrm{m/s}}{\sqrt{m}}$
		1.07249 $\frac{\mathrm{kt}}{\sqrt{ft}}$	$1\,\frac{\mathrm{kt}}{\sqrt{ft}} = 0.93241\,\frac{\mathrm{m/s}}{\sqrt{m}}$
Acceleration	1 m/s^2	100 cm/s^2(Gal) 0.101972 G	1 Gal = 0.01 m/s^2 1 G = 9.80665 m/s^2
Density	1 kg/m^3	3.61273×10^{-5} lb/in^3 1.00224×10^{-2} lb/gal (UK) 8.3454×10^{-3} lb/gal (US)	1 lb/in^3 = 2.76799×10^4 kg/m^3 1 lb/gal (UK) = 99.7764 kg/m^3 1 lb/gal (US) = 119.826 kg/m^3
Kinematic viscosity	1 m^2/s	10.7639 ft^2/s	1 ft^2/s = 9.2903×10^{-2} m^2/s
Force	1 N	0.101972 kgf 0.1 Mdyn 0.224809 lbf	1 kgf = 9.80665 N 1 Mdyn = 10 N 1 lbf = 4.44822 N

(continued)

(continued)

Quantity	SI unit	Other unit	Inverse factor
Pressure	1 Pa = 1 N/m^2 = 1.01972 × 10^{-5} kgf/cm^2	1.45038 × 10^{-4} lbf/in^2 (psi) 1.0 × 10^{-5} bar 9.86923 × 10^{-6} atm	1 psi = 6894.76 Pa 1 bar = 1.0 × 10^5 Pa 1 atm = 1.01325 × 10^5 Pa
Stress	1 N/mm^2 = 1 MPa = 0.101972 kgf/mm^2, 1 kgf/mm^2 = 9.80665 MPa		
	1 N/mm^2	145.038 lbf/in^2	1 lbf/in^2 = 6.89476 × 10^{-3} MPa
Impact value	1 J/cm^2 = 0.101972 kgf·m/cm^2	4.75845 lbf·ft/in^2	1 lbf·ft/in^2 = 0.210152 J/cm^2
Energy	1 J = 1 N·m, 1 kJ = 101.972 kgf·m, 1 kgf m = 9.80665 J		
	1 kJ	737.563 lbf ft 0.238889 kcal	1 lbf ft = 1.35582 × 10^{-3} kJ 1 kcal = 4.18605 kJ
Power	1 kW = 101.972 kgf m/s, 1 kgf·m/s = 9.80665 × 10^{-3} kW		
	1 kW	1.35962 PS (meter system)	1 PS (meter system) = 0.7355 kW
		1.34102 HP (yard–pound system)	1 HP (yard–pound system) = 7.457 × 10^{-3} kW
		737.562 lbf ft/s	1 lbf·ft/s = 1.35582 × 10^{-3} kW
		0.238889 kcal/s	1 kcal/s = 4.18605 kW
Temperature	°C = (°F – 32) × $\frac{5}{9}$, °F = °C × $\frac{9}{5}$ + 32, K = °C + 273.15		

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