

GUIDANCE ON CONCEPTUAL DESIGN, SELECTION AND LIFE CYCLE  
ASSURANCE OF PRODUCTS INTENDED TO IMPROVE INTEGRITY OF  
BASES OF ABOVE-GROUND STORAGE TANKS HOLDING PETROLEUM,  
PETROLEUM PRODUCTS OR OTHER FUELS

First edition

December 2018

Published by  
**Energy Institute, London**

The Energy Institute is a professional membership body incorporated by Royal Charter 2003  
Registered charity number 1097899

[This is a preview. Click here to purchase the full publication.](#)

The Energy Institute (EI) is the chartered professional membership body for the energy industry, supporting over 20 000 individuals working in or studying energy and 250 energy companies worldwide. The EI provides learning and networking opportunities to support professional development, as well as professional recognition and technical and scientific knowledge resources on energy in all its forms and applications.

The EI's purpose is to develop and disseminate knowledge, skills and good practice towards a safe, secure and sustainable energy system. In fulfilling this mission, the EI addresses the depth and breadth of the energy sector, from fuels and fuels distribution to health and safety, sustainability and the environment. It also informs policy by providing a platform for debate and scientifically-sound information on energy issues.

The EI is licensed by:

- the Engineering Council to award Chartered, Incorporated and Engineering Technician status, and
- the Society for the Environment to award Chartered Environmentalist status.

It also offers its own Chartered Energy Engineer, Chartered Petroleum Engineer, and Chartered Energy Manager titles.

A registered charity, the EI serves society with independence, professionalism and a wealth of expertise in all energy matters.

This publication has been produced as a result of work carried out within the Technical Team of the EI, funded by the EI's Technical Partners. The EI's Technical Work Programme provides industry with cost-effective, value-adding knowledge on key current and future issues affecting those operating in the energy sector, both in the UK and internationally.

For further information, please visit <http://www.energyinst.org>

The EI gratefully acknowledges the financial contributions towards the scientific and technical programme from the following companies

Andeavor	Phillips 66
BP Exploration Operating Co Ltd	Qatar Petroleum
BP Oil UK Ltd	Repsol Sinopec
Centrica	RWE npower
Chevron North Sea Ltd	Saudi Aramco
Chevron Products Company	Scottish Power
Chrysaor	SGS
CLH	Shell UK Oil Products Limited
ConocoPhillips Ltd	Shell U.K. Exploration and Production Ltd
DCC Energy	SSE
EDF Energy	TAQA Bratani
ENI	Total E&P UK Limited
E. ON UK	Total UK Limited
Equinor	Tullow Oil
ExxonMobil International Ltd	Uniper
Innogy	Valero
Kuwait Petroleum International Ltd	Vattenfall
Nexen CNOOC	Vitol Energy
Ørsted	Woodside
Perenco	World Fuel Services

However, it should be noted that the above organisations have not all been directly involved in the development of this publication, nor do they necessarily endorse its content.

Copyright © 2018 by the Energy Institute, London.  
The Energy Institute is a professional membership body incorporated by Royal Charter 2003.  
Registered charity number 1097899, England  
All rights reserved

No part of this book may be reproduced by any means, or transmitted or translated into a machine language without the written permission of the publisher.

ISBN 978 1 78725 055 0

Published by the Energy Institute

The information contained in this publication is provided for general information purposes only. Whilst the Energy Institute and the contributors have applied reasonable care in developing this publication, no representations or warranties, express or implied, are made by the Energy Institute or any of the contributors concerning the applicability, suitability, accuracy or completeness of the information contained herein and the Energy Institute and the contributors accept no responsibility whatsoever for the use of this information. Neither the Energy Institute nor any of the contributors shall be liable in any way for any liability, loss, cost or damage incurred as a result of the receipt or use of the information contained herein.

Hard copy and electronic access to EI and IP publications is available via our website, <https://publishing.energyinst.org>. Documents can be purchased online as downloadable pdfs or on an annual subscription for single users and companies. For more information, contact the EI Publications Team.  
e: [pubs@energyinst.org](mailto:pubs@energyinst.org)

This is a preview. Click here to purchase the full publication.

## CONTENTS

	Page
<b>Foreword</b> .....	<b>9</b>
<b>Acknowledgements</b> .....	<b>10</b>
<b>1 Introduction</b> .....	<b>11</b>
1.1 Introduction .....	11
1.2 Scope .....	13
1.3 Application .....	14
<b>2 Tank failure modes</b> .....	<b>15</b>
2.1 Common primary containment failure modes .....	15
2.2 Tank bottom .....	15
2.2.1 General .....	15
2.2.2 Settlement .....	16
2.2.2.1 Even .....	16
2.2.2.2 Uneven .....	16
2.2.2.3 Edge settlement .....	17
2.2.2.4 Planar tilt .....	17
2.2.2.5 Differential settlement .....	17
2.2.2.6 Other failure modes .....	18
2.2.3 Internal corrosion .....	18
2.2.4 External corrosion .....	18
<b>3 Tank foundations</b> .....	<b>20</b>
3.1 General .....	20
3.2 Granular foundations .....	20
3.2.1 General .....	20
3.2.2 Plain granular foundations .....	20
3.2.3 Sand pad with granular ring .....	21
3.2.4 Sand pad with concrete ring beam .....	21
3.2.5 Shoulders .....	21
3.2.6 Protective coatings .....	22
3.3 Concrete foundations .....	22
3.3.1 Concrete slab on piles .....	22
3.3.2 Concrete slab .....	22
3.3.3 Concrete ring beam .....	23
3.3.4 Assessment of existing concrete slabs .....	23
3.3.5 Interface with floor liner .....	23
<b>4 Secondary containment</b> .....	<b>24</b>
4.1 General .....	24
4.2 Natural clay and soil admixtures .....	24
4.3 Geosynthetic clay liners (GCL) .....	25
4.4 Fibre reinforced linings .....	27
4.5 Geo-membranes .....	28
4.5.1 General .....	28
4.5.2 Polythene: HDPE and LDPE .....	29
4.5.3 Reinforced PVC .....	30
4.5.4 EPDM rubber and butyl rubber .....	30

## Contents continued

	<b>Page</b>
4.5.5 Polyurethane (PU) . . . . .	30
4.5.6 Polypropylene (PP) . . . . .	31
4.6 Concrete . . . . .	31
4.7 Double bottoms in existing tanks . . . . .	31
4.7.1 Construction . . . . .	31
4.7.2 Secondary containment membrane . . . . .	32
4.7.3 Spacer . . . . .	33
4.7.4 Open/closed interstitial space . . . . .	33
4.8 Double bottoms in new tanks . . . . .	33
<b>5 Leak detection systems (LDS) . . . . .</b>	<b>34</b>
5.1 General . . . . .	34
5.2 Effectiveness . . . . .	34
5.2.1 Signal and noise . . . . .	34
5.2.2 Reliability . . . . .	35
5.3 Statistical inventory reconciliation (SIR) . . . . .	35
5.4 Volumetric/mass control . . . . .	36
5.4.1 Volumetric control . . . . .	36
5.4.2 Mass measurement . . . . .	37
5.4.3 Mass balancing . . . . .	37
5.4.4 Factors affecting accuracy . . . . .	37
5.4.5 Key requirements . . . . .	37
5.5 Acoustic emission (AE) . . . . .	38
5.6 Double bottom tank monitoring . . . . .	39
5.6.1 New double bottom tanks . . . . .	39
5.6.1.1 Compartments with vacuums . . . . .	39
5.6.1.2 Leak detection plug . . . . .	40
5.6.2 Retrofit . . . . .	40
5.7 Visual indicators . . . . .	40
5.7.1 Tell-tales and annular drains . . . . .	40
5.7.2 Central sump with remote chamber . . . . .	41
5.8 Liquid sensor systems . . . . .	43
5.8.1 Under-tank . . . . .	43
5.8.2 Monitoring wells . . . . .	44
5.9 Vapour detection systems . . . . .	44
5.9.1 Tank sub-base . . . . .	45
5.9.2 Monitoring wells . . . . .	45
5.10 Optical fibres . . . . .	45
5.11 Chemical fuses . . . . .	46
5.11.1 Tank sub-base . . . . .	46
5.11.2 Monitoring well . . . . .	47
5.12 Tracer/marker detection systems . . . . .	47
5.13 Multiple systems . . . . .	48
<b>6 Base system appraisal and selection . . . . .</b>	<b>49</b>
6.1 Introduction . . . . .	49
6.2 Performance requirements . . . . .	50
6.2.1 Baseline data . . . . .	53
6.2.2 Stakeholder requirements . . . . .	55
6.2.3 Category 1 considerations . . . . .	55

## Contents continued

	<b>Page</b>
6.2.4 Category 2 considerations . . . . .	56
6.2.5 Category 3 considerations . . . . .	59
6.3 Options appraisal. . . . .	74
6.4 Maintenance and operation. . . . .	74
<b>7 Base construction and installation . . . . .</b>	<b>75</b>
7.1 Introduction . . . . .	75
7.2 Pre-installation and planning . . . . .	76
7.2.1 QA/QC procedures. . . . .	76
7.2.2 Identification of potential problems and complex areas or activities . . . . .	77
7.2.3 Methodology . . . . .	77
7.2.4 Communication between parties . . . . .	77
7.2.5 Programming . . . . .	78
7.3 Installation activities. . . . .	78
7.3.1 Introduction . . . . .	78
7.3.2 QA/QC during installation . . . . .	79
7.3.3 Programme management. . . . .	83
7.3.4 Operational management . . . . .	83
7.3.5 Protection during installation . . . . .	84
7.3.6 Feedback from installers. . . . .	85
7.4 Post-installation/pre-commissioning . . . . .	85
<b>8 Operation . . . . .</b>	<b>87</b>
8.1 Introduction . . . . .	87
8.2 Monitoring integrity of secondary containment . . . . .	88
8.3 Monitoring integrity of LDS . . . . .	89
8.4 Monitoring integrity of double bottoms. . . . .	89
8.5 Management of site operations. . . . .	89
8.6 Management of tank maintenance and overhaul. . . . .	90
8.7 Repair and replacement of secondary containment and LDS . . . . .	91
8.8 Documented response procedures. . . . .	91
8.9 Integration with other secondary containment. . . . .	91
8.10 Feedback. . . . .	92
<b>9 Decommissioning . . . . .</b>	<b>93</b>
9.1 Introduction . . . . .	93
9.2 End of use. . . . .	93
9.3 Complete decommissioning. . . . .	94
9.4 Reuse, recycling and disposal. . . . .	94
9.5 Testing and feedback . . . . .	94
<b>Annexes</b>	
<b>Annex A Commentary on relevant GB and European legislation, and international publications. . . . .</b>	<b>95</b>
A.1 Introduction. . . . .	95
<b>Annex B Attributes of secondary containment (liner) . . . . .</b>	<b>105</b>
B.1 Introduction. . . . .	105

## Contents continued

	<b>Page</b>
<b>Annex C Liner selection pro-forma</b> .....	<b>112</b>
C.1 Introduction .....	112
<b>Annex D Attributes of LDSs</b> .....	<b>114</b>
D.1 Introduction .....	114
<b>Annex E LDS product selection pro-forma</b> .....	<b>120</b>
E.1 Introduction .....	120
<b>Annex F Tank base system baseline data</b> .....	<b>121</b>
F.1 Introduction .....	121
<b>Annex G Base system options appraisal</b> .....	<b>123</b>
G.1 Introduction .....	123
G.2 Example of tank liner appraisal, AB Tank farm – tank liner appraisal, O.I.L. co .....	143
G.2.1 Introduction .....	143
G.2.2 HDPE (high density polyethylene) .....	143
G.2.3 GCL (bentonite) liner .....	143
G.2.4 Recommendations (under-tank liners) .....	144
<b>Annex H Routine inspection checklist</b> .....	<b>145</b>
H.1 Introduction .....	145
<b>Annex I Review of existing practice</b> .....	<b>147</b>
I.1 Introduction .....	147
I.1.1 Legislation and guidance .....	147
I.1.2 Currently employed secondary containment techniques .....	149
I.2 Survey respondents .....	149
I.2.1 Number of compliant tanks .....	149
I.2.2 Provision of secondary containment under tanks .....	150
I.2.3 Liner types in use .....	150
I.2.4 Material selection .....	150
I.2.5 Technical issues .....	151
I.2.6 Construction and procurement issues .....	151
I.2.7 Quality assurance and guarantees .....	152
I.2.8 Lessons learned and feedback .....	152
I.2.9 Repairs and overhauls .....	152
I.2.10 Monitoring .....	153
I.2.11 Leak detection above secondary containment .....	153
I.2.12 Industry progress with secondary containment .....	154
<b>Annex J Glossaries of terms, abbreviations and acronyms</b> .....	<b>172</b>
J.1 Introduction .....	172
J.2 Glossary of terms .....	172
J.3 Glossary of abbreviations and acronyms .....	179
<b>Annex K References</b> .....	<b>181</b>

## LIST OF FIGURES, PHOTOGRAPHS AND TABLES

	<b>Page</b>
<b>Figures</b>	
Figure 1	Cone down (top) and cone up (bottom) base systems . . . . . 12
Figure 2	Base system life cycle . . . . . 13
Figure 3A	Factory prehydrated GCL lap detail . . . . . 25
Figure 3B	Dry GCL lap detail . . . . . 26
Figure 4	Laser scan of HDPE rippling during installation . . . . . 30
Figure 5	Double bottom detail . . . . . 32
Figure 6	Leak detection outcomes . . . . . 35
Figure 7	Example of output from AET on tank floor . . . . . 38
Figure 8	Cone down leak detection system for a granular base with HDPE liner . . 42
Figure 9	Hydrocarbon sensor below tank application . . . . . 43
Figure 10	Tracer probe array for a tank . . . . . 48
Figure 11	Base system life cycle stage 1: appraisal and selection . . . . . 49
Figure 12	Performance requirements depicting three categories . . . . . 51
Figure 13	Baseline data . . . . . 54
Figure 14	Base system life cycle stage 2: construction and installation process . . . 75
Figure 15	Base system life cycle stage 3: operation . . . . . 87
Figure 16	Base system life cycle stage 4: decommissioning . . . . . 93
Figure C.1	Liner selection pro-forma . . . . . 112
Figure E.1	LDS pro-forma . . . . . 120
Figure H.1	Example routine inspection checklist . . . . . 145
<b>Photographs</b>	
Photograph 1	Poorly constructed base, allowing water ingress into foundation, leading to potential bottom plate corrosion and tank shell/annular stress. . . . . 16
Photograph 2	New concrete base . . . . . 23
Photograph 3	GCL being installed under jacked-up tank . . . . . 27
Photograph 4	FRP installation . . . . . 28
Photograph 5	FRP curing . . . . . 28
Photograph 6	HDPE new base . . . . . 29
Photograph 7	HDPE retrofit, with tank jacked-up . . . . . 29
Photograph 8	Installation of HDPE liner under jacked-up tank . . . . . 29
Photograph 9	Combined tell-tale and tank drainage (under a tank with no liner). . . . 41
Photograph 10	Annular drain . . . . . 41
Photograph 11a	Central sump before foundation . . . . . 42
Photograph 11b	Constructing a concrete remote inspection chamber . . . . . 42
Photograph 12a	Positioning chemical fuse . . . . . 47
Photograph 12b	Inserting chemical fuse . . . . . 47
Photograph 13	GCL below jacked-up tanks, showing sequencing . . . . . 85
Photograph 14	Management of works during GCL installation . . . . . 85

## List of figures, photographs and tables continued

	<b>Page</b>
<b>Tables</b>	
Table 1	Design criteria – category overview . . . . . 52
Table 2	Category 1 – design criteria . . . . . 56
Table 3	Category 2 – design criteria . . . . . 57
Table 4	Category 3 – design criteria . . . . . 60
Table 5	Key QA/QC issues . . . . . 76
Table 6	Secondary containment installation testing techniques . . . . . 80
Table 7	LDS installation testing techniques . . . . . 83
Table A.1	Relevant GB and European legislation . . . . . 95
Table A.2	Relevant international publications . . . . . 98
Table B.1	Liner comparison . . . . . 105
Table D.1	LDS comparison . . . . . 114
Table F.1	Questions for gathering tank baseline data . . . . . 121
Table G.1	Example liner options appraisal and selection (optioneering) for under-tank application . . . . . 123
Table G.2	Comparison of two specific examples of under-tank liners . . . . . 126
Table I.1	Questionnaire summary . . . . . 153



# 1 INTRODUCTION

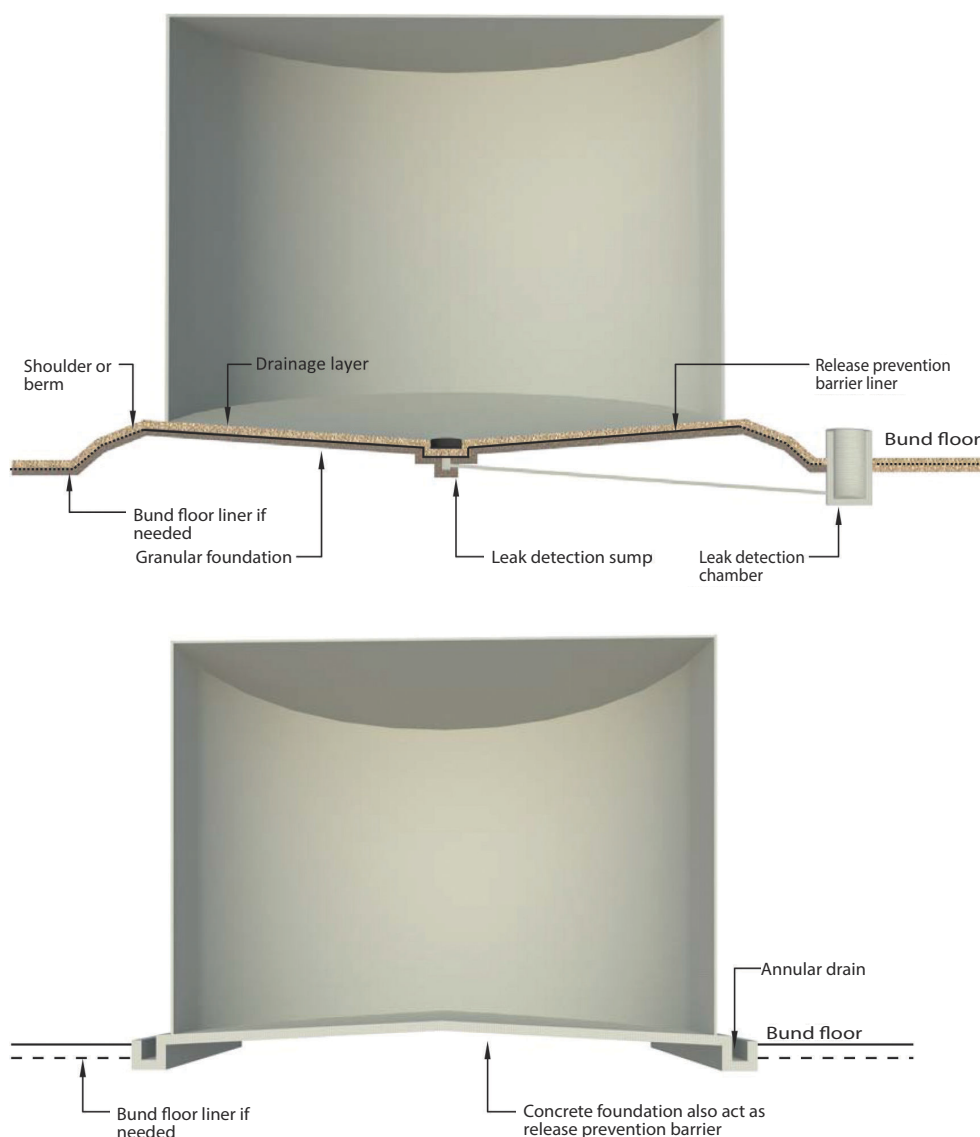
## 1.1 INTRODUCTION

In GB, bulk liquid hazardous product storage sites in the scope of the Control of major accident hazards (COMAH) regulations must comply with COMAH CA *Policy on containment of bulk hazardous liquids at COMAH establishments* ('Containment policy'): this applies primarily to new build installations and new facilities built on existing sites, but it also seeks improvements to existing installations on a risk-based prioritised approach.

The guidance contained in this publication follows the HSE *Process Safety Leadership Group (PSLG) Final report: Safety and environmental standards for fuel storage sites* and complements the EI *Guidance on conceptual design, selection and life cycle assurance of liners intended to improve integrity of bunds to above-ground storage tanks for bulk storage of petroleum, petroleum products or other fuels*, which focuses on bund floor and wall liners, rather than those situated beneath AST.

This publication is intended to build on a shortfall in knowledge regarding options for improving the integrity of ASTs, or tanks hereafter, and their application, which was identified in HSE *PSLG Final report*.

A base system, as referred to throughout this publication, consists of several components: the foundation, below tank secondary containment and a LDS, where installed. These are illustrated in Figure 1.

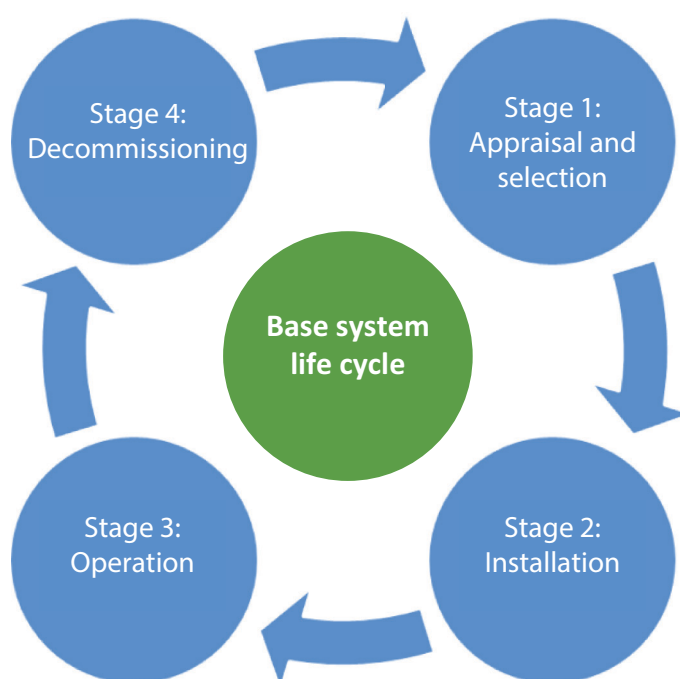


**Figure 1: Cone down (top) and cone up (bottom) base systems**

The first part of the publication (sections 2–5) provides background information on the current situation, as follows:

- main types of tank bottom failure (section 2);
- main types of tank base construction (section 3);
- main forms of secondary containment, including double bottom tanks and under-tank liners (section 4), and
- main LDSs available (section 5).

The rest of this publication is aligned to the life cycle of the tank base system, from the consideration of the design criteria, construction and installation of under-tank containment systems through to operation, including management and monitoring techniques and, finally, decommissioning. Figure 2 illustrates this tank base system life cycle.



**Figure 2: Base system life cycle**

The information is provided as:

- Stage 1: Base system appraisal and selection (section 6).
- Stage 2: Installation, including construction (section 7).
- Stage 3: Operation (section 8).
- Stage 4: Decommissioning (section 9).

Consideration of the four-stage tank base life cycle process in this publication should assist operating companies to maximise the performance of their under-tank secondary containment systems at all stages of the process.

The research upon which this publication is based was carried out in the latter part of 2013 and early 2014, and therefore references to current and existing circumstances and issues relate specifically to that time period.

Annex B and Annex D provide summaries of attributes and selection criteria for secondary containment (liner) types and LDSs. Checklists, *aides mémoire* and examples of option appraisals and quality assurance/quality control (QA/QC) procedures are included in additional annexes.

## 1.2 SCOPE

This publication provides a practical framework and source of information for those involved in the planning, management and operation of bulk storage facilities using AST, where under-tank liners are an important part of the secondary containment design (see Annex B). Whilst