PROGRESS ON GUIDANCE ON FIRES AND EXPLOSIONS

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ABSTRACT

This paper is a review of progress in the development of new guidance in fire and explosion engineering throughout the world.

The three main documents which are currently under development are discussed, compared and contrasted. These are:-

1. The three-phase project sponsored by UKOOA and the HSE to develop updated guidance (1,2) for the treatment of fire and explosion hazards.
2. ISO development of a standard dealing with accidental actions as part of ISO CD/19901-3 (3) .
3. API Recommended Practice (API RP) (4,5) for the Design of Offshore Facilities against Fire and Blast Loading.

Whilst the status, scope and applicability of these documents varies, it is still possible to compare the technical content and approaches in a meaningful way. It is desirable that all three documents should adopt compatible approaches as they reflect the same underlying hazards and confront common issues.

1. INTRODUCTION

It is now twelve years since the results of Phase 1 of the Joint Industry Project on 'Blast and Fire Engineering for Topside Structures' gave rise to the Interim Guidance Notes (6). There have been a number of significant developments since that time, some of which have been published in Technical Notes by the Fire and Blast Information Group (FABIG) (7,8,9,10,11,12) . Since 1992, approximately £40 million has been spent on research and testing resulting in significant technological developments, particularly in the areas of fire and explosion loading.

Other valuable work, mostly executed in Norway and following the probabilistic approach, has resulted in the NORSOK guidance documents, including references 13 and 14 which are also among the source documents for the proposed ISO Standards and the UKOOA Guidance.

The results of these and other major investigations are summarised in the new Engineering Handbook published by Corrocean (15).

In view of the recent maturity of the subject area and the thinking behind the UKOOA decision framework (16), the focus in the UKOOA documents and API RP is turning to more code-based and simpler methods of analysis and assessment, particularly in the early stages of design or assessment projects.

There is now widespread recognition that a multidisciplinary approach to design and assessment is required, involving structural, mechanical, process, control and instrumentation and other engineering disciplines.

For the purposes of discussion the term 'guidance' is taken to include the terms 'standard' and 'recommended practice' in this paper, although it is appreciated that the status of the documents discussed varies significantly. It is possible that before publication of the API and ISO guidance, some reassessment of the detailed points identified in this paper may occur and that the final documents may be modified in some respects.

2. HISTORICAL OVERVIEW

Since 1991, there has been a strong movement away from ad hoc consideration of fire and explosion in design by particular oil companies and their design contractors to a more consensual codes-and-standards approach based on shared industry experience, driven also by regulation. There have been a number of large experimental and research projects which have provided a basis to the new techniques which are now available. These are summarised in Table 2.1.

Philosophy/Management	Frequency/probability of occurrence	Consequences	Date
Interim Guidance Notes		Interim Guidance Notes	1992
SCR ALARP		Phase 2 BFETS	1992-1995
PFEER		FABIG Technical Notes	1995-1997
Inherently Safer Design		Phase 3a (Deluge)	1994-1997
		MEGGE - EMERGE	1992
UKOOA FEHMG			1995
DCR			1996
	GEEJIP		1998
NORSOK			2000
ISO 13702		Dispersion JIP	2000
		FABIG Technical Notes	1998-2002
		Phase 3b (Realistic releases)	2000-2001
	Explosion Handbook		2000-2001
UKOOA Guidance Parts 1 and 2		UKOOA Guidance Part 3	2000-2005

Table 2.1 Major experimental and Research projects, post 1992

The major advances in explosion hazard analysis have been in the understanding of the physical processes involved and the appreciation that the extreme event cannot always be designed against.

A probabilistic approach has enabled design explosion loads to be derived **which can and should be designed against.** This is reflected to a greater or lesser extent in all of the three documents under development.

In the case of fire hazard analysis, probabilistic methods appear to be of lesser importance, as the extreme events are not so disproportionately severe and can largely be prevented or designed against.

In Fire assessment, nominal fire loads and modified code check methods have been in widespread use for some years. Recent developments have given rise to the consideration of similar techniques for application in the explosion case.

2.1 Regulatory requirements

In the United Kingdom and its continental shelf, many of the legal requirements are set out in the Health and Safety at Work, etc Act 1974 and backed up by Regulations. General requirements for all industries are given in the Management of Health and Safety at Work Regulations 1999 (MHSWR), for example, and the more specific offshore requirements of PFEER (Prevention of Fire and Explosions, and Emergency Response Regulations) (24), MAR (Management and Administration Regulations) (26) and DCR (Design and Construction, etc Regulations) (25). Several of the requirements are derived from European Directives.

3. GUIDANCE AND STANDARDS

3.1 UKOOA Guidance

The UKOOA project 'Preparation of updated Guidance for fire and Explosion Hazards' is a three-part project financed by UKOOA and the HSE. The project is being managed by 'fireandblast.com' a company set up specifically for the project.

Part 1 – 'Guidance on design and operational considerations for the avoidance and mitigation of explosions' is now complete, with the document being delivered in December 2002.

Part 2 – 'Guidance on design and operational considerations for the avoidance and mitigation of fires' is currently in preparation.

Part 3 – 'Guidance on Design Practices for Fire and Explosion Engineering' is likely to be the most substantial document and will deal with the detailed implementation of the work described in the previous two parts.

3.2 API RP

In 2001 it was agreed that the existing guidance on fire and blast engineering which formed part of the 21st edition of API Recommended Practice (RP-2A-WSD) should be augmented by a new separate RP on fire and explosion engineering, 'Recommended Practice for the Design of Offshore Facilities against Fire and Blast loading'.

This document is likely to be limited largely to a discussion of consequence assessment, with philosophy and hazard management, including mitigation, dealt with by reference to other API and reference documents.

The required scope of assessment for both conceptual and detailed design may be limited for installations that can be considered less safety-critical. Simplified assessment methods will be described, including the use of nominal loads for certain compartments on an installation.

3.3 ISO 19900

The new suite of ISO codes for offshore structures is currently being prepared by a large number of national and international experts. Some of the codes have already been issued and others are due to be published worldwide between 2004 and 2006. Resistance to fire and explosion is covered particularly in ISO 19901-3 for Topside Structures (3) . This code will apply to the topsides of all types of substructure, including fixed steel and concrete platforms, FPSOs and floating drilling and production vessels. Both the API and ISO codes will make use of the findings of the UKOOA guidance.

The section on Accidental Actions includes requirements and useful guidance on fire and explosion hazard management as well as vessel collision, dropped objects and helicopter crash scenarios. (Natural hazards such as extreme weather and earthquake are dealt with in other codes.). Although the code will have a very wide audience, ISO 19901-3 is written with practising project engineers very much in mind. It makes full use of (and reference to) recently validated research so as to set out the minimum requirements and to indicate current good practice for design. Part of the code is Normative (mandatory), whilst the remainder is Informative to provide additional information about other considerations and to indicate sources of guidance.

Like the API code, which is proceeding in parallel, the ISO code recognises that the significance to life from fire and explosion events depends to a large extent on mitigation by the structural barriers that are fitted to protect the people and safety critical equipment on board an installation.

There is agreement that the ISO codes for offshore structures should apply across the European Union and other countries in place of any specific European (CEN) standards.

3.4 Subject areas

We have given below an overview of the subject areas being considered to a greater or lesser extent in the new documents. This uses the interpretation set out by UKOOA/HSE so as to facilitate subsequent discussion.

Hazard Philosophy

This sets out fundamental principles, goals and approaches, including the risk classification of compartments and installations in order to focus design effort where it is most needed and to give an early indication of the severity of the hazard. Suitable analysis methods should be identified. The scope of the required analysis will depend largely on the risk classification identified at an earlier stage in a project.

High level performance standards should be defined.

The derivation and use of Nominal loads may be considered at this stage. These ‘Nominal Loads’ are for use at an early project phase or for low risk installations as defined by a risk matrix for the hazard and installation/compartment.

Hazard Management

Describes how the philosophy is implemented and utilises the principles of inherently safer design; prevention, detection, control and mitigation; addresses scenario definition; the management and choice of systems and risk acceptance criteria. The interaction between fire and explosion hazard management should also be examined.

One particular aspect of the UKOOA guidance is the classification of Safety Critical Elements (SCEs) for explosions, this is intended to focus effort where it is most required and to guard against the possibility that this aspect is not considered at all.

A Safety Critical Element is defined as any structure, plant, equipment, system (including computer software) or component part whose failure could cause or contribute substantially to a major accident, including any element which is intended to prevent or limit the effect of a major accident.

Determination of fire and explosion loads

Describes how loads are derived; the advantages and limitations of the various methods and the determination of Design loads. Loads on equipment and piping should also be derived at this stage.

Response to fires and explosions

Defines the general principles of response calculation, including the consideration of; robustness, ductility, displacement and strength demands on the structure, barriers, equipment, SCEs and connections.

Evaluation

Reducing risks to ALARP must be demonstrated in the UKCS for all cases: both through the justification of the choice of design load and from a determination of the impairment frequency of the SCEs subjected to these loads and the consequences of the loading and possible escalation. In the US risk acceptance criteria are often defined in advance of any analysis of the particular installation.

The approach used in the UKOOA guidance is discussed in more detail in Reference 17.

3.5 Coverage of subject areas

Table 3.1 illustrates the coverage of the subject areas defined in the previous Section.

Subject area	UKOOA Guidance	API RP	ISO
Explosion and Fire Philosophy	Parts 1 and 2	API 75	ISO 13702 and 19900
Explosion and Fire Hazard Management	Parts 1 and 2	Refers to the API 14 Series	ISO 13702, 19900 and 19903
Interaction of Explosion and Fire Hazard Management	Parts 1 and 2	Refers to the API 14 Series	ISO 19901-3 Informative and 13702
Explosion and Fire Loads	Part 3 (preliminary treatment Parts 1 and 2)	API RP 'Fire and Blast'	ISO 19901-3
Design Explosion Loads	Part 1	To be addressed	ISO 19901-3
Response of structures to Fires and Explosions	Part 3 (preliminary treatment in Parts 1 and 2)	API RP 'Fire and Blast'	ISO 19901-3

* Fire will be dealt with in Phase 2 of the UKOOA Guidance project

Table 3.1 Scope and range for the new Guidance documents

3.6 Schedules for generation of the new guidance documents

Figure 3.1 below gives an indication of the current schedules for production of the new guidance documents.

Document	2002				2003				2004				2005
Quarter	1st	2nd	3rd	4th	1^{st}	2nd	3rd	4th	1st	2nd	3rd	4th	1st
UKOOA Part 1	■	■	■	■									
UKOOA Part 2								■	■	■	■	■	
UKOOA Part3												■	■
API RP fire and 'blast'	■	■	■	■	■	■	■	■					
ISO 19901 Accidental Actions					■	■	■	■					

Figure 3.1 Current schedules for the production of new guidance

UKOOA

The first part of the UKOOA guidance was issued in December 2002 and is available directly from the fireandblast.com web site. This part of the document will be published by SCI - probably after part 3 has been finalised (at the end of 2005 or mid 2006).

API RP

The 'Main Guidance' of the API RP was issued at the MMS workshop ‘Fire and Blast Considerations in the Future Design of Offshore Facilities’ held in Houston in June 2002. The ‘Commentary’ is in preparation. In the final version these will be integrated into one document.

A draft has been issued to API and has been posted on the API web site for comment by members of SC-2, but not yet for voting. The final draft will go out for voting by SC-2 some time this year. Depending on the reception the document receives it should be published as an API “yellow” RP next year, which is a way of getting industry comment before it becomes a full RP.

ISO

The current schedule for issue of ISO standards is set out both on the ISO website and galbraithconsulting.com. Several ISO codes have been published already and others are expected in 2004 and 2005, including the final version of ISO19901-3 for Topside Structure with its sections on Accidental Actions.

There is agreement that the ISO codes for offshore structures (described later) should apply across the European Union and other countries in place of any specific European (CEN) standards. Many other countries are contributing to the formation of these standards, with extensive input from Norway and Canada.

4. DISCUSSION OF NEW APPROACHES/ADVANCES

4.1 General review

The ISO document differs from the others in that it also encompasses accidental actions such as vessel collision, and dropped objects, in addition to fire and explosion hazards.

Following NORSOK, ISO uses a threshold probability of exceedance level (10^{-4} per year) below which the actions from each category may be eliminated from further consideration. Events above this level are considered to be ‘dimensioning’, requiring to be analysed further to determine the size and extent of the resulting loading and its effects.

The UKOOA Part 1 document takes a slightly different approach. An explosion event will be considered depending on whether the event impinges directly on the Temporary Refuge with probability of exceedance > 10^{-5} per year. Events directly affecting other regions where a barrier may be present to prevent impingement on the TR are considered if the probability of exceedance is greater than 10^{-4}.

The accepted level above which the overall risk is considered intolerable relates to an individual risk of greater than 10^{-3} per year or a TR impairment frequency of greater than 10^{-3} per year from all causes. The overall individual risk from all hazards must be less than this value. If risks are in the intolerable region then risk reduction measures must be implemented, irrespective of cost. Hence the risk from other hazards may indirectly affect the acceptability of risk from say explosions and these may need to be considered in setting the target risk levels for the explosion hazard, for example.

Topics discussed briefly in this Section include:-

?? Installation Screening, risk matrices
?? Nominal fire and explosion loads
?? Levels of analysis
?? Derivation of explosion loads
?? Design explosion loads using exceedance curves for exceedance probabilities
?? Strength Level Blast and Ductility Level Blast explosion load cases
?? Modified code checks (Explosions and fires)

4.1 Installation/compartment risk screening

The higher the *risk* (frequency x consequence) in an installation or compartment the greater should be the rigor that is employed to understand and reduce that risk. All three documents use risk matrices for risk screening.

A simple approach which is frequently adopted for qualitative risk analysis uses a 3 x 3 matrix of potential consequence versus frequency or likelihood of an accidental action/event as indicated in the risk matrices given below. The notation differs between the three documents and has been adjusted for comparison purposes.

Likelihood/ Probability		**UKOOA**			**API**			**ISO**		
	H	M	H	H	H	H	H	M	H	H
	M	L	M	H	L	H	H	L	M	H
	L	L	L	M	L	L	H	L	L	M
		L	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**
		Consequence			**Consequence**			**Exposure level**		

Table 4.1 Risk matrices from the three documents

There is a large degree of similarity between the three documents, the differences in notation and the differing treatment of the outcomes (risk) are summarised in Table 4.2 below:-

Notation	**UKOOA**	**API**	**ISO**
Likelihood/Probability	Likelihood	Probability of occurrence	Probability of exceedance
H	High	Higher	Risk level 1
M	Medium	(Higher)	Risk level 2
L	Low	Low Risk	Risk level 3
Outcome	**UKOOA**	**API**	**ISO**
H	Requires high sophistication analysis	(Higher risk) Risk level must be reduced	Significant risks which are likely to require prevention, control, mitigation
M	If nominal explosion loads apply, use them otherwise high sophistication analysis	Not explicitly considered but treat as above	Risks require further study to define probability, consequences, cost
L	Use low sophistication analysis, elastic analysis (nominal explosion loads)	Low risk need not be considered further	Insignificant or minimal risk which can be eliminated from further consideration

Table 4.2 Notation and treatment of outcome of risk matrix by document

UKOOA

A risk screening method described in the UKOOA Guidance for the explosion hazard, classifies installations and compartments according to their risk level. The measures for likelihood and consequence severity are based on process complexity and the exposure potential for people on board. These measures are combined in a risk matrix to give low, medium and high risk categories. The risk level is an indication of the level of sophistication to be used in the explosion assessment process.

The risk classification does not depend on specific scenarios but is a general indication of the vulnerability of the installation

API and ISO

Both API and ISO use the life safety, environmental (and other) consequence measures to develop the consequence level for a particular installation prior to its application in the risk matrix. The consequence level is the higher of the life safety and environmental consequence levels. This approach is similar to that in the original risk matrix formulation in API RP 2A. This approach is also used in the ISO document by reference to ISO 13702 (23).

API has a second stage of assessment based on scenarios if ‘nominal loadcases’ are not applicable and the risk level for the installation is in the ‘Higher’ category. In this case each scenario is assigned a risk value using the same risk matrix.

ISO follows a similar approach in that the risk matrix is also used for each identified event for a particular installation.

4.2 Load cases for explosion response

In the UKOOA, API and ISO documents, two levels of explosion loading are recommended by analogy with earthquake assessment. These are the ductility level blast (DLB) and the strength level blast (SLB). In UKOOA low risk installations may be assessed using only the DLB (or in some cases only the SLB if it can be justified), as the overpressures are likely to be low.

In the API document the SLB is optional but suggested for preliminary design to engender good practice and assist design contractors in achieving early consideration of blast (explosion) loads as a basic elastic response load case. API and UKOOA both suggest a lower bound level for the SLB of one third of the DLB.

The ductility level blast is the overpressure used to represent the extreme design event. This is a high consequence event important for the establishment of survivability. SCEs of high criticality will also be assessed for their resistance to this level of load.

The strength level blast represents a more frequent design event where it is required that the structure does not deform plastically and that the SCEs of high and lower criticality remain operational. This load case is suggested for the following reasons:-

- An SLB event may give rise to an unexpected DLB by escalation..
- The prediction of equipment and piping response in the elastic regime is much better understood than the conditions which give rise to rupture. The SLB enables these checks to be made at a lower load level often resulting in good performance at the higher level (strength in depth) and robustness.
- The SLB enables the classification of SCEs and a focussing of effort on the assessment of those most critical with respect to the explosion hazard.
- The SLB offers a degree of asset protection.
- The SLB is a low consequence event important for the establishment of operability.

The space averaged peak overpressure for the compartment is used for determination of the design explosion load cases as it is more representative of the severity of the event. A local overpressure peak may be used to generate exceedance curves for the determination of load cases for the local design of a blast wall for instance. Impulse exceedance curves may also be generated which take into account the duration of the load and its peak value; these give a better measure of the expected response of the target which will be dynamic in nature.

The SLB may then be identified from a space averaged peak overpressure exceedance curve. This is defined in the UKOOA document as that overpressure corresponding to a frequency one order of magnitude more frequent or with a magnitude of one third of the DLB overpressure whichever is the greater.

The UKOOA guidance suggests the use of modified code checks for the sizing of primary members, using an elastic analysis and the DLB. This represents the geometry and post yield response characteristics better than the definition of an equivalent ‘dimensioning’ load level intended for application in a linear elastic analysis.

4.3 Nominal fire and explosion loads

There is a need to find reliable methods to determine likely fire and explosion loads quickly at the start of any substantial offshore project so that the layout of plant and equipment can be defined within limits and modified later as necessary during detailed design. Nominal fire loads have been in use for some time and are tabulated in the original 'Interim Guidance Notes' (6) .

The intended use of nominal explosion loads is to minimise unexpected escalation of design overpressures at a late project phase when an optimum ALARP solution may not be possible and to aid in concept choice at an early project phase.

It was an intention of the UKOOA Guidance to gather and prepare preliminary explosion data that could be used in the determination of 'nominal explosion loads' for use in the early quantification of explosion hazards for new offshore facilities. The HSE made available a number of recent Safety Cases so that information on typical values of peak overpressure for various installation types could be derived. The base data collected has been published in Reference 18 and is available on the fireandblast.com web site. Nominal explosion overpressures were developed from this data and 'conditioning factors' or multipliers were generated to represent the expected variation of pressure with module size, confinement, congestion, production rate, gas pressure and number of production trains.

Unfortunately, the data was not considered to be sufficiently well defined or consistent and so the numerical values of 'nominal overpressures' were not published. It has also become clear that nominal dynamic pressures and some measure of appropriate load duration is also required to make these numbers useable. An attempt at the definition of nominal durations to reflect the fact that higher peak overpressures are associated with shorter durations (the gas burns quicker) was made in the UKOOA and API documents by reference to Hioset's paper (19) .

It is now hoped that these 'nominal explosion load' values will be available for inclusion in Part 3. Methods of deriving useable nominal explosion loads are discussed in the Commentary of the UKOOA guidance.

Examination of the results of the Advantica Spadeadam explosion tests (21) showed that the impulse associated with the overpressure trace was much less variable in time and space during the explosion than the peak overpressure. A nominal explosion impulse may hence be a much better characteristic parameter to represent an explosion than the overpressure, as well as being more useful in response calculations.

The API RP is expected to contain numerical values for nominal explosion loads ('Nominal Loadcases') and impulses with similar 'Conditioning Factors' as described above.

Nominal explosion loads must not be confused with bounding values which are minimum likely values (rather than representative of more probable loadings). Minimum overpressures that will be acceptable for design are given in DnV A101 (19) .

4.4 Levels of Analysis

Appropriate levels of analysis are discussed in all three documents. In particular the UKOOA and API documents define three levels of analysis.

Screening Analysis

Screening analysis for an existing installation consists of condition assessment which may involve a survey followed by design basis checks. The transfer of conclusions and load characteristics from the analysis of a similar platform is acceptable for this and for Strength level and Ductility level analyses if the similarity can be demonstrated.

Design basis checks consist of checking the basis of design for the installation and determining if the methods used for the design are acceptable in the context of the fire and explosion events considered.

Component checks may be employed if the component is non-load bearing in the operational condition or if the component does not form part of the main framing. Methods of dynamic response assessment such as Biggs method (22) may be used. Where loads from connected structures are represented component check methods may be employed. There are however many limitations on the method.

Strength Level Analysis

The integrity of an offshore structure may be checked using a linear, elastic, beam model.

Code checks may be re-interpreted to take account of the inherent reserves of strength, arising from material and plastic reserves and dynamic effects. A higher ‘utilization factor’ will often be acceptable.

This approach enables a fire or explosion assessment to be completed quickly and within the context of conventional elastic load case approach.

Ductility level Analysis

This is a full static time dependent large deflection analysis for fires, or a full dynamic large deflection analysis for explosions.

For most ductility level analyses, code checking will either not be appropriate or the response simulation software will not contain a code check module within the software. Checking of members will be done explicitly with regard to performance standards, which may take the following forms.

?? Strength limit
?? Deformation limit checks.
?? Buckling checks,
?? Fracture checks.

The application of these methods as described in UKOOA and API is as below for the fire and explosion hazards.

Analysis method	Load Calculation	Response Calculation
1. Screening analysis	Strength level, nominal explosion loads and component checks. Past experience	Design basis checks Past experience from demonstrably similar platform.
2. Strength level analysis	Strength level blast from Ductility level Blast	Strength level analysis with modified code checks for the Ductility level blast
3. Ductility level analysis	Strength level and Ductility level blast from CFD or Phenomenological simulations	Ductility level analysis or Strength level analysis with modified code checks

Table 4.3 Appropriate Method of analysis – explosions

Analysis method	Load Calculation	Response Calculation
1. Screening analysis	Allowable temperature (yield strength reduction of 60%)	Design basis checks Past experience from demonstrably similar platform.
2. Strength level analysis	Calculate peak temperature member by member.	Strength level analysis with modified code checks
3. Ductility level analysis	Calculate temperature - time history of primary members	Ductility level analysis or Strength level analysis with modified code checks

Table 4.4 Appropriate Method of analysis – fires

n.b. Fire and Explosion barriers and their connections must always be checked using the full overpressure for the Ductility Level Blast

Analyses should be performed in sequence to minimise effort and timescales, proceeding to the next level if results are unacceptable.

4.5 Summary of the inclusion of new methods by document

Topic/approach	UKOOA	API RP	ISO
Risk Matrices	Yes	Yes	Yes
Criticality of SCEs	Yes (explosions)	No	Yes but no classification
Performance standards	Yes	High level criteria	High level and refers to ISO 13702
Mitigation methods	Yes	Yes and Refers to ISO 13702	Yes Refers to ISO 13702
Loads on equipment and other SCEs	Yes Rule of thumb – 1/3 of overpressure with matched impulse	Deals with dynamic pressures.	Yes
Exceedance curves	Yes	No	Yes, Dimensioning events defined
Design explosion loads (SLB, DLB)	Yes	Yes	Yes
Appropriate levels of analysis	Yes	Yes	Yes
Nominal explosion loads	Yes (but numerical values not included in Part 1 – could appear in Part 3)	Yes – expected that numerical values will be included	Discussed by reference to UKOOA
Simplified methods	Yes - where allowed by risk classification	Yes	Yes
Modified code checks	Brief discussion – details left to Part 3 Modified code checks	Yes for fires and explosions	Yes for fires
Dynamic regime: td = load duration; T = natural period	0.3 < td/T < 3.0	0.4 < td/T <2.0	0.3 < td/T < 3.0

Table 4.5 Summary of new methods by document

ACKNOWLEDGEMENTS

This paper reflects the opinion of the authors and attempts to draw on the experience of all those who have been involved in the generation of the documents discussed and does not necessarily represent the policy of the Heath and Safety Executive.

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