

HARMFULNESS AND HAZARD CATEGORISATION – IMPACT OF EMERGING TECHNOLOGIES ON EQUIPMENT DESIGN IN THE MINING INDUSTRY

Dr David S Dolan[1] and John Frangos[2]
[1]Fluor Australia Pty Ltd
[2]Toxikos Pty Ltd

For the design, fabrication and installation of pressure equipment, knowledge of the harmfulness of the contents and the hazard allocation for the operating conditions is required.

For some processes where the substances in question are pure or common this is a straightforward procedure. However, when the process contains mixtures of substances the classification of the harmfulness of the substance and the hazard allocation becomes complicated, especially when the components of the mixture present toxicological interactions. This categorisation is further complicated by the differences between the Australian, American and European standards.

As technology advances, especially in the rapidly progressing mining industry, it is becoming increasingly important that this procedure is established and understood to ensure that plant is classified correctly and all appropriate standards and codes are complied with. Here, with a mixture of substances, a toxicologist may be required to develop a profile of the toxicological properties of the substances, the effects of concentration and the interactions with other components in the contents.

This paper details the multidisciplinary approach to the classification of the harmfulness of the contents and to the hazard allocation of a system, using examples taken from projects in the mining industry and also explores the variations between different standards used worldwide.

INTRODUCTION

The design of pressure equipment in most countries is governed by regulation, codes and standards. The purpose of these is to provide the framework for the safe, economic and equitable design, manufacture and use of the equipment. This paper discusses the use of the codes and standards particularly in Australia and with reference to the EU and USA with regards to hazard level and harmfulness of the contents.

In the 1970's, German pressure equipment law introduced a term with [Pressure times Volume] (Druckbehalter, 1974) and had considered the problem of hazard quantification. This has evolved into the current European Union Pressure Equipment Directives as enunciated in PED 97/23/EC of the European Parliament and of the Council of 29 May, 1997. This Directive considers pressure, volume or volume equivalent (i.e. pipe diameter) and fluid service. The Australian standards evolved to consider several factors that impact on the quantification of risk. These include pressure, volume or volume equivalent (i.e. pipe diameter), location, service or duty and the equipment contents (AS4343:2005).

Designers have the responsibility to ensure that the design meets the appropriate standards and the identification of hazards, risk assessment and control of risk to health or safety forms part of this process.

In Australia, the standards for the design of pressure equipment requires the designer to evaluate the harmfulness or toxicity of the contents of the equipment then use this information along with the pressure, volume and service conditions or location of the equipment to determine the quality assurance requirements in design, manufacture and operation. The codes and standards set this out and are readily interpreted for common substances where the codes provide adequate data on the substance properties. However, when the codes do not contain data on the contents, or the contents are mixtures that are uncommon the designer needs to work with toxicologists to determine the characteristics of the contents.

This paper discusses the classification of harmfulness and hazard levels of the contents in different standards for pressure equipment. Examples of how the different standards arrive at different results for the levels of quality assurance are given for several cases in the mineral processing industry where new processing technologies have resulted in the use of large high pressure equipment. The harmfulness level of the contents of some of this equipment could not be classified using the relevant standards or codes so the services of a toxicologist were used to find the relevant information. These differences in results may also occur in other industries, but will not be considered here.

These requirements have evolved with the development of high pressure and temperature processes which require the mineral processing engineer to investigate the harmfulness of contents and to coordinate the services of the toxicologist with the pressure equipment designers.

BASIS OF DESIGN FOR PRESSURE EQUIPMENT

The design, manufacture, installation, commissioning, operation, inspection, testing and decommissioning of pressure equipment in Australia and New Zealand is governed by regulations and a series of standards. The 'parent' Standard is AS/NZS 1200 - Pressure equipment. (AS/NZS 1200:2000). This standard lists the standards and codes applicable to pressure equipment for all periods of the equipment life cycle. The Standard AS 3920.1 Assurance of Product Quality - Part 1: Pressure equipment manufacture, (AS 3920.1:1993) describes the methods of selecting the degree of external design verification and fabrication inspection that are required. This selection is based on the hazard level of the equipment which is determined in accordance with the Standard AS 4343 – Pressure Equipment – Hazard Levels (AS 4343:2005).

Other Australian standards apply for advanced design and construction and to specialised services such as serially produced pressure vessels, sterilizers and LP gas vessels for automotive use.

The standard AS 4343 defines five hazard levels from Level A (high hazard) to Level E (negligible hazard). The hazard level depends on the design pressure, the volume of the equipment or the diameter of the pipe, the situation where the equipment is to be located or used (service and site factors), the degree of harmfulness of the contents and whether the fluid contents are gaseous or liquid. Thus the larger the volume, the higher the pressure, the more dangerous the fluid contents and the more likely the location could result in further damage, the higher the hazard level. There are four harmfulness categories for contents ranging from a non-harmful fluid, harmful fluid, very harmful fluid through to a lethal fluid. Each of these categories is further divided as to whether the contents are considered to be a liquid or a gas.

The standard lists the harmfulness for over 900 fluids as pure substances. The harmfulness parameters are quite readily determined by the designer or the engineering design team when the contents are one of the pure fluids listed in the standard. The difficulty arises when the contents are not listed, are substances that are diluted or are mixtures of various ingredients.

This commonly occurs when the pressure equipment is processing intermediate streams in the middle of a major processing facility. Thus the materials are "in process" or in a state of manufacture and the composition of the contents are under going change.

CATEGORIES OF FLUID SERVICE OR CATEGORIES OF FLUID CONTENTS AS USED FOR PRESSURE EQUIPMENT

The standards and codes used in countries such as Australia, USA and Europe use different definitions of fluid service or categories of fluid contents.

Firstly we will outline the similarities and differences in the descriptions of fluid contents or service conditions between the codes and standards in Australia, the USA and the European Union.

In Australia, Standard AS 4343 divides the fluid contents into the four categories: lethal, very harmful, harmful and non-harmful.

Lethal contents are classified as "containing a very toxic substance or highly radioactive substance which, under the expected concentration and operating conditions, is capable, on leakage, of producing death or serious irreversible harm to persons from a single short-term exposure to a very small amount of the substance by inhalation or contact, even when prompt restorative measures are taken". Guidance is given by examples. Contents are classified as lethal if the exposure limit is less than or equal to 0.1 ppm or equivalent.

Very harmful contents are "containing a substance, which, under expected concentration and operating conditions, are classified as extremely or highly flammable, very toxic, toxic, harmful, oxidizing, explosive, self-reactive, corrosive, or harmful to human tissue, but excluding lethal contents." This class includes carcinogenic, mutagenic and tetatogenic substances.

Harmful contents are "containing a substance which, under the expected concentration and operating conditions, is classified as a combustible liquid or fluid irritant to humans, or is harmful to the environment, above 90 °C, or below –30 °C, but excluding lethal or very harmful fluid."

Non-harmful contents are contents not covered by the above categories except for concentration effects such as oxygen depletion and pressure.

The Standard AS 4343 refers to several standards by the Australian National Occupational Health and Safety Commission (NOHSC) that can be used to determine the level of harmfulness. These standards are NOHSC 1003 – National Exposure Standards for Atmospheric Contaminants in the Occupational Environment (NOHSC1003:1995), NOHSC 1008 – National Standard for Approved Criteria for Classifying Hazardous Substances (NOHSC 1008:1999) and the Australian Safety and Compensation Council (ASCC) Hazardous Substance Information System (HSIS) The latter of these is a database accessible through the internet. In addition, the Australian Code for the Transport of Dangerous Goods by Road and Rail (Dangerous Goods Code ADG Code) (ADG: 2007) lists contents that are dangerous.

The first thing to note when comparing the codes and standards is that the use of the words "harmful" and "harmfulness" are not synonymous in various disciplines. This is discussed further below.

In the USA, two codes primarily cover the design of pressure equipment in chemical and mineral processing facilities. These are the ASME Boiler and Pressure Vessel Code Section VIII Division 1 (BPV-VIII-1:2007) and the ASME Code for Process Piping, B31.3 (ASME B31.3:2006). The ASME BPV code has two service conditions; vessels that are to contain lethal substances (lethal service applications) and vessels for any other contents.

The ASME Code for Process Piping, B31.3 (ASME B31.3:2006) notionally uses four classes for fluid contents. These are High Pressure Fluid Service, toxic (Category M), flammable and damaging to human tissue (Normal Fluid Service) or contents not included in any of the preceding classes (Category D). The Category M fluid service is defined in a very similar way to the definition of lethal contents in Australia. The Normal Fluid Service is very similar to the combination of the Australian Very Harmful and Harmful contents grouping. The Category D fluid service is very similar to the Australian contents group of Non-Harmful. Thus the ASME B31.3 range of classifications is reasonably close to the Australian classification.

In the EU, fluid contents are classified into two groups: Group 1 and Group 2 in accordance with Pressure Equipment Directive 97/23/EC (PED 97/23/EC: 1997).

The Group 1 fluids comprise dangerous fluids which are defined as: explosive, extremely flammable, highly flammable, flammable (where the maximum allowable temperature is above flashpoint), very toxic, toxic and oxidising. Guideline 2/7 of the PED lists the specific "risk" phrases for the classification of Group 1 fluids. Risk phrases are used to describe a hazard, and are applied to individual substances at defined cut-off based on concentration. The risk phrases are:

- R2, R3 for explosive
- R12 for extremely flammable
- R11, R15, R17 for highly flammable
- R26, R 27, R28, R39 for very toxic
- R23, R24, R25, R39, R48 for toxic
- R7, R8, R9 for oxidising

Group 2 fluids comprise all other fluids not covered by group 1.

Also in the EU, a dangerous fluid is a substance or preparation covered by the definitions in Article 2 (2) of the Directive on Dangerous Substances, Directive 67/548/EEC (Directive 67/548/EEC). According to the notes to Guideline 2/7, not all fluids that defined as a dangerous substance in accordance with this directive are a Group 1 fluid. Thus care is needed in the correct classification to Group 1.

It can be seen that each jurisdiction has a different way of describing and grouping the fluid contents of pressure equipment. Table 1 – "Comparison of fluid classifications between Australian, European and USA standards and regulations" provides an interpretation of the various categories or groupings and attempts to draw parallels between the various classifications. There are some general similarities but no direct relationships across the practices in Australia, the EU and the USA.

THE ENGINEERS DILEMMA – HOW TO MAKE SENSE OF ALL OF THIS

In Australia, for substances that are not mixtures and that are listed in the Standard AS 4343 the engineer can readily arrive at the appropriate harmfulness for the equipment contents.

If the designer does not find the contents listed in AS4343, it cannot be assumed that the substances to be contained in the equipment are not harmful. Firstly one needs to go to the National Exposure Standards in the Adopted National Exposure Standards (NOHSC 1003 1995). This standard applies to harmful gaseous substances. One can deduce the harmfulness of some gaseous substances from there. However if the contents are not listed in this standard the designer must go to the lists in the Australian Hazardous Substances Information System (HSIS Internet Database) in which there are many thousands of substances listed. There the designer will find the substance name, the CAS Number, the UN Number and the classification using the risk and safety phrases for the pure substance. The database includes the cut-off concentrations at and above which the risk and safety phrases apply. This is when the designer needs the advice and assistance of the toxicologist because the terminology used in the risk and safety phrases is not expressed in the terms of harmful, very harmful or lethal as used in the standard AS4343.

APPLICATION TO AN EXTRACTIVE METALLURGY PROJECT

In recent years the technologies used in the extraction of nickel and cobalt from lateritic nickel ores by the mineral processing industry have developed significantly with the availability of advanced materials that enable the economic fabrication of pressure equipment with superior corrosion resistance and strengths.

An example of one of these processes is the "high pressure acid leach" or HPAL process with subsequent recovery of the metals from the process slurries and solutions. This process utilises the reaction of the finely ground laterite ore with sulphuric acid at operating temperatures in the range of 250 to 270 °C (design temperatures of 260 to 280 °C) and design pressures of 4800 to 7000 kPag. Products produced in this process include nickel sulphate and cobalt sulphate and excess acid is used. Depending on the process route, nickel sulphide, cobalt sulphide, nickel ammonium sulphate and cobalt ammonium

Table 1. Comparison of fluid categories between Australian, European and USA standards and regulations

AUSTRALIA AS4343	DEFINITION		EU PED 97/23/EC: 1997	USA ASME BPV-VIII-1:2006	USA ASME B31.3:2006
Lethal	**Highly Radioactive^**	where a single short-term exposure to a very small amount by **inhalation or contact** can result in death or serious irreversible harm even when prompt restorative measure are taken	^Radioactive excluded from 97/23/EC	**Lethal (no mention of contact, only inhalation)**	**Category M**
	Toxic				
Very Harmful	Extremely Flammable		**Group 1**	**Other**	**Nominal Fluid Service**
	Highly Flammable				
	Very Toxic				
	Toxic				
	Oxidising				
	Explosive				
	Harmful		**Group 2 excluding radioactive**		
	Self-reactive				
	Corrosive				
	Harmful to human tissue*				
	Carcinogenic				
	Mutagenic				
	Teratogenic				
	Radioactive^				
Harmful	Combustible liquid				
	Fluid Irritant to humans				
	Harmful to the environment, above 90oC or below -30oC				
Non-Harmful	All other contents normally not harmful				**None (Category D)**

sulphate may be produced as further intermediate products before the final production of nickel and cobalt as powders. Typical concentrations for some of the major components for some typical process streams in the processing of the laterite ores are shown in Table 2. Depending on the ore being processed, other components in these streams can include compounds of iron, copper, chromium, manganese, aluminium, zinc, magnesium and/or silica in solution or as finely dispersed solids in slurries. For simplicity these other constituents are not considered here.

The risk phrases for some of these substances are shown in Table 3. Of course, rarely do these substances exist in pure from, they are usually in aqueous solution and in most cases they are present as mixtures in aqueous solution. This is when the designer requires the services of the toxicologist to determine the level of harmfulness of the contents so the correct fluid contents classification is used.

The determination of the harmfulness of these streams requires the interpretation of the combined impact of the mixture. This requires careful consideration of the characteristics and composition of the mixture. The health assessment of hazardous substances is complicated by the reality that most toxicological testing is performed on single chemicals, but human exposures are rarely limited to single chemicals. Potential exposures resulting from pressure vessels generally involve a complex mixture of substances. A particular issue is whether a mixture of components, may be hazardous due to additivity, interactions, or both. For mixtures that are made up of relatively heterogeneous components, it is also important to consider that the toxicity may be due to a small proportion of the mixtures constituents, for example, immediately following a release of petroleum hydrocarbons, inhalation exposure to the more volatile components, especially the low molecular weight alkanes, may be the immediate concern.

In the absence of data and health criteria for the mixture of concern or of data for a sufficiently similar mixture, the standard toxicological approach recommended by practically all regulatory guidance including the NOHSC and EU Dangerous Preparations Directive 1999/45/EEC has been to use the exposure and health criteria for the individual components of the mixture. The process involves evaluation of whether the exposures or risks for the components can reasonably be considered as additive based on the nature of the health effects. However it is the responsibility of the toxicologist to evaluate whether toxicological interactions among the components are likely to result in greater (or lesser) hazard or risk than would be expected on the basis of additivity alone. The concern for the toxicologist is that in terms of occupational health following exposure, toxicological interactions may increase the health hazard above what would be expected from an assessment of each component singly, or all components additively.

Toxicological interactions can either increase or decrease the apparent toxicity of a mixture relative to that expected on the basis of dose-response relationships for the components of the mixture. Table 4 provides definitions of terms used in describing interactions.

The toxicity of the constituents of a mixture therefore needs to be considered carefully to assess whether there is evidence that constituents in combination may interact in a different manner than additively, if not, additivity is assumed for the purposes of health hazard classification.

Table 2. Typical stream compositions for the significant components in the leach and other process streams for a nickel and cobalt laterite processing facility

Stream--->	(1) Leach feed laterite slurry	(2) Leach product	(3) "Purified" solution	(4) Sulphide precipitation	(5) Sulphide slurry product	(6) Cobalt reduction feed	(7) Nickel reduction feed
Stream components temperature °C	200	250	99	90	90	100	100
Gas/Vapour							
H_2S, % vol./vol.	–	–	–	30	–	–	–
Solution							
Ni as $NiSO_4$, g/L	–	6 to 10	5 to 6	5 to 6	0.04 to 0.08	–	40 to 60
Co as $CoSO_4$, g/L	–	0.3 to 0.7	0.15 to 0.5	0.15 to 0.5	0.01 to 0.02	40 to 60	–
H_2SO_4, g/L	0.05	50 to 70	0.5 to 1	0.5 to 1	5 to 10	–	–
$(NH_4)_2SO_4$, g/L	–	–	–	–	–	300 to 500	300 to 500
NH_3, g/L	–	–	–	–	–	20 to 40	20 to 40
Solids							
Wt % solids in Slurry	40	–	–	2 to 4	2 to 4	–	–
Ni as NiS, wt%	0	–	–	50 to 55	50 to 55	–	–
Co as CoS, wt%	0	–	–	5 to 7	5 to 7	–	–
Risk Phrases							
Classification according to AS4343							
Stream harmfulness	Harmful	Very harmful	Very harmful	Lethal	Very harmful	Very harmful	Very harmful
Classification according to Directive 97/23/EC – Annex II							
Fluid group	2	2	2	1	2	2	2

Table 3. Risk phrases for the significant components in the leach and other process streams

Substance name	Classification	Cutoffs	Source
Cobalt sulphate	Carc. Cat. 2; R49 Xn; R22; R42/R43 N; R50-53	Conc >= 25%: T; R49; R22; R42/43 >= 1%Conc < 25%: T; R49; R42/43 >= 0.01%Conc < 1%: T; R49	Eu
Aqueous ammonia	Corrosive; R34 N; R50	Conc >= 10%: C; R34 >= 5%Conc < 10%: Xi; R36/37/38	Eu
$CoSO_4$(0.5%) – NH_4OH(40%) complex	Corrosive; R34 Carc. Cat. 2; R49	Conc >= 10%: C; R34 >= 5%Conc < 10%: Xi; R36/37/38 >= 0.01%Conc < 1%: T; R49	Derived
Cobalt sulphide	Xi; R43; N; R50-53	Conc >= 1%: Xi; R43	Eu
Nickel sulphate	Carc. Cat.3; R40 Xn; R22; R42/43 N; R50-53	Conc >= 25%: Xn; R40; R22; R42/43 >= 1%Conc < 25%: Xn; R40; R42/43	Eu
Nickel sulphide	Carc. Cat. 1; R49; R43 N; R50-53	Conc >= 1%: T; R49; R43 >= 0.1%Conc <1%: T; R49	Eu; A
Hydrogen sulphide	F+; R12 T+; R26 N; R50	Conc >= 10%: T+; R26 >= 5%Conc < 10%: T; R23 >= 1%Conc < 5%: Xn; R20	Eu; A
Sulphuric acid	C; R35	Conc >= 15%: C; R35 >= 5%Conc < 15%: Xi; R36/38	Eu; A

Table 4. Interactions terminology (ATSDR 2004)

Term	Description
Interaction	When the effect of a mixture is different from additivity based on the dose-response relationships of the individual components.
Additivity	When the effect of the mixture can be estimated from the sum of the exposure levels weighted for potency or the effects of the individual components.
Influence	When a component which is not toxic to a particular organ system does not influence the toxicity of a second component on that organ system.
Synergism	When the effect of the mixture is greater than that estimated for additivity on the basis of the toxicities of the components.
Potentiation	When a component that does not have a toxic effect on an organ system increases the effect of a second chemical on that organ system.
Antagonism	When the effect of the mixture is less than that estimated for additivity on the basis of the toxicities of the components.
Inhibition	When a component that does not have a toxic effect on a certain organ system decreases the apparent effect of a second chemical on that organ system.
Masking	When the components produce opposite or functionally competing effects on the same organ system, and diminish the effects of each other, or one overrides the effect of the other.

In Australia, a substance is considered hazardous in pressure equipment if it classifiable based on health related criteria or if it is considered dangerous under the Australian Dangerous Goods Code or harmful to the environment. The process of classification based on health related criteria involves the placing of a chemical substance into a particular hazard category by identifying the hazard based on criteria stipulated in the Approved Criteria for Classifying Hazardous Substances (NOHSC:1008). The output at this point is a set of risk phrases. In Australia, the Hazardous Substance Information System (HSIS[1]) database provides a list of chemical substances for which the classification has been conducted and thus risk phrases are available.

Mixtures are classified by first determining the risk phrases for each ingredient and the concentration cut-offs that apply to each risk phrase. The interactions between ingredients are then considered to produce a hazard classification and set of risk phrases to describe the mixture. For instance a pressure vessel containing heated aqueous process stream (Stream 6 in Table 2) containing cobalt sulphate at 0.5% and ammonia at 40% would be classified in the following manner using HSIS data:

Cobalt Sulphate Classification

Substance Name	Classification[2]	CutOffs
Cobalt Sulphate	Carc. Cat. 2; R49 Xn; R22; R42/R43	Conc >= 25%: T; R49; R22; R42/43 >= 1%Conc<25%: T; R49; R42/43 >= 0.01%Conc<1%: Toxic; R49

Ammonia Classification

Substance Name	Classification[2]	CutOffs
Aqueous ammonia	Corrosive; R34	Conc >= 10%: C; R34 >= 5%Conc<10%: Xi; R36/37/38

Process Stream classification

Mixture	Classification	CutOffs
Process stream Cobalt sulphate 0.5% Ammonia 40%	Corrosive; R34 Toxic R49 (carcinogenic by inhalation.	Conc >= 10%: C; R34 >= 5%Conc<10%: Xi; R36/37/38 >= 1%Conc<25%: T; R49; R42/43

[1]Most of the classifications with the HSIS - Australian List of Designated Hazardous Substances have been taken from Annex I of the European Dangerous Substances Directive (DSD) 67/548/EEC. The Australian classification system is essentially the same as the European DSD.

[2]Human health classification only.

Although occupational hazard experts are conversant in the above terminology the application of the hazard classification to pressure equipment using AS4343 is not an intuitive process.

Standard AS4343 is intended to protect workers and the environment from accidental or short term release from a pressure vessel. There are four hazard levels described partly based on health hazard. The dilemma is how to relate these four hazard levels to the risk phrases identified within NOHSC 1008(2004). As the terminology between the two standards is different, expert judgement is required to bridge the gap. Table 5 provides one possible translation between AS4343 and NOHSC:1008. There is a further complication in the translation between AS4343 and health hazard classification. The standard provides guidance that categorises individual substances into a hazard level. The guidance provided within AS4343 refers the reader to the Australian Dangerous Goods Code (ADG). This code classifies substances based on the United Nations harmonised rules for classifying dangerous goods. The ADG is predominantly based on physical hazards but to a small extent it also classifies substances according to their acute toxicity and ability to cause corrosion. Thus there is an overlap between the hazard classification criteria of NOHSC:1008 and the ADG. Unfortunately the definitions and classification cut-offs differ between these two codes further confusing the hapless non-expert. Fortunately there is hope for the non-expert as a global harmonised classification scheme has been agreed at an international level and over the next five years will be implemented by various nations around the world including Australia and the European Union. Using a single system will help standardise interpretation of hazard criteria for human health and will thus simplify downstream applications of these hazard classifications such as that applied within AS4343.

Based on the above analysis and from inspection of Table 5 for interpretation of the Risk Phrases R34-Causes burns, R42/43- May cause sensitisation by inhalation and skin contact and R49-May cause cancer by inhalation, it is deduced that the cobalt ammonium sulphate stream is "Very Harmful".

A similar process to that described above is used by the toxicologist to determine the harmfulness level of the remaining streams in Table 2.

DETERMINATION OF THE HAZARD LEVEL AND CONFORMITY ASSESSMENT CATEGORY FOR TYPICAL VESSELS AND PIPING IN A MODERN HYDROMETALLURGICAL PROCESSING PLANT

For an example, the harmfulness levels for the contents shown in Table 2 will be used to determine the hazard level for typical pressure vessels and process piping in a modern nickel and cobalt hydrometallurgical processing plant.

Typical dimensions, design pressure and temperature of each vessel and pipe are given in Tables 6 and 7. In several of the examples, the fluids are liquids above their boiling point at atmospheric pressure and are considered to be a gas according to AS 4343. Table 8, which is Table 1 from AS4343, is used to derive the Hazard Level for each of the vessels and piping using the harmfulness, fluid state, values of pressure times volume (pV)

Table 5. Rough translation of the hazard levels of AS4343 to human health and non-health risk phrases

AS4343 Harmfulness level	AS4343 Terms for classification of contents	Hazard classification[3] (hazard category and risk phrases according to NOHSC:1008)	Risk phrases for health and non-health effects and ADG Code Class
(1) Highest harmfulness – "lethal contents"	Very toxic substance or highly radioactive substance	Very toxic (T+) , a harmful substance which can cause irreversible effects after acute exposure	R26, R27, R28, R32, R39 ADG Code Cl. 7
(2) High hazard – "very harmful contents"	Very toxic, toxic, harmful, very corrosive, corrosive or harmful to human tissue. Extremely or highly flammable, oxidizing, explosive, self reactive	Very toxic (T+), toxic (T), very corrosive, corrosive (C), carcinogenic (Carc.), mutagenic (Muta), teratogenic (Repr.), a skin or respiratory sensitiser (Xn) and classifications based on chronic health effects but where the evidence is not sufficient to classify the compound as a probable hazard to humans. Extremely flammable (F+), flammable (F), Oxidizing (O), explosive (E)	R23, R24, R25, R29, R31, R32, R34, R35, R40, R41, R42, R43, R45, R46, R48, R49, R60, R61, R62, R63. R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R14, R15, R16, R17, R18, R19, R30, R44. ADG Code Cl. 2.1, 3, 5, 8
(3) Moderate hazard – "harmful contents"	Fluid irritant to humans or combustible liquid or harmful to the environment, above 90 C or below – 30 C	Harmful (Xn), irritants (Xi), dangerous to the environment (N)	R20, R21, R22, R33, R36, R37, R38, R64, R65. R50, R51, R52, R53, R54, R55, R56, R57, R58, R59.
(4) Extra low/no hazard – "non-harmful contents"		Non hazardous but mild irritants	None

[3]The hazard classification for the mixture contained within the pressure vessel. This requires evaluation of each individual constituent and the lowest relevant concentration cut-off level for each constituent specified for the hazard classification in the NOHSC:1008.

Table 6. Determination of hazard levels and conformity assessment categories for various pressure vessels

	Vessel 1	**Vessel 2**	**Vessel 3**	**Vessel 4**	**Vessel 5**	**Vessel 6**
Pressure Equipment	**Preheater**	**Leach Autoclave 1**	**Leach Autoclave 2**	**Pressure Filter**	**Pptn Feed Vessel**	**Sulphide Precipitator**
Fluid Contents	**Feed Slurry**	**Leach Product**	**Leach Product**	**Purified Solution**	**Sulphide Slurry**	**Sulphide Precipitate**
Tan to Tan Length, m	7	35	20	3.5	5	7.5
Vessel Inside Dia, m	1.8	5	4	2	5	7.5
Vessel Volume, L	20,866	752,673	284,838	15,184	163,625	552,233
Vessel Design Pressure, p, MPa	3	4.5	7	0.7	0.5	0.5
Vessel Design Pressure, P, Bar	30	45	70	7	5	5
Vessel Design Temperture, C	200	270	270	90	90	90
	Classification according to AS4343 - Modification to value of pV is Nil					
Fluid State	Gas	Gas	Gas	Liquid	Liquid	Gas
Fluid Harmfulness	Harmful	Very Harmful	Very Harmful	Very Harmful	Very Harmful	Lethal
Value pV, MPa.L	6.3E+04	3.4E+06	2.0E+06	1.1E+04	8.2E+04	2.8E+05
Mod's to pV for special conditions	Zero	Zero	Zero	Zero	Zero	Zero
Hazard Level	B	A	B	B	B	A
	Classification according to AS4343 - Modification to value of pV is 3 for Location as Major Hazard Facility					
Fluid State	Gas	Gas	Gas	Liquid	Liquid	Gas
Fluid Harmfulness	Harmful	Very Harmful	Very Harmful	Very Harmful	Very Harmful	Lethal
Value pV, MPa.L	6.3E+04	3.4E+06	2.0E+06	1.1E+04	8.2E+04	2.8E+05
Mod's to pV for special conditions	3	3	3	3	3	3
Modified value pV, MPa.L	1.9E+05	1.0E+07	6.0E+06	3.2E+04	2.5E+05	8.3E+05
Hazard Level	B	A	A	B	B	A
	Classification according to Directive 97/23/EC - Annex II					
Fluid State	Gas	Gas	Gas	Liquid	Liquid	Gas
Fluid Group	2	2	2	2	2	1
PD, Bar.L	625,994	33,870,296	19,938,641	106,291	818,123	2,761,165
Conformity Assessment Category	IV	IV	IV	IV	IV	IV

Table 7. Determination of hazard levels and conformity assessment categories for various pipe duties

	Pipe 1	Pipe 2	Pipe 3	Pipe 4	Pipe 5	Pipe 6
Pressure Equipment	**Preheater**	**Leach Autoclave**	**Leach Autoclave**	**Pressure Filter**	**Pttn Feed vessel**	**Precipitator**
Pipe duty	**Preheater Feed Pipe**	**Autoclave Feed Pipe**	**Leach Disch. Pipe**	**Filter Feed Pipe**	**Feed Pipe**	**Precipitator Piping**
Fluid Contents	**Feed Slurry**	**Leach Feed**	**Leach Product**	**Purified Solution**	**Sulphide Slurry**	**Sulphide Precipitate**
Pipe Inside Dia, mm	250	250	250	500	600	600
Pipe Design Pressure, p, MPa	3	7	7	0.7	0.5	0.5
Pipe Design Pressure, P, Bar	30	70	70	7	5	5
Pipe Design Temperture, C	270	200	270	90	90	90
	Classification according to AS4343 - Modification to value of pD is Nil					
Fluid State	Gas	Gas	Gas	Liquid	Liquid	Gas
Fluid Harmfulness	Harmful	Harmful	Very Harmful	Very Harmful	Very Harmful	Lethal
pD, MPa.mm	750	1750	1750	350	300	300
Mod's to pD for special conditions	Zero	Zero	Zero	Zero	Zero	Zero
Hazard Level	B	B	B	C	C	B
	Classification according to AS4343 - Modification to value of pD is 1.5 for Location as Major Hazard Facility					
Fluid State	Gas	Gas	Gas	Liquid	Liquid	Gas
Fluid Harmfulness	Harmful	Harmful	Very Harmful	Very Harmful	Very Harmful	Lethal
Value pD, MPa.mm	750	1750	1750	350	300	300
Mod's to pD for special conditions	1.5	1.5	1.5	1.5	1.5	1.5
Modified value pD, MPa.mm	1125	2625	2625	525	450	450
Hazard Level	B	B	B	B	C	B
	Classification according to Directive 97/23/EC - Annex II					
Fluid State	Gas	Gas	Gas	Liquid	Liquid	Gas
Fluid Group	2	2	2	2	2	1
PD, Bar.mm	7500	17500	17500	3500	3000	3000
Conformity Assessment Category	III	III	III	Art. 3, Para. 3	Art. 3, Para. 3	III

Table 8. Hazard levels of pressure equipment (Part of Table 1 of AS4343 published with permission of SAI Global Ltd)

Equipment – Type and conditions (see Notes 6 & 9)					**Hazard level (see Notes 5, 7 & 8)**																			
1 PRESSURE VESSELS (except vacuum vessels and boilers) – includes unfired, fired, static & transportable vessels																								
Fluid Type of Contents (see Notes 1 & 2)			**Volume (V) L**	**Pressure (p) MPa** (see Notes 10 & 4(a)(v))	**Value of pV, (as modified by Notes 4 & 10) MPa.L (see Note 3)**																			
					0.1	0.3	1	3	10	30	10^2	3×10^2	10^3	3×10^3	10^4	3×10^4	10^5	3×10^5	10^6	3×10^6	10^7	3×10^7	10^8
1.1	Lethal (see Note 11)	Gas	>0.05	>0.05		C							B							A			
		Liquid	>0.2		E	D		C					B							A			
1.2	Very harmful	Gas	>0.2				E	D		C			B							A			
		Liquid	>1.0				E			D	C		B									A	
1.3	Harmful	Gas	>0.2				E		D		C		B									A	
		Liquid	>1.0				E				D		C			B							A
1.4	Non-harmful (see Note 5)	Gas	>0.2				E			D	C					B						A	
		Liquid	>10				E						D	C		B							

(or pressure times diameter (pD) for piping) and modification factor for special conditions. Two modification factors are considered in these examples. The first group of examples uses a factor of zero for no location or service modifier while the second group of examples uses a factor of three for the pressure vessels and 1.5 for piping on the basis that the vessels and piping are located in a major hazard facility.

Two of the vessels in the example have hazard levels of A and the other four are B. When the vessels are considered to be located in a major hazard facility, Vessel 3's hazard level increases from B to A while the other remain the same. Four of the pipes have hazard levels of B and two have C. When the modifier is increased, pipe 4 hazard level increases from C to B while the remainder are unchanged. These hazard levels determine the required degree of external design verification and fabrication inspection.

In Australia, the design and fabrication verification requirements are specified in AS 3920.1 – 1993 Assurance of product quality – Part 1: Pressure equipment manufacture (AS 3920.1 – 1993). Table 2.1 of the standard, titled "Relationship between hazard level of equipment and required degree of external design verification and fabrication inspection with and without a manufacturer's certified quality system" is used to select the level of verification.

The extent of verification required for the manufacture of the vessels and piping in the examples is described below for the case where the designer and fabricator have certified quality systems to ISO 9001 and ISO 9002.

Table 9. AS 3920.1 – 1993 Table 2.1 – Relationship between hazard level of equipment and required degree of external design verification and fabrication inspection with and without a manufacturer's certified quality system (Part of Table 2.1 of AS3920.1 published with permission of SAI Global Ltd)

	Design			Fabrication	
Hazard level of equipment (see Appendix B)	Certified quality system status	Design verifying body (see Note 1)		Quality system status	Fabrication inspection body required (see Notes 2 & 3)
A	AS/NZS ISO 9001	Yes		AS/NZS ISO 9002	Yes
B	AS/NZS ISO 9001	Yes	or	AS/NZS ISO 9002	No
	No CQS	Yes		No CQS	Yes
C	AS/NZS ISO 9001	No (Note 4)	or	AS/NZS ISO 9002	No
	No CQS	Yes		No CQS	Yes
D	AS/NZS ISO 9001	No		No CQS	No
	No CQS	Yes (Note 5)			
E	No CQS	No		No CQS	No

If the pV or pD modifier is zero, Vessels 2 and 6 require full independent verification of design and full independent fabrication inspection, while Vessels 1, 3, 4 and 5 only require full design verification. Pipe no's 1, 2, 3 and 6 require full independent design verification while pipe no's 4 and 5 do not need any independent verification. If the equipment is to be located in a major hazard facility where the pV or pD modifiers are 3 and 1.5 respectively Vessel 3 and Pipe no. 4 change up one level of verification.

The same pressure vessels and piping are also evaluated using the criteria in PED/97/23/EC to determine firstly the fluid contents grouping and then the categories of modules in accordance with Annex II. The modules define the conformity assessment procedures required for design verification and fabrication inspection. All of the pressure vessels are designated as Category IV, the highest level of conformity assessment. The conformity assessment categories for two of the pipes are the lowest level; Article 3, Paragraph 3. The remainder of the pipes are category III; the second highest level.

The hazard levels E, D, C, B and A in AS 3920.1 and AS4343 are similar but not the same as the Groups in the PED of Article 3, Paragraph 3, I, II, II and IV. Thus it can be seen that, for the examples given, the use of the Australian standards and the PED arrive at different quality assurance or conformity assessment requirements for the equipment in the same service. The PED is stricter for the pressure vessels while the Australian standard is stricter for the piping.

CONCLUSIONS

The quality assurance procedures for pressure equipment in Australia, the EU and the USA use classifications for the fluid contents as part of the procedure for arriving at the level of conformity assessment to be applied to the design and fabrication.

In Australia, the classifications are derived from the Australian Dangerous Goods Code and Australian List of Designated Hazardous Substances, taken from Annex I of the European Dangerous Substances Directive –DSD, or if not included there, the classification is to be derived using the procedures in the National Standard for Approved Criteria for Classifying Hazardous Substances. Often there is no clear path for arriving at one of the four harmfulness classes from these sources and it is recommended for the designer to use the services of a toxicologist for guidance in the classification. In the EU the derivation is deduced from the DSD using the Risk Phrases specified in the Pressure Equipment Directive Guideline 2/7 though care is needed when using the classifications in directive 67/548/EEC.

In the USA, the ASME Code for process piping has four fluid classes which are reasonably well defined in the code. The ASME BPV code only specifies substances that are lethal by inhalation with little guidance as to their classification.

Once the fluid contents have been classified the selection of the hazard level or category for conformity assessment is readily determined in AS3920.1 or PED Annex II.

It would appear that there are significant differences between the Australian and the EU PED conformity assessment or quality assurance requirements for pressure vessels or piping in the same duty. The PED requirements for pressure vessels are generally stricter while the reverse is the case for piping.

ADDRESS
Correspondence concerning this paper should be addressed to Dr David S. Dolan, Fluor Australia Pty Ltd, GPO Box 1320, Melbourne, Victoria, 3001, Australia *or email* david.dolan@fluor.com

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