Designing to proposed API WHB tube failure document

Dennis H. Martens
Consultant and Technical Advisor (martensdh@pm-engr.com)
Porter McGuffie Inc.

Lon Stern
Consultant (lhstern@earthlink.net)
Stern Treating & Sulfur Recovery Consulting, Inc

Presented at the 2014 Brimstone Sulfur Symposium Vail Colorado
Facilitated by Brimstone STS Limited

ABSTRACT

This paper highlights current API "TASK FORCE ON HRSG OVERPRESSURE" design considerations for WHB tube failure and provides information and comments for consideration for inclusion within API STD 521/ISO 23251 for the protection against the potential overpressure of a Claus Unit resulting from tube failure in the Waste Heat Boiler.

The results of Amine Best Practices Group's 2014 SRU industry survey update for years of SRU operational and fatalities/injuries resulting from a WHB tube failure are presented to focus on actual operational experience of WHB tube failures which resulted in loss of containment due to over pressure rupture. We discuss past WHB tube failures reported in the public domain.

The use of Layers Of Protection Analysis (LOPA) is discussed for addressing the probability of a tube failure occurrence, associated loss of containment occurrence and risk quantification. A summary table provides examples of LOPA application for various tube failure scenarios. The 2013 ASME Section VIII Div 1 UG-22 Loadings and UG-140 Overpressure Protection by System Design refers to utilizing the overpressure scenarios in API 521 and HAZOP procedures to determine credible failure scenarios

The use of an alternate allowable pressure design methodology is presented. This paper provides a suggested pressure design approach for consideration by the SRU community and the API Task Force.

ABPG -- SRU Waste Heat Boiler Safety Survey – Updated to 2014

In 2001, the Amine Best Practices Group (ABPG) conducted an internal survey on Claus Thermal Reactor Waste Heat Boiler safety history, as well as determining if there had been loss of containment experiences. The survey was bifurcated into WHB's operating at <400 psig and those operating >400 psig. The results were very re-assuring, in terms of safety performance, with no injuries/fatalities reported. Within ABPG membership, there was a total of nearly 2800 SRU-years of safe operation. When an estimate by Strom Smith, Sulfur Operation Services, of 580 additional SRU's (425 refinery and 75 gas plant SRU's in the US and 80 SRU's in Canada) was included at 25 years (= 14,500 SRU-years), that brought the grand total of safe experience to ca. **17,300 SRU-years.**

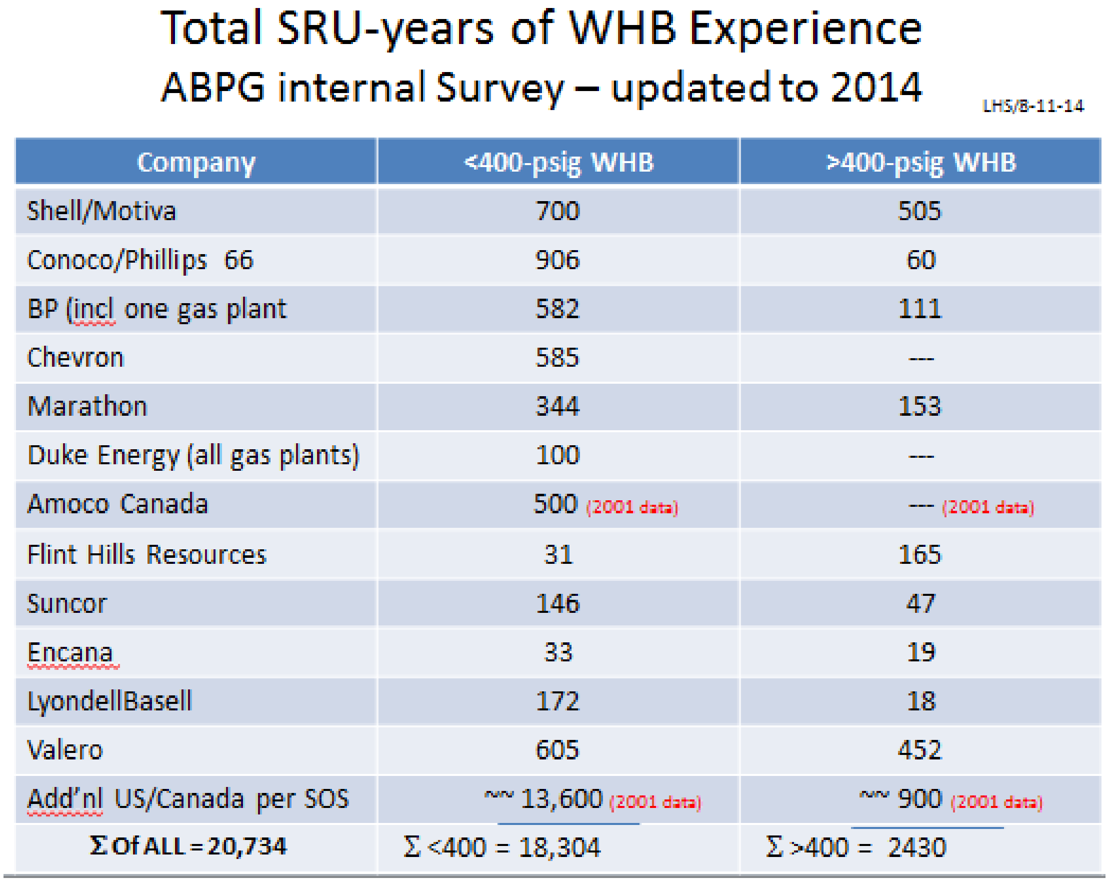
This year, 2014, the ABPG internal survey was updated with data from the members for 11 companies' experience. The result was an additional **3434 SRU-years**. When adding the sum of ABPG survey data (3434) to the 2001 data from Strom Smith, the grand total of safe experience is now at ca. **20,734 SRU-years.**

Note: the SOS estimates of 2001 were not updated, thus remain unchanged; the split between <400 and >400 psig is an estimate.

There were, unfortunately, three loss of containment experiences in the update. At one refinery with Low Pressure-rated SRU's (<15 psi), the loss of containment occurred following an attempted "recovery" of loss-of-level by adding boiler feed water. There was only equipment damage; no personnel injuries. The one loss of containment event, based on the current data below results in a loss of containment event frequency of $1/20734 = 4.8\text{x}10^{-5}$.

In the other case, there were two similar loss of containment events at the same SRU, within about a six-month span. <u>These two incidents were not related to an overpressure event</u> . Neither incident resulted in any injuries/fatalities. The cause is believed to have been localized corrosion resulting in leaks in the boiler tube(s) and subsequent water and process gas two-phase impingement and corrosion on the boiler outlet channel head dollar plate that resulted in a "hole-through" loss of containment.

Attached, below, is the tabulation of the current ABPG total years of experience survey data:



Total SRU-years of WHB Experience

ABPG internal Survey – updated to 2014

LHS/B-11-14

Company	<400-psig WHB	>400-psig WHB
Shell/Motiva	700	505
Conoco/Phillips 66	906	60
BP (incl one gas plant	582	111
Chevron	585	---
Marathon	344	153
Duke Energy (all gas plants)	100	---
Amoco Canada	500 (2001 data)	--- (2001 data)
Flint Hills Resources	31	165
Suncor	146	47
Encana	33	19
LyondellBasell	172	18
Valero	605	452
Add'nl US/Canada per SOS	~~ 13,600 (2001 data)	~~ 900 (2001 data)
Σ Of ALL = 20,734	Σ <400 = 18,304	Σ >400 = 2430

LOPA

Layer Of Protection Analysis (LOPA) is described in the CPS book "LAYER OF PROTECTION ANALYSIS simplified process risk assessment" [1]. LOPA is a semi-quantitative analysis typically applied after a qualitative hazard evaluation (e.g., Process Hazard Analysis (PHA)) such as a Hazard and

Operability Study (HAZOP). LOPA may also be utilized as a screening tool prior to applying a more rigorous quantitative risk assessment method.

Similar to other PHA's the responsibility for conducting a LOPA rests on the owner/operator of the facility. LOPA, like all analytical methods, has rules and utilizes experience based criteria which are described in reference [1]. LOPA utilizes the steps of; Selection of a scenario and establishing a consequence, identification of initiating event Frequency (F), identification of the Independent Protection layer (IPL), estimation of the Probability of Failure on Demand (PFD) and combining these to calculate an estimated quantitative risk (R). For a typical LOPA each scenario has a single initiating event. The initiating event frequency (F) and the probability of failure on demand (PFD) are best established by related industry experience. The calculated Risk (R) result must be suitable for confirming adequate mitigation for avoidance of the original failure consequence for the scenario. For R values deemed to be unacceptable a more complicated scenario including additional IPL's may be utilized which requires additional calculation steps as indicated in reference [1].

For the LOPA scenario examples in Appendix Table A the "scenarios" are variations of WHB tube failures. The failure rate (F) is estimated based on SRU industry experience and the value is stated as occurrence per operating year. The independent protection layer (IPL) is the plant pressure containment equipment and the probability of failure on demand (PFD) of this equipment is based on overpressure failure defined as equipment rupture and stated as failure per overpressure occurrence. The PFD values were estimated based on the survey information presented above, data provided in reference [1] and the SRU industry use of ASME BPVC Section VIII Div1 [2] and NFPA 69 [3] deflagration design methodology. The experience of rupture occurrence due to deflagration events is based on the NFPA 69 [3] Appendix statement that "the requirements of this standard and the review and approval processes stated are intended to establish an acceptable level of reliability". The calculated Risk (R) is developed by multiplying the F and PDF values. The acceptable risk (R) criterial is taken from reference [1]. Reference [1] Chapter 6 includes this LOPA Example statement, "if equipment is designed to withstand an internal deflagration than all scenarios that lead to a rupture of a vessel due to an internal explosion have thereby been eliminated".

The numerical values for F, PFD and R presented in Table A are for example use only. The values utilized for a LOPA must be selected by the owner/operator conducting the analysis based on their experience and knowledge.

Angela E. Summers, in a presentation at the AIChE 8th Global Congress on Process Safety (2012) [5] states, "Extensive guidance on the credibility analysis can be found in the WRC Bulletin 498, "Guidance on the Application of the Code Case 2211 – Overpressure Protection by System Design". The guidance document warns that the justification for using system design or a combination of system design and pressure relief devices is based on likelihood alone and should not take consequence severity into account. The guidance further suggests that the likelihood of overpressure should be reduced to less than 1 in 10,000 years.".

This WRC guidance [6] when applied in a LOPA analysis would require a minimum of a $1x10^{-4}$ event per year risk of vessel (equipment) failure for a scenario to be considered not credible. The current SRU industry experience for a tube failure event resulting in a rupture, as reported in the ABPG data sited above is $4.8x10^{-5}$ event per operating year for all design pressure units. This confirms that the experience based risk of an overpressure loss of containment due to WHB tube failure is a "not credible" scenario. It must be noted that there is no ABPG data for the number or low design pressure units (<15 psi) versus higher design pressure units (>15 psi) therefore the authors caution that the use of the $4.8x10^{-5}$ event per operating year experience may not be appropriate for low design pressure units without additional experience data evaluation.

Rationale for Proposed Alternate Equipment Design Pressure Methodology

This proposal is justified based on the SRU industry WHB experience data provided in the ABPG survey which documents a risk experience of an overpressure loss of containment due to WHB tube failure of $4.8\text{x}10^{-5}$ event per operating year. This experienced based event frequency, compared to the commonly utilized criteria of $1\text{x}10^{-4}$ Risk event per operating year from WRC Bulletin 498 [6], results in a "Not Credible" scenario rating.

Even though the LOPA analysis example in Table A, for a double ended failure, results in a loss of containment Risk value of $1\text{x}10^{-7}$and would be considered to be an acceptable risk, the venting of the SRU high temperature process gas should be avoided whenever possible. It is proposed that the maximum allowable pressure buildup, for a worst case tube failure scenario, be established utilizing a similar methodology as the NFPA 69 [3] deflagration resulting in equipment deformation but not rupture.

When considering the consequences of a possible SRU WHB tube failure, it is necessary to establish a maximum pressure buildup in the equipment that can be tolerated without loss of containment. Good engineering practice, that follows ASME Boiler and Pressure Vessel Section VIII Div 1 [2] and NFPA 69 [3] methodology for deflagration design, results in a typical air blown SRU design pressure of 55 psi. Equipment with an ASME Maximum Allowable Working Pressure (MAWP) of 55 psi is also suitable for an ASME/NFPA deflagration event design maximum pressure buildup of 130 psi with an acceptable level of safety and reliability based on NFPA 69 deformation not rupture methodology (sample calculation in Appendix). This good engineering practice for deflagration scenarios, as defined by ASME/NFPA, is proposed to be directly applicable to the determination of the maximum allowable pressure buildup from WHB tube failure scenarios.

It is proposed that the NFPA 69 Chapter 13 methodology, utilizing the 1.5 safety margin for a Design Deflagration pressure without rupture, is appropriate for an API 521 Tube Rupture scenario to establish the equipment ASME Section VIII Div1 MAWP. The SRU industry recognizes that deflagrations and tube failures can and do occur. The industry experience is SRU units designed per ASME/NFPA [2][3] deflagration methodology of deformation without rupture has been suitable to withstand deflagrations that have occurred and also for tube failures that have occurred.

The 2013 ASME Section VIII Div 1 [2] Paragraph UG 22 LOADINGS provides a listing of conditions that shall be considered which includes subparagraph (i) "abnormal pressures, such as those caused by deflagration;". Subparagraph (i) is considered to include all causes not explicitly stated in UG 22 which would include considerations for pressure loading from tube leaks and failures. Paragraph UG 140 OVERPRESSURE PROTECTION BY SYSTEM DESIGN subparagraph (2) states "The user shall conduct a detailed analysis to identify and examine all potential overpressure scenarios. The "Causes of Overpressure" described in ANSI/API Standard 521, Pressure Relieving and Depressuring Systems shall be considered. Other standards or recommended practices that are more appropriate to the specific application may also be considered. A multidisciplinary team experienced in methods such as hazards and operability analysis (HazOp); failure modes, effects, and criticality analysis (FMECA); "what-if" analysis; or other equivalent methodology shall establish that there are no sources of pressure that can exceed the MAWP at the coincident temperature.".

The wording in this paragraph would at first appear to indicate that all potential overpressure scenarios must not exceed the MAWP of the equipment and the potential overpressure from a deflagration would be subject to the MAWP requirement. However the ASME recognizes the NFPA methodology for deflagration overpressure design and ASME does not impose the limitation of not exceeding the MAWP.

API 521[4] in paragraph 4.4.10.1 Internal Explosion (Excluding Detonation) states “Some alternate means of explosion protection are described in NFPA, including explosion containment, explosion suppression, oxidant-concentration reduction, and so forth”. This statement indicates API recongizes good engineering practice to include the utilization of ASME/NFPA methodology for explosion (deflagration) containment. The NFPA 69 [3] methodology of deformation not rupture is utilized by owners and operators in the SRU industry for deflagration scenario considerations.

The information above clarifies that good engineering practice as defined by ASME section VIII Div 1 [2] for MAWP design methodology provides a safety margin of maximum allowable stress to minimum tensile stress of ~ 3.5. MAWP methodology is typically applied to all pressure loadings. ASME defines good engineering practice for deflagration scenarios by referencing NFPA 69 [3] for deflagration design methodology, utilizing deformation without rupture criteria, which provides a safety margin of maximum allowable stress to minimum tensile stress of ~1.5. The ASME Section VIII Div 1 [2] Nonmandatory Appendix H GUIDANCE TO ACCOMMODATE LOADINGS PRODUCED BY DEFLAGRATION clarifies the approaches to designing for deflagration events and references NFPA 69. Paragraph H-4 DESIGN CRITERIA subparagraph H-4.1 SAFETY MARGIN states “As described in NFPA – 69, a vessel may be designed to withstand the loads produced by deflagration”.

Additional Discussion

NFPA 69 [3] Chapter 1 ADMINSTRATION section 1.2 PURPOSE states in subparagraph 1.2.3 “To meet a minimum level of reliability-------“ but this subparagraph does not specifically address system reliability. However Annex A EXPLANATORY MATERIAL paragraph 1.2.3 discusses and further clarifies system reliability and system integrity levels and states “The requirements of this standard and the review processes stated are intended to establish an acceptable level of reliability”.

A sample NFPA 69 deflagration calculation is provided in the Appendix for a methane and air blown deflagration occurrence during a cold startup which calculates a 130 psi deflagration pressure buildup which results in a 55 psi MAWP for ASME Section VIII Div 1 equipment based on the NFPA 69 criteria of deformation but not rupture. This design methodology is accepted by ASME and NFPA as providing good engineering practice and providing an acceptable level of safety and reliability. It is the author’s opinion that utilization of the ASME/NFPA deflagration methodology, including deformation not rupture criteria, for establishing a maximum allowable pressure buildup is directly applicable for a SRU WHB maximum tube rupture scenario and consistent with good engineering practice and SRU industry experience.

Table A, utilizing the deflagration methodology and LOPA information is provided as a sample of possible design approaches for tube leak scenarios that could be considered to provide an acceptable risk for possible tube rupture scenarios and good engineering practice. Table A provides an example of a LOPA risk analysis and application of acceptable risk criteria for tube leak scenarios. The table includes ASME MAWP, NFPA no deformation and deformation but not rupture criteria methodology. A specific SRU LOPA analysis, including establishing the necessary failure criteria and acceptable risk criteria, must be the responsibility of the owner/operator similar to the PSA HAZOP owner responsibility.

Additional layers of protection maybe applicable for other scenarios related to WHB tube failures and maybe included, as described in [1], for establishing a risk level. Additional LOPA scenarios may include the loss of water level resulting in a tube failure and maintaining the gas path to atmosphere both which could then include enhanced instrument/controls and operating procedures to provide an acceptable risk result.

References [ ]

1. LAYERS OF PROTECTION ANALYSIS Simplified Process Risk Assessment; Center for Chemical Process Safety American Institute of Chemical Engineers Copyright 2001
2. ASME Boiler and Pressure Vessel Code Section VIII Rules for Construction of Pressure Vessels Division 1 2013 Copyright ASME International
3. NFPA 69 Standard on Explosion Prevention Systems 2014 Copyright National Fire Protection Association
4. API STANDARD 521 Pressure-relieving and Depressuring Systems Sixth Edition 2014 Copyright American Petroleum Institute
5. Working Under Pressure presentation by Angela Summers (SIS-TECH Solutions, Houston TX) at the AIChE 8th Global Congress on Process Safety and at Texas Chemistry Council Annual Environment, Health & Safety Seminar 2012 (public domain)
6. WRC Bulletin 498 GUIDANCE ON THE APPLICATION OF CODE CASE 2211-OVERPRESSURE PROTECTION BY SYSTEM DESIGN January 2005 published by the Welding Research Council, INC.
7. Lamar, J.A., “*SRU Overpressure in a Waste Heat Boiler Failure*”, Brimstone Sulfur Symposium - Vail, September 2005.

Appendix

- Table A - LOPA example for WHB tube failure scenarios

- Sample NFPA 69 deflagration calculation

TABLE A

LOPA example for WHB tube failure scenarios including design leak criteria, pressure design, F,PDF and R estimated values (see notes for table)

Scenario	Leak rate qualification by steady state or dynamic simulation calculations	Max developed (1) pressure basis criteria for design based on ASME 55 PSI MAWP and NFPA 69 using ductile strain hardening materials such as SA 516-70	Occurrence frequency **(F)** (2) (7)	Risk of loss of containment due to rquipment rupture occurrence frequency **(PDF)** (3) (5) (6)	LOPA acceptable risk criteria **(R)** (4) (7) Reference one Appendix E page 245 “one scenario” rate of 1x10^{-4} to 1x10^{-6} Indicated a General industry at 1x10^{-5} **Calculated risk Values**
BP/Lamar paper Reference [7]	Leak equivalent to a 1 square inch orifice	ASME API 521 MAWP or Hydro test pressure corrected for temperature ~3.5 SF **(55 or ~= 72 psi)**	Most often, perhaps one every 5 operating years Frequency rate **2x10^{-1}**	No loss of containment/rupture no equipment deformation rupture frequency rate **1x10^{-6}**	**(2x10^{-1})*(1x10^{-6}) = 2x10^{-7}**
Alternative, no public papers	Leak equivalent to 20% of a tube cross section hole orifice	ASME API 521 MAWP or Hydro test pressure corrected for temperature ~3.5 SF **(55 or ~= 72 psi)**	sometimes, perhaps one every 10 operating years Frequency rate **1x10^{-1}**	No loss of containment/rupture no equipment deformation rupture frequency rate **1x10^{-6}**	**(1x10^{-1})*(1x10^{-6}) = 1x10^{-7}**
Alternate, no public papers	Leak equivalent to Severed tube, single end	ASME/NFPA 69 ASME 55 MAWP NFPA deflagration with deformation and avoiding Tensile/rupture with 1.5 Safety Factor **(130 psi)**	Low frequency, perhaps one every 100 to 500 operating years Frequency rate **1x10^{-2}**	No loss of containment/rupture expect equipment deformation rupture frequency rate **1x10^{-4}** (estimated data)	**(1x10^{-2})*(1x10^{-4}) = 1x10^{-6}**
API 521 std	Severed Tube, double end	ASME/NFPA 69 ASME 55 MAWP NFPA deflagration with deformation and avoiding Tensile/rupture with 1.5 Safety Factor **(130 psi)**	Seldom, perhaps one every 1000 to 5000 operating years Frequency rate **1x10^{-3}**	No loss of containment/rupture expect equipment deformation rupture frequency rate **1x10^{-4}** (estimated data)	**(1x10^{-3})*(1x10^{-4}) = 1x10^{-7}**
API 521 std	Severed Tube, double end	Based on ABPG data for all SRU reporting for design (low) pressure (<15 psi) and higher design pressure units	**See note 7**	No loss of containment/rupture expect equipment deformation rupture frequency rate **1x10^{-4}** (estimated data)	Based on survey data of ~20,734 operating years 1 loss of containment in a low design pressure unit none in a high design pressure unit **Survey Risk factor 4.8x10^{-5}**

(1) Maximum developed process side pressure to be based on criteria of ASME MAWP of 55 PSI, and use of NFPA 69 deflagration based methodology resulting in no expected equipment permanent deformation with expectation of return to service after inspection. NFPA 69 methodology utilizing 1.5 Safety Factors (SF) from rupture pressure with resulting expected equipment deformation with expectation of not being able to return to service immediately and

possibility requiring repair or replacement after inspection. The 1.5 SF from rupture design basis is taken from ASME BPVC provisions for deflagration design and NFPA 69 deflagration design basis without rupture (loss of containment). The authors consider this basis to be reasonable as there is considerable use of this methodology for deflagration design and the SRU industry experience is the NFPA deformation without rupture design provides an acceptable risk and Life Safety design basis.

(2) Occurrence frequency is authors' estimation based on industry data and SRU industry experience, however each user must assign a frequency based on their experience.

(3) It is the author's opinion that the risk of damage due to single or double ended tube failure in an SRU WHB is of a lesser or same magnitude as the risk of deflagration in an SRU unit as described in NFPA 69. It is the authors' experience that deflagrations and tube leaks occur in the SRU industry without equipment rupture and injuries or fatalities occurring in equipment that has a design pressure of at least 50 psi MAWP. The industry public domain reported experience does not indicate equipment rupture occurring from deflagration events or for tube failures. There are some urban legends and none documented loss of containment due to deflagration and tube failure however these are old reports that are related to low pressure designs and lack of adequate safety systems and operating procedures. The current implemented SRU industry practice for safety systems and operating procedures have been shown to provide adequate safety to avoid the worst case scenarios and the SRU industry safety record related to deflagration or tube failure is excellent.

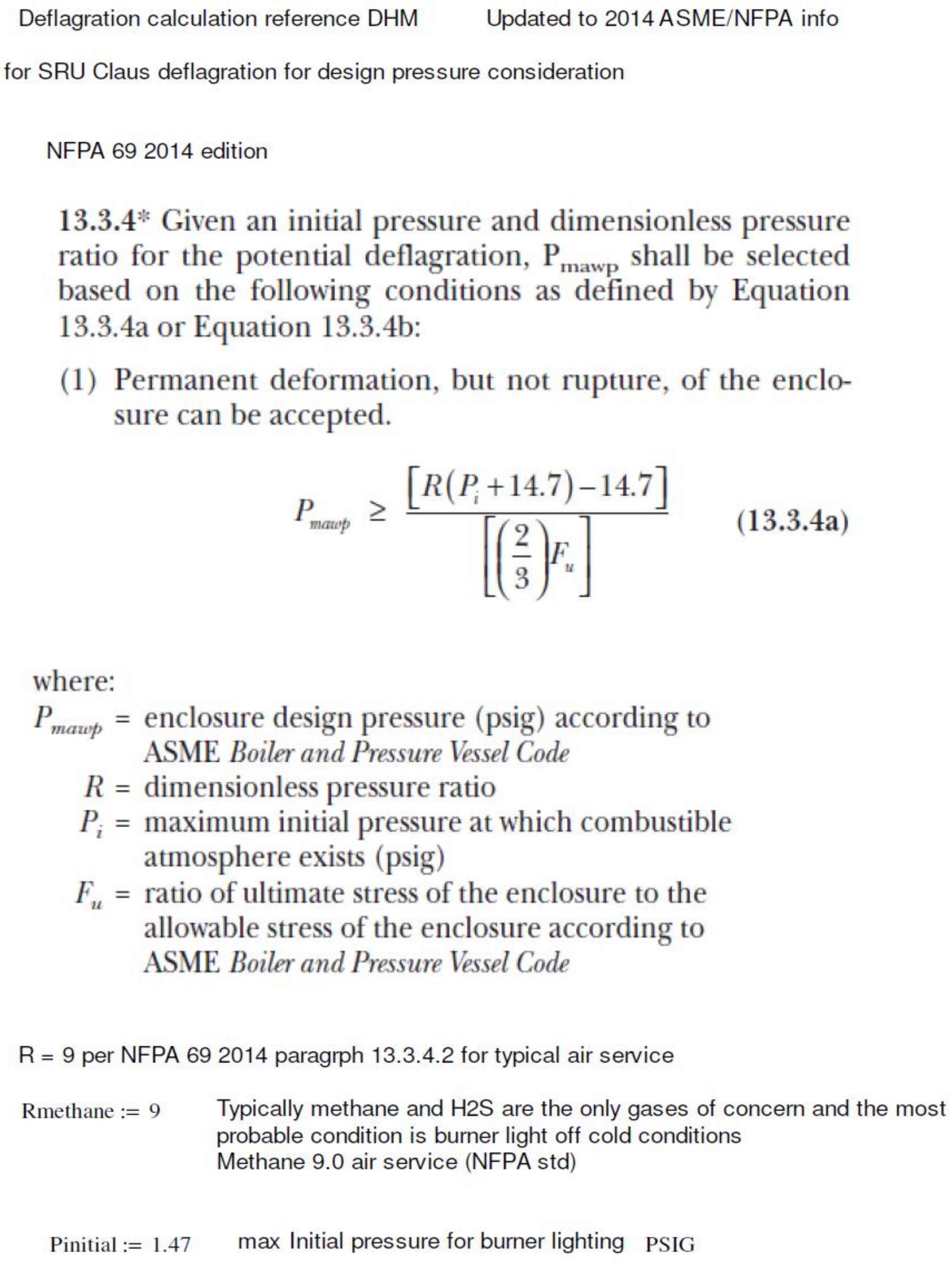
(4) CCPS publication "LAYERS OF PROTECTION ANALYSIS" (LOPA), authored by AIChE copyright 2001, provides methodology that may be used to quantify and evaluate risk. LOPA may be utilized as an extension of HAZOP studies when the HAZOP scenarios are difficult to satisfactorily evaluate. LOPA methodology provides a rational, objective, risk based approach for evaluating the risk for loss of containment. The acceptable risk criteria is discussed in this publication and additional guidance is provided in ASME Code Case 2211-1999, this case has been annulled and is now incorporated in Section VIII Div 1 UG-140, based on WRC 498, however each user must establish an acceptable risk value based on their experience.

(5) NFPA 69 Chapter 4 General Requirements Paragraph 4.2.1 Life Safety Subparagraph 4.2.1.2 states "Deflagration prevention and control for unoccupied enclosures shall prevent rupture of the enclosure". Typically a HAZOP considers a injury or fatality as a consequence of a pressure vessel rupture. Chapter 13 Deflagration Control by Pressure Containment provides guidance for addressing the maximum pressure a containment system may be subjected to without rupture and providing an acceptable Life Safety consideration design. The use of the NFPA deflagration design methodology based on deformation without rupture methodology for establishing the allowable pressure buildup up due to a double ended tube rupture scenario per API 521 is suggested for inclusion in the API 521consensus if the double tube end failure continues to be considered as a scenario for SRU WHB tube failures.

(6) Reference to CCPS publication "LAYERS OF PROTECTION ANALYSIS" (LOPA) authored by AIChE copyright 2001 Table 5.1 page 71, for ~ 3.5 Safety Factor Pressure Vessel failure rate @ $1x10^{-6}$, for a 1.5 Safety Factor vessel failure rate is estimated to be $1x10^{-4}$ (a factor of 100 times greater failure probability than a standard PV failure rate). No data appears to be published for the ASME/NFPA consensus standards acceptable deflagration design criteria for maintaining life safety using a 1.5 Safety Factor for rupture.

(7) The ABPG SRU industry survey data presented in this paper confirms 20,734 SRU operational years with one reported loss of containment in a low design pressure SRU (~15 psi) due to reentrance of boiler feed water after a loss of water level had occurred. Note that the other two loss of containment incidents were not included in the calculations related to overpressure failure scenarios. The incident was not reported as directly related to a double ended tube failure or a tube leakage. No personnel injuries were reported. The data would indicate a frequency of occurrence of 1/20,734 = **$4.8x10^{-5}$** event per operating year has been achieved based on currently available data for all SRU reporting which confirms a WRC 498 not credible scenario rating requirement of $1x10^{-4}$. The survey includes low pressure design units (<15 psi). Low pressure units would be expected to have a significantly greater PFD factor than SRU units designed per ASME/NFPA deflagration methodology.

Sample NFPA 69 deflagration calculation



Deflagration calculation reference DHM Updated to 2014 ASME/NFPA info

for SRU Claus deflagration for design pressure consideration

NFPA 69 2014 edition

13.3.4* Given an initial pressure and dimensionless pressure ratio for the potential deflagration, P_{mawp} shall be selected based on the following conditions as defined by Equation 13.3.4a or Equation 13.3.4b:

(1) Permanent deformation, but not rupture, of the enclosure can be accepted.

$$P_{mawp} \geq \frac{\left[R\left(P_i + 14.7\right) - 14.7\right]}{\left[\left(\frac{2}{3}\right)F_u\right]} \qquad \textbf{(13.3.4a)}$$

where:

P_{mawp} = enclosure design pressure (psig) according to ASME *Boiler and Pressure Vessel Code*

R = dimensionless pressure ratio

P_i = maximum initial pressure at which combustible atmosphere exists (psig)

F_u = ratio of ultimate stress of the enclosure to the allowable stress of the enclosure according to ASME *Boiler and Pressure Vessel Code*

R = 9 per NFPA 69 2014 paragrph 13.3.4.2 for typical air service

Rmethane := 9	Typically methane and H2S are the only gases of concern and the most probable condition is burner light off cold conditions Methane 9.0 air service (NFPA std)
Pinitial := 1.47	max Initial pressure for burner lighting PSIG

using SA 516-70 materials and similar ductile piping materials

$\text{Sdesign} := 19.4$ ASME 2014 VIII Div 1 allowable design stress Sect II D KPSI at 600 F note piping materials may have a lower design stress available

$\text{Stensile} := 70$ ASME 2014 VIII Div 1 min tensile Sect II D KPSI at 600 F note piping materials may have a lower tensile available

$\text{Fu} := \dfrac{\text{Stensile}}{\text{Sdesign}}$ $\text{Fu} = 3.608$

$\text{STDatmos} := 14.7$

$$\text{Pmaw} := \frac{[\text{Rmethane}\cdot(\text{Pinitial} + \text{STDatmos}) - (\text{STDatmos})]}{\left(\frac{2}{3}\right)\cdot\text{Fu}}$$

$\text{Pmaw} = 54.388$ Use 55 psi for 2014 ASME design

$$\text{Pdef} := \text{Pmaw}\cdot\left[\left(\frac{2}{3}\right)\cdot\text{Fu}\right]$$

$\text{Pdef} = 130.83$ PSI to tensile failure/rupture failure with 1.5 safety factor