HITACHI

GE Hitachi Nuclear Energy

Richard E. Kingston
Vice President, ESBWR Licensing

P.O. Box 780
3901 Castle Hayne Road, M/C A-65
Wilmington, NC 28402 USA

T 910.819.6192
F 910.362.6192
rick.kingston@ge.com

MFN 09-547,

Docket No. 52-010

August 13, 2009

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Subject: NEDE-11146, dated January 26, 1972

Enclosed is a copy of NEDE-11146, "Pressure Integrity Design Basis for New Gas Systems" (July 1971). This document is referenced in the ESBWR Design Control Document ("DCD"), Chapter 11, as Reference 11.3-11. Although the DCD currently states that the report is proprietary, GEH has determined that it contains no information that is now considered proprietary.

If you have any questions or require additional information, please contact me.

Sincerely,

Richard E. Kingston

Richard E. Kingston
Vice President, ESBWR Licensing

D068
NRO

Enclosure:

1. NEDE-11146, Design Basis for New Gas Systems, January 26, 1972.

cc:	AE Cubbage	USNRC (with enclosures)
	JG Head	GEH/Wilmington (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)

NEDE-11146
71 NED 19
CLASS II
JULY 1971

EMPLOYEES ONLY

PRESSURE INTEGRITY DESIGN BASIS FOR NEW OFF-GAS SYSTEMS

C. S. PARKER
L. B. NESBITT

GENERAL ELECTRIC

NEDE-11146
71NED19
Class II
July 1971

EMPLOYEES ONLY

PRESSURE INTEGRITY DESIGN BASIS FOR NEW OFF-GAS SYSTEMS

C. S. Parker, Piping Design CSP
L. B. Nesbitt, Chemical Systems Design

Approved: J. E. Kjemtrup, Manager
Plant & Equipment Engineering
12/8/71

15/25 P&EE
wjh 1/72
Reprint
200 Copies
5/72

ATOMIC POWER EQUIPMENT DEPARTMENT • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

GENERAL ELECTRIC

DISCLAIMER OF RESPONSIBILITY

This report was prepared as an account of research and development work performed by General Electric Company. It is being made available by General Electric Company without consideration in the interest of promoting the spread of technical knowledge. Neither General Electric Company nor the individual author:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information disclosed in this report may not infringe privately owned rights; or

B. Assumes any responsibility for liability or damage which may result from the use of any information disclosed in this report.

SUMMARY

This report presents a method for the design of circular-section steel systems to contain explosions of near-stoichiometric mixtures of gaseous hydrogen and oxygen. It is intended for application to BWR Process Off-Gas System components under the restrictive set of conditions detailed herein.

The method consists of three (3) parts:

Part 1 outlines the detonation phenomena as applied to H_2 and O_2 in off-gas systems and specifically establishes the peak instantaneous pressures and the pressure pulse duration.

Part 2 defines the method of analysis used to relate the detonation variables with the equipment material properties to obtain an equipment wall thickness. Two thicknesses are found, one which will just contain the event (H) and one which will be reusable without repair (H').

Part 3 presents the rules for obtaining the "code equivalent pressure" P_{se}' when H or H' is given.

Appendix A provides sample calculations applying the above steps taking into account the fact that different codes permit different stresses for a given material and temperature tables of P_{se} nongeneral. However, for the specific case of C1010 carbon steel and B31.1.0., some examples are given.

The recommended stress design method is that of Marin and Sharma, "Design of a Thin-Walled Cylindrical Pressure Vessel Based Upon the Plastic Range and Considering Anisotropy," (Reference 1), which results in a desirable balance of confirmed methods of analysis and material cost. This choice of method was strongly influenced by the availability of materials data covering the required range of variables.

The analytical method can be described as a static analysis using dynamic material properties; as such it is appreciably simpler and easier to use than the real problem with its time dependent stresses. The dynamic analysis of Costantino (Reference 2), which in general would require a wall thickness one-half of that being proposed, indicates that the design method herein is sufficiently conservative for general use.

PART 1 – DETONATION GAS DYNAMICS

It has been determined from the literature that the maximum peak pressure that can be experienced by parts of a long pipe filled with a detonable mixture of hydrogen and oxygen is given by $P_f/P_i = 170$; where P_f = maximum peak pressure and P_i = the initial pressure in the pipe. This pressure is experienced on the reflection of a detonation wave, due to the attenuation of the reflected shock wave a conservative envelope for $P_f/P_i \leq 170$ includes all points inside of the equipment within 10 feet of a change of internal pipe geometry or direction. The region is hereby defined as an "end." In the absence of a reflection, the maximum peak pressure ratio is given by $P_f/P_i \leq 68$. It has further been determined that the maximum pressure ratio experienced inside of a vessel with length-to-diameter ratio less than 7 ($\ell/d \leq 7$) is given by $P_f/P_i \leq 17$.

The peak pressure (P_f) from detonation exists for a very short time, less than 10 μsec; it has a very short rise time (less than 10 μsec) and the pulse pressure drops rapidly with time to a residual value that is less than 10 times the initial value. The pulse duration is a function of the distance the detonation travels.

$$t_o = \frac{\text{distance detonation travels}}{V_d = 18{,}000 \text{ ft/sec}} \tag{1}$$

where

t_o = pulse duration

V_d = velocity at detonation

It has also been determined that for the design of pipes a major expansion in the internal area $\left(\frac{\text{Area final } (A_f)}{\text{Area initial } (A_i)} \geq 4\right)$ effectively interrupts the motion of a detonation. Therefore, the pulse duration should be determined from the maximum path of continuous detonation.

For the design of vessels where $\ell/d \leq 7$ the pulse duration is defined to be the maximum possible from any pipe leading to the vessels.

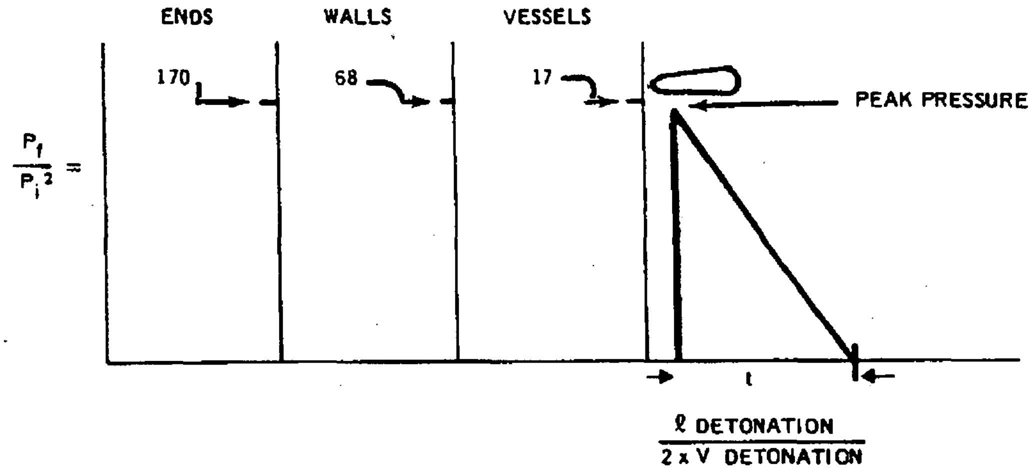


Figure 1

For a specific analysis of a detonating system the time profile and duration of the pulse is important. In the interest of being conservative, the design method of Part 2 assumes the pulse always resonates with the natural oscillations of the pipe. This conservatism has the effect of increasing the calculated stress above the real stress by a factor nearly 2 for systems less than 30 feet in maximum dimension.

PART 2 – RELATING THE DETONATION VARIABLES

The Marin-Sharma design method (Reference 1) is the basic source for this analysis. The Marin-Sharma method is a plastic analysis that allows deformation up to the point where the structure accommodates the load in the most efficient way and is a static analysis in that it assumes that the load is continuously applied. For this application conservatism has been added by assuming mechanical resonance.

The distinction between the use of ultimate strength and yield strength in the minimum thickness equation is based upon the requirement of the system for reusability after a combustion event.

The system designer must make the basic decision as to operating philosophy and event probability. In general the ultimate strength (Su) is used when considering one (1) event and produces the smallest thickness, H. The yield strength (Sy) is used when ten (10) or more events are expected in the life of the system and produces a thickness H'.

The wall thickness is calculated from Equation (2).

$$H = \frac{pd}{2.31\,(0.577)^{n}} \frac{\eta F}{S} \qquad (2)$$

where:

p = maximum pressure, psi

d = actual pipe o.d. inches

S = design stress (Su or Sy) – p

F = safety factor = 1.15

η = dynamic load factor = 2

n = strain hardening exponent

The use of p in the evaluation of S accounts for the biaxial stress on the i.d. of the pipe or vessel.

Table 1
DYNAMIC MATERIAL PROPERTIES FOR C1010 CARBON STEEL
(Reference 3)

	T = 70°F	T = 400°F	T = 900°F
n	0.30	0.04	0.06
Su	120,000 psi	50,000 psi	50,000 psi
Sy	63,000 psi	42,000 psi	31,500 psi

NOTE: In the absence of dynamic properties the use of quasi-static properties which are normally available is, in most cases conservative.

PART 3 – RULES FOR OBTAINING CODE EQUIVALENT PRESSURE

The static pressure equivalent (P_{se}) is determined from the thickness by means of a code equation. Several typical equations are:

B31.1.0 Paragraph 104.1.2. (a) 1

$$P_{se} = \frac{2\ SE\ (tm - A)}{D_O - 2\ y\ (tm - A)} \tag{3}$$

where

tm = H = wall thickness, inches

P = pressure, psi

SE = maximum allowed stress in the material due to internal pressure and joint effectiveness.

D_O = outside diameter, inches

A = design factor

= 0.065 for plain-ended steel pipe up to 3.5-inch nominal size

= 0.000 for plain-ended steel pipe greater than 4-inch nominal size

y = design factor = 0.4 for ferritic and stainless steel 900°F and below

ASME B&PV Code, Section III, article 1-2 paragraph 1-222, Cylindrical Shells

$$P_{se} = \frac{2St}{2R + t} \qquad (4)$$

where:

t = H thickness, inches

P = internal pressure, psi

R = inside radius, inches

S = primary design stress, psi

ASME B&PV Code, Section III, NB-3641.1

1) Straight Pipe under internal pressure

$$P_{se} = \frac{2St}{D - 0.8t} \qquad (5)$$

where:

t = H thickness, inches

S = allowable design stress, psi

D = outside diameter, inches

These thicknesses assume no structural discontinuities and no longitudinal stress concentration factors. In practice, this implies the use of devices such as the smoothly varying wall thickness of a weld neck flange to avoid overall thickness increase.

CONCLUSION

A step-by-step procedure is presented whereby a designer can advance from a specific equipment design of a system, which normally or possibly contains a detonable mixture of hydrogen and oxygen, to the lowest defensible, detonation containing, static equipment pressure rating.

The method assumes the absence of simultaneous secondary events such as earthquakes.

A description of the probability and consequences of equipment stress and failure that in part justifies the method chosen is presented in Appendix B.

The procedure presented herein is the simplest that has been found that does not include a detailed and laborious analysis of the gas dynamics of the system. It presents an analysis that will sustain the whole envelope of feasible detonations. In the event that the economics of a particular situation warrant it, a more detailed analysis leading to a modification of Figure 1 is possible. An example of this modification is presented in Appendix C. Care must be exercised that the uncertainty in this extended analysis does not extend the risk beyond that covered by the safety factors, i.e., the application of Appendix C should be restricted to identical systems unless the analysis is re-established.

REFERENCES

1. Marin, Joseph and Sharma, M. G., *Design of a Thin-Walled Cylindrical Pressure Vessel Based Upon the Plastic Range and Considering Anisotropy*, Welding Research Supplement.

2. Costantino, C. J., *The Strength of Thin Walled Cylinders Subjected to Dynamic Internal Pressure*, Journal of Applied Mechanics, ASME, No. 64-WA/APM-16.

3. Schultz, Albert B., *Dynamic Behavior of Metals Under Tensile Impact*, AFML-TR-69-76, Part I; Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio (1969).

APPENDIX A

A semi-typical off-gas system for a BWR is sketched in Figure A-1.

This simple system contains an example of most of the important pressure determining factors.

Note that this takes no consideration of corrosion allowance which must enter in a real case.

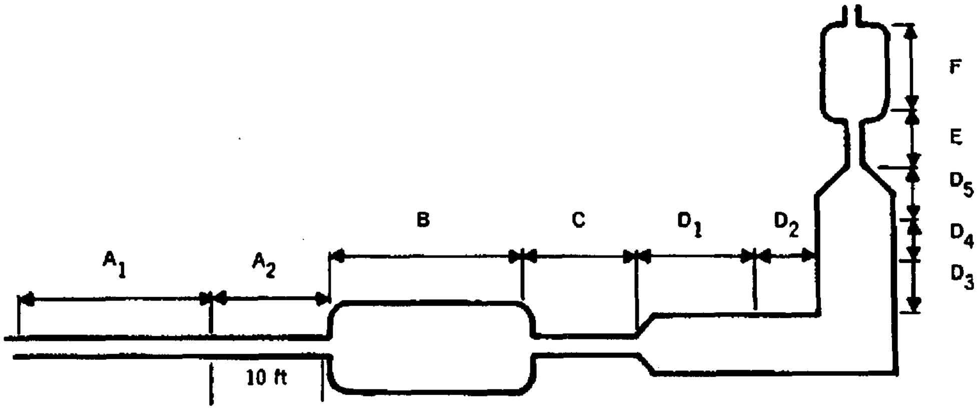


Figure A-1

a) The material is C1010 steel.
b) The temperature is 100°F.
c) B31.1.0 applicable for piping
ASME B&PV Code, Section VIII, applicable for vessels.

ASME B&PV Code, Section VIII, applicable for vessels.

Piece	Length (ft)	Diameter (in.)	Normal Operating Pressure (Atmos)
A_1	100	20	0.1
A_2	10	20	0.1
B	10	24	0.1
C	10	10	1.0
D_1	10	40	1.0
D_2	10	40	1.0
D_3	10	40	1.1
D_4	100	40	1.0
D_5	10	40	1.0
E	10	10	1.0
F	5	36	1.0

Equation 2 and Table 1 applied to piece A_1 yields the following:

$$H_{A_1} = \frac{0.1 \times 14.7 \times 68 \times 20 \times 2 \times 1.15}{2.31 \times (0.577)^{0.3} \times 120{,}000}$$

$$= \frac{4650}{2.35 \times 105} = 19.5$$

$$\doteq 0.0195$$

$$H_{A_1}' = \frac{0.1 \times 14.7 \times 68 \times 20 \times 2 \times 1.15}{2.31 \times (0.577)^{0.3} \times 63.000}$$

$$= \frac{4650}{1.24 \times 10^5}$$

$$\doteq 0.0375$$

Equation 3 applied to these values:

$$P_{se} = \frac{2\,SE\,(tm-A)}{D_0 - 2y\,(tm-A)} \qquad tm = H + A$$

$$= \frac{2 \times 15{,}000\,(0.020)}{20 - 0.8\,(0.020)}$$

$$P_{se} \doteq 30 \text{ psi}$$

$$P_{se}' = 57 \text{ psi}$$

As further examples:

$$H_B = \frac{0.1 \times 14.7 \times 170 \times 24 \times 2 \times 1.15}{2.31\,(0.577)^{0.3} \times 120{,}000}$$

$$= \frac{13{,}800}{2.35 \times 105}$$

$$\doteq 0.059 \text{ in.}$$

$$H_B' = 0.112 \text{ in.}$$

$$P_{se}\,(\text{Sec. VIII}) = \frac{SEt}{R + 0.6\,t}$$

$$= \frac{15{,}000 \times 0.059}{12 + 0.6 \times 0.059}$$

$$P_{se} = 74 \text{ psi}$$

$$P_{se}' = 140 \text{ psi}$$

$$H_{D_1} = \frac{170 \times 14.7 \times 40 \times 2 \times 1.15}{2.31\ (0.577)^{0.3}\ 120{,}000}$$

$$\doteq 0.98 \text{ in.}$$

$H_{D_1}' = 1.87$ in.

P_{se} (B31.1.0) $\doteq$ 760 psi

P_{se}' (B31.1.0) $\doteq$ 1505 psi

As a general rule for B31.1.0 and Section VIII type calculations for C1010 at room temperature.

$P_{se} = 0.3\ P_{peak}$

$P_{se}' = 0.6\ P_{peak}$

For B31.1.10 and Section VIII calculations for C1010 at 800°F

$P_{se} = 0.5\ P_{peak}$

$P_{se}' = 1.0\ P_{peak}$

APPENDIX B

A. EVENT PROBABILITY

An important factor in developing a design criteria for detonation must be the probability of the event. An event is defined as the ignition of a combustible mixture followed by a transition from subsonic to supersonic reaction (detonation). The probability of the peak pressure, at any point in the system, reaching the design value for a detonation is a function of the system geometry. By careful design and practice the total number of events in BWR systems has been made to be very small. The combination of these two probabilities yields a net probability that is set forth in Table B-1.

Table B-1
PROBABILITY OF PEAK DYNAMIC PRESSURE ACTUALLY BEING REACHED AT ANY POINT DURING THE 40-YEAR LIFE OF A 1969 PRODUCT LINE BOILING WATER REACTOR OFF-GAS SYSTEM

	Container	Peak Dynamic Pressure	Probability*	
30-Minute	Vessels	270 psi	2	Events/Plant Life
System	Walls	1,000 psi	1/2	Events/Plant Life
	Ends	2,500 psi	1/10	Events/Plant Life
Ambient				
Recombiner	Vessels	325 psi	1/10	Events/Plant Life
Charcoal	Walls	1,200 psi	1/200	Events/Plant Life
System	Ends	3,000 psi	1/10,000	Events/Plant Life

* These numbers are subjective, however, they are based on the details of the system involved and the applicable phenomenology and give considerable weight to common mode failure.

B. SIGNIFICANCE OF FAILURE

The radiation level resulting from the activity in the off-gas assures that personnel are not in the immediate vicinity of the system. Thus, the probability of mechanically induced personnel injuries in the event of detonation is small. The off-gas system does delay the release of noble gas activity for a period of time to allow decay of the radioactivity. The failure of a 30-minute holdup system operating at 100,000 μci/sec 30 min (diffusion mix) has the possibility of releasing approximately 600 curies of gaseous activity. A cloud with this activity could cause an integrated dose of approximately 20 mrem (within a few minutes) at a site boundary (assuming 400 meters and standard meteorology). Averaged over 1 year, this is a small fraction of the 10CFR20 limit.

The solid daughters formed in the delay pipe, though small in mass (less than 1 milligram per year), might accumulate and be released on detonative failure. Experience has shown that most of the daughters leave the holdup system through the condensate drains. The small remaining fraction is bonded to the interior surfaces of the system. On detonation these solid daughters would most probably be either so finely divided and so widely dispersed as to have negligible radiological significance or attached to solid material such as rust or scale which do not travel outside of the site boundary.

APPENDIX C

In response to a specific question, the system defined in Figure C-1 was analyzed using the format of Randall and Ginsburgh (Reference 1C). (This is a dynamic stress, static strength analysis.) The dynamic load factor η is given by:

$$\eta = \left[1 - \text{Cos} \frac{to}{R_o} \frac{(gE)}{\rho}^{1/2}\right] \tag{1}$$

where:

to = pulse duration

R_o = IR of pipe

g = acceleration of gravity

E = Young's modules

ρ = density

The pulse duration t for the maximum intensity pulse $\left(\frac{Pf}{Pi} = 170\right)$ is given by:

$$t = \frac{\ell \quad k}{2 \times V_o} \tag{2}$$

ℓ = maximum detonation path length

V_o = detonation velocity = 9000 ft/sec

k = fractional length of detonation path = 1/7 for compression factor of 4 or $\left(\frac{Pf}{Pi} = 170\right)$

Equation (1) evaluated for an 18-inch i.d. carbon steel pipe is reduced to:

$$\eta \leqslant (1 - \cos \theta) \tag{3}$$

where θ = 21.333t X 1000 $0 \leqslant \theta \leqslant \pi$, t is given in seconds, θ is given in radians.

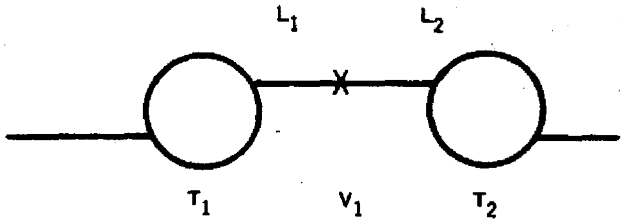
Equation (2) evaluated for ℓ = 10 ft yields the value = 80 μsec. This substituted into (3) yields:

$$\eta = 1 - \cos 1.70$$

$$= 1.13$$

Therefore for this case it is safe to make the following statement:

$H_{special} \doteq 1/2 \; H_{eq2}$ H = the thickness needed to contain the event.



T_1, TANK #1	$\ell/d \leq 7$	
T_2, TANK #2	$\ell/d \leq 7$	
PIPE #1 –	$\ell_1 \sim$	20 ft
	d_1	18 in.
PIPE #2 –	ℓ_2	10 ft
	d_2	18 in.

Figure C-1

REFERENCE

1C. Randall, P. N. and Ginsburgh, I., *Bursting of Tubular Specimens by Gaseous Detonation*, Journal of Basic Engineering, p 519, December 1961.

DISTRIBUTION

Name	M/C
Gilbert, W. D.	631
Hill, P. R.	135
Kent, C. E.	372
Kjemtrup, J. E.	752
Loy, H. L.	372
Michels, L. R.	372
Nelson, R. C.	Svl
Nesbitt, L. B.	372
Parker, C. S.	760
Schultheis, W.	760
Siegler, M.	585
Swain, E. O.	760
Tagart, S. W.	375
Witt, F. F.	372
NED Library (5)	328
VNC Library (2)	VNC
TIE (2 + 6 Title Pages)	