MANDATORY APPENDIX 1
SUPPLEMENTARY DESIGN FORMULAS

1-1 THICKNESS OF CYLINDRICAL AND SPHERICAL SHELLS

(a) The following equations, in terms of the outside radius, are equivalent to and may be used instead of those given in UG-27(c) and UG-27(d):

(1) For cylindrical shells (circumferential stress),

\[ t = \frac{P R_o}{S E + 0.4P} \quad \text{or} \quad P = \frac{S E t}{R_o - 0.4t} \]  

(1)

where

\[ R_o = \text{outside radius of the shell course under consideration} \]

(2) For spherical shells,

\[ t = \frac{P R_o}{2 S E + 0.8P} \quad \text{or} \quad P = \frac{2 S E t}{R_o - 0.8t} \]  

(2)

Other symbols are as defined in UG-27.

1-2 CYLINDRICAL SHELLS

(a) See below.

(1) Circumferential Stress (Longitudinal Joints). When the thickness of the cylindrical shell under internal design pressure exceeds one-half of the inside radius, or when \( P \) exceeds 0.385\( SE \), the following equations shall apply. The following equations may be used in lieu of those given in UG-27(c):

When \( P \) is known and \( t \) is desired,

\[ t = R \left( \exp \left( \frac{P}{SE} \right) - 1 \right) = R_o \left( 1 - \exp \left( -\frac{P}{SE} \right) \right) \]  

(1)

Where \( t \) is known and \( P \) is desired,

\[ P = S E \log_e \left( \frac{R + t}{R} \right) = S E \log_e \left( \frac{R_o}{R_o - t} \right) \]  

(2)

(2) Longitudinal Stress (Circumferential Joints). When the thickness of the cylindrical shell under internal design pressure exceeds one-half of the inside radius, or when \( P \) exceeds 1.25\( SE \), the following equations shall apply:

When \( P \) is known and \( t \) is desired,

\[ t = R \left( \frac{\sqrt{Z} - 1}{\sqrt{Z} + 1} \right) = R_o \left( \frac{\sqrt{Z} - 1}{\sqrt{Z} + 1} \right) \]  

(3)

where

\[ Z = \left( \frac{P}{SE} + 1 \right) \]

When \( t \) is known and \( P \) is desired,

\[ P = SE(Z - 1) \]  

(4)

where

\[ Z = \left( \frac{R + t}{R} \right)^2 = \left( \frac{R_o}{R_o - t} \right)^2 \]

Symbols are as defined in UG-27 and 1-1.

1-3 SPHERICAL SHELLS

When the thickness of the shell of a wholly spherical vessel or of a hemispherical head under internal design pressure exceeds 0.356\( R \), or when \( P \) exceeds 0.665\( SE \), the following equations shall apply. The following equations may be used in lieu of those given in UG-27(d).

When \( P \) is known and \( t \) is desired,

\[ t = R \left( \exp \left( \frac{0.50 \cdot P}{SE} \right) - 1 \right) = R_o \left( 1 - \exp \left( -\frac{0.50 \cdot P}{SE} \right) \right) \]  

(1)

When \( t \) is known and \( P \) is desired,

\[ P = 2.0 \cdot SE \log_e \left( \frac{R + t}{R} \right) = 2.0 \cdot SE \log_e \left( \frac{R_o}{R_o - t} \right) \]  

(2)

Symbols are as defined in UG-27 and 1-1.
Step 7. Determine the effective thickness for nozzles in cylindrical or conical shells as follows:

\[ t_{eff} = t + t_e \]  

(31)

If \( t_e \geq 0.5t \) and \( W \geq 8(t + t_e) \) then the effective thickness is modified as follows:

\[ t_{eff} = t + t_e \]  

(32)

Step 8. Determine the average local primary membrane stress and the general primary membrane stress in the vessel:

\[ \sigma_{avg} = \left( f_N + f_S + f_Y \right) / A_T \]  

(33)

\[ \sigma_{circ} = \frac{PR_{eff}}{teff} \]  

(34)

Step 9. Determine the maximum local primary membrane stress at the nozzle intersection:

\[ P_L = \max \left[ 2\sigma_{avg} - \sigma_{circ}, \sigma_{circ} \right] \]  

(35)

Step 10. The calculated maximum local primary membrane stress should satisfy the following:

\[ P_L \leq S_{allow} \]  

(36)

For nozzles subjected to internal pressure, the allowable stress is:

\[ S_{allow} = 1.5SE \]  

(37)

Step 11. Determine the maximum allowable working pressure of the nozzle:

\[ P_{max} = \frac{S_{allow}}{\left( \frac{A_p}{A_T} - \frac{R_{eff}}{teff} \right)} \]  

(38)

where

\[ R_{max} = \left[ \frac{\sigma}{R_{eff}} \right] \]  

(39)

\[ A_p = R_n(L_H - t) + R_{eff}(L_R + t_n + R_{nc}) \]  

(40)

\[ P_{max} = \min \left[ P_{max1}, P_{max2} \right] \]  

(41)

(2) Nozzle in a Cylindrical Shell Oriented at an Angle From the Longitudinal Axis. The maximum local primary membrane stress and the nozzle maximum allowable working pressure shall be determined following Steps (1)1 through (1)10, but substituting the following (see Figure 1-10-4):

\[ R_{nc} = \frac{R_n}{\sin \theta} \]  

(42)

(3) Radial Nozzle in a Conical Shell. The maximum local primary membrane stress and the nozzle maximum allowable working pressure shall be determined following Steps (1)1 through (1)10, but substituting the following (see Figure 1-10-5):

\[ f_s = \frac{P}{\cos \alpha} \left[ R_{eff} + \left( \frac{L_R + t_n + R_{nc}}{2} \right) \sin \alpha \right] \left( L_R + t_n \right) \]  

(43)

\[ f_Y = \frac{P \left[ R_{eff} + \frac{R_{nc}}{2 \sin \alpha} \right] R_{nc}}{\cos \alpha} \]  

(44)

\[ \sigma_{circ} = \frac{P \left[ R_{eff} + \left( L_R + t_n + R_{nc} \right) \sin \alpha \right]}{teff \cos \alpha} \]  

(45)

\[ P_{max} = \frac{S_{allow}}{\left( \frac{A_p}{A_T} - \frac{R_{eff} + \left( L_R + t_n + R_{nc} \right) \sin \alpha}{teff \cos \alpha} \right)} \]  

(46)
(c) For Integral Type Reverse Flanges

1. Stresses at the Outside Diameter

\[
S_H = \frac{f M_o}{L_r \theta_1 t^2 B'}
\]
\[
S_R = \left( \frac{1.33 t e_r + 1}{L_r t^2 B'} \right) M_o
\]
\[
S_{T1} = \left( \frac{Y M_o}{t^2 B'} - Z S_R \left( 0.67 t e_r + 1 \right) \right) / 1.33 t e_r + 1
\]

2. Stress at Inside Diameter \( B' \)

\[
S_{T2} = \left( M_o / t^2 B' \right) \left[ Y - \frac{2K^2 \left( 1 + \frac{1}{2} t e_r \right)}{(K^2 - 1)L_r} \right]
\]

(d) For Loose Ring Type Reverse Flanges

\[
S_T = Y M_o / t^2 B'
\]
\[
S_R = 0 \quad S_H = 0
\]