X-822

UNCLASSIFIED

OAK RIDGE NATIONAL LABORATORY

Operated By

UNION CARBIDE NUCLEAR COMPANY

POST OFFICE BOX P
OAK RIDGE, TENNESSEE

EXTERNAL TRANSMITTAL AUTHORIZED

ORNL
CENTRAL FILES NUMBER

CF- 56-5-188

"For Release Under GDS"

COPY NO. 18

DATE: May 25, 1956

SUBJECT: Pressure Shell Stress Analysis HRR

TO: Distribution

FROM: M. C. Lawrence

DISTRIBUTION

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

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

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

Photostat Price \$ 3.30

Microfilm Price \$ 2.40

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

NOTICE

This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision, correction and therefore does not represent

UNCLASSIFIED

794 001

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Summary

Figure 1 shows the calculated, total tangential stress for the HRR pressure vessel at steady state operation (500 Mw) as a function of wall thickness and thermal shielding. The maximum stress, located at the inside shell surface, results from both internal pressure and irradiation heating.

With thermal shields four inches thick or less, mounted inside the reactor shell, the lowest stress is more than 23,000 psi. For these conditions the shell irradiation heating varies from about 2100 to 20 Btu's/hr x in³, decreasing with penetration through the steel. Following five inches of shielding the irradiation heating of the pressure shell decreases very slowly and can be expected to average from 5 to 10 Btu's/hr x in³ for the shell thicknesses considered. For these conditions stresses below 17,500 psi are calculated.

For steel designation, A-212B, having an allowable working stress of 17,500 psi, a minimum wall thickness of about 3.3 inches is required.

The curves are based upon the nuclear properties of iron and are applicable to low alloy-steel thermal shields and pressure vessels only.

Calculation of Pressure Stress

Tangential stress caused by internal pressure is greatest at the inside surface for any given wall thickness and decreases as the wall is made thicker. The variation of pressure stress at the inside surface, as a function of wall thickness, is shown by Figure 2. Design constants and the formula used are also indicated.

Calculation of Thermal Stress

Thermal stress may be determined for a spherical vessel by use of the following relationship (1).

$$\sigma_t = \frac{3\alpha E}{1-\nu} \left[\frac{2r^3 + a^3}{z(b^3 - a^3)r^3} \int_a^b T r^2 dr + \frac{1}{2r^3} \int_a^r T r^2 dr - 1/2T \right]$$

where σ_t = thermal stress at any wall location

α = coefficient of thermal expansion per $^{\circ}\text{F}$ (6.75×10^{-6})

E = modulus of elasticity (26×10^6 psi, steel at 600°F)

ν = Poissons ratio (0.3)

r = radius at point of stress, inches

a = inside shell radius (60 inches)

b = outside shell radius, inches

T = Temperature ($^{\circ}\text{F}$) gradient across wall

The temperature gradient across the vessel wall depends upon the rate at which heat is generated in the wall by nuclear irradiation and the rate & method by which it is removed. Chapman (2) has shown that heat generation by irradiation may be approximated by an exponential function which when substituted for (T) in the stress formula above, will give -

(1) Theory of Elasticity, Timoshenko and Goodier; 2nd Ed., p. 416, McGraw-Hill, 1951.

(2) ORNL CF-54-10-76, October 26, 1954

UNCLASSIFIED

4.

$$\sigma_t = \frac{3xE H}{(1-\nu)(m^3)(b^3-d^3)K} \left[\left(\frac{A-B}{a} \right) \left(\frac{b^3-a^3}{3} \right) + B \left(\frac{b^2-a^2}{2} \right) + \left(\frac{mb+2}{m} \right)^2 e^{-m(b-a)} - \left(\frac{ma+2}{m} \right)^2 \right]$$

where: m = slope of heating curve (0.79)

K = thermal conductivity (2 Btu/hr x in x $^{\circ}$ F)

H = heating rate of wall (Btu's/hr x in³)

$A = (ma + 2)$

$B = (m^2b^2 + 2mb + 2)e^{-m(b-a)}$

Thermal stress values determined from the above relationship are plotted in figure 3. These are maximum for the boundary conditions assumed and occur at the inside shell surface, coincident with the maximum pressure stresses for given wall thicknesses. Thermal stress, caused by differential thermal expansion across a heavy wall because of temperature gradient, is greatest at the point of minimum temperature. The boundary conditions chosen assume that all heat generated in the wall is removed from the inner surface which, therefore, is the lowest temperature across the wall.

Incident thermal and fast neutron currents together with gamma photons of various energy levels resulting from fission, cause heating in passing through the shell. It is assumed that thermal neutron capture, the major contributor, accounts for 2/3 of the total heating. Curve 1, figure 4 shows the heat generation rate, with penetration, for the thermal neutron current.

Curve 2 represents the assumed overall heating rate. From this curve, the incident heating rate (H) and slope (m) are taken for use in determining thermal stress.

794 004

UNCLASSIFIED

Shell heating may be reduced by the use of thermal shielding which consist of layers of steel mounted concentrically inside the shell. These serve to reduce the incident heating rate (H) at the inside shell surface with (m) remaining constant. The thermal shield is not subjected to pressure stress and is normally cooled on both surfaces, being separated from the shell by a one-inch space.

The method used for establishing curves 1 and 2 of figure 4 follows.

The thermal neutron current at the face of the shell or thermal shield, a function of reactor power, self attenuation in the core solution and core radius, is calculated from the following:

$$I_{o, th} = \left[\frac{3.1 \times 10^{10} P \nu_p}{4\pi r} \right] \left[\frac{L^2 B^2}{(1-L^2 B^2)(1+B^2 \tau)} \right]$$

where $I_{o, th}$ = thermal neutron current, (n/cm² x sec)

P = reactor power (500 Mw)

ν = neutrons emitted per fission (2.46)

$L^2 B^2$ = diffusion length x buckling (0.6715)

$B^2 \tau$ = buckling x Fermi age (0.0946)

p = resonance escape probability (1)

r = radius of core (60 inches)

3.1×10^{10} = fissions taking place per watt of power

Thermal neutron heating, a function of gamma photon energy release on capture, the slow neutron current and the capture cross sections of steel, is calculated from the following:

$$H_r = n E \gamma \frac{I_o}{2} \mu_a f(\beta, \mu_{mt})$$

794 005

where H_r = heating rate at point of incidence (mev/sec x cm³)

n = average number of gamma photons emitted per capture (1.7)

E_γ = average energy of gamma photons (7.6 Mev)

μ_a = energy absorption coefficient for steel (0.187/cm)

μ_m = mass absorption coefficient for steel (0.192/cm)

$f(\beta, \mu_m t)$ = plotted on p. 103, ref (2)

t = wall thickness (cm)

$$\beta = 2.89$$

The subscripts 1, 2, 3 and 4 indicate the incident shell heating rate following 1, 2, 3 or 4 inches of thermal shielding. The values listed below were picked off curve 2, figure 4 and corrected by a geometrical factor $(59/60)^2$ common to all shields because of the one inch spacing between the outside thermal shield surface and the pressure vessel.

for $t = 0$, $H_0 = 2100$

$$H_1 = 950 \times 0.9669 = 920$$

$$H_2 = 430 \times 0.9669 = 415$$

$$H_3 = 195 \times 0.9669 = 189$$

$$H_4 = 89 \times 0.9669 = 86$$

The thermal neutron heating function (curve 1, figure 4) approaches a constant heating rate of about 10 Btu's/hr x in³ for penetration distances through steel greater than seven inches. The thermal stress curves, based upon this function, therefore, are only valid for combined thermal shield and vessel wall thicknesses not exceeding seven inches.

Thermal stress, based upon a constant heat production rate is evaluated from the following temperature function and the general stress function given above.

Temperature function vs wall thickness - constant heat source

let $Q = 10 \text{ Btu's/hr} \times \text{in}^3$ or $17280 \text{ Btu's/hr} \times \text{ft}^3$

$K = 26 \text{ Btu's/hr} \times \text{ft} \times ^\circ\text{F}$ (conductivity of steel at 600°F)

$$H_0 = Q/K = ^\circ\text{F}/\text{ft}^2$$

$a = \text{inside radius, } b = \text{outside radius in feet}$

the temperature gradient, at steady state, as a function of penetration (x) is:

$$\frac{d^2 T}{dx^2} = -H$$

$$\frac{dT}{dx} = H_0 x + C,$$

$$T = -1/2 H_0 x^2 + C_1 x + C_2$$

if all heat is removed from the inside surface

for $x = 0, T = T_a = C_2$ (inside surface)

for $x = (b-a), dT/dx = 0, C_1 = H_0(b-a)$ (outside surface)

$$T = -1/2 H_0 x^2 + H_0(b-a)x + T_a$$

for $x = (r-a), r$ is any shell radius

$$T = -1/2 H_0 (r^2 - a^2) + H_0 b(r-a) + T_a$$

combining the temperature function (T) and stress function

$$\sigma_t = \frac{2xE}{1-\nu} \left\{ \frac{2r^3 + a^3}{2(b^3 - a^3)r^3} \int_a^b T r^2 dr + \frac{1}{2r^3} \int_a^b T r^2 dr + \frac{1}{2} T \right\}$$

794 007

and solving for at the inner surface ($r = a$) gives,

$$\sigma_t = \frac{2xE}{1-} \left\{ \frac{1.5}{b^3 - a^3} \left[- \frac{H_o}{2} \left(\frac{b^5 - a^5}{5} - a^2 \frac{b^3 - a^3}{3} \right) + H_o b \left(\frac{b^4 - a^4}{4} - a \frac{b^3 - a^3}{3} \right) + T_a \left(\frac{b^3 - a^3}{3} \right) \right] - 1/2 T_a \right\}$$

For the case in which a five inch thermal shield is used the total stress is shown in figure 1, taking into account constant heating rates of 5 and 10 Btu's/hr x in³.

MCL:jsw

for M. J. Lander
M. C. Lawrence

TOTAL STRESS - HRR VESSEL 9

ORNL-IR-Dwg-14312
UNCLASSIFIED

KUSFEL & SIBER CO., N.Y. NO. 395-516
Scale X 10 to the Inch, 5th Lines Accented.
MADE IN U.S.A.

ORNL-IP-Dwg.-14313
UNCLASSIFIED

$$\sigma_p = \frac{p}{2} \left[\frac{2a^3 + b^3}{b^3 - a^3} \right]$$

 σ_p = pressure stress, psi p = internal pressure, (1400 psi) a = inside shell radius (60 in) b = outside shell radius (inches)

Maximum Thermal Stress, HRR 11

ORNL-IR-Dwg.-11311
UNCLASSIFIED

σ_t (thermal stress), psi

WALL THICKNESS, INCHES

794 C11
FIG 3

12 SPECIFIC HEAT PRODUCTION, HRR SHELL

ORNL-LE-176-12.315
UNCLASSIFIED

H, Btu's/hr x in³

KUFFEL & ESSER CO., N. Y. NO. 389-71
Semi-Logarithmic, 3 Cycles X 10 to the inch; 8 1/2 inch uncoated.
MADE IN U. S. A.

FIG 4