NONMANDATORY APPENDIX G
FRACTURE TOUGHNESS CRITERIA FOR PROTECTION AGAINST FAILURE

ARTICLE G-1000
INTRODUCTION

This Appendix presents a procedure for obtaining the allowable loadings for ferritic pressure retaining materials in components. This procedure is based on the principles of linear elastic fracture mechanics. At each location being investigated a maximum postulated flaw is assumed. At the same location the mode I stress intensity factor K_I is produced by each of the specified loadings as calculated and the summation of the K_I values is compared to a reference value K_{Ic} which is the highest critical value of K_I that can be ensured for the material and temperature involved. Different procedures are recommended for different components and operating conditions. Both conventional and risk-informed methods are provided for determining the allowable loadings for vessels.

ARTICLE G-2000
VESSELS

G-2100 General Requirements

G-2110 REFERENCE CRITICAL STRESS INTENSITY FACTOR
No change

G-2120 MAXIMUM POSTULATED DEFECT
No change

G-2200 Risk-Informed Level A and Level B Service Limits

G-2210 SHELLS AND HEADS REMOTE FROM DISCONTINUTIES

G-2211 Recommendations

The assumptions of this Subarticle are recommended for shell and head regions during Level A and B Service Limits.

G-2212 Material Fracture Toughness

G-2212.1 Reference Critical Stress Intensity Factor for Material.
No change

G-2212.2 Irradiation Effects. Subarticle A-4400 of Appendix A is recommended to define the change inreference critical stress intensity factor due to irradiation.

No change required for conventional Appendix G Limit.

For Risk-Informed P-T limits, update procedure to define an appropriate embrittlement correlation for risk-informed approach

G-2213 Maximum Postulated Defects
No change

G-2214 Calculated Stress Intensity Factors
No change

G-2215 Allowable Pressure
No change

It is proposed to add the following paragraph. This paragraph is an alternative risk-informed procedure to the current Paragraph G-2215, which provides a deterministic procedure to determine the allowable pressure temperature curves for Level A and Level B Service Limits. The following paragraph essentially duplicates G-2215 except it uses risk adjusted margins instead of deterministic margins as shown by "Track Changes".

G-2216 Risk-informed Allowable Pressure

The equations given in this Subarticle provide the basis for determination of the allowable pressure at any temperature at the depth of the postulated defect during Service Conditions for which Level A and Level B Service Limits are specified. In addition to the conservatism of these assumptions, it is recommended that a factor be applied to the calculated K_I values produced by primary stresses. In shell and head regions remote from discontinuities, the only significant loadings are: (1) general primary membrane stress due to pressure; and (2) thermal stress due to thermal gradient through the thickness during startup and shutdown. Therefore, the requirement to be satisfied and from which the allowable pressure for any assumed rate of temperature change can be determined is:

$$K_{Im} + K_{It} < K_{Ic} \qquad (1)$$

throughout the life of the component at each temperature with K_{Im} from G-2214.1, K_{It} from G-2214.3, and K_{Ic} from Fig. G-2210-1, where

$RT_{NDT} = RT_{NDT(u)} + \Delta RT_{NDT} + M_{RTNDT}$,
$RT_{NDT(u)}$ is determined from NB-2300,

ΔRT_{NDT} is the change in $RT_{NDT(u)}$ due to irradiation effects, and is determined from paragraph G-2212.2
M_{RTNDT} is a risk adjusted factor applied to K_{IC} and is determined from Fig. G-2216-1.

The allowable pressure at any temperature shall be determined as follows.
(a) For the startup condition,
(1) consider postulated defects in accordance with G-2120;
(2) perform calculations for thermal stress intensity factors due to the specified range of heat-up rates from G-2214.3;
(3) calculate the K_{Ic} toughness for all vessel beltline materials from G-2212 using temperatures and RT_{NDT} values for the corresponding locations of interest; and
(4) calculate the pressure as a function of coolant inlet temperature for each material and location. The allowable pressure-temperature relationship is the minimum pressure at any temperature determined from
(a) the calculated steady-state ($K_{It} = 0$) results for the 1⁄4-thickness inside surface postulated defects using the equation

$$P = K_{IC} \times (t/R_i) / M_m,$$

(b) the calculated results from all vessel beltline materials for the heatup stress intensity factors using the corresponding 1⁄4-thickness outside-surface postulated 3defects and the equation

$$P = (K_{IC} - K_{It}) \times (t/R_i) / M_m,$$

(b) For the cooldown condition,
(1) consider postulated defects in accordance with G-2120;
(2) perform calculations for thermal stress intensity factors due to the specified range of cooldown rates from G-2214.3;
(3) calculate the K_{Ic} toughness for all vessel beltline materials from G-2212 using temperatures and RT_{NDT} values for the corresponding location of interest; and
(4) calculate the pressure as a function of coolant inlet temperature for each material and location using the equation.

$$P = (K_{IC} - K_{It}) \times (t/R_i) / M_m,$$

The allowable pressure-temperature relationship is the minimum pressure at any temperature, determined from all vessel beltline materials for the cooldown stress intensity factors using the corresponding 1⁄4-thickness inside-surface postulated defects.

Those plants having low temperature overpressure protection (LTOP) systems can use the following load and temperature conditions to provide protection against failure during reactor start-up and shutdown operation due to low temperature overpressure events that have been classified as Service Level A or B events. LTOP systems shall be effective at coolant

temperatures less than 200°F (95°C) or at coolant temperatures corresponding to a reactor vessel metal temperature less than RT_{NDT} + 50°F (28°C), whichever is greater.2,3 LTOP systems shall limit the maximum pressure in the vessel to 100% of the pressure determined to satisfy Eq. (1).

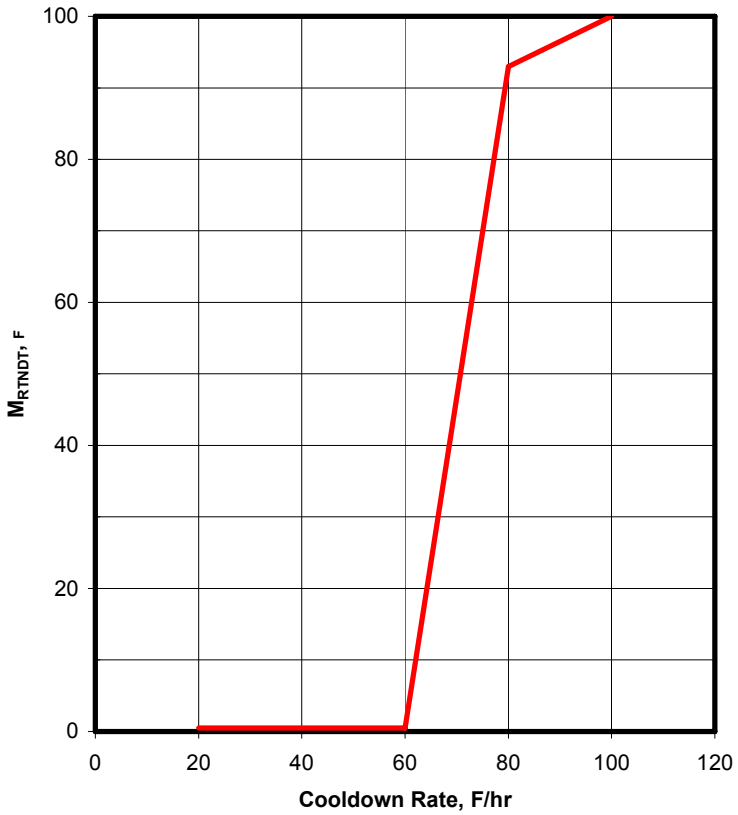

Fig. G-2216-1

G-2220 NOZZLES, FLANGES, AND SHELL REGIONS NEAR GEOMETRIC DISCONTINUITIES

Conventional evaluation procedures to be developed and placed into this section by the WGOPC

G-2300 LEVEL C AND LEVEL D SERVICE LIMITS

No change

G-2400 HYDROSTATIC TEST TEMPERATURE

No change

G-2500 RISK-INFORMED HYDROSTATIC TEST TEMPERATURE

Under development

ARTICLE G-3000
PIPING, PUMPS, AND VALVES

No change

ARTICLE G-4000
BOLTING

No change