Reduction of Design Margin (“Safety Factor”) in the ASME Boiler and Pressure Vessel Code in the 1999 Addenda

In the 1999 addenda of the ASME Boiler Code, the design margin (formerly known as the “Safety Factor”) was changed from 4.0 to 3.5. The following is a discussion of the basis for that change. This discussion, prepared by Walter J. Sperko, P.E., is the opinion of Mr. Sperko, not the official opinion of the ASME Boiler Code Committee.

Background and Historical Context

The allowable pressure of a cylindrical component is calculated based on the following formula:

$$P = t \times TS / R$$

Where P is the maximum pressure, t is the wall thickness, TS is the tensile strength of the materials in the shell and R is the radius of the shell.

If one calculates the ultimate pressure of 1,000 psi using the tensile strength of the material, the component will be designed at its limits -- no margin for error.

To ensure safety, one reduces the maximum pressure by only using a “fraction” of the calculated maximum pressure. For example, if the maximum pressure is reduced to 500 psi or 1/2 of the ultimate pressure, the safety factor would be 2. If it were reduced to 250 psi or 1/4 of the ultimate pressure, the safety factor would be 4. The number that one divides the maximum pressure by (the divisor) is the “safety factor” or the “Design Margin.”

In the early editions of the Code, calculations were performed using the tensile strength of the steel and the safety factor (FS) was included in the formula.

$$P = (t \times TS) / (R \times SF)$$

In the 1915 edition, the margin was 5. It stayed at 5 until 1943 when is was changed to 4 largely to conserve materials during WWII. Immediately after the war, the margin was changed back to 5. In 1950, the performance of the vessels that had been made using a margin of 4 was reviewed and found satisfactory. As a result, the margin was changed to 4 in 1951.

Current Basis for Determining the Allowable Stress

As a result of the introduction of new materials and increases in service temperatures, use of “Safety factors” was abandoned and the factor became part of the allowable stress for a material at any temperature. The allowable stress is based on the least of the following:

- Room-temperature tensile strength / 3.5
- Room-temperature yield strength / 1.5
- The stress required to cause a creep rate of 0.0001%/1000 hours
- The average stress to cause rupture at 100,000 hours / 1.5
- The minimum stress to cause rupture at 100,000 hours / 1.25

Source of the 1999 Change in the Design Margin from 4.0 to 3.5

In 1996, the Chairman of Subcommittee VIII challenged the margin of 4. Although it may seem so to some, revisions to the design margin were not made without due technical consideration. The Pressure Vessel Research Committee studied the matter for 2 years and concluded that ASME could safely change the margin to 3.5. The results of the study are published in WRC Bulletin 435 published in September, 1998.

That study examined the service history of pressure vessels and observed that most failures were the results of poor notch toughness, service degradation and operating problems. Few failures were associated with inadequate design rules in Section VIII.

Based on the service history and burst testing of pressure vessels with different strain-hardening coefficients (type 304 stainless, SA516-70 and SA-517 Grade F). These vessels contained nozzles and end closures to provide realistic local strain concentrations. It was determined that failure mode due to simple pressurization was predictable -- a function of wall thickness, toughness and the strength of the material.

The study examined the toughness of materials. Many failures in the historical database occurred during hydrostatic testing -- a combination of simultaneously very high stress and low temperature. 1987 changes in Section VIII imposed engineering-based toughness requirements on materials based on fracture mechanics. Fracture mechanics did not exist as an engineering discipline in 1951 when the design margin of 4 was established; today, fracture mechanics allows an engineer to establish the minimum toughness required in a material based on the stress applied and the maximum credible size flaw. These changes eliminated concern over brittle fracture. In addition, Section VIII requires that hydrostatic testing be performed at the minimum design metal temperature plus at least 30°F, ensuring that brittle failure will not occur during hydrostatic testing.

Other failure modes considered were fatigue, incremental collapse, elastic instability, plastic instability, creep rupture and buckling. None of these are affected by the change in design margin.

The biggest change that justifies the change in design margin is advancements in materials and more thorough understanding of materials behavior. Due to the improved toughness rules, advanced materials that have been electric furnace or basic oxygen melted, some followed by electroslag remelting, argon degassing and vacuum degassing, have resulted in the availability of "cleaner" steels. These steels have lower levels of carbon, hydrogen, phosphorous and sulfur -- elements that reduce toughness -- than ever before.

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The materials used in today's construction are simply better than those used as little as 20 years ago.

In addition, welding consumables are better, and welding processes are under better control than they were in 1950. Hhydrogen cracking and the need to use preheat and low-hydrogen electrodes is understood by the fabrication and construction industry. Postweld heat treatment is commonplace, whereas it was unusual in 1950.

In 1935, radiography was done using x-ray tubes and the thickness limit was 4 inches. More powerful energy sources, including radioactive isotopes, were developed after WWII, but their use was not commonplace until well after 1950. The quality and sensitivity of radiographic film has improved significantly since then, too. Ultrasonic examination has also advanced to where a competent technician can find and characterize very small flaws in very thick materials.

The Changes. . . .

Some allowable stresses <u>did not change</u> as a result of this change to the design margin:

- The design margins for cast and ductile iron.
- The design margins for materials in which yield strength governs (like 304 stainless)
- The design margins for elevated temperature (i.e. creep range) service.

What did change mostly was the allowable stress for low to mid-temperature service for carbon and low alloy steel. The typical increase in allowable stress is 14%. This advantage disappears as service temperature increases. For example, typical increases are:

Material	650°F	750°F	900°F
SA-516-70	7.4%	0%	Not permitted
SA-299	14%	5.3%	Not permitted
SA-213-T11	14%	3.6%	0%
SA-213-T22	14%	3.6%	0%

Conclusions

The change in design margin is the consequence of advancements in materials technology, including maturing of fracture mechanics as an engineering discipline and superior steelmaking technology, advancements in welding technology and advancements in nondestructive examination techniques. In addition, refinements in code rules and better understanding of how failures occur since 1951 make the reduction in design margin inconsequential to safety.

Further work is being done to reduce the margins for Division 2to less than 3.0.

ASME B31.3 has had a design margin of 3.0 for more than 20 years

ASME B31.1 is in the process of changing to 3.5, but may change to 3.0.