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Comparison of RG 1.99 Rev.2 and an Intercept-Adjusted ASTM E900-15 Model for RPV Embrittlement Evaluation

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1. Introduction

RPV steels experience irradiation embrittlement under long-term neutron exposure, requiring predictive embrittlement trend curves (ETCs) for safe operation. RG 1.99 Rev.2, developed in 1988 with a limited dataset, remains widely used for regulatory purposes due to its simplicity [1]. ASTM E900-15, based on a much larger database, offers improved statistical robustness but requires adjustments for regulatory application [2]. This study evaluates an intercept-adjusted E900-15 model in comparison with RG 1.99 Rev. 2, emphasizing predictive accuracy and conservatism under regulatory conditions.

2. Methodology

A dataset of 1,034 Charpy surveillance results was compiled from 20 Korean units and the Baseline22 U.S. database. RG 1.99 Rev. 2 Model uses two differenct method to calculate TTS along the avaiablity of surveillance test results. The E900-15 model was modified through an intercept adjustment derived from mixed-effects modeling, enabling plant-specific applicability while preserving a closed-form expression suitable for regulatory use [3-4]. Both models were applied to this dataset, and statistical metrics (residual bias, RMS deviation) were calculated with and without margins.

3. Results and Discussion

The comparative evaluation revealed substantial improvements when the intercept-adjusted E900-15 was employed. Fig. 1 shows the residuals between measured and predicted TTS versus fluence, with quadratic fits to the trends in Korean surveillance data. Outliers from Kori-1 welds were excluded due to unusually high Cu contents. The unadjusted models (RG 1.99 P1.1 and E900-15 reference) exhibited large scatter, while the adjusted versions (RG 1.99 P2.1 and adjusted E900-15) showed notably reduced residuals, lowering RMSD from 13.17 °C to 7.63 °C and from 12.55 °C to 7.68 °C, respectively. RG 1.99 tended to underestimate TTS at high fluence, whereas the adjusted E900-15 provided more stable and accurate predictions, especially in the high-fluence regime.

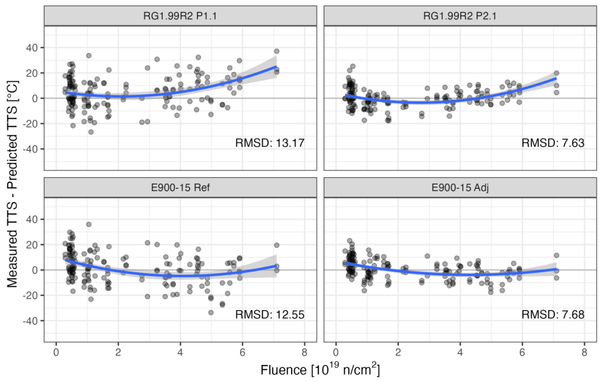

Fig. 1. Residuals between measured and predicted TTS values for Korean surveillance data, showing improved accuracy after model adjustment, as indicated by reduced RMSD.

Fig. 2 compares residual distributions of RG 1.99 Rev.2 P2.1 and the adjusted E900-15 across the full dataset. In the left panel, LOESS-smoothed trends show that RG 1.99 underpredicts at high fluence, while E900-15 maintains near-zero residuals, confirming better long-term accuracy. Although both models yielded similar RMSD values for the Korean dataset (Fig. 1), the overall RMSD across the full dataset was lower for E900-15, indicating superior predictive accuracy. The right panel shows near-linear residual patterns for both models, with E900-15 exhibiting an even smaller slope than in the Korean-only case. Adjusted E900-15 exhibited consistently low bias, confirming that the intercept adjustment can be effectively generalized to broader datasets.

Fig. 3 shows residuals after applying model-specific margins. For RG 1.99 Rev.2 P2.1, 53 of 1,034 data points exceeded the margin, with residuals stable at low fluence but increasingly insufficient at high fluence, indicating limited conservatism. In contrast, the adjusted E900-15 had only 26 exceedances and maintained a flat residual trend across fluence, providing consistent margins. The right panels reveal that RG 1.99 became over-conservative at high embrittlement, while E900-15 remained stable. Overall, the adjusted E900-15 achieves a more balanced combination of accuracy and conservatism, particularly for long-term, high-fluence conditions.

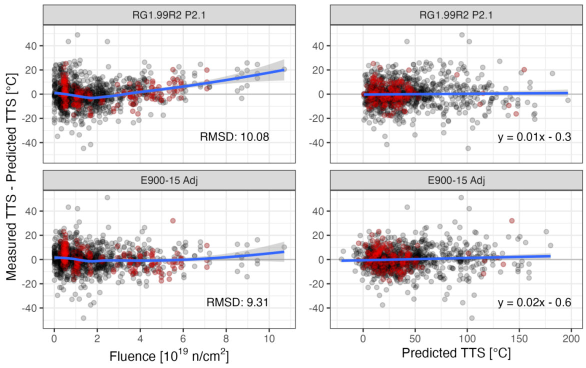

Fig. 2. Residuals between measured and predicted TTS values for surveillance data from Korea and the United States. Korean data are marked in red.

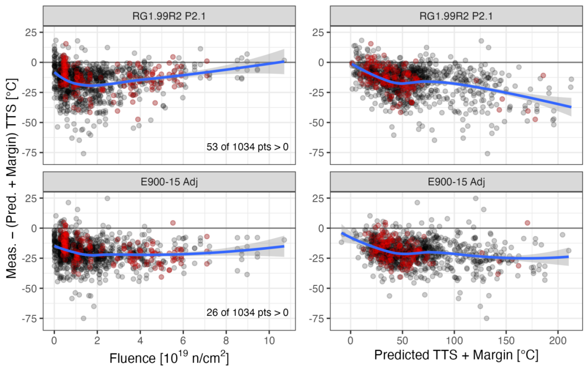

Fig. 3. Residuals between measured and predicted TTS values, including margins, for surveillance data from Korea and the United States. Korean data are shown in red.

Fig. 4 compares ΔART (TTS + Margin) predictions from E900-15 and RG 1.99 Rev.2 across 303 material groups. For forgings, E900-15 consistently predicted higher ART values, while plates showed small differences at low fluence that increased with exposure. Welds displayed the most complex behavior, with ΔART decreasing slightly before rising at higher fluence, and some groups even yielding negative ΔART. At 6×10^{19} n/cm², many forging and plate groups exceeded a 20 °C difference, while welds showed fewer but more variable responses. These results suggest E900-15 generally predicts higher ART, though weld behavior requires cautious interpretation to avoid non-conservative assessments.

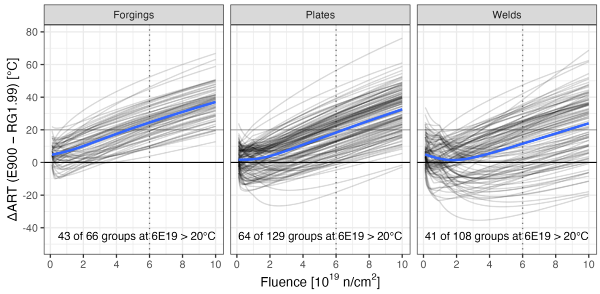

Fig. 4. ΔART between E900-15 and RG 1.99 Rev.2 versus fluence, separated by product form with average trends highlighted in blue.

4. Conclusions

The intercept-adjusted ASTM E900-15 significantly improves predictive accuracy while maintaining regulatory conservatism, outperforming RG 1.99 Rev.2 particularly at high fluence levels. Its closed-form adjustment is straightforward for practical implementation, and the model's robustness across product forms enhances its value for plant-specific surveillance evaluation. These findings suggest that the adjusted E900-15 can serve as a more reliable framework for embrittlement assessment in the context of long-term operation and life-extension of nuclear power plants.

REFERENCES

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