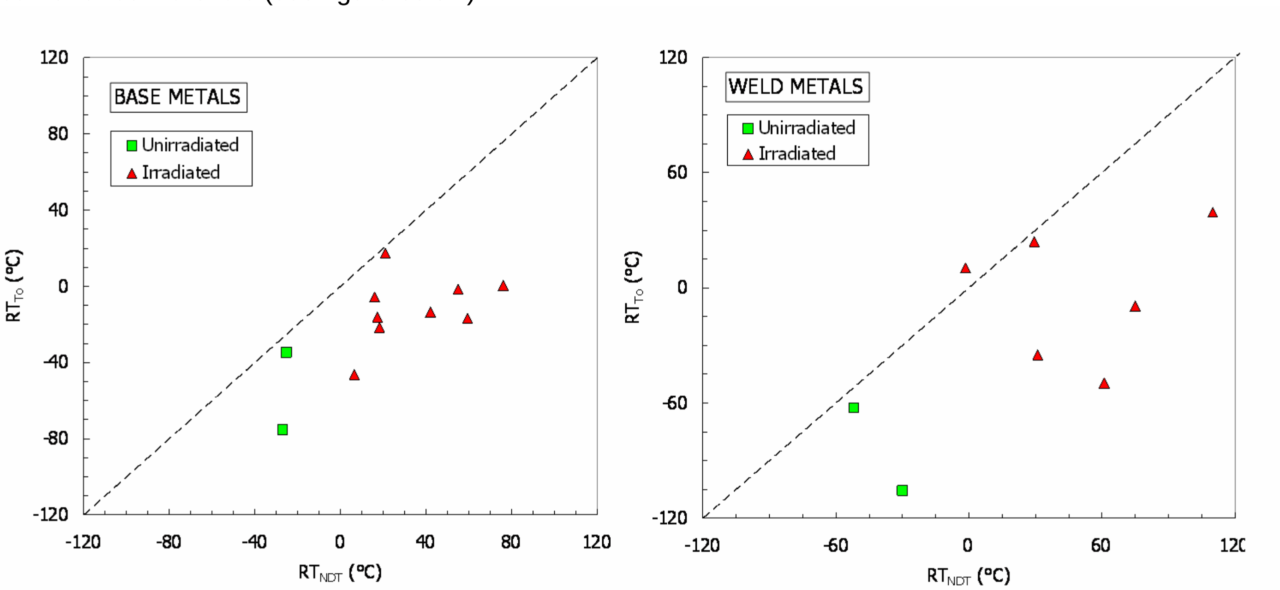
IMPROVED SAFETY MARGINS FOR BELGIAN NUCLEAR POWER PLANTS BY THE APPLICATION OF THE MASTER CURVE APPROACH TO RPV STEELS

Background

In the context of existing regulatory codes, the integrity assessment of the pressure vessel of a nuclear power plant (NPP) is based on the empirical assumption that the fracture toughness of the surveillance materials, expressed in terms of a lower bound curve indexed by a reference temperature RT_{NDT}, undergoes a shift under irradiation by an amount equal to the increment of the T_{41J} index temperature measured from surveillance Charpy tests. Nowadays, an alternative route exists, based on: reconstitution of previously tested specimens, execution of fracture toughness tests in the irradiated condition, Master Curve analysis of the results obtained and finally determination of an alternative toughness-based reference temperature (RT_{To}) which can be used to index the lower bound K_{Ic} curve.

Principal results

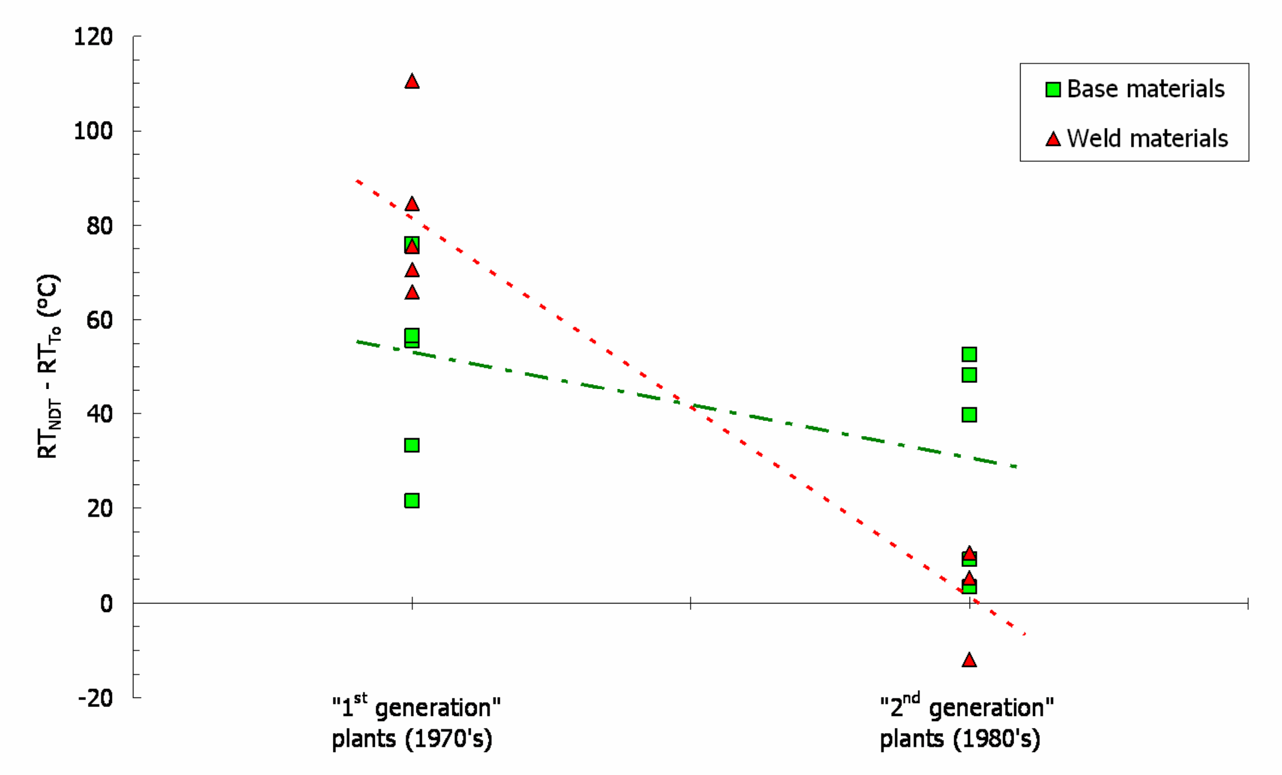
This "advanced" integrity assessment approach, based on specimen reconstitution, direct fracture measurements and application of the Master Curve analysis through the ASME Code Cases N-629 and N-631, has been applied to the surveillance materials of several Belgian nuclear power plants.
For none of the investigated Belgian plants, RT_{NDT} is close to the PTS screening criteria for any of the surveillance materials (see figure below).



Values of reference temperatures measured from Charpy (RT_{NDT}) and fracture toughness tests (RT_{T0}) for various Belgian NPP materials.

The figure above also shows that significant advantages are entailed by the use of RT_{To}, as compared to the regulatory Charpy-based RT_{NDT}, in terms of additional safety margins. These additional margins, more than 50 °C for some of the investigated materials, were generally observed in association with one or more of the following conditions:

- highly irradiated materials, corresponding to reactor operation times of 40 years and beyond;
- highly irradiation-sensitive surveillance materials (Cu > 0.1-0.15%);
- surveillance materials with limited $RT_{NDT(unirr)}$ in baseline condition (> -30 °C);
- first generation NPP's (see figure below).



Dependence of the difference between RT_{NDT} and RT_{T0} from the plant age.

In Belgium, the toughness-based approach is presently used in a "defense in depth" perspective, to demonstrate the existence of important margins as compared to the regulatory approach, and to give an increased confidence in the integrity of the reactor pressure vessels at high doses. It appears more beneficial for weld than for base metals (which normally have lower Cu content and are less irradiation-sensitive).
The "conventional" and the "advanced" integrity assessment methodologies appear substantially equivalent when materials from newer plants are investigated.

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Main reference

E. Lucon, M. Scibetta, R. Chaouadi, E. van Walle and R. Gérard, " Improved Safety Margins for Belgian Nuclear Power Plants by the Application of the Master Curve Approach to RPV Surveillance Materials", International Journal of Pressure Vessels and Piping, Volume 84, Issue 9, September 2007, Pages 536-544.