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# Application of the French Codes to the Pressurized Thermal Shocks Assessment

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ABSTRACT

The integrity of a reactor pressure vessel (RPV) related to pressurized thermal shocks (PTSs) has been extensively studied. This paper introduces an integrity assessment of an RPV subjected to a PTS transient based on the French codes. In the USA, the "screening criterion" for maximum allowable embrittlement of RPV material is developed based on the probabilistic fracture mechanics. However, in the French RCC-M and RSE-M codes, which are developed based on the deterministic fracture mechanics, there is no "screening criterion". In this paper, the methodology in the RCC-M and RSE-M codes, which are used for PTS analysis, are firstly discussed. The bases of the French codes are compared with ASME and FAVOR codes. A case study is also presented. The results show that the method in the RCC-M code that accounts for the influence of cladding on the stress intensity factor (SIF) may be nonconservative. The SIF almost doubles if the weld residual stress is considered. The approaches included in the codes differ in many aspects, which may result in significant differences in the assessment results. Therefore, homogenization of the codes in the long time operation of nuclear power plants is needed.


## 1. Introduction

The reactor pressure vessel (RPV) is a key component of nuclear power plants (NPPs) with regard to safety and lifetime [1]. Although long time operation (LTO) is a main concern, the pressurized thermal shock (PTS) event poses a potentially significant challenge to the structural integrity of the RPV [2]. Prior to 1978, it was postulated that the most severe PTS event was a large-break loss-of-coolant accident (LOCA). During that type of overcooling transient, low-temperature emergency coolant would rapidly enter and cool the vessel wall which would result in high thermal stresses. In 1978, the occurrence

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of an event at the Rancho Seco NPP in the USA showed that rapid cool-down could be accompanied by repressurization during some types of overcooling transients. Following the incident, the USA Nuclear Regulatory Commission (NRC) designated PTS as an unresolved safety issue, and the effects of PTS were extensively analyzed [3]. On the basis of those analyses, the NRC established the Regulatory Guide (RG) 1.154 [4] and 10 Code of Federal Regulation (CFR) 50.61 [5] rules. The 10 CFR 50.61 establishes a “screening criterion” based on the reactor vessel nil-ductility-transition temperature ($RT_{NDT}$). The screening criterion $RT_{NDT}$ (called $RT_{PTS}$ in the rule) was selected according to the studies that the risk due to PTS events is acceptable based on the probabilistic fracture mechanics (PFM). In 10 CFR 50.61, the $RT_{PTS}$ is 132°C for plates, forgings, and axial welds, and 149°C for circumferential welds. As long as the limiting temperature is not reached, the risk caused by the PTS events is considered to be acceptable. The PTS issues are widely studied in the USA. However, the technical basis of FAVOR, which is developed by Oak Ridge National Laboratory (ORNL) in Washington, DC and used by the US NRC to perform the PTS analysis [6–8], is not consistent with other codes and standards, such as the ASME [9], RCC-M [10], and RSE-M [11] codes.

Furthermore, no such “screening criterion” exists in the French codes, e.g., RCC-M and RSE-M which were developed based on the deterministic fracture mechanics (DFM). The RPV assessment is mainly based on simplified methods (“engineering approach”) instead of the more sophisticated approach in these codes. The criteria of the Level C “exceptional conditions” and Level D “highly improbable conditions”, which may be classified as the PTS transients, are lacking clear descriptions. In addition, some fracture mechanics inputs, such as the thermal and stress analyses, have not been revisited since their original design. Therefore, it may be difficult to reassess the safety of the RPV under PTS loadings during the LTO operation according to the RCC-M and RSE-M codes. In fact, there is only a small amount of literature based on the RCC-M or RSE-M codes to assess RPV integrity, even though the resistance of RPV against fast fracture has been comprehensively studied.

This paper aims to apply the French codes, RCC-M and RSE-M, to perform an RPV integrity assessment, to compare the two codes with the ASME codes, and to discuss the limitations of the three codes. In this paper, the methodology of the Level C and Level D in the French codes, which is classified as the PTS assessment, is firstly discussed. Meanwhile, the methodology is further compared with the fundamental of the FAVOR software. A case study according to the RCC-M and RSE-M codes is presented. Lastly, the limitations of the RCC-M and RSE-M codes, as well as the important factors for the RPV structural assessment, i.e., weld residual stress, cladding influence, and crack arrest assessment criteria, are discussed.

### 1.1. *PTS assessment procedure*

The PTS assessment of RPV integrity is based on comparisons of crack driving forces (such as stress intensity factor, SIF $K_I$) calculated for assessed points along the crack front with its allowable value (such as fracture toughness $K_{IC}$) for PTS events [12,13]. The flowchart of the PTS analysis is shown in Fig. 1, and the main evaluations are described in the following steps: (1) prediction of material toughness according to the chemical compositions, initial toughness, neutron fluence and material embrittlement; (2) calculation of PTS transients according to thermal-hydraulic analysis; (3) analyses of thermal-mechanical and welding residual stress; (4) definition crack information (position, orientation, size, and type): perform fracture mechanics analysis to calculate the SIF of the postulated cracks; (5) definition failure criteria according to the code (failure model and margin); and (6) assessment: compare SIFs of the postulated cracks with the failure criteria (fracture toughness of the embrittled material).

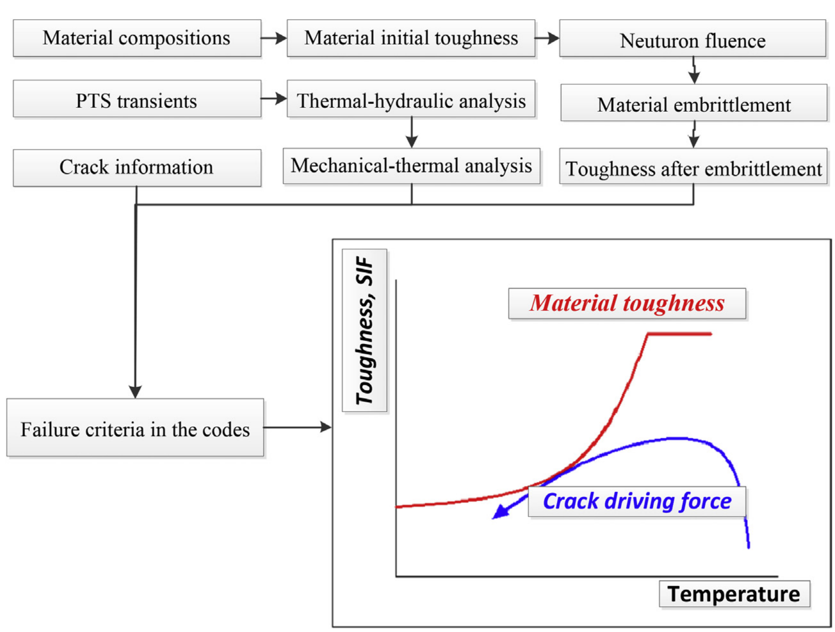


**Fig. 1 – Diagrammatic representation of the PTS analysis. PTS, pressurized thermal shock; SIF, stress intensity factor.**

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