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VVER 440 INTEGRITY ASSESSMENT WITH RESPECT TO PTS EVENTS

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ABSTRACT

The present state of art in VVER 440 RPV integrity assessment with respect to PTS events utilized in Slovakia is reviewed briefly in this paper. Recent results of some PTS's (very severe) analyses, shortly described in our paper, have confirmed the necessity of elaboration of new more sophisticated procedures again. Such methodology should be based on prepared IAEA Guidance.

NOMENCLATURE

K_I	stress intensity factor
K_{IC}	fracture toughness
J	J-integral
T_K	critical temperature of brittleness
T_{ka}	allowable critical temperature of brittleness
t	vessel wall thickness a semielliptical surface crack depth
c	semielliptical surface crack half-length
RPV	reactor pressure vessel
NPP	nuclear power plant
FEM	finite element method
LEFM	linear elastic fracture mechanics

1. INTRODUCTION

RPV structural integrity is one of the most limiting factors with regard to NPP operational safety. Therefore experimental and calculational assessment of pressure vessel integrity has to be carried out both in design and in service stages. Structural integrity assessment approach commonly applied in analyses performed for operating Slovak VVER 440 RPV's is briefly described in this paper. Recent results of some PTS's analyses, shortly presented in our paper, have confirmed the necessity of elaboration of new more sophisticated procedures again. Such methodology should be based on internationally accepted recommendations.

2. INTEGRITY ASSESMENT

Common approach in the area of NPP RPV integrity assessment should be based on following steps in principle :

a) selection of integrity limiting events (PTS),

b) thermal hydraulic analyses,

c) RPV structural integrity analysis

Only problems referring to the RPV structural analysis will be dealt with in this presentation. Up to now applied approach to the evaluation of resistance against non-ductile fracture of Slovak VVER NPP RPV's has been based on LEFM procedures and namely on the philosophy of Russian Strength Calculation Code [1]. With no regard to the fact this Code is valid only for design stage it has been commonly utilized in inservice stage analyses too. Using other Code (ASME) without any additional very deep analysis not only of used methods and approaches but also of main principles put into Code construction is practically impossible (detail comparison of both Codes was presented by Brumovský in [3]). For the reason of calculation rationality (including time and money consumption) typical RPV structural integrity analysis has been divided into separate steps :

a) temperature and stress field time course calculation by means of FEM computer programmes (PMD, ADINA),

b) postulated defect stability assessment by means of LEFM criterion K_I (t) (K_{IC} (t))

Commonly used linear elastic material model seems to be adequate for most stress analyses conditions, but in some PTS cases vessel cladding exhibits stresses over yielding point and plasticity effects should be taken into account. Nevertheless the influence of plasticity on structural analysis results seems to be very limited under applied approach due to the fact only RPV wall thickness without cladding is considered in stage b), i.e. in postulated defect stability calculations cladding is not considered as load bearing component. The second important problem comprised in stress analysis is connected with a way how to respect the existence of residual stresses which arise by vessel manufacturing but which course is "deformed" by vessel operation cycles. According to our knowledge one conservative solution of this problem, which has been utilized also in our practise, consists in the application of TREF (temperature when thermal stresses are at zero level) equal to the temperature of RPV under normal operation conditions. This approach supposes that residual stresses are eliminated under normal operation conditions on account of arisen thermal stresses (with the same value but opposite sign).

Subsequent step of RPV structural integrity analysis utilizes stress and temperature fields calculated for the whole event time course in the first step. K_I and K_{IC} dependences on time are calculated and compared in all RPV important locations and allowable value of critical temperature of brittleness T_{ka} is identified. K_I are evaluated for reference circumferential and axial surface defects (on the border between cladding and base metal or weld and on the outer vessel surface) with a/t (0.25, a/c=2/3 in the deepest crack point and on the surface. K_I is calculated by the use of stress component courses through the vessel wall. Various K_I calculation schemes are available which differ on the way of stress course processing. Both well known simplified analytical methods utilizing stress linearization and weight function method were applied. Stress linearization is able to be carried out by different manners and output membrane and bending stress can lead to very different results with respect to K_I. In accordance with our experience and with results of some comparative calculations weight function method seems to be most suitable (and accurate) analytical method of K_I calculation. The weakness of all above mentioned analytical procedures consist in they process results of linear elastic stress analysis with no respect to possible influence of plastic deformation arising especially in the area close to cladding.

In case of plastic deformations due to cladding existence can not be neglected numerical calculations of J integral by means of FEM computer codes using meshes with crack presence should be applied to validate analytical procedures and to establish correction factors applicable on pure K_I linear elastic solutions for given RPV geometry. Routine use of FEM J-integral calculation in common and frequently repeated integrity analyses should be avoided.

With the aim to solve problems connected with Bohunice VVER V 230 RPV's integrity evaluation a new research project "Assessment of Resistance of Reactor Pressure Vessels in the NPP V-1 Jaslovske Bohunice against Non-ductile Failure" has been started in 1996. The analysis of above mentioned problems shall be a part of much more broadly defined solution.

3. THE RESULTS OF THE ANALYSIS OF SEVERE PTS EVENTS

In 1996 calculations were carried out to prove the resistance against nonductile fracture of both Bohunice V1 NPP RPV's and Bohunice V2 NPP RPV's with respect to a small set of PTS events which were expected to be probably most severe ones . The list of these events was determined studying international experience and conditions of our NPP's operation. The definition of time course of these events gave us very severe loading combining high thermal and pressure stresses. We would like to illustrate some problems existing in applied current integrity assessment methodology (shortly described in chapter 2) on the example of V1 NPP RPV's analyses.

The V1 NPP RPV's integrity assessment with respect to selected PTS events was carried out. Two severe transients were chosen for RPV structural integrity analysis in accordance with present experience. The first PTS is connected with spurious opening and later reclosing of pressurizer safety valve and the second one is the result of SG header opening with later isolation of affected loop by operator. In the first stage thorough stress and strain calculations were performed. Boundary conditions describing temperature and heat transfer coefficients time course were defined during preceding thermal-hydraulic analysis. In the second stage RPV integrity was investigated.

Stress and deformation components arising within vessel wall due to thermal and pressure changes connected with above mentioned PTS transients were determined at important time points of analysed regime by means of FEM Computer code PMD II. V1 NPP RPV resistance against brittle fracture was investigated with the use of computer code INTEG [5] partially based on Russian Strength Calculation Code [1]. Boundary conditions inside the RPV vessel during investigated event were supplied as results and input data of calculations performed by computer codes RELAP and NEWMIX. Applied RPV vessel FEM mesh containing vessel cladding and all welds is shown on Fig.1. Reference temperature equal to 269 C (the beginning of event) was used for the purpose of thermal stresses calculation.

K_I and K_{IC} dependences on time were calculated and compared in RPV important locations (weld No.4 and basic metal near to core) and allowable value of critical temperature of brittleness T_{ka} was identified. K_I was evaluated for postulated circumferential and axial surface cracks (on the border between cladding and base metal or weld and on the outer vessel surface) with a/t (0.25, a/c=2/3 in the deepest crack point (point A) and on the "surface" (point B). K_I was calculated by the use of stress component courses through the vessel wall. In accordance with Russian Code [1] only stress and temperature courses through the thickness of basic or weld material without cladding were used for K_I and K_{IC} calculation in evaluated RPV sections. Various available K_I calculation schemes (5 variants) were applied. They differ in the way of stress course processing. Both well known simplified analytical methods utilizing stress linearization [6], [7], [1] and weight function method [8], [10] were applied. Stress linearization is able to be carried out by different manners and output membrane and bending stress can lead to very different results with respect to KI. Some calculation results are presented in Fig 2 - , single K_I curves correspond to following K_I calculation schemes :

var.1 - calculation according to [7] - $K_I$csn on figures

var.2 - calculation according to [6] - $K_I$me on figures

var.3 - calculation according to [8] - $K_I$kfk on figures

var.4 - calculation according to [10]- $K_I$om on figures

var.5 - calculation according to [1] $K_I$ntd on figures (calculation only for point A of postulated crack)

All applied K_I calculation schemes (including original Russian Code procedure [1] !!) provide for V1 2nd unit RPV the same result, i.e. the weld 0.1.4 integrity can't be ensured for cracks with dimensions postulated by Russian Code during both analysed PTS events. All applied K_I calculation schemes provide for 1.st unit weld 0.1.4 the same result, i.e. its integrity is ensured for cracks with dimensions postulated by Russian Code during both analysed PTS events. Results obtained by K_I calculation variants 2,3 and 4 are very close, values obtained by two different weight function methods application (variants 3 a 4) are almost identical in all cases.

For postulated cracks with dimensions up to 20 mm, RPV integrity would be ensured in all events and all vessel sections. Therefore similar reference cracks with assured high detection probability could be used instead of Russian Code postulated maximum cracks preparing more sophisticated RPV integrity assessment methodology. The assessment of V1 NPP RPV integrity is complex problem including material properties determination, selection of important PTS events, thermal-hydraulic analyses and structural integrity analyses. One must consider that these problems should be solved in the whole complexity, therefore longterm research project has been started for this purpose. All questions connected with partial problems such as suitability of various K_I calculation methods, their accuracy in compare with direct FEM calculation results and development of suitable correction factors are contained in this project. Therefore all partial results achieved at present stage are not final with regard to V1 NPP RPV integrity assessment. Neverthless some preliminary measures ought to be considered. Both analysed PTS events, and especially the first of them, have very severe time course. High stress level is caused by the combination of thermal stresses due to temperature shock and stresses due to high pressure appearing during this shock in primary circuit. Both effects are the result of PTS definition (or course), therefore operational measures to limit the possibility of such PTS events occurence should be adopted.

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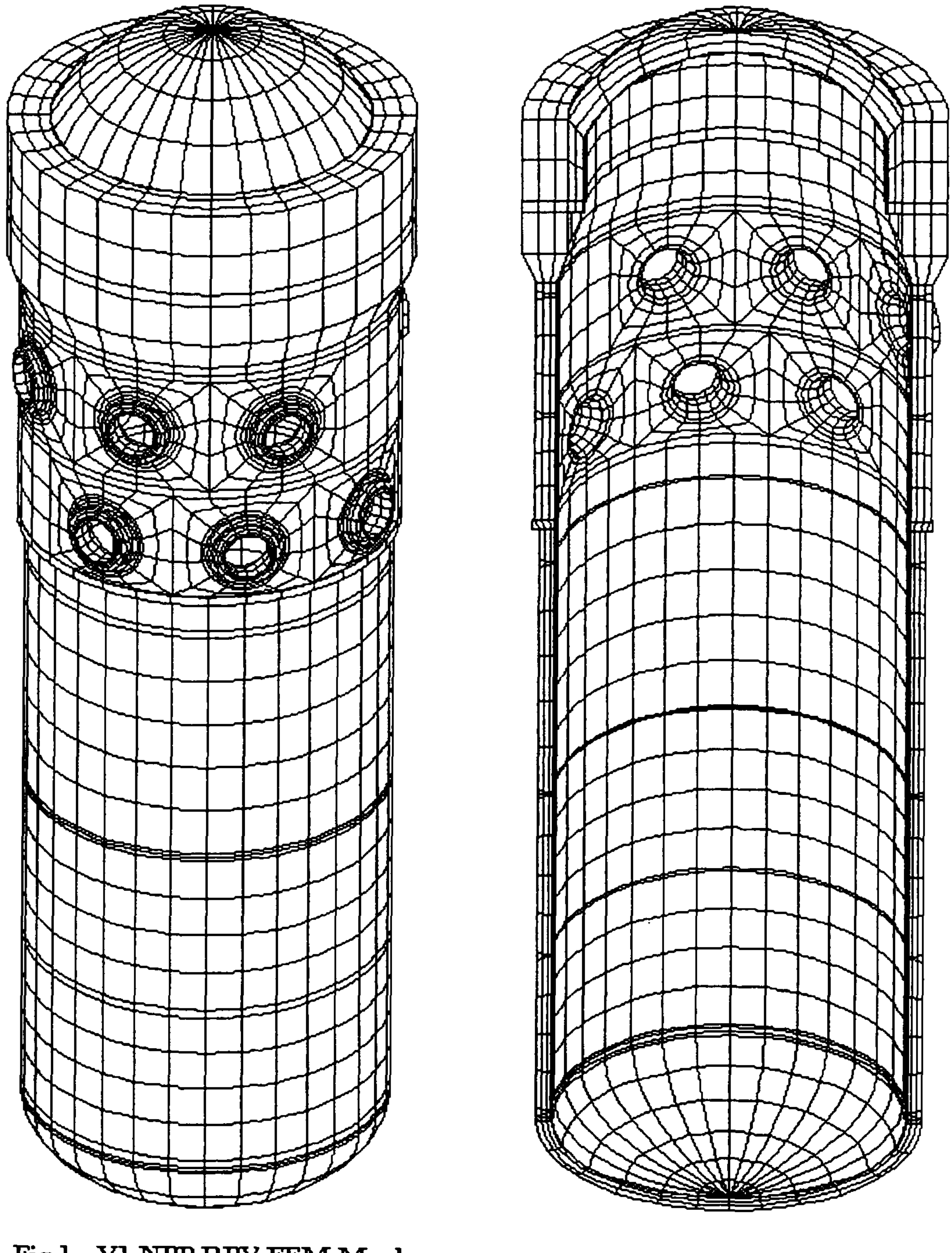

Fig.1 - V1 NPP RPV FEM Mesh

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