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Summary of International PFM Round Robin analyses among Asian Countries on reactor pressure vessel integrity during pressurized thermal shock

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A B S T R A C T

The international Round Robin (RR) activity was performed by the Probabilistic Fracture Mechanics (PFM) sub-committees of the Atomic Energy Research Committee of the Japan Welding Engineering Society (JWES) in conjunction with Korean and Taiwanese research groups. The purposes of this program are to establish reliable procedures for evaluating the fracture probability of reactor pressure vessels (RPVs) during pressurized thermal shock (PTS) and to maintain the continuous cooperation among Asian institutes in the probabilistic approach to nuclear safety.

This paper describes the outline of the problems and summarizes the results from all participant countries. The RR activity consists of two parts; deterministic analyses on stress and temperature in the reactor pressure vessel wall during PTS, and probabilistic analyses on vessel fracture probability due to PTS transients. The differences caused by the selection of analyzing programs and some input parameters will be discussed.

1. Introduction

Tsuruga Unit 1, the oldest commercial nuclear power plant (NPP) in Japan, marked the 40th anniversary on the 14th March, 2010 from its start of the commercial operation. The life-time extension until 2016 was decided in January 2010 [1]. Other old NPPs will also need rational evaluation of plant safety to make a judgment about life extension in the near future. Probabilistic fracture mechanics (PFM) has been regarded as a promising technique for this purpose.

The Japan Atomic Energy Agency (JAEA: formerly called as JAERI) had sponsored research committees on PFM organized by the Japan Society of Mechanical Engineers (JSME) and the Japan Welding Engineering Society (JWES) for about two decades. This work still continues with almost the same members in JWES. The purpose of the continuous activity is to provide probabilistic approaches in several fields of integrity problems for NPPs. These Japanese research activities on PFM are summarized in Table 1 [2,3]. Significant efforts have been focused on Round Robin analyses as shown in the table. The purpose of these Round Robin analyses was to evaluate the precision of PFM programs and to increase the awareness and use of analyzers' technique in the participating research groups. In order to enhance this activity, an international Round Robin program in Asian countries was planned to develop international communication and cooperative use of the PFM technique in this area where the nuclear power development appears to be focused. This paper summarizes the Round Robin (RR) problems and the results obtained by the participating research groups.

2. International RR program

2.1. Participants

The RR program was proposed at the 7th ASINCO conference in 2008 and performed starting in 2009 with participants from six research groups from Japan, four from Korea and one from Taiwan. After the program started, one group joined from China. The

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Table 1
Progress of PFM researches sponsored by JAEA[a](formerly JAERI) (Reproduced from Ref. [2]).

Period	Executing Organization	Components	Main Activities	Remarks
1988–1990	JWES[b] PFM WG under LE Sub-Committee	RPV	• Survey of existing PFM code and numerical and fracture mechanics models for PFM analysis • PFM Round Robin Analysis of RPV • Research on numerical algorithm	
1991	MRI[c] PFM Committee	RPV Piping	• Survey of input data • Survey of analysis model	
1992–1994	JSME[d] RC111 Committee	RPV Piping	• Survey of input data • Survey of analysis model and research on numerical algorithm • Round Robin Analysis of RPV under operating load and PTS • Round Robin Analysis of Piping	Proposal of a standard guideline for PFM analysis
1996–2000	JWES PFM Sub-Committee	RPV Piping SG	• Refinement of PFM methodology: Input seismic load, SIF database, Treatment of embedded crack • Application to ISI code • Application to RII, cost/benefit analysis in inspection strategy • Utilization of PASCAL by Round Robin analyses • Survey of application in other fields, need in structural integrity issues in LWR components	Practical application to structural integrity issues of LWR components
2001–Present	JWES[a] PFM Sub-Committee	Ditto	Ditto	Ditto

[a] PFM researches sponsored by JAERI were completed in 2000. PFM Sub-Committee in JWES has succeeded the research activities as a voluntary research.
[b] The Japan Welding Engineering Society.
[c] Mitsubishi Research Institute Incorporation.
[d] The Japan Society of Mechanical Engineers.

number of all participants was therefore 12 from four Asian countries as shown in Table 2. Each member will be indicated by an alphabetical letter from A to M, excluding I, in this paper for anonymity. A variety of software was used in the RR studies, such as ANSYS, ABAQUS and PASCAL 2, for calculation of temperature and stress distributions in reactor pressure vessels (RPVs), and WinPraise and PASCAL 2 [4,5] for PFM analyses. Software used in this program is summarized in Table 3.

Table 2
Participants of the International RR analyses.

Institute	Country
Japan Atomic Energy Agency(1)	Japan
Japan Atomic Energy Agency(2)	Japan
Mizuho Information & Research Institute	Japan
Japan Nuclear Energy Safety Organization	Japan
The University of Tokyo	Japan
Ibaraki University	Japan
Korea Institute of Nuclear Safety	Korea
Sungkyunkwan University	Korea
Korea Power Engineering Company	Korea
Korea Atomic Energy Research Institute	Korea
Lunghwa University of Sci. & Tech.	Taiwan
Shanghai Nuclear Engineering Research & Design Institute	China

Table 3
Software used in the International RR program.

Research Group	Deterministic	Model	Probabilistic
A	Pre-PASCAL	Axisymmetric	PASCAL 2
B1	Pre-PASCAL	Axisymmetric	PASCAL 2
B2	In-house FDM	1D	
C	Pre-PASCAL	Axisymmetric	PASCAL 2
D1	Pre-PASCAL	Axisymmetric	PASCAL 2
D2	ABAQUS	Axisymmetric	
E	Pre-PASCAL	Axisymmetric	PASCAL 2
F	Pre-PASCAL	Axisymmetric	PASCAL 2
G	Analytical	1D	In-house
H	ABAQUS	3D	PASCAL
J	ABAQUS	3D	In-house
K	ABAQUS	3D	In-house
L	ANSYS	Axisymmetric	WinPraise
M	ANSYS	Axisymmetric	PASCAL

2.2. Description of RR problem

In this program, two sorts of pressurized thermal shock (PTS) transients are applied to the RR problems; Typical PTS and steam generator tube rupture (SGTR) transients [6]. These transients are characterized by different cooling rates during the transients with a constant system pressure as shown in Fig. 1. The other conditions are summarized in detail in Table 4.

Before performing the probabilistic analyses, deterministic analyses for temperature and stress distributions in the vessel wall during transients were solved by each participant and the results were compared.

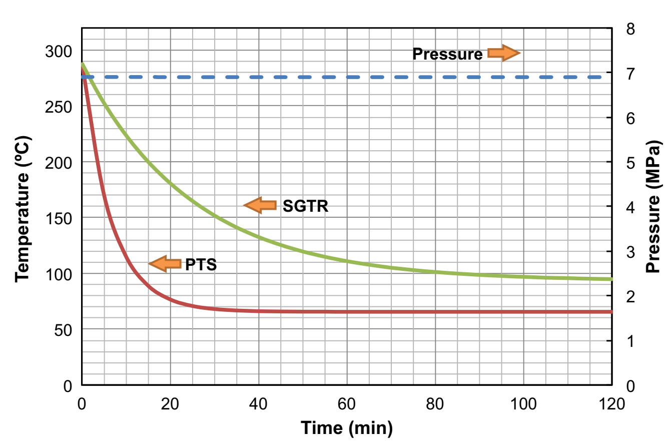

Fig. 1. PTS and SGTR transients used in this Round Robin Study.