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METHODOLOGY ON AGEING MANAGEMENT REVIEW FOR MAIN COMPONENTS AND STRUCTURES OF A PWR NPP

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ABSTRACT

According to the requirements of NNSA, for Chinese operational NPPs periodical safety review (PSR) should be carried out every 10 years. Ageing management is one of the important safety factors to be reviewed. Entrusted by Qinshan Nuclear Power Plant (QNPP), Shanghai Nuclear Engineering Research and Design Institute (SNERDI) carried out the ageing management review (AMR), as a part of the first PSR of QNPP, from 2001 to 2003. This paper summarizes the methodology of the AMR process, including screening of critical components and structures, identification of main ageing mechanisms and their indicators and the tabulated review process, etc. 15 components and structures, hereafter referred as equipments, were selected as review objects based on their significance of safety, replaceability and cost-benefit considerations. To these objects, the main ageing mechanisms and relevant ageing indicators were identified according to specific working and environmental condition, design and manufacture information, operation and maintenance history, etc. The review can be divided into two parallel parts, the review for specific equipment and the review for overall management procedures and their implementation. To typical components, such as RPV and SG, fatigue analysis based on operational transient accounting was carried out to observe the actual safety margins. Through the review, the weaknesses in ageing management and potential threats to structural integrity were identified and thus continued improvement can be made in the next period of 10 years.

Keywords: ageing management, ageing mechanism, PSR, safety margin, structural integrity

1. INTRODUCTION

The history of nuclear power in mainland of China started in 1991. Up till now China has totally 9 reactors in operation with whole power capacity about 6800 MWe. The safety of operational NPPs draws considerable attention both of nuclear safety regulatory organizations, owners and technical supporters. According to the requirements of NNSA[1], to every operational NPP, a periodic safety review (PSR) should be carried out every 10 years. Ageing management is one of the safety factors for PSR, which mainly focuses on ageing and its countermeasures for critical, safety related and limited in number components or structures, hereafter referred as equipments, such as RPV, SG, etc.. Entrusted by Qinshan Nuclear Power Plant (QNPP), Shanghai Nuclear Engineering Research and Design Institute (SNERDI) carried out the AMR, as a part of the first PSR of QNPP from 2001 to 2003. This paper summarizes the methodology of the review process, including screening of critical components and structures, identification of main ageing mechanisms and their indicators and the tabulated review process, etc. In the following paragraphs, we will mention the main elements and steps of the AMR with a flow diagram, main ageing mechanisms for equipments as AMR objects, tabulated review method which could be divided into two parts as equipment oriented review and programme oriented review, and finally fatigue analysis for two critical equipments, RPV and SG will be briefly summarized.

2. MAIN ELEMENTS AND STEPS OF AMR

As a part of PSR, AMR should generally follow the requirements of PSR while focusing on specific ageing management problems. NNSA published a PSR guideline[1], which mainly refers to relevant IAEA's guideline[2] and combines with Chinese practice. The PSR requires owner of NPP to perform self-review, which usually lasts about 2~3 years, and then, to hand over a whole set of self-review reports to NNSA. Then, NNSA performs an independent review to the reports. In this paper, the AMR is a self-review carried out by owner or by technical supporter entrusted by owner.

According to the NNSA's guideline, the following elements should be focused on during AMR:

1) Programme policy, organization and resources;
2) A documented method and criteria for identifying SSCs covered by the ageing management programme;
3) A list of SSCs covered by the ageing management and records which provide information to support management of ageing;
4) Evaluation and documentation of potential ageing degradation that may affect the safety functions of SSCs;
5) The extent of understanding of dominant ageing mechanisms of SSCs;
6) The availability of data for assessing ageing degradation, including baseline, operating and maintenance history;
7) The effectiveness of operational and maintenance programmes in managing ageing of replaceable components;
8) The programme for timely detection and mitigation of ageing processes and/or ageing effects;
9) Acceptance criteria and required safety margins for SSCs;
10) Awareness of physical condition of SSCs, including actual safety margins and any features that would limit service life.

Before the AMR was carried out, a technical guideline was firstly formulated to harmonize the understanding of different reviewers whose technical backgrounds were quite different.

Aiming at the above elements, the AMR process goes through the flow as shown in Figure 1. The review can be divided into two parallel parts: equipment-oriented review and program-oriented review, including 5 steps shown in the follows.

Step 1 Screening Firstly, some typical equipments should be selected as AMR objects from large numbers of SSCs according to their significance of safety, feasibility and cost-effective for replacement. Although screening process and results may vary from plants to plants, main components of primary loop such as RPV, SG and RI and some significant structures and components such as containment and cables will usually be selected as AMR objects.

Step 2 Ageing mechanism analysis To AMR object components, their ageing mechanisms which may affect lifetime should be described carefully according to the environment and working conditions.

Step 3 Investigation and information collection AMR is a process of information collection and evaluation. Information on design, manufacture, installation, commissioning, operation, inspection and maintenance is helpful to determine whether suitable countermeasures against ageing identified in Step 2 are taken during different stages, especially in operation, inspection and maintenance process and how the countermeasures are effectively mitigate the degradations. The investigation should also identify in what degree management documents and their implementation consider mitigation of ageing degradation, whether plant resource configuration on daily ageing management is sufficient and whether new technical development and concept renovation are reflected in programs for maintenance, inspection and chemical control, etc. An AMR tabulated form will be described later in detail.

Step 4 Assessment Ageing management status for specific equipment should be assessed in detail and relevant improvement suggestions should also be given. To some significant and quantifiable ageing mechanisms such as fatigue caused by transient fluctuation, a structural integrity analysis may be performed according to actual operating conditions so that actual safety margin can be measured.

Step 5 AMR report AMR reports for specific components will be compiled individually and finally a summary report will be made. All the reports will be sent to NNSA for approval. During approval procedure, good communication between owner and NNSA is necessary. The approved AMR reports will be taken as basis for continuing improvement in next 10 years.

3 SCREENING

There are thousands of SSCs in NPP and the resources used in ageing management are limited, it is neither possible nor necessary to carry out ageing management for all SSCs. It is advisable to select several typical, safety-related and cost impact SSCs as the ageing management objects. The screening is based on significance of safety, economic concerns and feasibility of replacement. Sufficient discussions with the owner of NPP and communications with safety regulatory are also necessary. The following equipments were finally selected as objects of ageing management and AMR would focus on the selected equipments.

(1) RPV;
(2) Reactor internals;
(3) SG;
(4) Pressurizer;
(5) Primary piping;
(6) Pressurizer surge line;
(7) RCP;
(8) Centrifugal upper charge pump;
(9) Pressurizer safety valve;
(10) Electric gate valve for shutdown cooling system;
(11) Class 1E cables;
(12) 1152, 1153 transformers;
(13) SPEC 200 assembly and cabinet;
(14) Containment;
(15) Concrete structure near the core.

4 AGEING MECHANISM ANALYSIS

For PWR NPP, the degradations due to various ageing mechanisms of the selected quipments can be observed in different stages of their lifetime. The degradation can mainly be classified into five categories, i.e. corrosion, fatigue, thermal embirittlement, irradiation and wear. For containment and structures near core, the concrete degradation should also be taken into account. Each ageing category may include a variety of failure modes. For example, stress corrosion cracking can occur as transgranular stress corrosion cracking, intergranular stress corrosion cracking and irradiation assisted stress corrosion cracking etc.. The location of SCC occurred could be in primary water or in secondary water. Equipment failures often result from compositive effects of multi-ageing mechanisms. For instance, the RPV core beltline suffers from a long-term strong irradiation and will become non-ductile. Flaws may initiate due to fatigue induced by fluctuation of temperature and pressure of coolant and in case PTS event, non-ductile failure of RPV under the combined action of irradiation embrittlement and fatigue may happen. So enough attention should be paid to each leading ageing mechanism during the ageing management and the combined action of multi-ageing mechanism should also be considered so that ageing or degradation of components can be effectively controlled. Therefore, AMR should start with understanding of dominant ageing mechanisms and investigating if management countermeasures aiming at the ageing mechanisms have been well prepared and effectively implemented. The summary of the dominant ageing mechanisms for all selected equipments is listed in Table 1, where, SCC stands for Stress Corrosion Cracking; PWSCC, Primary Water Stress Corrosion Cracking; ODSCC, Outside Diameter Stress Corrosion Cracking; IGSCC, Intergranular Stress Corrosion Cracking; IASCC, Irradiation Assisted Stress Corrosion cracking; FIV, Flow induced vibration.

From the table, it can de concluded that for the selected equipments, fatigue and wear caused by various reasons are the dominant ageing mechanisms. For RPV and RI, irradiation effects should also be taken into account. The AMR will main focus on investigating whether and how countermeasures were taken to mitigate the ageing effect caused by the dominant ageing mechanisms and for typical equipments, the review will extend to investigate current ageing status.

During AMR for QNPP, 15 ageing mechanism analysis reports were provided to focus on significant ageing degradations for individual equipment. A comprehensive summary report was then formulated based on the these reports.

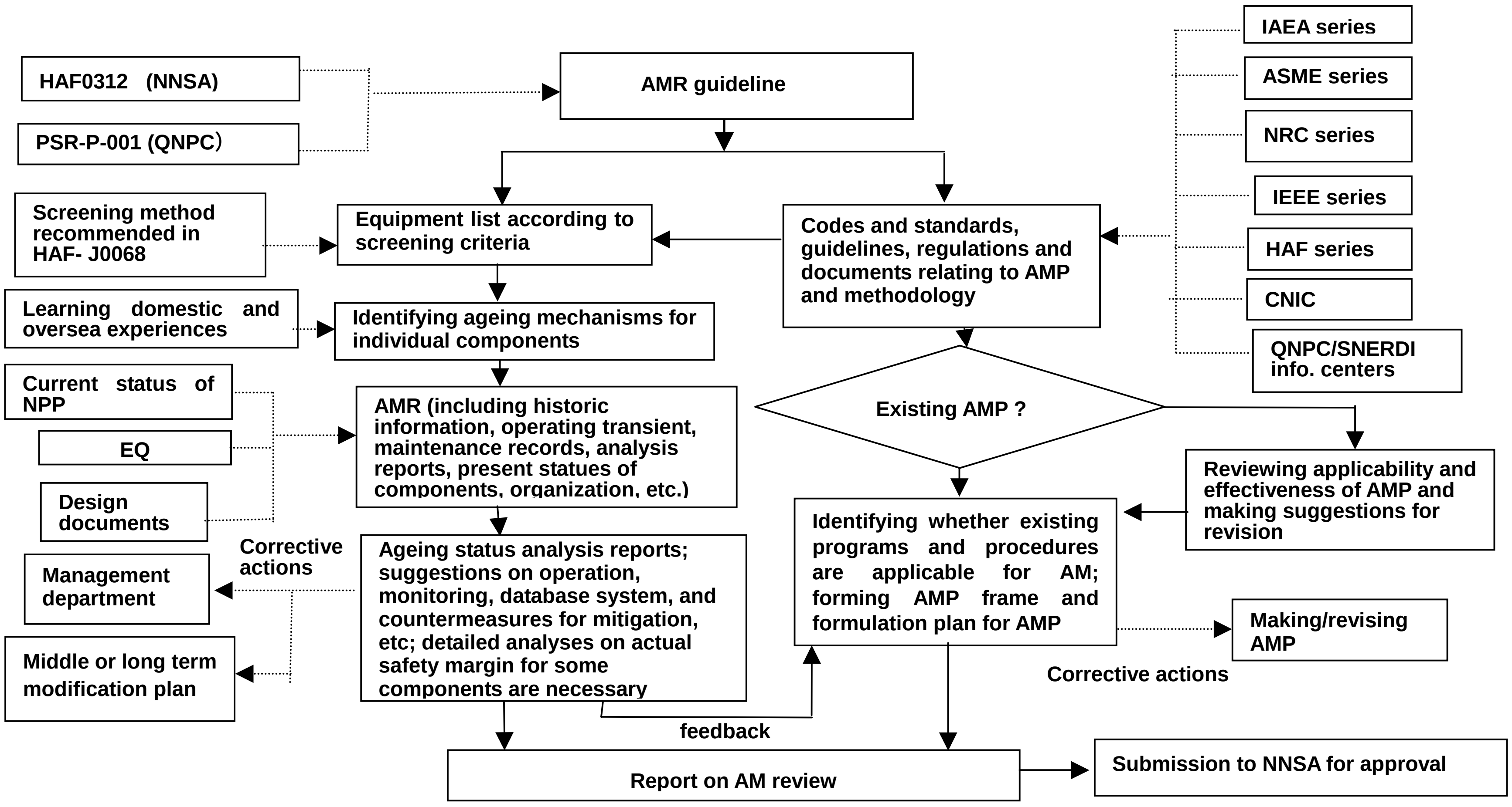


Figure 1 Procedure of AMR as part of PSR

Table 1 Main Ageing Mechanisms of RPV, SG and RI

	Component/Location \ Phenomenon	Corrosion	Fatigue	Thermal embrittlement	Irradiation	Wear / concrete degradation
RPV	Core beltline		Environment fatigue		Neutral irradiation	
	Stud bolts	Boric acid corrosion	Mechanical and thermal stress			
	Corner of nozzle		Mechanical and thermal stress			
	CRDM penetrations	PWSCC	Mechanical and thermal stress			
	Outer surface of dome head	Boric acid corrosion				
	Bottom head	PWSCC				Loosing parts
SG	Tube to tube-sheet crevices	ODSCC				
	Tube support plate	ODSCC				
	Sludge pile	ODSCC				
	Free span	ODSCC				
	Contacts between tubes and anti-vibration bars					Fretting, wear
	Contacts between tubes and loose parts					Fretting, wear
	Feedwater nozzle and nozzle-to-piping weld	Erosion-corrosion	High and low cycle fatigue			
	Shell girth welds	SCC	Corrosion fatigue			
	Feedwater nozzle bore, blend radius, shell inside surface beneath nozzle		High-cycle thermal fatigue			
	J-tubes and feedwater nozzle	Erosion-corrosion				
RI	Barrel		Thermal stress, FIV		Neutral irradiation	
	Baffle and former		Thermal stress		Irradiation swelling	
	Secondary support assembly		FIV			Fretting, wear
	Guide tube assembly		FIV			Fretting , wear
	Radial locating key		FIV			Fretting, wear
	Instrumentation sleeve, control rod guide tube		FIV			wear
	Irradiation surveillance capsule		FIV		Neutral irradiation	Fretting, wear
	Connect parts such as bolts and pins	IGSCC IASCC	FIV		Irradiation, swelling and creeping	
	Hold-down spring		Mechanical axial force			
Pressurizer (Spray tube)			Thermal fatigue			
RCP (rotating parts)			Vibration			
Centrifugal upper charge pump (rotating parts)			Vibration			

Phenomenon / Component/Location		Corrosion	Fatigue	Thermal embrittlement	Irradiation	Wear / concrete degradation
Pressurizer safety valve			Thermal stratification	CF8M thermal ageing		Mech. Vibration
Electric Gate Valve			Thermal stratification	CF8M thermal ageing		Mech. Vibration
Primary Piping			Thermal / Mechanics	Thermal ageing		
Class 1E cables		Oxide and Chemical		Thermal ageing	Irradiation	Vibration and wear
Transformers			Operation cycles	Thermal ageing		
SPEC 200			Vibration and mechanical	Thermal ageing		Mechanical wear
Containment and structure near core	Concrete	Acidic or basic corro.	Fatigue			Decency, leach
	Reinforced concrete	General corrosion or pitting of reinforced bar		Thermal ageing		
	Prestressed system	Pitting, erosion				Loss of prestress
	Steel liner	Corrosion caused by failure of rust protection				

5 AMR REPORT FOR INDIVIDUAL EQUIPMENT

The outcomes of equipment-oriented review are a series of AMR reports for individual equipments.The AMR for equipments will finally finish a series of AMR reports. These reports shall include a whole description for structure feature of the equipments, design requirements, manufacture process, information noticed during installation and test, operation environment, inspection results, maintenance records, etc. The reports shall also include a description for some significant ageing mechanisms. The kernel content of the reports is a series of tabulated assessment forms for the specific ageing mechanisms on different locations. Each ageing mechanisms at different locations will have an independent table. As ageing mechanisms for different equipments are differ from each other, the numbers of review forms for different equipments are quite different.

Table 2 shows the format of review form with remarks. From the above, it can be seen that when performing review for the specific ageing mechanism at specific location, the reviewer should, first of all, access and understand well the information on material, environment, ageing mechanism, ageing indicator, degradation effects and consequence, relevant codes, standards and specifications, existing ageing management programmes and procedures etc. Afterwards, can reviewer work out an assessment for ageing management and ageing status and, finally, give out review conclusions and countermeasure suggestions.

During AMR for QNPP, 15 equipment-oriented review reports for individual equipments were provided to NNSA, showing existence of some weaknesses and some improvement actions were necessary.

Table 2 AMR form and relevant remarks

Name of equipment	List name of reviewed equipment, for example, RPV.
Serial number of the review	List serial number of the review table. From serial number, the reviewed equipment can be distinguished.
Concerned location	List specific location of the reviewed equipment, for example, upper head of RPV and concerned area (such as dome, flange, bolt and so on) corresponding to this form.
Material	List material brand corresponding to the specific concerned location.
Environment	Describe in detail the environment of reviewed part with measurable parameters, such as working temperature, pressure, humidity, etc.
Ageing mechanism and its indicator	List ageing mechanism concerned and its corresponding indicator.
Degradation consequence	Describe effects and consequences of the degradation caused by the ageing, especially ageing effect on safety.
Codes, standards and technical information	List codes, standards and relevant technical information on detecting, mitigating and solving the specific ageing problem.
Existing programs and procedures	List management programmes and/or procedures made by NPP for effectively managing the specific ageing problem. If no corresponding programs or procedures in the NPP, programs, procedures and requirement from outside could also be listed.
Assessment on ageing management and on actual ageing status	List comprehensive assessment on ageing management and ageing degradation status. For example, the following information can be listed: ● Whether there are preventive measures to the specific ageing mechanism; ● Whether there are surveillance, inspection requirements and measures; ● Whether there are acceptance criteria for the ageing; ● Have any events caused by ageing degradation ever happened after the equipment started operation; ● Once the degradation is not acceptable, are there any countermeasures ready for maintenance, repair and replacement; ● Whether experience on ageing problems both from internal of NPP and outside organization can timely and effectively reach to persons responsible for ageing management; ● Actual status of the component; etc.
Review conclusions	List review conclusions. Strong points and weaknesses should be emphasized in the conclusion.
Suggestions on countermeasures and corrective actions	Put forward suggestions on countermeasures and corrective actions aiming at weaknesses.

6 PROGRAMME ORIENTED AMR

As the plant had not established a systematic ageing management program, the programmed oriented AMR mainly focused on whether the existing programmes and procedures can be used to timely detect and mitigate degradations of ageing. The review can also be divided into two parts: (1) organizational review and (2) programmatic review.

6.1 organizational review

The organizational review mainly investigated whether the plant organizational structures was suitable and well coordinative to establish an effective general ageing management programme (AMP) and to implement it efficiently afterward. The review could be carried out from top level to individual departments. During AMR for QNPP, it is recommended from the top organizational review that at least a deputy GM of the plant should be designated to take charge of establishment of AMP and to allocate resources for AMP implementation. All the related departments were also investigated to observe whether the related responsibilities were clarified to related departments and persons. For QNPP, the reviewed departments included: System Engineering; Technical Support; Planning; Operation; Maintenance; Nuclear Safety and License; Quality Assurance; Training; Procurement, etc.. Comments and suggestions for improvement were made for every department and top management level in the final review report.

6.2 programmatic review

The programmatic review mainly concerned the existing programmes and procedures used for daily activities of the plant, such as operation, inspection, maintenance, etc.. First of all, a general comment was made for management document systems and then individual remarks to specific programmes and/or procedures were given. During AMR for QNPP, the following programmes and/or procedures were reviewed:

(1) Preventive Maintenance Programme (2 documents were reviewed) ;
(2) Programmes for In-service Inspection, Surveillance, Testing and Monitoring (13 documents were reviewed);
(3) Data Collecting and Record Keeping Programmes (16 documents were reviewed);
(4) Specific Procedures for Critical Equipments (7 documents were reviewed);
(5) Chemical Control Programme (3 documents were reviewed);
(6) Related Operational Procedures (5 documents were reviewed);
(7) Feedback of Operational Experience and Study on Significant Events (2 documents were reviewed);
(8) Procedure on Spare Parts Management (1 document was reviewed).

Through the review, some weaknesses in management were pointed out and suggestions for correction were also put forward.

7 FATIGUE ANALYSIS BASED ON ACTUAL TRANSIENT ACCOUNTING FOR RPV AND SG

To investigate the actual fatigue ageing status and to make sure that safety margin was still maintained, two critical equipments, these were RPV and SG, were selected to perform transient stress analysis and fatigue evaluation based on actual transient accounting.

All the transients were categorized into 7 conditions:

(1) Plant heatup
(2) Normal heatup and unit loading (0~15% P_f)
(3) Plant Cool-down
(4) Normal cool-down and unit unloading (0~15% P_f)
(5) Normal shutdown (from P_f , temperature drop without injection)
(6) Manual shutdown under accident condition (from $P_{f,}$ temperature drop without injection)
(7) Automatic emergent shutdown under accident condition (from $P_{f,}$ temperature drop without injection)

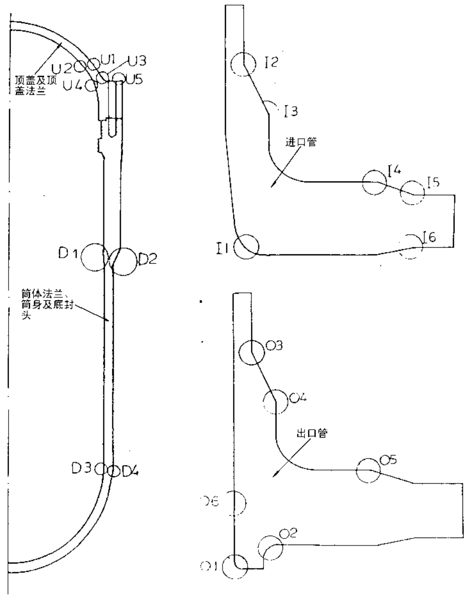
The statistic of transients for the past 10-year operation were sorted out and compared with that of design transients, which were used to perform fatigue analysis at design stage. A simplified envelop based on conservative principle was made. Finite element analysis was carried out using ANSYS programme to evaluate the actual cumulative usage factors of RPV and SG. Figure 2 and 3 are respectively the sections of fatigue evaluation for RPV and SG under actual transients. The fatigue evaluation results are listed in Table 3 and Table 4.

Table 3 Cumulative Usage Factors of RPV

Position (refer to Figure 2)	$(CUF_{10})_{actual}$ (under actual transients after 10 years operation)	$(CUF_{30}/3)_{design}$ (under design transients, 1/3 of its design life)	$(CUF_{10})_{actual}/(CUF_{30}/3)_{design}$
U5	0.00539	0.0225143	0.24
D4	0.00026	0.0010895	0.24
I1	0.00323	0.0134817	0.24
O1	0.00281	0.0116823	0.24
CRDM nozzle	0.00215	0.0089767	0.24

Table 4 Cumulative Usage Factors of SG

Position (refer to Figure 3, at inner wall)	CUF_{10} (under actual transients after 10 years operation)	$CUF_{30}/3$ (under design transients, 1/3 of its design life)	$(CUF_{10})_{actual}/(CUF_{30}/3)_{design}$
1	0.00131	0.00994	0.13
2	0.00158	0.01203	0.13
3	0.00173	0.01316	0.13
4	0.00055	0.00419	0.13
5	0.00002	0.00015	0.13
6	0.00007	0.00050	0.14
7	0.00003	0.00017	0.17
8	0.00164	0.01245	0.13
9	0.00001	0.00010	0.1
10	0.00015	0.00111	0.13



Fiaure 2 Fatiaue evaluation sections for RPV

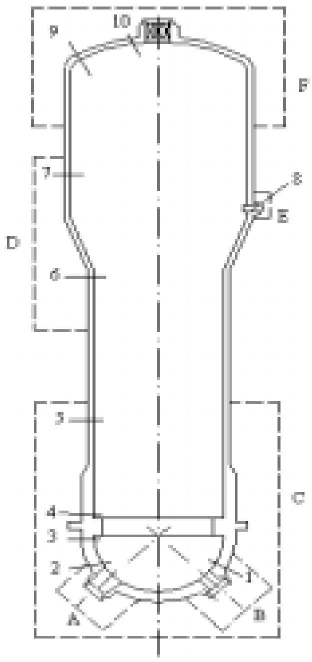


Figure 3 Fatigue evaluation sections for SG

Column 2 of Table 3 and 4 are respectively the CUFs under actual operational transients and column 3 are equivalent CUFs under one third of design transient for 30-year design life. It shows that from perspective of fatigue caused by transient variation, the CUFs still have a considerable margin comparing with the results under design transients. From view of fatigue failure, we have confidence of life extension for the two equipments. Of course, whether life extension is feasible or not depends not only on fatigue but also on some other factors, such as irradiation embrittlement for RPV and PWSCC nd or ODSCC for SG. Thus, comprehensive life management under a system management programme is of significance for a long-term.

8 CONCLUSIONS

This paper presents main steps and methodology of AMR as part of PSR. The methodology has been applied in PSR for QNPP, the first nuclear power plant in China, showing its soundness and effectiveness. Carrying out AMR for main components of NPP is helpful to make an overall and comprehensive assessment on ageing management and on actual ageing status of the components. It will form a basis for continuing improvement on ageing management and for future life extension.

Although AMR is effective and constructive, it could not substitute daily ageing management activities of NPP. According to IAEA's point of view[3], only after a systematic ageing management programme is established, can an operational NPP continuously improve its safety features, component reliability and economic benefit through effective ageing management. A systematic ageing management programme is not only aiming at concrete ageing problems for specific components, but also reflecting effective control to ageing process from various aspects, including management concept, program and procedure system, management operation inside NPP, resource configuration, communication and correlation with outside supporters and suppliers. Through a Plan-Do-Check-Act cycle[3], a systematic ageing management process can become more and more effective and adaptive.

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