PRESSURIZED WATER REACTOR OWNERS GROUP

PWROG-17011-NP
Revision 2

WESTINGHOUSE NON-PROPRIETARY CLASS 3

Update for Subsequent License Renewal: WCAP-14535A, "Topical Report on Reactor Coolant Pump Flywheel Inspection Elimination" and WCAP-15666-A, "Extension of Reactor Coolant Pump Motor Flywheel Examination"

Materials Committee

PA-MSC-1500

January 2019

Westinghouse

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PA-MSC-1500

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		Yes	No
Ameren Missouri	Callaway (W)	X	
American Electric Power	D.C. Cook 1 & 2 (W)	X	
Arizona Public Service	Palo Verde Unit 1, 2, & 3 (CE)		X
Dominion Connecticut	Millstone 2 (CE)		X
	Millstone 3 (W)	X	
Dominion VA	North Anna 1 & 2 (W)	X	
	Surry 1 & 2 (W)	X	
Duke Energy Carolinas	Catawba 1 & 2 (W)	X	
	McGuire 1 & 2 (W)	X	
	Oconee 1, 2, & 3 (B&W)	X	
Duke Energy Progress	Robinson 2 (W)	X	
	Shearon Harris (W)	X	
Entergy Palisades	Palisades (CE)		X
Entergy Nuclear Northeast	Indian Point 2 & 3 (W)		X
Entergy Operations South	Arkansas 1 (B&W)		X
	Arkansas 2 (CE)		X
	Waterford 3 (CE)		X
Exelon Generation Co. LLC	Braidwood 1 & 2 (W)	X	
	Byron 1 & 2 (W)	X	
	TMI 1 (B&W)		X
	Calvert Cliffs 1 & 2 (CE)	X	
	Ginna (W)		X
FirstEnergy Nuclear Operating Co.	Beaver Valley 1 & 2 (W)		X
	Davis-Besse (B&W)		X
Florida Power & Light \ NextEra	St. Lucie 1 & 2 (CE)		X
	Turkey Point 3 & 4 (W)	X	
	Seabrook (W)	X	
	Pt. Beach 1 & 2 (W)	X	
Luminant Power	Comanche Peak 1 & 2 (W)		X
Omaha Public Power District	Fort Calhoun (CE)		X
Pacific Gas & Electric	Diablo Canyon 1 & 2 (W)		X
PSEG – Nuclear	Salem 1 & 2 (W)		X
South Carolina Electric & Gas	V.C. Summer (W)	X	
So. Texas Project Nuclear Operating Co.	South Texas Project 1 & 2 (W)		X
Southern Nuclear Operating Co.	Farley 1 & 2 (W)		X
	Vogtle 1 & 2 (W)		X
Tennessee Valley Authority	Sequoyah 1 & 2 (W)		X
	Watts Bar 1 & 2 (W)		X
Wolf Creek Nuclear Operating Co.	Wolf Creek (W)		X
Xcel Energy	Prairie Island 1 & 2 (W)	X	

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PWR Owners Group
International Member Participation* for PA-MSC-1500

Utility Member	Plant Site(s)	Participant Yes	Participant No
Asociación Nuclear Ascó-Vandellòs	Asco 1 & 2 (W)		X
	Vandellos 2 (W)		X
Axpo AG	Beznau 1 & 2 (W)		X
Centrales Nucleares Almaraz-Trillo	Almaraz 1 & 2 (W)		X
EDF Energy	Sizewell B (W)		X
Electrabel	Doel 1, 2 & 4 (W)		X
	Tihange 1 & 3 (W)		X
Electricite de France	58 Units		X
Eletronuclear-Eletrobras	Angra 1 (W)		X
Emirates Nuclear Energy Corporation	Barakah 1 & 2		X
EPZ	Borssele		X
Eskom	Koeberg 1 & 2 (W)		X
Hokkaido	Tomari 1, 2 & 3 (MHI)		X
Japan Atomic Power Company	Tsuruga 2 (MHI)		X
Kansai Electric Co., LTD	Mihama 3 (W)		X
	Ohi 1, 2, 3 & 4 (W & MHI)		X
	Takahama 1, 2, 3 & 4 (W & MHI)		X
Korea Hydro & Nuclear Power Corp.	Kori 1, 2, 3 & 4 (W)		X
	Hanbit 1 & 2 (W)		X
	Hanbit 3, 4, 5 & 6 (CE)		X
	Hanul 3, 4 , 5 & 6 (CE)		X
Kyushu	Genkai 2, 3 & 4 (MHI)		X
	Sendai 1 & 2 (MHI)		X
Nuklearna Electrarna KRSKO	Krsko (W)		X
Ringhals AB	Ringhals 2, 3 & 4 (W)		X
Shikoku	Ikata 1, 2 & 3 (MHI)		X
Taiwan Power Co.	Maanshan 1 & 2 (W)		X

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List of Acronyms

B&W	Babcock and Wilcox
CCDP	conditional core damage probability
CCL	critical crack length
CCNPP	Calvert Cliffs Nuclear Power Plant
CDF	core damage frequency
CE	Combustion Engineering
DEGB	double ended guillotine break
DLE	design limiting events
FCG	fatigue crack growth
FSAR	final safety analysis report
FSAR	final safety analysis report
GQA	graded quality assurance
ISI	inservice inspection
IST	inservice testing
LBB	leak-before-break
LERF	large early release frequency
LOCA	loss of coolant accident
LOOP	loss offsite power
MT	magnetic particle testing
NDE	non-destructive examination
NRC	Nuclear Regulatory Commission
OD	outer diameter
PMSC	Pump & Motor Services
PRA	probabilistic risk assessment
PROF	probability of failure
PT	penetrant testing
PWROG	Pressurized Water Reactor Owners Group
RCP	reactor coolant pump
RCPM	reactor coolant pump motor
RCS	reactor coolant system
RG	regulatory guide
rpm	revolutions per minute
RT_{NDT}	reference nil-ductility transition temperature
SER	safety evaluation report
SLR	subsequent license renewal
SRP	standard review plan
SRRA	structural reliability and risk assessment
SSCs	systems, structures and components
USAR	updated safety analysis report
UT	ultrasonic examination/ultrasonic test
W	Westinghouse
WOG	Westinghouse Owners Group
W-PROF	Westinghouse PROF Software Library

Record of Revisions

Revision	Date	Revision Description
0	Nov. 2017	Original issue.
1	May 2018	Rev. 1 removes unnecessary contents that are duplicates in WCAP-14535A [1] and WCAP-15666-A [2]. All evaluation results and conclusions are unchanged.
2	See PRIME	Rev. 2 addresses NRC Request for Additional Information (RAI). In seeking to address the NRC's RAI, it was determined that the RPFWPROF executable file used in PWROG-17011-NP, Revisions 0 and 1 cannot reproduce the results of WCAP-15666-A when run on original computer platforms. Westinghouse reestablished configuration and control, verified and validated the RPFWPROF program. The risk assessment is revised in Section 3 based on the corrected RPFWPROF runs. The deterministic evaluations in Section 2 are unchanged. The error is captured in Westinghouse CAP system.

1 INTRODUCTION

The purpose of this topical report (TR) is to extend the applicability of WCAP-14535A [1] and WCAP-15666-A [2] to subsequent license renewal (SLR), i.e., 80 years of operation.

Westinghouse provided the technical basis in WCAP-14535A [1] for the elimination of inspection requirements for the reactor coolant pump (RCP) motor flywheels for all operating domestic Westinghouse and several B&W plants. The NRC issued a Safety Evaluation Report (SER) in September 12, 1996, accepting the technical arguments but did not allow for total elimination of examinations as WCAP-14535A [1] requested. The SER provided partial relief from the reactor coolant pump (RCP) motor flywheels examination requirements in NRC RG 1.14 [3], by allowing an extension in the examination frequency from 40 months to 10 years. It further relaxed the RG 1.14 examination guidance by recommending an in-place ultrasonic examination (UT) over the volume from the inner bore of the flywheel to the circle of one-half the outer radius or an alternative surface examination, i.e., magnetic particle testing (MT) and/or liquid penetrant testing (PT), of the exposed surfaces defined by the volume of disassembled flywheel. As Section 3.6 of the SER for [1] stated, NRC staff relied solely on the deterministic methodology to review the submittal. The risk assessment was not included in [1] and was not reviewed. WCAP-14535A [1] is applicable to the RCP motor flywheels in all domestic Westinghouse nuclear steam supply system (NSSS) plants, and Oconee Units 1, 2, and 3, Davis Besse, and Three Mile Island Unit 1, which are Babcock and Wilcox (B&W) NSSS plants.

WCAP-15666-A [2] is a follow-up TR that justified extending the 10-year inspection frequency that was approved by the NRC in WCAP-14535A [1] to 20 years. WCAP-15666-A [2] demonstrated that the deterministic results in WCAP-14535A [1] remain valid, and also performed a failure probability analysis to show that the change in risk for a 20-year inspection frequency meet the RG 1.174 [5] acceptance guidelines. The NRC SER for WCAP-15666-A [2] concluded that both the deterministic and probabilistic calculations contained in [2] were acceptable, and approved the 20-year inspection frequency.

WCAP-15666-A [2] is applicable to plants with Westinghouse-designed NSSS plants. Although it included some data for B&W NSSS plants, however, the TR and the NRC SER did not specifically address the applicability of the risk assessments and other evaluations to the three B&W NSSS plants that WCAP-14535-A [1] was applicable to. The following is a quote from the NRC SER for [2].

> *"The NRC staff acknowledges that some of the supporting material for TSTF-421 may also help to support plant-specific applications for the B&W units included in portions of WCAP-15666. The NRC staff will work with licensees for the applicable B&W units to ensure that our processes work as efficiently as possible for those applying for license amendments similar to that described in TSTF-421. The affected licensees are encouraged to discuss this matter with the NRC staff before submitting an application."*

This same applicability is carried over for the TR presented herein. This TR is not applicable to Combustion Engineering (CE) NSSS plants, with the exception of Calvert Cliffs Units 1 and 2. This TR is applicable to Calvert Cliff Units 1 and 2 as these plants have Westinghouse RCP motors and flywheels. However, these flywheels and motor operating speeds are different than those evaluated in WCAP-15666-A [2]. Westinghouse performed a plant-specific evaluation for Calvert Cliffs Unit 1 and 2, that applied the using the same methods detailed in WCAP-15666-A [2] for 60 years of operation. This 60-year evaluation is extended to 80 years of operation in this TR.

Revision 1 of this TR removes unnecessary contents that are duplicates in WCAP-14535A [1] and WCAP-15666-A [2]. Change bars are not used. All evaluation results and conclusions are unchanged.

Revision 2 of this TR addresses NRC Request for Additional Information on Turkey Point Subsequent License Renewal (Set 5, RAI 4.3.5-2). In seeking to address the NRC's RAI, Westinghouse engineers determined that the RPFWPROF executable file used in PWROG-17011-NP cannot reproduce the results of WCAP-15666-A when run on original computer platforms.

To correct for this, Westinghouse has performed a review of the deterministic aspects of the analysis to ensure their continued appropriateness, re-establish configuration control of the RPFWPROF program and determined revised RCP Flywheel probabilities of failure for 40, 60, and 80 years of operation. In efforts to address NRC's question regarding the basis for the K_{IC} model in the RPFWPROF probabilistic assessment, an error was uncovered in the available hard copy of the original independently reviewed source code for RPFWPROF. Removing computer platform differences, the RPFWPROF results in WCAP-15666-A were reproduced, then the error in the median K_{IC} model was corrected per [15]. This error is captured in the Westinghouse corrective action program (CAP). The corrected RPFWPROF was verified and validated per Westinghouse software control procedures.

Revision 2 of this TR revised the risk assessment in Section 3 based on the corrected RPFWPROF runs. The deterministic evaluations in Section 2 are unchanged.

2 BACKGROUND

2.1 DESIGN AND FABRICATION

Westinghouse RCP motor flywheels consist of two large steel discs that are shrunk fit directly to the RCP motor shaft. The individual flywheel discs are bolted together to form an integral flywheel assembly, which is located above the RCP rotor core. Typically, each flywheel disc is keyed to the motor shaft by means of three vertical keyways, positioned at 120° intervals. The bottom disc usually has a circumferential notch along the outside diameter bottom surface for placement of anti-rotation pawls. See Figure 2-1 for the configuration of a typical Westinghouse flywheel.

Westinghouse has manufactured the RCP motors for all operating Westinghouse plants. All of the RCP motor flywheels for Westinghouse plants are made of SA-533 Grade B Class 1 steel. As in WCAP-15666-A [2], a range of RT_{NDT} values from 0°F to 60°F was assumed in the integrity evaluations of [1], which are discussed later in this report.

Westinghouse designed flywheels are also used for Calvert Cliffs Units 1 and 2. They will be addressed separately in Section 3 for the risk assessment, and in Appendix A for the deterministic evaluations.

Consistent with the evaluations performed in [1], larger flywheel outside diameter for the flywheel assembly is used in this TR, because it is conservative with respect to stress and fracture.

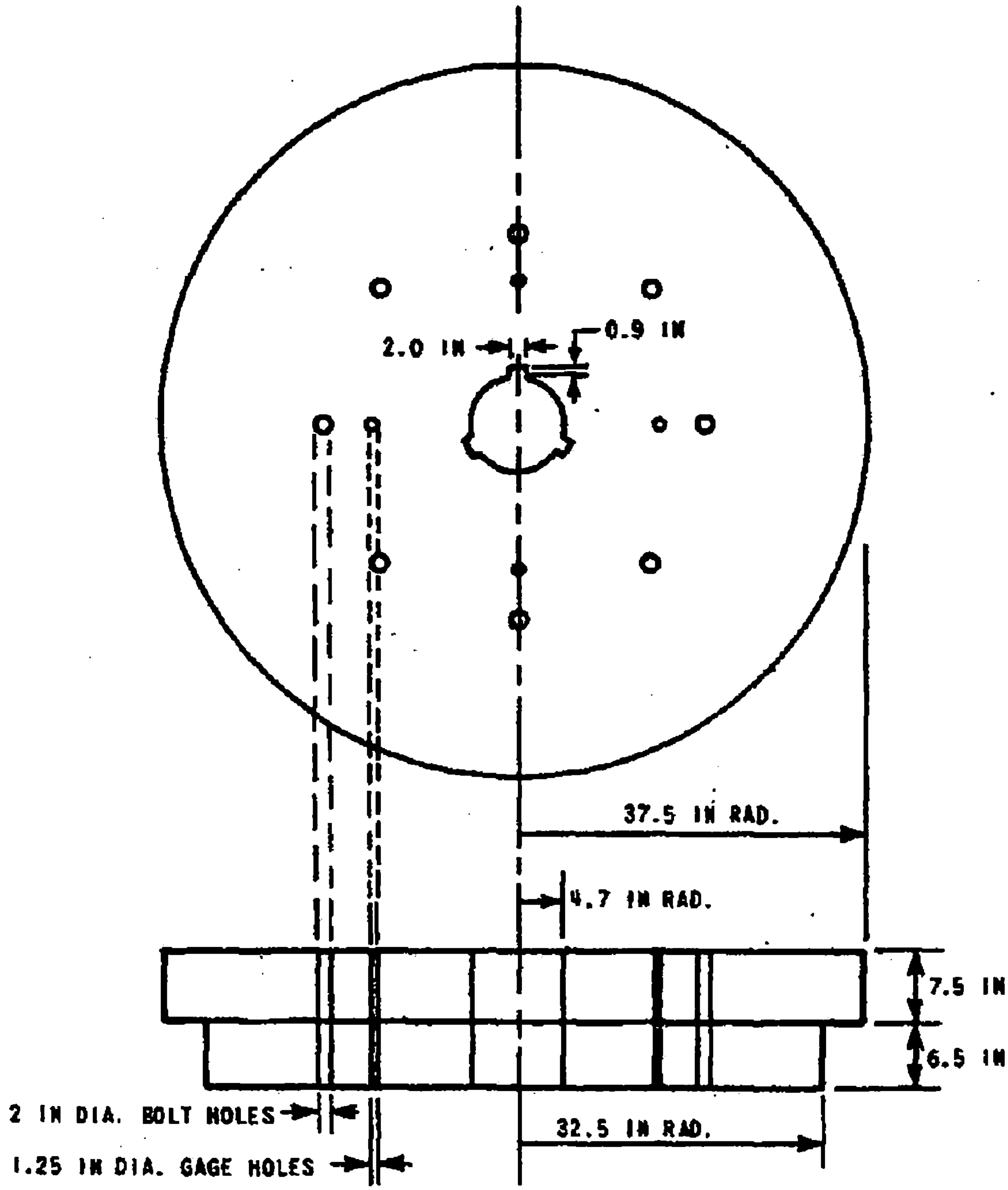

Figure 2-1: Example of a Typical Westinghouse RCP Motor Flywheel

2.2 INSPECTION

Flywheels are inspected at the plant or during motor refurbishment at an offsite facility. Inspections are conducted under the ASME Boiler and Pressure Vessel Code, Section XI [4], which identifies the standard practice for control of instrumentation and personnel qualification. Ultrasonic test (UT) level II and III examiners conduct the inspections.

WCAP-15666-A [2] discussed the examination volume, approach, access and exposure in detail. This discussion remains applicable for SLR.

Inspection History

The flywheel inspection results and the summary of recordable indications from the MUHP-5042 study are presented in Table 2-3 and Table 2-4 of WCAP-15666-A [2].

Inspection History Update

A summary of all Westinghouse RCP flywheels that were inspected by Framatome (formerly AREVA) is summarized in Table 2-1.

Four RCP flywheels where determined to have recordable indications. All four indications were determined to be non-relevant; no repairs were required to be performed on any of those RCP flywheels.

The four recordable indications are discussed in Table 2-2.

Table 2-1: RCP Flywheel Inspection Data

Plant	Number of Flywheels	Total Number of Flywheel Inspections	Total Number of Inspection with No Indications or Non-recordable Indications	Total Number of Inspection With Recordable Indications	Number of Indications Affecting Flywheel Integrity
A	9	9	8	1	0
B	9	9	8	1	0
C	2	2	2	0	0
D	9	14	14	0	0
E	2	2	2	0	0
F	3	3	3	0	0
G	7	7	7	0	0
H	13	13	13	0	0
I	1	1	1	0	0
J	9	9	8	1	0
K	1	1	1	0	0
L	8	9	8	1	0
M	1	1	1	0	0
N	1	1	1	0	0
Total	**75**	**81**	**77**	**4**	**0**

Table 2-2: Flywheel Inspection Data Recordable Indications

Plant	Year	Description of Recordable Indications
A	2015	A Recordable UT indication – Accepted. Lamination with 50% of back wall loss 1" x 4".
B	2006	Procedurally recordable UT indications were identified in the bottom flywheel plate during the 45 degree shear wave examination. – Accepted per NB-2530.
J	2005	Indications were identified in two of three keyways in the lower thickness. The indications were dispositioned as acceptable because they are considered to be "non-relevant due to the machining process."
L	2012	These were determined to be non-relevant indications. There were several low amplitude responses that were identified during the radial examinations. These responses were indicative of small machine grooves or marks that extend 360° around the flywheel.

2.3 STRESS AND FRACTURE EVALUATION

Section 2.3 of WCAP-15666-A [2] summarized the stress and fracture evaluation. The ductile and brittle failure mechanisms were considered in flywheel evaluation. The methodology is unchanged for this TR. The evaluation requirements are per RG 1.14 [3].

2.3.1 Selection of Flywheel Groups for Evaluation

As discussed in [2], stresses in the flywheel are a strong function of the outer diameter (approximately proportional to the square of the OD dimension). Therefore, the two groups shown in Table 2-3 with the largest flywheel outer diameter (Groups 1 and 2) bound all other groups defined in WCAP-15666-A [2], and were selected for the deterministic and probabilistic evaluations.

Table 2-3: Flywheel Groups Evaluated for Program MUHP-5043 [2]

Flywheel Evaluation Group	Outer Diameter (inch)	Bore (inch)	Keyway Radial Length (inch)	Comments
1	76.50	9.375	0.937	Maximum OD.
2	75.75	8.375	0.906	Large OD, minimum bore.

2.3.2 Ductile Failure Analysis

The flywheel stresses are dependent on dimensions and rotation speed. Extending the operating period to 80 years does not affect the stress calculation. Therefore, the ductile failure analysis in [2] remains valid for 80 years of operation.

These results from [2] are summarized in Table 2-4. The RG 1.14 acceptance criteria for ductile failure of the flywheels are satisfied.

Table 2-4: Ductile Failure Limiting Speed

Flywheel Evaluation Group	Assuming No Cracks		Crack Length (as measured from the maximum radial location of the keyway)			
	Neglecting Keyway Radial Length	Considering Keyway Radial Length	1" Crack	2" Crack	5" Crack	10" Crack
1	3487	3430	3378	3333	3240	3012
2	3553	3493	3435	3386	3281	3060

2.3.3 Non-ductile Failure Analysis

The flywheel stress intensity factor, K_I, is dependent on geometry, postulated flaw dimensions and stress condition (due to rotation speed). Extending the operating period to 80 years does not affect the K_I calculations. Furthermore, the flywheel is not local or adjacent to the reactor core; therefore, the effect of irradiated embrittlement is negligible, and the fracture toughness, K_{Ic} does not change due to the 80-year extension. Therefore, the non-ductile failure analysis in [2] remains valid for 80 years of operation.

The results from [2] are shown in Table 2-5. The ambient temperature of 70°F was conservatively used as the operating temperature, while the typical containment ambient temperature is 100°F to 120°F. At the maximum flywheel overspeed condition of 1500 rpm (considering LBB), the critical crack lengths were calculated for cracks emanating radially from the keyway. The crack length is defined as radially from the keyway. The percentage through the flywheel is defined as the crack length divided by the radial length from the maximum radial keyway location to the flywheel outer radius, i.e., percentage through-wall. The critical crack lengths are quite large, even when considering higher values of RT_{NDT} and a lower than expected operating temperature.

Table 2-5: Critical Crack Lengths for Flywheel Overspeed of 1500 rpm (Considering LBB)

Flywheel Evaluation Group	Critical Crack Length in Inches and % through Flywheel		
	RT_{NDT} = 0°F	RT_{NDT} = 30°F	RT_{NDT} = 60°F
1	16.6" (50%)	7.7" (24%)	3.1" (9%)
2	17.5" (53%)	8.5" (26%)	3.6" (11%)

2.3.4 Fatigue Crack Growth

FCG is dependent on the flywheel K_I at operating and rest states (ΔK_I), and the number of start and shutdown cycles. As discussed previously, the 80-year extension has no impact on the K_I calculations. The 6000 cycles used in the FCG calculation of [2] was determined to be conservative for 80 years of operation because it is unlikely the RCP would go through a more than 6 start and stop cycles every month for 80 years. However, the 6000 cycles for 80 years of operation must be confirmed to be applicable on a plant-specific basis.

The FCG calculations assumed the 6000 cycles of RCP start and shutdown for the 80-year plant life. The FCG results from [2] are applicable and are shown in Table 2-6. The crack growth is negligible over an 80-year life of the flywheel, even when assuming a conservative initial crack length as shown in Table 2-6.

Table 2-6: Fatigue Crack Growth Assuming 6000 RCP Starts and Stops

Flywheel Evaluation Group	Flywheel OD (inch)	Flywheel Bore (inch)	Keyway Radial Length (inch)	Length From Keyway to OD (inch)	Assumed Initial Crack Length (inch)	ΔK_I (ksi$\sqrt{in}$)	Crack Growth after 6000 cycles (inch)
1	76.50	9.375	0.937	32.63	3.26	38	0.08
2	75.75	8.375	0.906	32.78	3.28	37	0.08

2.3.5 Excessive Deformation Analysis

The deformation of the flywheel is only dependent on the rotation speed and physical attributes of the flywheel. The 80-year extension has no impact on the excessive deformation analysis of the flywheel. The results in [2] remain applicable to 80 years of operation.

At the flywheel over speed condition of 1500 rpm (157.08 radians/second), the change in the bore radius and outer radius is shown in Table 2-7. A maximum deformation of 0.006 inch is anticipated for the flywheel over speed condition. As deformation is proportional to the square of angular speed, ω^2, this represents an increase of 56% over the normal operating deformation of 0.004 inch. This increase would not result in any adverse conditions such as excessive vibrational stress leading to crack propagation, since the flywheel assemblies are typically shrunk fit to the flywheel shaft, and the deformations calculated are negligible.

Table 2-7: Flywheel Deformation at 1500 rpm

Flywheel Evaluation Group	Change in Bore Radius (inch)	Change in Outer Radius (inch)
1	0.003	0.006
2	0.003	0.006

2.4 SUMMARY OF STRESS AND FRACTURE RESULTS

The deterministic integrity evaluations in WCAP-15666-A [2] remain applicable for 80 years of operation. The evaluations concluded that the RCP motor flywheels have a very high tolerance for the presence of flaws, especially with the 1500 rpm overspeed due to the application of LBB [2]. As noted in [2], the probabilistic assessment evaluates all credible flywheel speeds. This TR uses the same probabilistic assessment methodology as [2], which is discussed in Section 3.

There are no significant mechanisms for inservice degradation of the flywheels, since they are isolated from the primary coolant environment. The evaluations presented in this section have shown there is no significant deformation of the flywheels, even at maximum overspeed conditions. FCG calculations have shown that even with a large assumed flaw, the crack growth for 80 years of operation is negligible. Therefore, based on these deterministic evaluations, the flywheel inspections completed following manufacture and prior to service are sufficient to ensure their integrity during 80 years of service. As discussed in Section 2.2 and [1 and 2], the most likely source of inservice degradation is damage to the keyway region that could occur during disassembly or reassembly for refurbishment and inspection.

3 RISK ASSESSMENT

The quantitative risk assessment discussed below provides the justification for applying the WCAP-15666-A [2] 20-year flywheel inspection interval for 80 years of operation. Specifically, the risk analyses confirms that applying the inspection extension to flywheels in operation up to 80 years has a negligible impact on risk (CDF and LERF), i.e., it is within the risk acceptance criteria of RG 1.174 [5]. This section provides a discussion on the requirements of [5], and extends the previous flywheel failure probability assessment in [2] to 80 years of operation.

3.1 RISK-INFORMED REGULATORY GUIDE 1.174 METHODOLOGY

The NRC risk-informed regulatory framework for modifying a plant's licensing basis is contained in RG 1.174, Revision 2 [5]. The intent of this risk-informed process is to allow insights derived from probabilistic risk assessments to be used in combination with traditional engineering analysis to focus licensee and regulatory attention on issues commensurate with their importance to safety. Additional regulatory guidance is contained in [6].

The approach described in RG-1.174 is used in each of the application-specific RGs/SRPs, and has four basic steps as shown in Figure 3-1. The four (4) basic steps are discussed below.

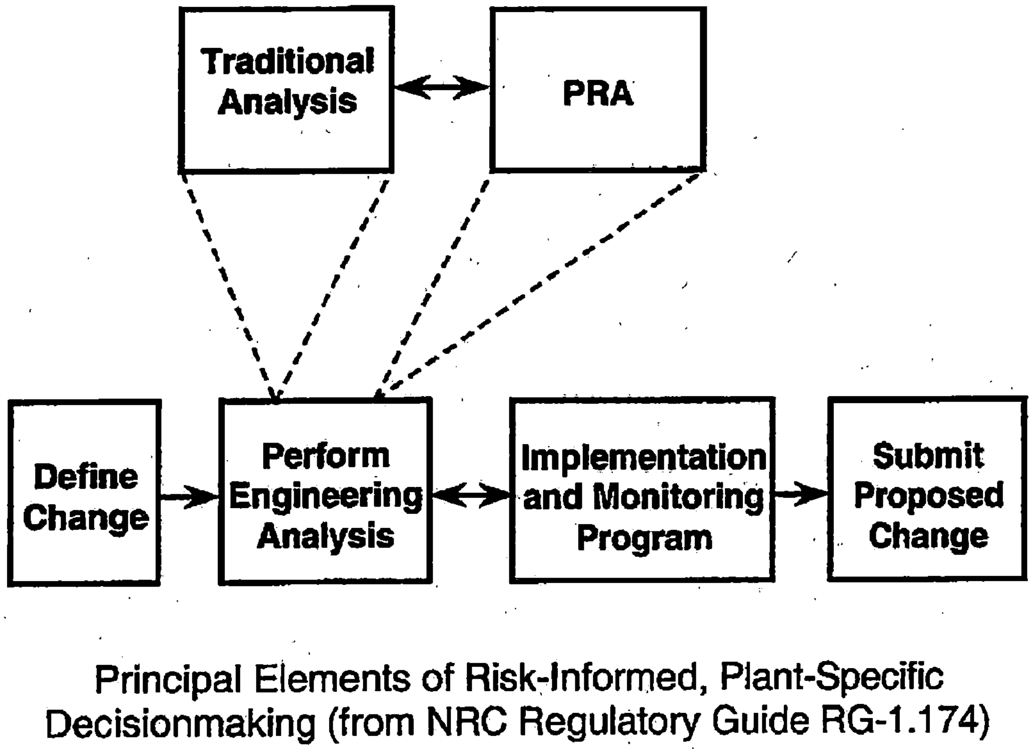

Figure 3-1: NRC Regulatory Guide 1.174 Basic Steps

Step 1: Define the proposed change

This element includes identifying:

1. Those aspects of the plant's licensing bases that may be affected by the change
2. All systems, structures, and components (SSCs), procedures, and activities that are covered by the change and consider the original reasons for inclusion of each program requirement
3. Any engineering studies, methods, codes, applicable plant-specific and industry data and operational experience, PRA findings, and research and analysis results relevant to the proposed change.

Step 2: Perform engineering analysis

This element includes performing the evaluation to show that the fundamental safety principles on which the plant design was based are not compromised (defense-in-depth attributes are maintained) and that sufficient safety margins are maintained. The engineering analysis includes both traditional deterministic analysis and probabilistic risk assessment. The evaluation of risk impact should also assess the expected change in CDF and LERF, including a treatment of uncertainties. The results from the traditional

analysis and the probabilistic risk assessment must be considered in an integrated manner when making a decision.

Step 3: Define implementation and monitoring program

This element's goal is to assess SSC performance under the proposed change by establishing performance monitoring strategies to confirm assumptions and analyses that were conducted to justify the change.

This is to ensure that no unexpected adverse safety degradation occurs because of the changes. Decisions concerning implementation of changes should be made in light of the uncertainty associated with the results of the evaluation. A monitoring program should have measurable parameters, objective criteria, and parameters that provide an early indication of problems before becoming a safety concern. In addition, the monitoring program should include a cause determination and corrective action plan.

Step 4: Submit proposed change

This element includes:

1. Carefully reviewing the proposed change in order to determine the appropriate form of the change request
2. Assuring that information required by the relevant regulation(s) in support of the request is developed
3. Preparing and submitting the request in accordance with relevant procedural requirements.

Five (5) fundamental safety principles are described which should be met for each application for a modification. These are shown in Figure 3-2 and are discussed below.

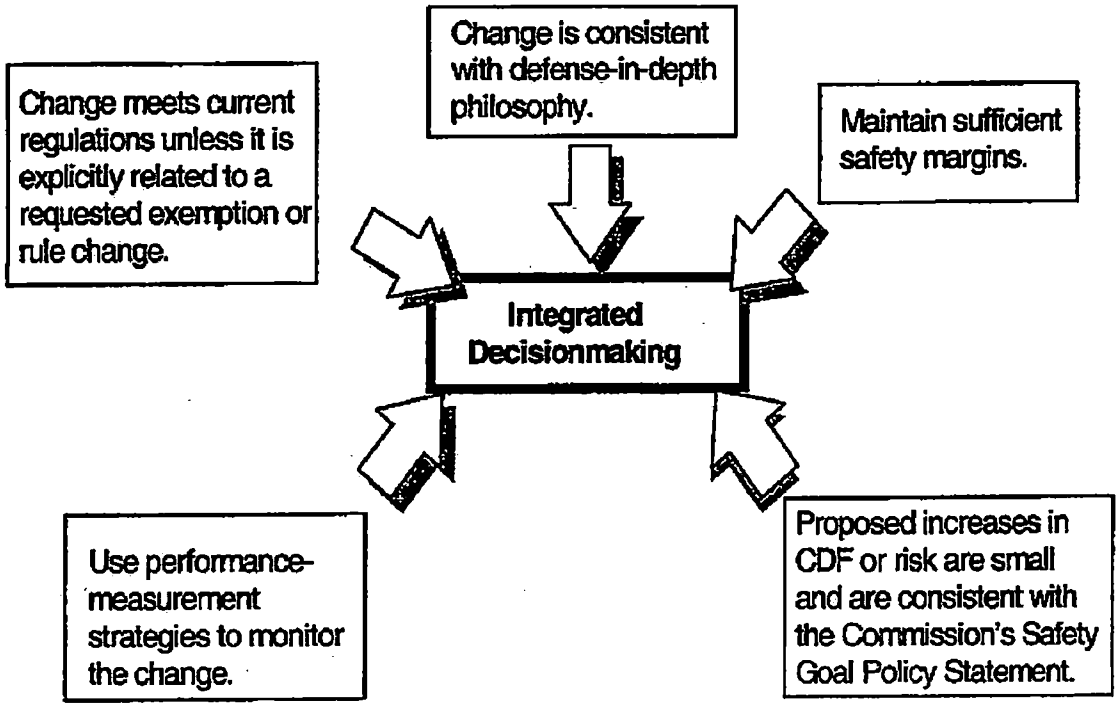

Figure 3-2: Principles of Risk-Informed Regulation [5]

Principle 1: Change meets current regulations unless it is explicitly related to a requested exemption or rule change

The proposed change is evaluated against the current regulations (including the general design criteria) to either identify where changes are proposed to the current regulations (e.g., technical specification, license conditions, and FSAR), or where additional information may be required to meet the current regulations.

Principle 2: Change is consistent with defense-in-depth philosophy

Defense-in-depth has traditionally been applied in reactor design and operation to provide a multiple means to accomplish safety functions and prevent the release of radioactive material. As defined in RG-1.174, defense-in-depth is maintained by assuring that:

- A reasonable balance among prevention of core damage, prevention of containment failure, and consequence mitigation is preserved
- Over-reliance on programmatic activities to compensate for weaknesses in plant design is avoided

- System redundancy, independence, and diversity are preserved commensurate with the expected frequency and consequences to the system (e.g., no risk outliers)
- Defenses against potential common cause failures are preserved and the potential for introduction of new common cause failure mechanisms is assessed.
- Independence of barriers is not degraded (the barriers are identified as the fuel cladding, reactor coolant pressure boundary, and containment structure)
- Defenses against human errors are preserved

Defense-in-depth philosophy is not expected to change unless:

- A significant increase in the existing challenges to the integrity of the barriers occurs
- The probability of failure of each barrier changes significantly,
- New or additional failure dependencies are introduced that increase the likelihood of failure compared to the existing conditions, or
- The overall redundancy and diversity in the barriers changes.

Principle 3: Maintain sufficient safety margins

Safety margins must also be maintained. As described in RG-1.174, sufficient safety margins are maintained by assuring that:

- Codes and standards, or alternatives proposed for use by the NRC, are met, and
- Safety analysis acceptance criteria in the licensing basis (e.g., FSARs, supporting analyses) are met, or proposed revisions provide sufficient margin to account for analysis and data uncertainty.

Principle 4: Proposed increases in CDF or risk are small and are consistent with the Commissions Safety Goal Policy Statement

To evaluate the proposed change with regard to a possible increase in risk, the risk assessment should be of sufficient quality to evaluate the change. The expected change in CDF and LERF are evaluated to address this principle. An assessment of the uncertainties associated with the evaluation is conducted. Additional qualitative assessments are also performed.

There are two acceptance guidelines, one for CDF and one for LERF, both of which should be used.

The guidelines for CDF are:

- If the application can be clearly shown to result in a decrease in CDF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to CDF.
- When the calculated increase in CDF is very small, which is taken as less than 10^{-6} per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF.

- When the calculated increase in CDF is in the range of 10^{-6} per reactor year to 10^{-5} per reactor year, applications will be considered only if it can be reasonably shown that the total CDF is less than 10^{-4} per reactor year.
- Applications which result in increases to CDF above 10^{-5} per reactor year would not normally be considered.

AND

The guidelines for LERF are:

- If the application can be clearly shown to result in a decrease in LERF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to LERF
- When the calculated increase in LERF is very small, which is taken as being less than 10^{-7} per reactor year, the change will be considered regardless of whether there is a calculation of the total LERF.
- When the calculated increase in LERF is in the range of 10^{-7} per reactor year to 10^{-6} per reactor year, applications will be considered only if it can be reasonably shown that the total LERF is less than 10^{-5} per reactor year.
- Applications which result in increases to LERF above 10^{-6} per reactor year would not normally be considered.

These guidelines are intended to provide assurance that proposed increases in CDF and LERF are small and are consistent with the intent of the Commission's Safety Goal Policy Statement.

Principle 5: The impact of the proposed change should be monitored using performance-measurement strategies to monitor the change

Performance-based implementation and monitoring strategies are also addressed as part of the key elements of the evaluation as described previously.

The following sections address the principle elements of the RG-1.174 process and the principles of risk-informed regulation to RCP motor flywheel examination frequency reduction.

3.2 FAILURE MODES AND EFFECTS ANALYSIS

A failure modes and effects analysis is used to identify the potential failure modes of a RCP motor flywheel and the effect that each failure mode would have on the plant SSCs in relation to overall plant safety.

Failure Modes

The primary failure mode of the RCP motor flywheel is growth of an undetected fabrication induced flaw in the keyway of the flywheel that emanates radially from that location to a point such that it reaches a critical flaw size during normal or accident conditions. Once the critical flaw size is reached during plant operation, the flywheel has the potential to catastrophically fail, resulting in flywheel fragments, which are essentially high energy missiles that could impact other SSCs important to plant safety. The growth of a flaw is primarily related to stresses generated from changes in the flywheel speed. The flywheel inspection process, which itself has the potential to introduce flywheel damage as discussed in [1], is not considered in the assessment. This is because the purpose of the assessment is to support interval extension, which will reduce unnecessary occurrences for introducing potential damage.

As discussed in [1], the normal operating speed of the RCP motor flywheel for Westinghouse RCPs is 1189 revolutions per minute (rpm), with a synchronous speed of 1200 rpm. It is designed for an overspeed of 1500 rpm, which is 125% of the synchronous speed. The flywheel speed can also vary as a result of plant events, including accidents such as a double ended guillotine break (DEGB) in the main reactor coolant loop piping.

Westinghouse designed flywheels are also used for Calvert Cliffs Units 1 and 2. These plants include Byron-Jackson designed pumps and motors and therefore have different normal flywheel operating speeds and different flywheel accident responses. The normal operating speed of the RCP motor flywheel for these RCPs is 900 rpm, with a design limiting speed of 1125 rpm. The maximum overspeed following a design basis LOCA is limited to 1368 rpm as stated in the Calvert Cliffs UFSAR.

When operating as a motor, the rotor of a polyphase induction machine rotates in the direction of, but slightly lower than, the rotating magnetic flux provided by the stator. This slight speed difference is typically expressed in percent and designated slip. If the shaft of the machine is driven above synchronous speed by a prime mover (with line voltage maintained on the stator) the rotor conductors rotate faster than the magnetic flux and the slip becomes negative. The rotor current and consequently the stator current reverse under the condition of negative slip and the machine operates as an induction, or asynchronous, generator. The RCP motor functions as an efficient torque producer under normal conditions. In the unlikely event that a hydraulic torque is applied to the motor shaft in the direction of increasing shaft speed (thus acting as a prime mover), the slip would become negative and, with the stator connected to the grid, the motor would function as a dynamic brake.

If the power supply to the motor is interrupted (zero voltage), the motor torque would be reduced to a negligible value, since torque is proportional to the supplied voltage.

However, a design feature of Westinghouse NSSS plants ensures that the electrical power supply to the RCP will be maintained for at least 30 seconds after a turbine trip following a LOCA. This design feature is also maintained following a loss of offsite power (LOOP); for the expected case of available off-site power, power to the RCP would continue through the LOCA transient. As a result, reverse torque is provided.

Westinghouse also performed several sensitivity studies to evaluate the effect of the break opening area on the RCP flywheel speed for typical Westinghouse NSSS plants. Specifically, break sizes equal to a DEGB of the main coolant piping, 60% of that DEGB, and a 3 ft^2 have been analyzed. A 3 ft^2 break size corresponds to a pipe of approximately 23 inches in inside diameter; the only RCS piping greater than this, is the main coolant loop piping. The first two breaks have blowdown times equal to or less than the RCP trip time; therefore, the applied voltage prevents overspeed. The latter break has an extended blowdown time, but the RCP flow at the time of RCP trip is reduced such that the speed decreases. Smaller breaks are not limiting even though the voltage is maintained for only 30 seconds. Results of these studies were discussed in [1].

To investigate the consequences of RCP overspeed, [2] analyzed a spectrum of LOCA events resulting in a range of flywheel transients. Results of that analysis indicated that the limiting event was the DEGB with an instantaneous loss of power, this led to a peak flywheel speed of 3321 rpm. It was also noted that the 3 ft^2 break area case showed a decrease in speed such that the normal operating speed is not exceeded.

Based on the WCAP-15666-A assessments, the following scenarios are associated with the primary mode of potential failure in the Westinghouse RCP motor flywheel that are related to operating speed and potential overspeed during various conditions:

- Failure during normal plant operation resulting in a plant trip (1200 rpm peak speed)
- Failure of the RCP motor flywheel associated with a plant transient or LOCA event with no loss of electrical power to the RCP (1200 rpm peak speed)
- Failure of the RCP motor flywheel associated with a plant transient or LOCA event (up to 3 ft^2 with an instantaneous loss of electrical power to the RCP (1200 rpm peak speed)
- Failure of the RCP motor flywheel associated with a DEGB coincident with an instantaneous loss of electrical power, such as LOOP (3321 rpm peak speed). This case bounds and is conservatively applied to all flywheel transients for LOCA break areas.

WCAP-15666-A [2] was limited in scope to RCPs with Westinghouse supplied pumps and flywheels. It is also the intent of this topical report to extend the applicability of the flywheel inspection extension to Calvert Cliffs Units 1 and 2 which contain Byron Jackson RCPs but use Westinghouse supplied flywheels. It is important to note that as a result of significant design differences between the Westinghouse and Calvert Cliffs units, the Calvert Cliffs RCP operational and transient conditions are different. Specifically, Calvert Cliffs pumps normally operate at 900 rpm with a design speed of

1125 rpm. Furthermore, the peak RCP post LOCA speed is limited to 1368 rpm. Therefore, the Calvert Cliffs Units 1 and 2 Pump/Flywheel Combinations analyses were based on the following:

- Failure during normal plant operation resulting in a plant trip (1125 rpm peak speed)
- Failure of the RCP motor flywheel associated with a plant transient or LOCA event with no loss of electrical power to the RCP (1125 rpm peak speed)
- Failure of the RCP motor flywheel associated with a plant transient or LOCA event (up to 3 ft^2) with an instantaneous loss of electrical power to the RCP (1125 rpm peak speed)
- Failure of the RCP motor flywheel associated with a DEGB coincident with an instantaneous loss of electrical power, such as, loss of offsite power (LOOP) (1368 rpm peak speed). As for the Westinghouse flywheel analysis, this case is conservatively assumed to bound all flywheel transients for LOCA break areas resulting from equivalent reactor coolant pipe breaks greater than a 3.0 ft^2 break and less than a double ended break.

Failure Effects

The failure of the RCP motor flywheel during normal plant operation would directly result in a reactor trip. However, the potential indirect or spatial effects associated with a postulated flywheel failure present a greater challenge in terms of failure effects or consequences. As discussed previously, the flywheel has the potential to catastrophically fail, resulting in flywheel fragments, which are essentially high energy missiles, which could impact other SSCs important to plant safety. Failure of these other SSCs could potentially impact the overall plant safety in terms of core damage (e.g., as a result of the loss of safety injection) or large, early release (as a result of potential impacts on containment structures or systems).

In order to address plant specific design differences on a generic basis, it is conservatively assumed that failure of the RCP motor flywheel results in core damage and a large early release, i.e., the flywheel failure frequency is equal to CDF and LERF.

Section 3.3 discusses the process for estimating the likelihood of the primary failure mode of the RCP motor flywheel. Section 3.4 then combines this failure probability estimation with the likelihood of various plant events and consequences to estimate the change in risk for extending the flywheel examination interval from 10 years to 20 years, for RCP/Flywheels in service up to 80 years.

3.3 FLYWHEEL FAILURE PROBABILITY

The quantitative risk assessment discussed below updates the risk assessment performed in WCAP-15666-A [2] and provides the justification for extending the 20-year flywheel inspection interval for 80 years of operation. Specifically, the risk analyses confirms that applying the inspection extension to flywheels in operation up to 80 years

has a negligible impact on risk (CDF and LERF), i.e., it is within the risk acceptance criteria of RG 1.174 [5]. The update of the WCAP-15666 analysis was necessary as it was discovered that the equation used to define the flywheel fracture toughness (K_{IC}) was incorrectly programmed in the probabilistic fracture mechanics (PFM) code RPFWPROF used to establish the probability of flywheel failure. This section provides a brief description of the code change and applies the revised code to demonstrate that the conclusions from WCAP-15666-A remain valid and that the 20 year flywheel inspection interval can be extended to 80 years of operation. A discussion of the change to the PFM model is discussed in Section 3.3.1

The risk assessments in this section apply to all Westinghouse RCP/flywheels, as well as the Calvert Cliffs Units 1 and 2 RCP/flywheels which contain a Byron Jackson [13] RCP with a Westinghouse flywheel.

To investigate the effect of flywheel inspections on the risk of failure, a structural reliability and risk assessment is performed for flywheels with up to 80 years of operation. Twelve (12) month operating (or fuel) cycles are conservatively assumed for the evaluation. This section discusses the methodology used and summarizes the results from this assessment.

As described in Section 3.2, the Westinghouse RCP has a normal operating speed of 1189 rpm, a synchronous speed of 1200 rpm, and an overspeed of 1500 rpm, considering LBB [2]. Therefore, a peak speed of 1500 rpm is conservatively used in the evaluation of RCP motor flywheel integrity to represent all conditions except a DEGB coincident with an instantaneous loss of electrical power. For this more limiting event, a peak speed of 3321 rpm is used.

The structural reliability evaluation for a Westinghouse RCP utilizes the work previously performed and summarized in [1], where the 1500 rpm overspeed speed had been assumed. In addition, this evaluation builds upon the initial analysis discussed in [2].

The structural reliability evaluation for the Calvert Cliffs RCP is based on plant-specific analyses and flywheel failure probabilities which are based on nominal and transient flywheel operation at 1125 rpm and a post design basis LOCA flywheel transient overspeed of 1368 rpm.

3.3.1 Method of Calculation Failure Probabilities

The method for calculating flywheel failure probabilities is based on the method in WCAP-15666-A [2]. While there are no changes to methodology, this evaluation corrects a significant error in the flywheel-specific PFM code, RPFWPROF, used for calculation of flywheel failure probability. The WCAP-15666-A version of RPFWPROF included an embedded error for the median value of K_{IC}. Specifically, the RPFWPROF intended to define the median value of K_{IC} as follows:

$$K_{IC} = 55.1 + 28.8 \exp(0.0214 (T-RT_{NDT}) \text{ for } T-RT_{NDT} > -50°F \text{ [15]}$$

However, due to an undetected programming error the K_{IC} parameter was included in RPFWPROF as:

$$K_{IC} = 55.1 + 28.8 \exp(0.214\ (T\text{-}RT_{NDT})) \text{ for } T\text{-}RT_{NDT} > -50\ ^\circ F$$

The implication was to increase the fracture toughness for $T\text{-}RT_{NDT} > 0\ ^\circ F$ and decrease the parameter for $T\text{-}RT_{NDT} < 0\ ^\circ F$. Re-evaluation of flywheel failure probability for various reactor scenarios indicated that the net effect was to predict lower failure probabilities for flywheels subjected to normal operation, design limiting transients and LOCAs smaller than 0.3 ft^2, and to increase failure probabilities the very low probability large LOCA scenarios (LOCAs > 0.3 ft^2) with loss of off-site power.

To ensure that the extent of condition was limited to this error, hand calculations and EXCEL based analyses were used to confirm predictions of RPFWPROF for representative sample cases.

The following discussion applies to the updated version of RPFWPROF.

The probability of failure of the RCP motor flywheel as a function of operating time t, Pr(t < t1), is calculated directly for each set of input values using Monte-Carlo simulation with importance sampling. The Monte-Carlo simulation does not force the calculated distribution of time to failure to be of a fixed type (e.g., Weibull, Log-normal or Extreme Value). The actual failure distribution is estimated based upon the distributions of the uncertainties in the key structural reliability model parameters and plant specific input parameters. Importance sampling, as described by Witt [7], is a variance reduction technique to greatly reduce the number of trials required for calculating small failure probabilities. In this technique, random values are selected from the more severe regions to increase the probability of an observable failure occurring. However, when a failure is calculated, the count is corrected to account for the lower probability of simultaneously obtaining all of the more severe random values.

The application of the probability of failure methodology is described based on the Westinghouse RPFWPROF program which is generally described in WCAP-14535A [1] and WCAP-15666-A [2].

The description of the key input parameters and associated data used in the RPFWPROF program is presented in Table 3-1 and Table 3-2. Table 3-1 includes the key parameters needed for failure probability calculation. Its usage in the program is specified as shown in the last column of Table 3-1 and schematically in the flow chart of Figure 3-3. "Initial" conditions do not change with time, "Steady-State" is not needed for RPFWPROF, "Transient" calculates fatigue crack growth and "Failure" checks to see if the accumulated crack length exceeds the critical length. In addition, parameter RPM-DLE is included in the model to address the impact of design limiting events (DLE).

Table 3-1: Variables for RCP Motor Flywheel Failure Probability Model			
No.	**Name**	**Description of Input Variable**	**Usage Type**
1	ORADIUS	Outer Flywheel Radius (inch)	Initial
2	IRADIUS	Inner Flywheel Radius (inch)	Initial
3	PFE-PSI	Probability of Flaw Existing (PFE) after Preservice ISI	Initial
4	ILENGTH	Initial Radial Flaw Length (inch)	Initial
5	CY1-ISI	Operating Cycle for First Inservice Inspection	Inspection
6	DCY-ISI	Operating Cycle between Inservice Inspections	Inspection
7	POD-ISI	Flaw Detection Probability per Inservice Inspection	Inspection
8	DFP-ISI	Fraction PFE Increases per Inservice Inspection	Inspection
9	NOTR/CY	Number of Transients per Operating Cycle	Transient
10	DRPM-TR	Speed Change per Transient (RPM)	Transient
11	RATE-FCG	Fatigue Crack Growth Rate (Inch/Transient)	Transient
12	KEXP-FCG	Fatigue Crack Growth Rate SIF Exponent	Transient
13	RPM-DLE	Speed for Design Limiting Event (RPM)	Failure
14	TEMP-F	Temperature for Design Limiting Event (F)	Failure
15	RT-NDT	Reference Nil Ductility Transition Temperature (F)	Failure
16	F-KIC	Crack Initiation Toughness Factor	Failure
17	DLENGTH	Flywheel Keyway Radial Length (Inch)	Failure

Variables 5 to 8 are available to calculate the effects of an ISI in the RPFWPROF program. The effect of ISI calculated using these equations, which are used in the SRRA model for the effect of ISI, are consistent with those described in the pc-PRAISE Code User's Manual [9]. The parameters needed to describe the selected ISI program are the time of the first inspection, the frequency of subsequent inspections (expressed as the number of fuel or operating cycles between inspections) and the probability of non-detection as a function of crack length. For the RCP motor flywheel, the non-detection probability, which is independent of crack length, is simply one minus a constant value of detection probability, variable 7 (POD-ISI) in Table 3-1. An increase in failure probability due to RCP inspection (chance of incorrect disassembly and reassembly) is included in the ISI model but conservatively not used (variable 8 set to zero) in this evaluation.

The median input values and their uncertainties for each of the parameters of Table 3-1 are shown in Table 3-2. The median is the value at 50% probability (half above and half below this value); it is also the mean (average) value for symmetric distributions, like the normal (bell-shaped curve) distribution.

Uncertainties are based upon expert engineering judgment and previous structural reliability modeling experience. For example, the fracture toughness for initiation as a function of the RT_{NDT} and the uncertainties on these parameters are based upon prior probabilistic fracture mechanics analyses of the reactor pressure vessel (RPV) [10]. Also note that the stress intensity factor calculation for crack growth and failure used the flywheel keyway radial length in addition to the calculated flaw length.

Table 3-2: Input Values for RCP Motor Flywheel Failure Probability Model				
No.	**Name**	**Median**	**Distribution**	**Uncertainty***
1	ORADIUS	Per Flywheel Group	Constant	-----
2	IRADIUS	Per Flywheel Group	Constant	-----
3	PFE-PSI	1.000E-01	Constant	-----
4	ILENGTH	1.000E-01	Log-Normal	2.153E+00
5	CY1-ISI	3.000E+00	Constant	-----
6	DCY-ISI	4.000E+00	Constant	-----
7	POD-ISI	5.000E-01	Constant	-----
8	DFP-ISI	0.000E+00	Constant	-----
9	NOTR-CY	1.000E+02	Normal	1.000E+01
10	DRPM-TR	1.200E+03 (W) 9.00E+02 (CCNPP)	Normal	1.200E+02 (W) 9.00E+01 (CCNPP)
11	RATE-FCG	9.950E-11	Log-Normal	1.414E+00
12	KEXP-FCG	3.070E+00	Constant	-----
13	RPM-DLE**	1.50E+3, 3.321E+3 (W) 1.125E+3, 1.368E+3 (CCNPP)	Normal	1.50E+2, 3.321E+2 (W) 1.125E+2, 1.368E+2 (CCNPP)
14	TEMP-F***	9.500E+01 (W) 7.0E+01 (CCNPP)	Normal	1.250E+01
15	RT-NDT	3.000E+01	Normal	1.700E+01
16	F-KIC	1.000E+00	Normal	1.000E-01
17	DLENGTH	Per Flywheel Group	Constant	-----

* The uncertainty is a normal standard deviation, the range (median to maximum) for uniform distributions or the corresponding factor for logarithmic distributions.

** RPM-DLE is modified in each case to allow for risk analysis of various plant conditions and their associated flywheel speeds for both Westinghouse (W) Plants and Calvert Cliffs (CCNPP) Units 1 and 2. The values used for this variable are discussed in Section 3.3 and results of analyses are summarized in Table 3-3.

DLE-RPM Values used for RPFWPROF Analyses		
Plant Design	Transient Speeds (Also used to bounds Normal Operation) (RPM)	Maximum Flywheel Rotational Speed: Large LOCA (RPM)
Westinghouse Plants	1500	3321
Calvert Cliffs	1125	1368

Group specific input variables used in the probability of failure calculations are summarized below:

Flywheel Group	ORadius (inch)	IRadius (inch)	DLength (inch)
Group1	38.25	4.6875	0.937
Group 2	37.875	4.1875	0.906
Calvert Cliffs	41.00	4.719	0.937

Evaluations were performed to determine the effect on the probability of flywheel failure for continuing the previously approved current inservice inspections in accordance with Reference [2] over the life of the plant through 80 years of operation and for discontinuing the inspections. The evaluation also calculated the effects of the inspections being discontinued after ten years. This calculation bounds the effects of any subsequent inservice inspections at 10- to 20-year intervals.

The probability of failure determined by these evaluations is a conservatively calculated parameter because the evaluation conservatively assumes that the probability of a flaw existing after the preservice inspection is 10%, and that the ISI flaw detection probability is only 50%. In reality, most preservice inspection and ISI flaws would be detected, especially for the larger flaw depths which could result in failure. Therefore, the calculated values are very conservative. (The effects of some important parameters on the calculated probability of failure are discussed later in this section). The most important result of the evaluation is the change in calculated probability of failure from continuing versus discontinuing the ISI after 10 years of plant life.

As shown in Figure 3-4, Figure 3-5 and Figure 3-6 and Table 3-3, the ISI provides a negligible benefit for minimizing the potential of failure of the flywheel. The results of this assessment are summarized as follows for a plant life of 40, 60, and 80 years. Note that results presented in Table 3-3 supersedes equivalent information presented in Reference [2].

Table 3-3: Cumulative Probability of Failure over 40, 60 and 80 Years with and without Inservice Inspection

Flywheel Group	Design Limiting Speed (rpm)	Cumulative Probability of Flywheel Failure with ISI at 4-Year Intervals	Cumulative Probability of Flywheel Failure with ISI at 4-Year Intervals Prior to 10 Years and without ISI after 10 Years			% Increase in Cumulative Failure Probability for Eliminating Inspections		
		Over 80 Years	Over 40 Years	Over 60 Years	Over 80 Years	Over 40 Years	Over 60 Years	Over 80 Years
1	1500	1.99E-08	2.00E-08	2.01E-08	2.02E-08	0.95%	1.16%	1.75%
1	3321	5.88E-02	5.88E-02	5.88E-02	5.88E-02	<0.01%	<0.01%	<0.01%
2	1500	1.26E-08	1.26E-08	1.36E-08	1.37E-08	0.51%	8.35%	9.19%
2	3321	1.66E-02	1.66E-02	1.66E-02	1.66E-02	<0.01%	<0.01%	<0.01%
CCNPP	1125	1.14E-10	1.14E-10	1.14E-10	1.14E-10	0.09%	0.09%	0.09%
CCNPP	1368	1.61E-07	1.62E-07	1.63E-07	1.63E-07	0.47%	1.13%	1.28%

As can be seen in Table 3-3, continuing inspection after 10 years has a very minimal impact on the failure probabilities.

Note that for the Westinghouse Group 1 and 2 flywheels subject to Large LOCAs with a consequential LOOP (limiting speed of 3321 rpm), the flywheel failure probability is primarily dependent on the assumed existence of a large unidentified flaw, conservatively selected flywheel properties and operating conditions and the high post-accident flywheel rotational speed. Thus, the probabilistic models predict the same number of failures from the first through the 80th year of operation.

The post LOCA limiting speed of Calvert Cliffs Units 1 and 2 of 1368 RPM resulted in significantly reduced flywheel failure probabilities, when compared with the Westinghouse RCPs.

3.3.2 Sensitivity Study

A sensitivity study was performed to determine the effect of select flywheel risk assessment parameters on the probability of failure, as done in [2]. Consistent with [2], sensitivity studies were performed on a Westinghouse Group 10 flywheel, as this flywheel is representative of average Westinghouse and Byron Jackson flywheel dimensions and configuration. The intent of the sensitivity studies was to illustrate the impact of relatively significant changes to model input parameters on probability of failure predictions. The specific parameters evaluated in this sensitivity study were the probability of detection and the initial flaw length. The results of this study are summarized in the Table 3-4 and sections 3.3.2.1 and 3.3.2.2.

Table 3-4: Effect of Flywheel Risk Parameter on Failure Probability (Flywheel Group 10)

Description of Flywheel Risk Parameter Varied	Probability of Flywheel Failure after 40 years with ISI	Probability of Flywheel Failure after 40 years without ISI
Base Case (Group 10 of [1])	7.3636E-09	7.3709E-09
Probability of Detection of 10%	7.3684E-09	7.3709E-09
Probability of Detection of 80%	7.3625E-09	7.3709E-09
Initial flaw length of 0.05 inches	2.0487E-09	2.0490E-09
Initial flaw length of 0.20 inches	1.0260E-07	1.0314E-07

The values for the base case were for:

- 10% probability of a flaw existing after preservice inspection
- an initial flaw length of 0.10 inch (1.006 inch with keyway)

- an initial ISI at 3 years of plant life, and subsequent inspections at 4-year intervals
- probability of detection of 50% per ISI (see [1], Table 5-5, flywheel Group 10)

A discussion of the results of the sensitivity studies are summarized below.

3.3.2.1 Sensitivity to Change in Flaw Detection Probability

The flaw detection probability was varied from the base case 50% to 10% and 80%. The failure probability increased less than 0.1% for a decrease in flaw detection probability from 50% to 10%. A similarly small increase in failure probability was noted for an increase in flaw detection probability from 50% to 80%. Therefore, the flaw detection probability, which is a measure of how well the inspections are performed, has essentially no effect on the flywheel failure probability.

3.3.2.2 Sensitivity to Initial Flaw Length

The initial flaw length was varied from the base case value of 0.10 inch to 0.05 inch, and 0.20 inch. The failure probability decreased by more than a factor or 3 for a decrease in initial flaw length from 0.10 inch to 0.05 inch, and the failure probability increased an order of magnitude for an increase in initial flaw length from 0.10 inch to 0.20 inch. Therefore, the initial flaw length does affect the flywheel failure probability, but the failure probability remained small, even for larger initial flaw lengths. Moreover, it is expected that the probability of the larger flaw being missed during preservice inspection is smaller than the assumed 10% based on reviews of pre-service inspection records in [2].

3.3.3 Failure Probability Assessment Conclusions

An evaluation of flywheel structural reliability was performed for each of the flywheel groups selected for evaluation following the process outlined in WCAP-15666-A. Using conservative input values for; preservice flaw existence, initial flaw length, inservice flaw detection capability and RCP start/stop transients, it was shown that flywheel inspections beyond ten years of plant life have no significant benefit relative to the probability of flywheel failure. The reasons are that most flaws that could lead to failure would be detected during the preservice inspection or early in the plant life, and the crack growth is negligible over the plant life. It should be noted that the effect on potential flywheel failure from damage through disassembly and reassembly for inspection has not been evaluated. This is because the purpose of the assessment is to support an inspection interval extension, which will reduce unnecessary occurrences for introducing potential damage.

Sensitivity studies showed that improved flaw detection capability and more inspections result in a small relative change in the calculated failure probability. The failure probability is most affected by the initial flaw length and its uncertainty. These parameters are determined by the accuracy of the preservice inspection. The uncertainty could be reduced using the results from the first inservice inspection, but would probably not change much during subsequent inspections.

The failure probability estimates identified in [2] show that inspections after 10 years have a very minimal impact on the failure probabilities. These results bound the effects of any subsequent ISI at 10 to 20 year intervals. No credit has been taken for other indications of potential degradation such as pump vibration monitoring and pump maintenance.

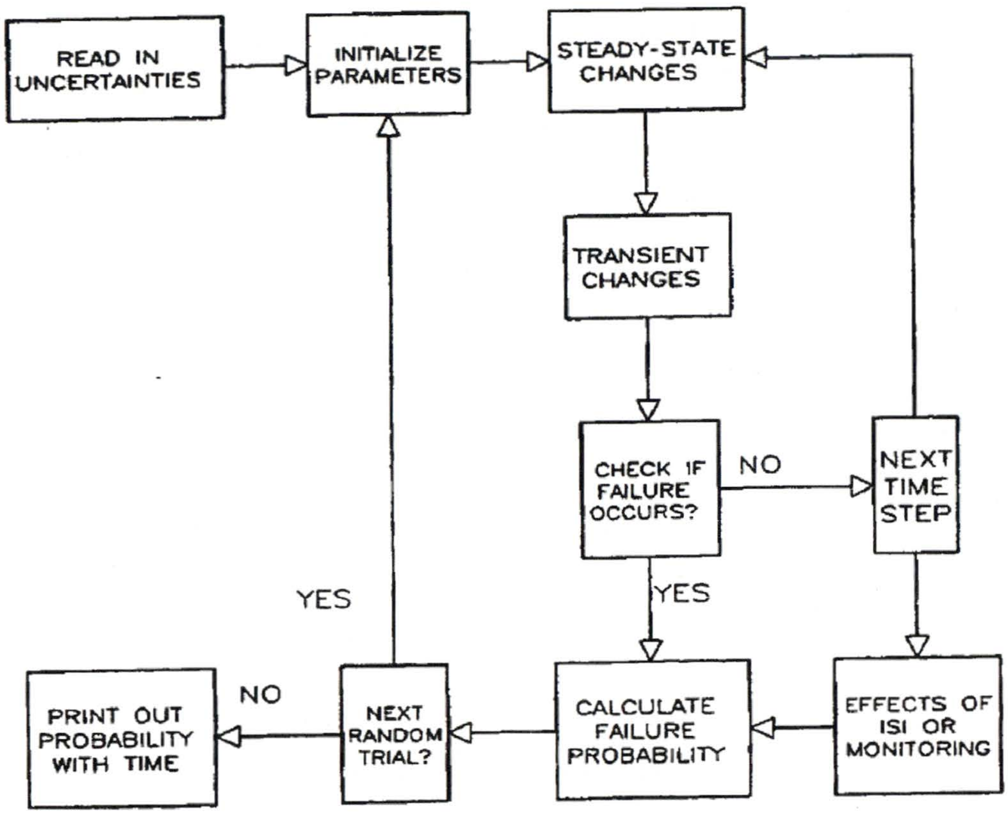

Figure 3-3: Westinghouse PROF Program Flow Chart for Calculating Failure Probability

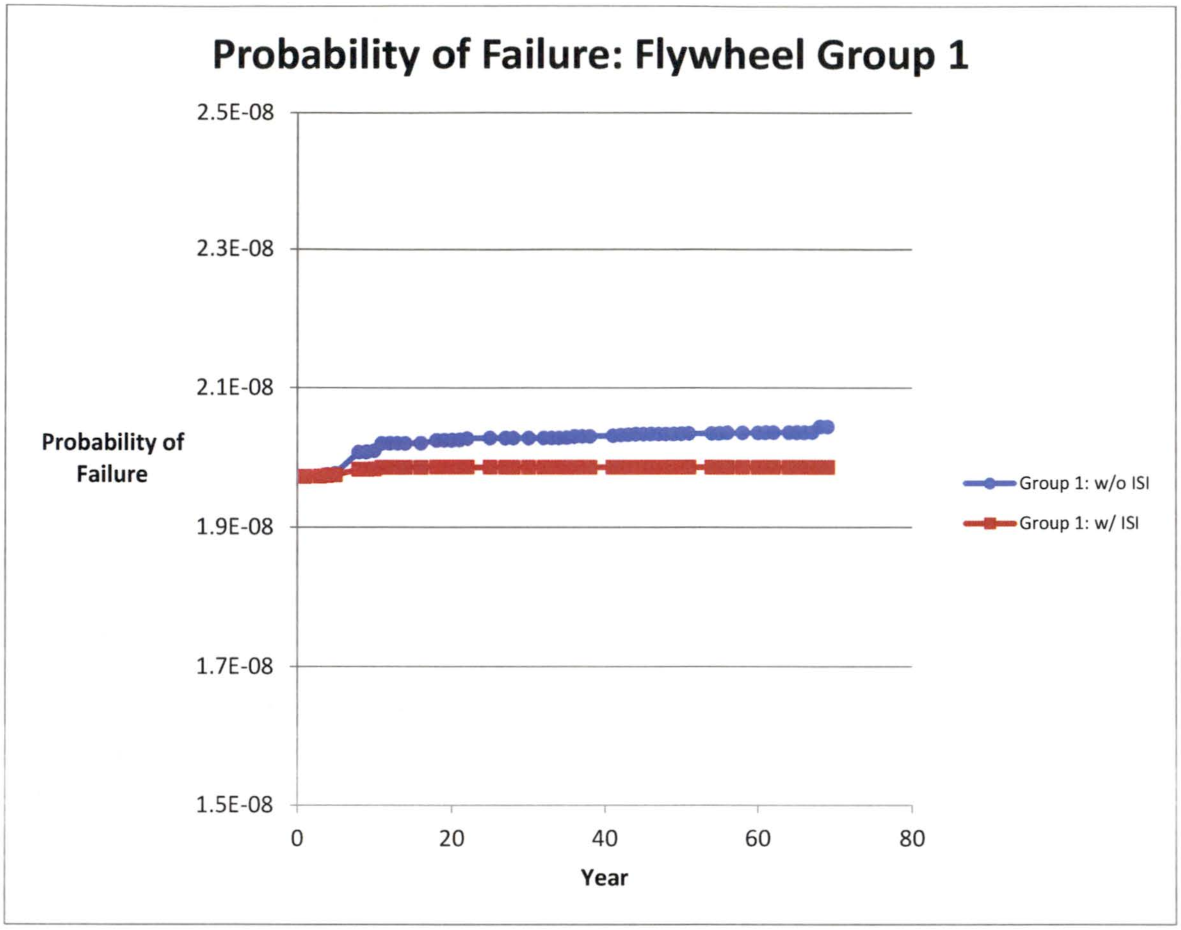

Figure 3-4: Probability of Failure for Flywheel Evaluation Group 1

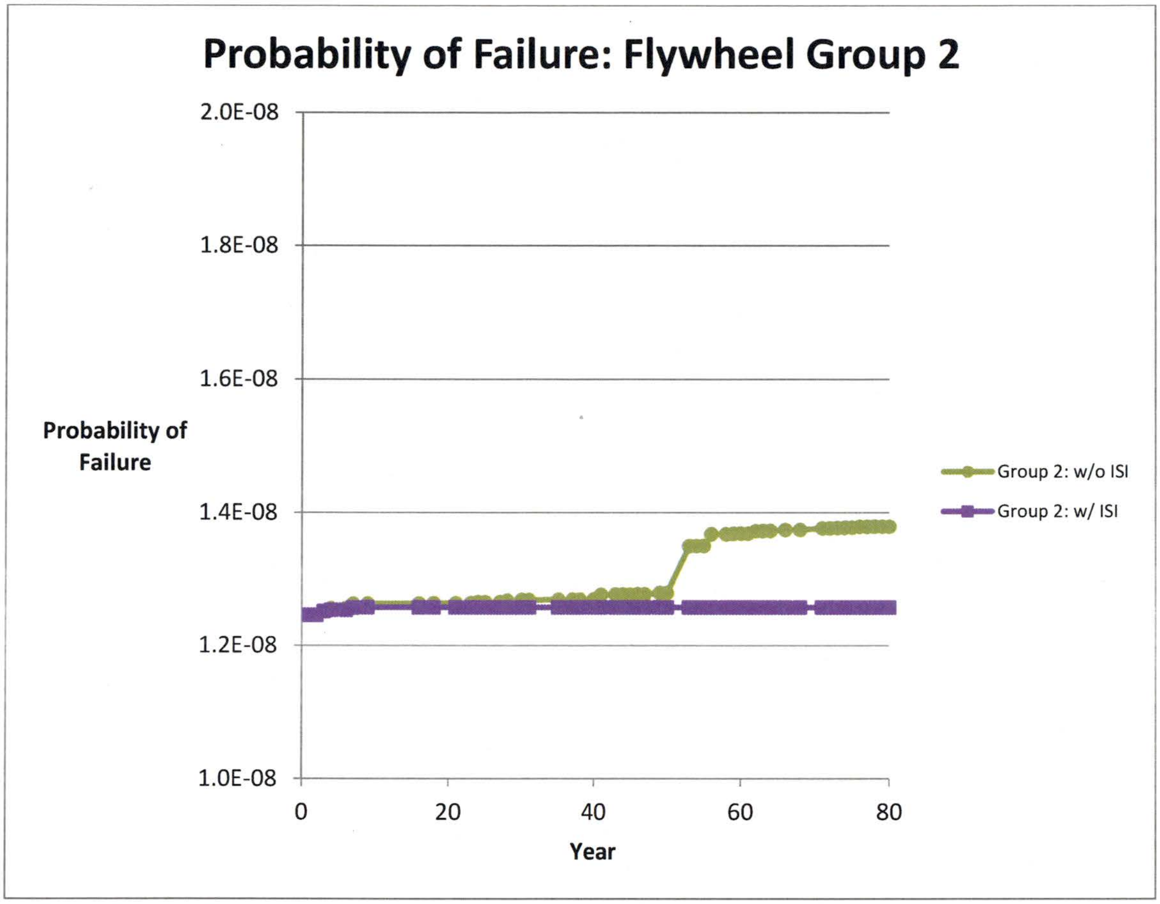

Figure 3-5: Probability of Failure for Flywheel Evaluation Group 2

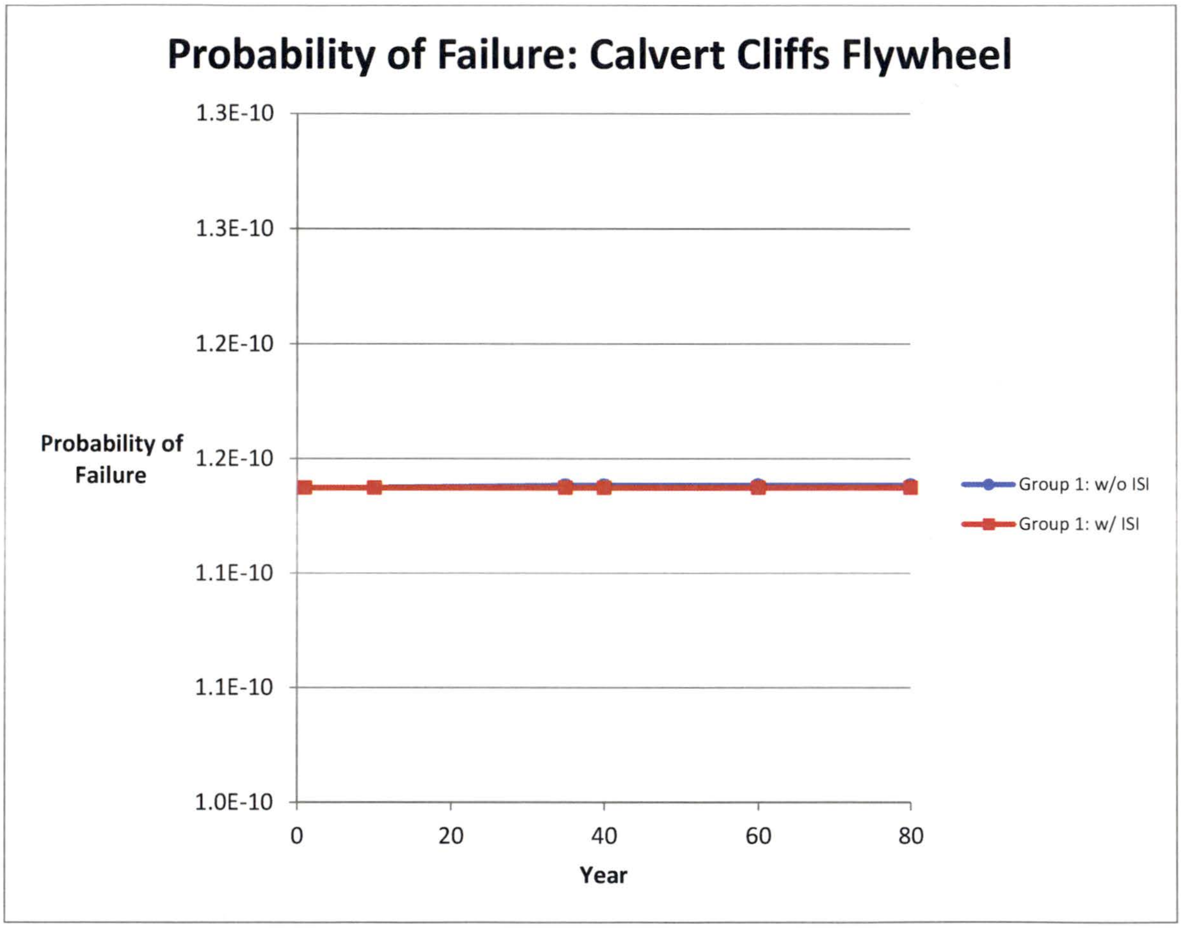

Figure 3-6: Probability of Failure for Calvert Cliffs Units 1 and 2

3.4 CORE DAMAGE EVALUATION

The objective of the risk assessment is to evaluate the core damage risk from the extension of the examination of the RCP motor flywheel, over an extended 80 year in-service duration, relative to other plant risk contributors through a qualitative and quantitative evaluation.

RG 1.174, Revision 2 [5] provides the basis for this evaluation and also provides the acceptance guidelines to make a change to the current licensing basis.

Risk is defined as the combination of likelihood of an event and severity of consequences of an event. Therefore, the following two questions are addressed:

- What is the likelihood of the event?
- What are the consequences?

The following sections discuss the likelihood and postulated consequences. The likelihood and consequences are then combined in the risk calculation and the results of the evaluation are presented.

Several different scenarios have been identified for potential RCP motor flywheel failures that are related to its operating speed and potential overspeed under certain conditions. These scenarios are summarized in Table 3-5.

Table 3-5: Summary of Flywheel Analysis Parameters

	Westinghouse RCP/Flywheel (rpm)	**Calvert Cliffs RCP/Flywheel (rpm)**
Failure during normal plant operation resulting in a plant trip	1500*	1125*
Failure of the RCP motor flywheel associated with a plant transient or LOCA event with NO loss of electrical power to the RCP	1500*	1125*
Failure of the RCP motor flywheel associated with a plant transient or LOCA event (up to a three square foot break in the main loop) with loss of electrical power to the RCP	1500*	1125*
Failure of the RCP motor flywheel associated with a large LOCA (from a greater than 3 ft2 break up to the DEGB of the RC loop piping) coincident with an instantaneous electrical power loss (e.g., loss of offsite power (LOOP) or loss of electrical power to the RCP) and therefore no electrical braking to the RCP	3321	1368

* Overspeed flywheel RPM for normal/accident conditions.

3.4.1 What is the Likelihood of the Event

The likelihood is addressed by identifying a plant transient or LOCA event combined with the postulated failure of the flywheel and estimating the probability/frequency of these events. The likelihood of the flywheel failure is discussed in Section 3.3 and the results are provided in Table 3-3 for the two flywheel evaluation groups that bound the other flywheel groups and for the Calvert Cliffs Units 1 and 2 flywheels. The estimated failure probabilities for the different conditions for the various flywheel types and event combinations are shown in Table 3-6.

Table 3-6: Estimated RCP Motor Flywheel Failure Probabilities

Flywheel Group and Conditions*	**Cumulative Probabilities of Flywheel Failure over 60 Years***		**Cumulative Probabilities of Flywheel Failure over 80 Years***	
	With ISI at 4-Year Intervals	**With ISI at 4-Year Intervals Prior to 10 Years and without ISI after 10 Years**	**With ISI at 4-Year Intervals**	**With ISI at 4-Year Intervals Prior to 10 Years, and without ISI after 10 Years**
Group 1 – Normal/Accident*	1.99E-08	2.01E-08	1.99E-08	2.02E-08
Group 1 – LOCA/LOOP*	5.88E-02	5.88E-02	5.88E-02	5.88E-02***
Group 2 – Normal/Accident*	1.26E-08	1.36E-08	1.26E-08	1.37E-08
Group 2 – LOCA/LOOP*	1.66E-02	1.66E-02	1.66E-02	1.66E-02
Calvert Cliffs Units 1&2 – Normal/Accident**	1.14E-10	1.14E-10	1.14E-10	1.14E-10
Calvert Cliffs Units 1&2-LOCA/LOOP**	1.61E-07	1.63E-07	1.61E-07	1.63E-07

* For the failure probability calculations the mean flywheel speed for normal/accident conditions is 1500 rpm; for LOCA/LOOP is it 3321 rpm.

** For the failure probability calculations the mean flywheel speed for normal/accident conditions is 1125 rpm; for LOCA/LOOP is it 1368 rpm.

*** Selected as bounding value

3.4.2 What are the Consequences?

The consequence evaluation is performed to identify the potential consequences from the failure of the RCP motor flywheel from an integrity standpoint. The consequences are briefly discussed in Section 3.2.

The consequence evaluation includes both direct effects and indirect effects of a flywheel failure. Direct effects are those effects associated directly with the component being evaluated, such as loss of process fluid flow. Indirect effects are those effects on surrounding equipment that may be impacted by mechanisms such as jet impingement, pipe whip, missiles, and flooding.

The direct consequences are defined as failure of the RCP motor flywheel resulting in a failure of the RCP. If a failure of the RCP occurs, a reactor trip would result.

The potential indirect or spatial effects associated with the postulated flywheel failure are associated with the potential missiles generated from the fragmented portions of the flywheel associated with a significant flywheel crack.

For this evaluation, the conditional core damage probability associated with the failure of the flywheel will be assumed to be 1.0 (no credit for safety system actuation to mitigate the consequences of the failure).

3.4.3 Risk Calculation

This methodology is described in detail in WCAP-14572, Revision 1-NP-A, Supplement 1 [8]. For failures that cause only an initiating event, the portion of the PRA model that is impacted is the initiating event and its frequency. The core damage frequency from the failure is calculated by:

$$CDF = IE * CCDP_{IE}$$

Where:

CDF = Core Damage Frequency from a failure (events per year)

$CCDP_{IE}$ = Conditional Core Damage Probability for the Initiator

IE = Initiating Event Frequency (in events per year)

The initiating event frequency (in events per year) is obtained differently for the different conditions. For the normal operating mode, the initiating event frequency is determined from the RCP motor flywheel failure probability model as described in Section 3.3. Because the model generates a probability, the probability must be transformed into a failure rate. The cumulative probability at a given time is divided by the number of years to end of operating license. In other words,

$$IE = FP/EOL$$

where:

FP = Failure probability from failure probability model (dimensionless)

EOL = Number of years used in the failure probability model (80 years used to cover an extended plant life). Between 40 and 80 years, the failure probability is relatively constant.

For the RCP motor flywheel failure following an overspeed event, the core damage frequency of associated with that event (initiating event with flywheel failure) is defined as:

$$CDF = (IE * CFP) * CCDP$$

where:

CDF = Core Damage Frequency from a failure (events per year)

CCDP = Conditional Core Damage Probability for the initiator and flywheel failure

IE = Initiating Event frequency (in events per year)

CFP = Conditional Failure Probability of the flywheel by initiating event

The frequencies of the initiating events for the different conditions were identified as follows:

The initiating event frequency for a plant trip or non-LOCA transient is estimated as 1 event/year (plants on average experience 1 plant trip per year).

The probability of a loss of offsite power or loss of power to the RCP following a plant trip was conservatively established from NUREG/CR-6890 [13] as 0.01. This value was based on the observation that the conditional LOOP probability had increased from 0.003 in the 1986-1996 time frame to 0.0053 based on 1997 to 2004 data. Furthermore, the authors noted that the conditional probability in the summer months increase to 0.0091. The LOOP conditional on a LOCA event was estimated from Table 4.2 of NUREG/CR-6538 [12] as 1.4E-02 for PWR plants. LOCAs < 3 ft^2 and other plant transient events were conservatively combined, and the probability of a plant transient, concurrent with a LOOP, was conservatively represented by 0.014 and was used.

The frequency of a large break LOCA events with break areas in excess of 3 ft^2 (~23 inches in diameter) was estimated from NUREG-1829 [11]. Mean failure rates of piping are presented in Table 7.19 of that reference. Using 25 and 40 year failure rates, failure rates provided in that table were linearly extrapolated to 60 years and 80 years and then interpolated to obtain a mean frequency of exceeding 3.0 ft^2 , Using this process the LOCA exceedance frequency for break areas > 3 ft^2 was estimated to be approximately 3.8E-07 per year. For this analysis, the LOCA IE was assigned a bounding value of 1E-06 per year.

Table 3-7, Table 3-8, and Table 3-9 show the calculations that were used to estimate the frequency of the initiating event combined with the probability of the RCP motor flywheel failure. These calculations are also estimates of the core damage frequency given that the assumption of the CCDP is set to 1.0 (no credit taken for any safety systems).

The resulting calculations show that the change in CDF for flywheel Evaluation Group 1 is 3.57E-10/year/RCP, the change in the CDF for flywheel Evaluation Group 2 is 1.19E-09/year/RCP and the change in the CDF for the Calvert Cliffs flywheel is

1.05E-13/year/RCP as shown in Table 3-7, Table 3-8, and Table 3-9. The RG-1.174 criteria for an acceptable change in risk for CDF are 1E-06/year and for LERF is 1E07/year. These calculations show the change in risk from extending the inspection interval for the RCP motor flywheel is significantly below the acceptance criteria.

Table 3-7: Westinghouse RCP Motor Flywheel Evaluation Group 1

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@80 years)		Event with RCP Motor Flywheel Failure (and Core Damage Frequency, CCDP = 1.0) (per year)	
	(per year)	With ISI after 10 Years	Without ISI after 10 Years	With IS After 10 Years	Without ISI after 10 Years
1. Normal Operating Condition	N/A	1.99E-08	2.02E-08	2.48E-10	2.53E-10
2. Failure of the RCP motor flywheel associated with a plant with NO loss of electrical power to the RCP at 1500 RPM.	1	1.99E-08	2.02E-08	1.99E-08	2.02E-08
3. Failure of the RCP motor flywheel associated with a plant transient (including LOCA event (up to a 3 ft^2 break in the RCS loop piping)) with loss of electrical power to the RCP (1200 rpm peak speed)** 1.0 x (1.4E-02)	1.40E-02	1.99E-08	2.02E-08	2.78E-10	2.83E-10
4. Failure of the RCP motor flywheel associated with a large LOCA (from a greater than 3 ft' break up to a DEGB of the RCS loop piping) coincident with an instantaneous power loss (e.g., loss of offsite power (LOOP) or loss of electrical power to the RCP) and therefore no electrical braking effects (3321 rpm peak speed)	1.40E-08	5.88E-02	5.88E-02	8.23E-10	8.23E-10
Totals				2.12E-08	2.16E-08
Change in CDF for one Flywheel (per RCP risk)					3.57E-10
Change in CDF for 4 RCPs (4 Flywheels)					1.43E-09

** 1500 rpm is used for the failure probability calculations.

Table 3-8: Westinghouse RCP Motor Flywheel Evaluation Group 2

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@80 years)		Event with RCP Motor Flywheel Failure (and Core Damage Frequency, CCDP = 1.0) (per year)	
	(per year)	With ISI after 10 Years	Without ISI after 10 Years	With IS After 10 Years	Without ISI after 10 Years
1. Normal Operating Condition	N/A	1.26E-08	1.37E-08	1.57E-10	1.72E-10
2. Failure of the RCP motor flywheel associated with a plant with NO loss of electrical power to the RCP at 1500 RPM.	1	1.26E-08	1.37E-08	1.26E-08	1.37E-08
3. Failure of the RCP motor flywheel associated with a plant transient (including LOCA event (up to a 3 ft^2 break in the RCS loop piping)) with loss of electrical power to the RCP (1200 rpm peak speed)** 1.0 x (1.4E-02)	7.52E-09	1.26E-08	1.37E-08	1.76E-10	1.92E-10
4. Failure of the RCP motor flywheel associated with a large LOCA (from a greater than 3 ft^2 break up to a DEGB of the RCS loop piping) coincident with an instantaneous power loss (e.g., loss of offsite power (LOOP) or loss of electrical power to the RCP) and therefore no electrical braking effects (3321 rpm peak speed)	1.66E-02	1.66E-02	1.66E-02	2.32E-10	2.32E-10
Totals				1.31E-08	1.43E-08
Change in CDF for one Flywheel (per RCP risk)					1.19E-09
Change in CDF for 4 RCPs (4 Flywheels)					4.75E-09

** 1500 rpm is used for the failure probability calculations.

Table 3-9: Calvert Cliffs Units 1 and 2 RCP Motor Flywheel Evaluation

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@80 years)		Event with RCP Motor Flywheel Failure (and Core Damage Frequency, CCDP = 1.0) (per year)	
	(per year)	With ISI after 10 Years	Without ISI after 10 Years	With IS After 10 Years	Without ISI after 10 Years
1. Normal Operating Condition	N/A	1.14E-10	1.14E-10	1.42E-12	1.42E-12
2. Failure of the RCP motor flywheel associated with a plant with NO loss of electrical power to the RCP 1200 RPM.	1	1.14E-10	1.14E-10	1.14E-10	1.14E-10
3. Failure of the RCP motor flywheel associated with a plant transient (including LOCA event (up to a 3 ft^2 break in the RCS loop piping)) with loss of electrical power to the RCP (900 rpm peak speed)** 1.0 x (1.4E-02)	1.40E-02	1.14E-10	1.14E-10	1.59E-12	1.59E-12
4. Failure of the RCP motor flywheel associated with a large LOCA (from a greater than 3 ft' break up to a DEGB of the RCS loop piping) coincident with an instantaneous power loss (e.g., loss of offsite power (LOOP) or loss of electrical power to the RCP) and therefore no electrical braking effects (1368 rpm peak speed)	1.40E-08	1.61E-07	1.63E-07	2.25E-15	2.28E-15
Totals				1.17E-10	1.17E-10
Change in CDF for one Flywheel (per RCP risk)					1.05E-13
Change in CDF for 4 RCPs (4 Flywheels)					4.19E-13

3.5 CONSIDERATION OF UNCERTAINTY

This section provides a discussion of uncertainties associated with the core damage risk assessment. The discussion follows the general guidance of NUREG-1855 [14] in that the potential key model assumptions and uncertainties are identified and their impact is evaluated with respect to the current application.

The baseline risk assessment discussed in Section 3.4 includes several significant conservatisms which are intended to bias the results of the analysis in a conservative direction. Specifically, these assumptions include:

1. All flywheel failure events result in both core damage and a large early release. This tacitly assumes that the missiles generated by the flywheel will result in both an unrecoverable LOCA and a loss in containment integrity sufficient to support a large release of radionuclides. This is a highly unlikely sequence as events resulting from a reactor trip would have control rods inserted prior to the failure and the potential for flywheel fragments to render all safety injection flow paths unavailable is unlikely. Furthermore, there is virtually no likelihood that flywheel fragments could significantly impact the ability of the containment to perform its function or prevent containment isolation.
2. The flywheel failure probability is based on a bounding selection of rotational flywheel speeds. This assumption is intended to simplify the event grouping while upwardly biasing the flywheel failure probabilities. The flywheel failure probability model used to assess the failure probability has been developed as a realistic model. Details of that model are provided in [2] and a sensitivity study to typical input assumptions is provided in Section 3.2.
3. Non-LOCA plant events that could result in a LOOP were assigned a LOOP probability of 0.014. This value is representative of the conditional LOCA/LOOP failure probability and as previously discussed overstates the LOOP potential for the more likely events.
4. The failure probabilities of flywheels are based on the cumulative failure probability over the lifetime of the flywheel. This is conservative because the failure rates are observed to stabilize during the later years of operation.
5. Probability of failure calculations assume crack growth is based on 100 flywheel start and stop cycles per year. This results in 8000 cycles for 80 years of operation. It is estimated that 6000 cycles will bound the lifetime operation of the flywheel, even when it is extended to 80 years of operation.

While these assumptions are intended to provide a bounding estimate of risk, uncertainty associated with other parameters may be of interest in understanding the potential risks of the risk evaluation. As discussed in Section 3.4, the risk of the inspection interval extension to 80 years has three elements: the frequency of the initiating event, the probability of flywheel failure associated with an event, and the conditional probability of core damage associated with the failure. Sensitivity studies were performed to investigate the potential impact in changes to the risk assessment

modeling assumptions. The results of these studies are included in Table 3-10. The uncertainty associated with each of these factors is discussed below.

3.5.1 Initiating Event Frequency

As discussed in Table 3-7 through Table 3-9 the flywheel failure risks are assigned to four bins: normal operation, plant transient events without a loss of off-site power, plant transient events (non-large LOCA) with a loss of off-site power and large LOCA events with a loss of offsite power. Normal operational events (for example RCP start-ups and shutdowns) are based on the flywheel operating life and a bounding number of start-up and shutdown cycles. This is a low contributor to flywheel failure risks. Transient events are assumed to result in acceleration of the flywheel to design speeds. The risk assessment assumed that the plant will experience one transient event per year. A review of plant operation in the United States between 1988 and 2015 demonstrates that overall plant operation has improved and more typical plant failure probabilities are less than 0.80 per year[1] . The impact of the reduction in the plant trip frequency results in a 3.57E-10 per year per Group 1 RCP reduction in CDF from the baseline value shown in Table 3-10. The conditional LOOP probability contributes to the event frequencies for transient and LOCA events. Increasing the conditional LOOP probability from 0.014 to 0.05 only increases the incremental CDF by 3.70E-10 per year per RCP for Group 1 flywheels as shown in Table 3-10. Finally, the frequency of a large LOCA has a significant uncertainty attached to its mean value. In this study the large LOCA frequency (for breaks greater than 3 ft^2) was increased an order of magnitude from 1E-06 per year to 1E-05 per year with no observable impact on plant risk.

3.5.2 Conditional Flywheel Failure Probability

To simplify analyses flywheel failure probabilities were based on 80 year end of life failure assumption and, with the exception of the large LOCA event, the assumption that the flywheel failure condition occurs at the plant design flywheel speed. For Westinghouse plants this was 1500 rpm. However, many plant transients are expected to result in events with lower flywheel speeds closer to that of nominal operation. Assuming flywheel failure probabilities associated with 1200 rpm operation, per RCP core damage frequency would reduce to 5.28E-13 per year per Table 3-10.

3.5.3 Conditional Core Damage/Large Early Release Probability Associated with a Flywheel Failure Event

The baseline analysis assumes a conditional core damage probability and a conditional large early release probability of 1.0. As discussed above, this is a limiting assumption and the actual values are expected to be much lower; therefore, the conditional LERP probabilities would be negligible.

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[1] IN/EXT-16-39534, Initiating Event Rates at U.S. Nuclear Power Plants: 1988-2015, INL, May 2016.

Table 3-10: CDF Sensitivity to Variations in PRA evaluation assumptions for RCP Flywheel Failure Risk Assessment for Extending 10-year inspection intervals to 80 years –(Flywheel Group 1)

	Incremental Change in CDF (per Year)	
	Risk Impact of Single Flywheel Failure	**Risk impact of Flywheel Failure (4 RCP Plant)**
Baseline Change in CDF	3.57E-10	1.43E-09
PWR general and other transient reduction to 0.8 per year	2.88E-10	1.15E-09
Increase the Conditional LOOP probability to 0.05	3.70E-10	1.48E-09
Increase the LOCA frequency for breaks >3 ft^2 to 1 E-05/year	3.57E-10	1.43E-09
Flywheel Failure probability reduced for normal operation and the non-large LOCA transient based on 1200 rpm	5.28E-13	2.11E-12

3.5.4 Conclusion Regarding Treatment of Uncertainty

The above sensitivity studies confirm that even for a relatively large increase in modeling parameters, the incremental CDF would continue to remain below the 1.0E-06 per year core damage and 1.0E-07 per year LERF criteria in [5] supporting the conclusion that this is a very small risk increase. This report assumes the incremental LERF and incremental CDF are equal. This is an extremely conservative assumption.

3.6 RISK RESULTS AND CONCLUSIONS

Given the extremely low failure probabilities for the RCP motor flywheel during normal/accident conditions and the extremely low probability of LOCA/LOOP, and assuming a CCDP of 1.0 (complete failure of the safety systems), the CDF and change in risk would still not exceed the risk criteria in [5] (ΔCDF<1.0E-6 per year and ΔLERF <1.0E-07 per year).

Even considering the uncertainties associated with this evaluation, the risk associated with the postulated failure of an RCP motor flywheel is significantly low. Even when all four RCP motor flywheels are considered in the bounding plant configuration case, the risk is still acceptably low.

Because of the evaluation results for core damage frequency and the conservative assumption that failure of the RCP motor flywheel results in core damage and a large early release, the calculations were not performed for the LERF. If detailed LERF analyses were performed, it is expected that the relative LERF contribution associated with these events would be significantly less than 20%. Regardless, this assessment assumes the calculated CDF is equal to LERF and that results are less than the LERF acceptance criterion (1E-07/reactor year).

The key principles identified in RG-1.174 were also reviewed and the responses based on the evaluation are provided in Table 3-11.

This evaluation, in conjunction with the previous deterministic calculations described throughout the report, concludes that the extension of the RCP motor flywheel examination from 10 to 20 years for RCP flywheels in operation up to 80 years would not be expected to result in a significant increase in risk; therefore, the proposed change is acceptable.

Table 3-11: Evaluation with Respect to Regulatory Guide 1.174 (Key Principles)

Key Principles	Evaluation Response
Change meets current regulations unless it is explicitly related to a requested exemption or rule change	No exemption or rule change is requested. This TR documents applicability of current ISI inspection intervals through 80 years of operation.
Change is consistent with defense-in-depth philosophy	The potential for failure of the RCP motor flywheel is negligible during normal accident conditions, and does not impact any plant structures, systems or components (SSCs).
Maintain sufficient safety margins	No safety analysis margins are changed.
Proposed increases in CDF or risk are small and are consistent with the Commission's Safety Goal Policy Statement	The proposed increase in risk is estimated to be negligible. The RCS leakage exists prior to a LOCA (no core damage consequences are associated with the RCS leakage). No credit taken is taken for RCS leakage detection.
Use performance-measurement to monitor the change	NDE examinations are performed on a 20-year frequency for up to 80 years. Other indications of potential degradation of the RCP motor flywheel are available (e.g., pump vibration monitoring, and pump maintenance).

4 CONCLUSIONS

The results and conclusions as summarized in WCAP-14535A [1] remain valid and are reiterated below:

1. RCP flywheels are carefully designed and manufactured from excellent quality steel, which has a high fracture toughness.
2. The RCP flywheel overspeed is the critical loading; however, LBB has limited the maximum speed to 1500 rpm. *(Note, however, that LBB for LBLOCA was not considered in the risk assessment performed in WCAP-15666-A [2], which does consider the overspeed due to the LBLOCA.)*
3. RCP flywheel inspections have been performed for over 20 years, with no service-induced flaws.
4. The RCP flywheel integrity evaluations determined a very high flaw tolerance for the RCP flywheels.
5. Crack growth during service is negligible.
6. The structural reliability studies concluded that eliminating inspections will not change the probability of failure.
7. The inspections result in man-rem exposure and the potential for flywheel damage during assembly and reassembly.

The deterministic results as summarized in WCAP-15666-A [2] remain applicable for 80 years of operation. The risk assessments are updated and presented in Section 3 of this report.

1. The failure probabilities for the RCP motor flywheels are small.
2. The change in risk is less than the Regulatory Guide 1.174 CDF and LERF acceptance criteria.
3. The 20-year ISI frequency for the RCP motor flywheel, approved by the NRC in [2], remains applicable for 80 years of operation.

5 REFERENCES

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15. NRC Policy Issue SECY-82-465, "Pressurized Thermal Shock," 11/23/1982.

APPENDIX A: CALVERT CLIFFS UNIT 1 & 2 RCP MOTOR FLYWHEEL EVALUATIONS FOR EXTENSION OF ISI INTERVAL

Background and Purpose

WCAP-15666-A [2] extended the ISI intervals for Westinghouse RCP motors from 10 to 20 years. Although Calvert Cliffs Units 1 and 2 are Combustion Engineering NSSS plants, they have Westinghouse RCP motors and flywheels; however, the motor operating speeds are different than those evaluated in WCAP-15666-A [2]. A Calvert Cliffs plant-specific deterministic calculation and a probabilistic evaluation were performed using the methodology of [2] to justify 20-year ISI interval for 60 years of plant operation.

The probabilistic evaluations for Calvert Cliffs were updated in Section 3 of this report for 80 years of operation. The purpose of this Appendix is to evaluate and extend the applicability of [2] to 80-year plant operation for Calvert Cliffs Units 1 and 2.

Ductile Failure Analysis

As discussed in Section 2.3.2 of this report, the flywheel stresses are dependent on dimensions and rotation speed. Extending the operating period to 80 years does not affect the stress calculation. Therefore, the current ductile failure analysis for 60 years remains valid for 80 years of operation.

The ductile failure limiting speed was determined for the flywheel for two cases. Case 1 considered that no cracks were present but accounted for the reduced cross sectional area resulting from the keyway. Case 2 considered that a 10-inch radial crack existed emanating from the center of the keyway through the full thickness of the flywheel.

The calculated limiting speeds are:

Case 1: 3219 rpm (considering the keyway only, no crack)

Case 2: 2856 rpm (considering the keyway and a 10" crack)

Given the nominal operating speed of 900 rpm for Calvert Cliffs plants, criterion item f [3] is satisfied since this is lower than one half of the lowest calculated critical speed of 2856/2 = 1428 rpm, considering both no cracks present and a large crack (10") present.

Given the LOCA over speed of 1368 rpm for the Calvert Cliffs plants, criterion item f [3] is satisfied because it is less than any calculated critical speeds considering both no cracks present and a large crack present.

Non-ductile Failure Analysis

As discussed in Section 2.3.3 of this report, extending the operating period to 80 years does not affect the K_I calculations, and the flywheel fracture toughness, K_{Ic} would not change due to the 80 year extension. Therefore, the current non-ductile failure analysis for 60 years remains valid for 80 years of operation. As in discussed in Section 2.3.3, Table 2-5, RTNDT values of 0°F, 30°F and 60°F were used to calculate the critical flaw sizes shown in Table A-1.

Table A-1: Critical Crack Length in Inches and % Through Flywheel

RT_{NDT}	0°F	30°F	60°F
Critical Crack Length	18.5"	8.8"	3.7"
% Through the Flywheel	52%	25%	10%

Note: The % through the flywheel is calculated as CCL in the table divided by the radial length from the maximum radial keyway location to the flywheel outer radius [CCL / (41.0" - 4.7188" – 0.937")].

Fatigue Crack Growth

As discussed in Section 2.3.4 of this report, extending the operating period to 80 years does not affect the K_I and ΔK_I calculations. The 6000 design cycles of start and shutdown used for the FCG was determined to be bounding for 80 years of operation. However, the 6000 cycles for 80 years of operation must be confirmed for this TR to be applicable. The FCG of 0.025 inch after 80 years or 6000 cycles is negligible even when assuming a large initial crack length of 3.7 inches.

Excessive Deformation Analysis

As discussed in Section 2.3.5 of this report, the 80-year extension has no impact on the excessive deformation analysis of the flywheel. The current deformation results for 60 years remain applicable to 80 years of operation.

The change in the RCP flywheel bore radius and outer diameter at overspeed condition of 1368 rpm are:

Δa = the change in the flywheel bore radius at overspeed = 0.003 inch

Δb = the change in the flywheel outside radius at overspeed = 0.006 inch

Since Δ is proportional to ω^2, this represents a 231% increase $[(\omega_{os}/\omega_n)^2 = (1368 / 900)^2 = 2.31$ = 231% over the deformation at the normal operating speed.

This increase would not result in any adverse conditions, such as excessive flywheel vibrational stresses that would result in crack propagation since the flywheel assemblies are interference fit to the flywheel shaft and the calculated deformations are small and insignificant. It is noted that the deformation for Calvert Cliffs flywheels is less than the that of Westinghouse flywheels reported in Section 2.3.5 of this report.

Conclusion

The current Calvert Cliffs evaluation and results for 60 years are applicable for 80 years of operation. The stress and fracture evaluation results for Calvert Cliffs flywheels are consistent with the flywheels evaluated in [3]. The probabilistic risk evaluation, in conjunction with the deterministic calculations described above, concluded that extension of the RCP motor flywheel ISI from 10 to 20 years for flywheels in service up to 80 years is acceptable.