OG-01-051
August 24, 2001

WCAP-15666, Rev. 0
Project Number 694

Domestic Members
AmerenUE
Callaway
American Electric Power Co.
D.C. Cook 1 & 2
Carolina Power & Light Co.
H.B. Robinson 2
Shearon Harris
Consolidated Edison Company of NY, Inc.
Indian Point 2
Duke Power Company
Catawba 1 & 2
McGuire 1 & 2
Entergy Nuclear Operations Inc.
Indian Point 3
Exelon
Braidwood 1 & 2
Byron 1 & 2
First Energy Nuclear Operating Co.
Beaver Valley 1 & 2
Florida Power & Light Co.
Turkey Point 3 & 4
Northeast Utilities
Seabrook
Millstone 3
Nuclear Management Co.
Point Beach 1 & 2
Prairie Island 1 & 2
Kewaunee
Pacific Gas & Electric Co.
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PSEG - Nuclear
Salem 1 & 2
Rochester Gas & Electric Co.
R.E. Ginna
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STP Nuclear Operating Co.
South Texas Project 1 & 2
Southern Nuclear Operating Co.
J.M. Farley 1 & 2
A.W. Vogtle 1 & 2
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Sequoyah 1 & 2
Watts Bar 1
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Wolf Creek

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Tihange 1, 3
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Takahama 1
Ohi 1 & 2
Korea Electric Power Co.
Kori 1 - 4
Yonggwang 1 & 2
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Sizewell B
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Krsko
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Almaraz 1 & 2
Vattenfall AB
Ringhals 2 - 4
Taiwan Power Co.
Maanshan 1 & 2

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Attention: Chief, Information Management Branch,
Division of Inspection and Support Programs

Subject: Westinghouse Owners Group
Transmittal of WCAP-15666, "Extension of Reactor Coolant Pump Motor Flywheel Examination," Non-Proprietary Class 3 (MUHP-3043)

This letter transmits twelve (12) copies of the WCAP-15666, "Extension of Reactor Coolant Pump Motor Flywheel Examination," Non-Proprietary Class 3, dated July 2001. WCAP-15666 provides the technical justification to extend the Reactor Coolant Pump (RCP) motor flywheel examination frequency for all domestic Westinghouse Owners Group (WOG) plants from the currently approved 10 year inspection interval, to an interval not to exceed 20 years. The currently approved 10-year inspection interval does not coincide with the actual RCP refurbishment schedules. Refurbishment currently occurs at 10 to 15 year intervals, but could be extended to 20 years. The technical justification in WCAP-15666 involves use of Leak-Before-Break (LBB) to limit RCP overspeed to 1500 rpm, and risk assessment of all credible flywheel speeds.

The risk assessment approach used in WCAP-15666 is consistent with Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Current Licensing Basis." The change in risk for extending the In-Service Inspection (ISI) interval from 10 to 20 years is 3 to 4 orders of magnitude below the Regulatory Guide 1.174 Core Damage Frequency (CDF) and Large Early Release Frequency (LERF) acceptance guidelines. Thus, extending the ISI interval for the RCP motor flywheel from 10 years to 20 years satisfies the Regulatory Guide 1.174 risk criteria as an acceptable change.

Section 4 of WCAP-15666 provides the proposed changes to Specification 5.5.7, "Reactor Coolant Pump Flywheel Inspection Program," of NUREG-1431, Revision 2, Improved Standard Technical Specifications. The proposed changes will be incorporated into an NEI Technical Specification Task Force (TSTF) traveler that will be submitted to the NRC for review following submittal of this report. The proposed changes contained in the TSTF traveler will supercede the technical specification changes contained in WCAP-15666.

The WOG is submitting WCAP-15666, under the NRC licensing topical report program for review and acceptance for referencing in licensing actions. The objective is that once approved, each WOG member can reference this report to request amendments to their Technical Specifications. Furthermore, the WOG requests that the NRC make these changes available to the WOG members utilizing the Consolidated Line Item Improvement Process for Adopting Standard Technical Specification Changes for Power Reactors.

D048

The WOG requests that the NRC complete the review of WCAP-15666 by June 30, 2002 so that when WCAP-15666 is approved licensees can utilize the WCAP to extend the interval for the RCP motor flywheel from 10 years to 20 years. Consistent with the Office of Nuclear Reactor Regulation, Office Instruction LIC-500, "Processing Request for Reviews of Topical Reports," the WOG requests that the NRC provide an estimate of the review hours, and target dates for any Request(s) for Additional Information and for completion of the Safety Evaluation for this WCAP.

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Invoices associated with the review of this WCAP should be addressed to:

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If you require further information, please contact Mr. Ken Vavrek in the Westinghouse Owners Group Project Office at 412-374-4302.

Very truly yours,

Robert H. Bryan

Robert H. Bryan, Chairman
Westinghouse Owners Group

enclosures

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A.P. Drake, W- ECE 5-16 (1L)

Westinghouse Non-Proprietary Class 3

WCAP - 15666

Extension of Reactor Coolant Pump Motor Flywheel Examination

Westinghouse Electric Company LLC

WCAP-15666

Extension of Reactor Coolant Pump Motor Flywheel Examination

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July 2001

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Work performed for the Westinghouse Owners Group under WOG Project MUHP-5043
(SAP Project Number ES-99-0200, Charge Number 5500810010, Sales Order 1869 Line Item 20)

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EXECUTIVE SUMMARY

A previous Westinghouse Owners Group (WOG) program MUHP-5042 established the technical basis that allowed for relaxation of reactor coolant pump (RCP) motor flywheel examinations for all domestic WOG plants and several Babcock and Wilcox plants. This was summarized in Westinghouse report WCAP-14535, which concluded that flywheels are well-designed, are manufactured from excellent materials, have an excellent inspection history, and are structurally sound based on deterministic stress and fracture analyses. An assessment concluded that flywheel inspections beyond 10 years of plant life have no significant benefit on reducing the likelihood of flywheel failure.

WCAP-14535 was submitted for review by the United States Nuclear Regulatory Commission (NRC) in January 1996, with Beaver Valley as the lead plant. Following two requests for additional information (RAI), the NRC issued a Safety Evaluation Report (SER) in September 1996, wherein they accepted the technical arguments, but did not allow for total elimination of examinations. The SER did provide for partial relief from the examination requirements of NRC Regulatory Guide 1.14, by allowing for an extension of the examination frequency from 40 months to 10 years, and a reduction in the required examination volume. The NRC stated in the SER that they had not reviewed the risk assessment in WCAP-14535, but had relied solely on the deterministic methodology to review the submittal. The final NRC-approved version of the report, which includes the RAIs and SER, is WCAP-14535A, which was issued in November 1996.

The currently approved 10-year inspection interval does not coincide with actual RCP refurbishment schedule at many WOG plants. Refurbishment currently occurs at 10 to 15 year intervals at all domestic WOG plants, but could be extended to 20 years, at most. The current WOG program, MUHP-5043, which is summarized in this report, provides the technical basis for the extension of the RCP motor flywheel examination frequency for all domestic WOG plants from the currently approved 10-years to a maximum of 20 years. The current WOG program builds on the MUHP-5042 arguments, which assumed Leak-Before-Break (LBB) limits the RCP overspeed to 1500 rpm. It also provides additional rationale, including a risk assessment of all credible flywheel speeds, following the guidance of Regulatory Guide 1.174, to justify the interval extension to 20 years to allow for inspection coincident with RCP refurbishment. The change in risk for extending the ISI interval is 3 to 4 orders of magnitude below the Regulatory Guide 1.174 core damage frequency (CDF) and large early release frequency (LERF) acceptance guidelines. The extension of the inservice inspection frequency for the RCP motor flywheel from 10 years to 20 years satisfies Regulatory Guide 1.174 risk criteria as an acceptable change. Proposed changes to Specification 5.5.7, "Reactor Coolant Pump Flywheel Inspection Program," of NUREG-1431, Revision 2, Improved Standard Technical Specifications, are provided in Section 4 of this report.

LIST OF ACRONYMS

ASME	American Society of Mechanical Engineers
CCDP	Conditional Core Damage Probability
CDF	Core Damage Frequency
DEGB	Double-Ended Guillotine Break
EOL	End of Life
FP	Failure Probability
IE	Initiating Event Frequency
ISI	Inservice Inspection
LBB	Leak-Before-Break
LBLOCA	Large Break Loss of Coolant Accident
LERF	Large Early Release Frequency
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
MT	Magnetic Particle Examination
NDE	Nondestructive Examination
NRC	Nuclear Regulatory Commission
PRA	Probabilistic Risk Assessment
PT	Liquid Penetrant Examination
PWR	Pressurized Water Reactor
RAI	NRC Request for Additional Information
RAW	Risk Achievement Worth
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RG	NRC Regulatory Guide
rpm	Revolutions Per Minute
RRW	Risk Reduction Worth
RT_{NDT}	Reference Nil-Ductility Transition Temperature
SER	NRC Safety Evaluation Report
SRP	Standard Review Plan
SSC	Structures, Systems, and Components
UT	Ultrasonic Test
VT	Visual Examination
WOG	Westinghouse Owners Group

1. INTRODUCTION

An integral part of the reactor coolant system (RCS) in pressurized water reactor (PWR) plants is the reactor coolant pump (RCP), a vertical, single stage, single-suction, centrifugal, shaft seal pump. The RCP ensures an adequate cooling flow rate by circulating large volumes of primary coolant water at high temperature and pressure through the RCS. Following an assumed loss of power to the RCP motor, the flywheel, in conjunction with the impeller and motor assembly, provide sufficient rotational inertia to assure adequate primary coolant flow during RCP coastdown, thus resulting in adequate core cooling.

During normal power operation, the RCP motor flywheel possesses sufficient kinetic energy to produce high-energy missiles in the event of flywheel failure. Conditions which may result in overspeed of the RCP, such as a postulated loss of coolant accident (LOCA), increase both the potential for failure and the kinetic energy of the flywheel. This concern led to the United States Nuclear Regulatory Commission (NRC) issuing Regulatory Guide (RG) 1.14 (Reference 1), which described a range of actions to ensure flywheel integrity, including inservice inspections (ISI) at 40-month intervals. As a result of Westinghouse Owners Group (WOG) program MUHP-5042, summarized in Reference 2, the NRC approved the extension of the 40-month interval to 10-year intervals (Reference 3).

The original goal of the current WOG program (MUHP-5043), summarized in this report, was total elimination of RCP motor flywheel inspections. This was to be accomplished by demonstrating that eliminating inspections beyond 10 years of plant life would have an insignificant effect on core damage frequency (CDF) and large early release frequency (LERF), using the guidance of RG-1.174 and Standard Review Plan (SRP) 19.0 (References 4 and 5). Structures, systems and components (SSCs) important to plant safety may pass through the RCP compartments in WOG plants. Initial investigations were performed and indicated that there is not much uniformity regarding the spatial orientation of potential critical targets with respect to the RCP. Therefore, a conservative bounding evaluation of the potential failure of targets could not be used to accurately assess the true risk.

The currently approved 10-year inspection interval does not coincide with the actual RCP refurbishment schedule at many plants. Therefore, it is desirable to extend the ISI interval to a maximum 20-year interval to allow for inspection coincident with RCP refurbishment. This justification for this extension is summarized in this report, builds on the MUHP-5042 arguments, and provides additional rationale, including a risk assessment of all credible flywheel speeds, following the guidance of RG-1.174, to justify the interval extension.

The purpose of this report is to provide the engineering basis to allow for the extension of RCP motor flywheel ISI frequency for all domestic WOG plants from the currently approved 10 years to 20 years. RCP motor refurbishment normally occurs at 10 to 15 year intervals for all domestic WOG plants.

Section 2 of the report provides background information from Reference 2. Section 3 provides details on the risk assessment. The proposed changes to Specification 5.5.7, "Reactor Coolant Pump Flywheel Inspection Program," of NUREG-1431, Revision 2, Improved Standard Technical Specifications, are contained in Section 4. Conclusions and references are provided in Sections 5 and 6, respectively.

2. BACKGROUND

In a previous WOG program (MUHP-5042, summarized in Reference 2), the engineering basis was established that led to NRC approval to lengthen the surveillance interval for the RCP motor flywheel from 40 months to 10 years. The various aspects of this previous program are discussed in the following subsections. Applicable plants in the previous program included all operating domestic WOG plants and several Babcock and Wilcox plants including Crystal River 3, Oconee 1, 2 and 3, Davis Besse and Three Mile Island 1. The current program MUHP-5043 applies only to operating domestic WOG plants. Plant alpha designations used in this report are identified in Table 2-1.

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 antirotation pawls. See Figure 2-1 for the configuration of a typical Westinghouse flywheel.

Westinghouse manufactured the RCP motors for all of the Westinghouse plants. All of the RCP motor flywheels for operating Westinghouse plants are made of SA533 Grade B Class 1 steel. It was not possible to locate each of the certified material test reports for all of the flywheels. A sample is provided in Appendix D of Reference 2. The ordering specifications for the Westinghouse flywheel materials (the first specification is dated December 1969) required that the reference nil-ductility transition temperature (RT_{NDT}) from both longitudinal and transverse Charpy specimens be less than 10°F. The Westinghouse equipment specification was changed in January 1973 to require both Charpy and drop weight tests to ensure that RT_{NDT} is no greater than 10°F. Even though it is likely that most, if not all, of the flywheels in operation have an RT_{NDT} of 10°F or less, a range of RT_{NDT} values from 10°F to 60°F was assumed in the integrity evaluations of Reference 2, which are discussed later in this report.

A summary of pertinent flywheel parameters is provided in Table 2-2. Note that for the evaluations performed in Reference 2, and summarized in this report, the larger flywheel outside diameter for a particular flywheel assembly was used, since this was judged to be conservative with respect to stress and fracture. This larger dimension is provided in Table 2-2.

Table 2-1: Westinghouse Domestic Plant Alpha Designation Listing

Plant Alpha Designation(s)	Plant(s)
AEP/AMP	D.C. Cook Units 1 and 2
ALA/APR	J.M. Farley Units 1 and 2
CAE/CBE	Byron Units 1 and 2
CCE/CDE	Braidwood Units 1 and 2
CGE	V.C. Summer
CPL	H.B. Robinson Unit 2
CQL	Shearon Harris
DAP/DBP	McGuire Units 1 and 2
DCP/DDP	Catawba Units 1 and 2
DLW/DMW	Beaver Valley Units 1 and 2
FPL/FLA	Turkey Point Units 3 and 4
GAE/GBE	Vogtle Units 1 and 2
IPP/INT	Indian Point Units 2 and 3
NAH	Seabrook
NEU	Millstone Unit 3
NSP/NRP	Prairie Island Units 1 and 2
PGE/PEG	Diablo Canyon Units 1 and 2
PSE/PNJ	Salem Units 1 and 2
RGE	Ginna
SAP	Wolf Creek
SCP	Callaway
TBX/TCX	Comanche Peak Units 1 and 2
TVA/TEN	Sequoyah Units 1 and 2
TGX/THX	South Texas Units 1 and 2
VGB/VRA	North Anna Units 1 and 2
VPA/VIR	Surry Units 1 and 2
WAT	Watts Bar Unit 1
WEP/WIS	Point Beach Units 1 and 2
WPS	Kewaunee

Table 2-2: Summary of Westinghouse Domestic Plant RCP Motor Flywheel Information

Group	Outer Diam. (Inches)	Bore (Inches)	Keyway Radial Length (Inches)	Pump & Motor Inertia (Lb_m-ft^2)	Material Type	Applicable Plants (Plant Alpha Designation)
1	76.50	9.375	0.937	110,000	SA533B	TGX/THX/Spare
2	75.75	8.375	0.906	82,000	SA533B	PSE[3]/PNJ/Spare
3	75.00	9.375	0.937	95,000	SA533B	CQL; CAE/CBE/CCE/CDE[1]; DAP/DBP/DCP/DDP; GAE/GBE[1]; SAP/Spare; NEU; NAH; CGE/Spare; WAT/Spare; TBX/TCX/Spare; SCP; VRA/VGB/Spare
4	75.00	9.375	0.937	83,000	SA533B	TVA/TEN/Spare
5	75.00	9.375	0.937	82,000	SA533B	ALA/APR/Spare; AEP/AMP/Spare; DLW/DMW, PGE Spare[1,6]
6	75.00	9.375	0.937	80,000	SA533B	NSP/NRP[2]; WPS[2]
7	75.00	8.375	0.911	82,000	SA533B	INT Spare, PGE Spare[5,6]
8	75.00	8.375	0.906	82,000	SA533B	IPP/INT; PGE/PEG
9	75.00	8.375	0.906	80,000	SA533B	WEP[4]/WIS
12	72.00	8.375	0.906	80,000	SA533B	RGE[3]
13	72.00	8.375	0.906	70,000	SA533B	CPL/Spare; FPL/FLA/Spare; VPA/VIR[4]

Notes:
1) Spare has a keyway radial length of 0.885".
2) Spare has a keyway radial length of 0.883".
3) Spare has a keyway radial length of 0.911".
4) Spare has a keyway radial length of 0.937".
5) Spare has a keyway radial length of 0.863".
6) The spares for PGE/PEG are bounded by Reference 2 per Reference 18.
7) Groups 10, 11, 15 and 16 include non-WOG plants from Reference 2. Group 14 includes Haddam Neck, which is no longer in service. These groups are not included in the current WOG program MUHP-5043, summarized in this report.

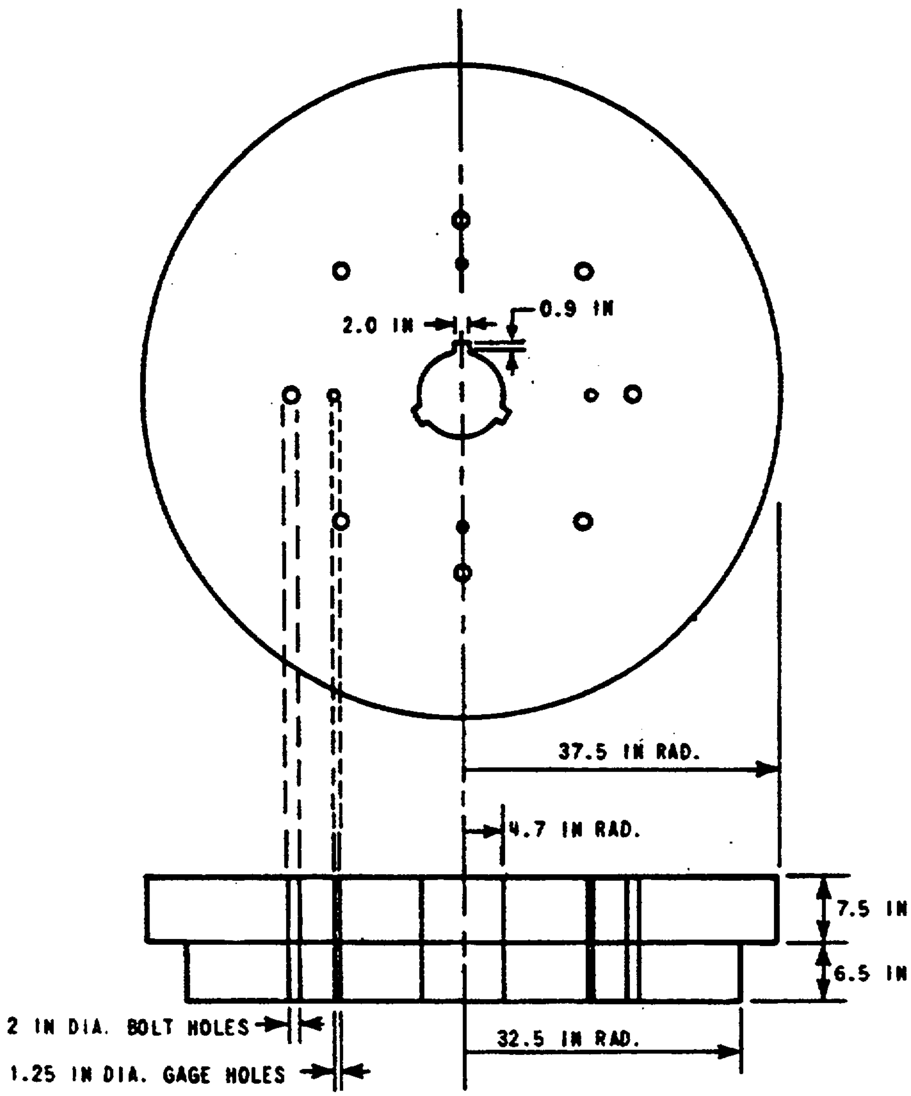

Figure 2-1: Example of a Typical Westinghouse RCP Motor Flywheel

2.2 INSPECTION

Flywheels are inspected at the plant or during motor refurbishment. Inspections are conducted under the ASME Boiler and Pressure Vessel Code, Section XI (Reference 6) standard practice for control of instrumentation and personnel qualification. Ultrasonic test (UT) level II and level III examiners conduct the inspections.

Examination Volumes

RCP motor flywheel examinations are conducted under the control of Utility ISI programs according to surveillance schedules governed by individual plant Technical Specifications. The volumetric examinations recommended in RG-1.14 have been uniformly applied to the accessible surfaces of the RCP motor flywheel after removal of the shroud cover and gauge hole plugs. The volume of flywheel is inspected generally with straight beam techniques applied laterally, checking the plate material for planar defects emanating from the bore, keyways, and around the gauge holes and ream bolt holes.

Examination Approaches

Generally, three examinations are performed. The keyway corner exam is conducted by inserting specially designed ultrasonic probes into the gauge holes and directing the sound laterally through the plate material so that reflections are obtained from the center bore radius. Normal reflections will then be seen from the corners of the keyways. These reflections are predictable in distance and rate of occurrence, with abnormalities such as cracking branching out from the keyway being detectable as an abnormal response. A second examination is performed when the sound is projected laterally towards the other remaining gauge holes, for evidence of cracking emanating from the bores of the holes and plate material between the holes. The third examination is commonly referred to as the "Periphery" examination. In this test, standard contact transducers are placed on the outer edges of both upper and lower flywheel plates. The sound is directed laterally into the plate material for examination of the material between the peripheral holes and the plate outer edge.

Access and Exposure

Access to the exam surfaces is made possible by permanent walkways or by erecting scaffolding. Radiation exposure depends greatly on the amount of RCP motor work being conducted nearby and can range from 20-100 millirem/hour.

Inspection History

A survey was conducted of historical plant inservice inspection results in the previous MUHP-5042 project, and all member utilities contributed, including utilities with Babcock and Wilcox plants. The flywheel population surveyed was a total of 217. A total of 729 examination results were reported, and no indications that would affect the integrity of the flywheels were found. These results are summarized on a plant by plant basis in Table 2-3.

A summary of recordable indications from the previous MUHP-5042 program is provided in Table 2-4. It is interesting to note from this table that a number of indications in the form of nicks, gashes, etc. were found at the keyway area, having been created by the act of removing or reassembling the flywheel. These were all dispositioned as not affecting flywheel integrity, but are clear evidence that disassembly for inspection and reassembly actually can produce damage.

Indications were found at the Haddam Neck plant, in the weld used to join the two flywheel plates together. The indications identified were associated with this seal weld and resulted in no radially oriented cracking, and no impact on the integrity of the flywheels. A detailed summary of this finding is given in Appendix B of Reference 2. Sample flywheel inspection procedures are provided in Appendix C of Reference 2.

Since the time that Reference 2 was published, a number of flywheel inspections have been performed, and no flaws have been discovered.

Table 2-3: Flywheel Inspection Results from MUHP-5042 Study

Plant Alpha Designation	Plant	Number of Flywheels	Total Number of Flywheel Inspections	Total Number of Inspections with No Indications or Nonrecordable Indications	Total Number of Inspections with Recordable Indications	Number of Indications Affecting Flywheel Integrity
AEP	Cook 1	4	14	13	1	0
AMP	Cook 2	4	12	12	0	0
ALA	Farley 1	3	17	17	0	0
APR	Farley 2	3	19	19	0	0
CAE/CBE	Byron 1 & 2	8	20	19	1	0
CCE	Braidwood 1	4	13	11	2	0
CDE	Braidwood 2	4	9	8	1	0
CGE	Summer	4	10	10	0	0
CWE	Zion 1	4	10	9	1	0
COM	Zion 2	4	16	16	0	0
CPL	Robinson 2	4	22	20	2	0
CQL	Harris	3	17	17	0	0
CYW	Haddam Neck	4	32	28	4	0
DAP	McGuire 1	4	13	13	0	0
DBP	McGuire 2	4	8	8	0	0
DCP	Catawba 1	4	6	6	0	0
DDP	Catawba 2	4	6	6	0	0
DLW	Beaver Valley 1	3	15	11	4	0
DMW	Beaver Valley 2	3	5	5	0	0

Table 2-3: Flywheel Inspection Results from MUHP-5042 Study (Continued)

Plant Alpha Designation	Plant	Number of Flywheels	Total Number of Flywheel Inspections	Total Number of Inspections with No Indications or Nonrecordable Indications	Total Number of Inspections with Recordable Indications	Number of Indications Affecting Flywheel Integrity
FPL/FLA	Turkey Point 3 & 4	7	36	34	2	0
GAE/GBE	Vogtle 1 and 2	9	19	19	0	0
IPP	Indian Point 2	5	21	21	0	0
INT	Indian Point 3	5	17	17	0	0
NAH	Seabrook	4	8	8	0	0
NEU	Millstone 3	5	12	12	0	0
NSP	Prairie Island 1	2	13	12	1	0
NRP	Prairie Island 2	2	11	10	1	0
PGE	Diablo Canyon 1	4	12	11	1	0
PEG	Diablo Canyon 2	4	11	11	0	0
PSE/PNJ	Salem 1 and 2	9	24	13	11	0
RGE	Ginna	3	21	21	0	0
SAP	Wolf Creek	4	13	12	1	0
SCP	Callaway	4	11	11	0	0
TBX	Comanche Peak 1	4	8	8	0	0
TCX	Comanche Peak 2	4	4	4	0	0
TVA/TEN	Sequoyah 1 and 2	9	37	36	1	0
TGX	South Texas 1	4	12	12	0	0
THX	South Texas 2	4	12	12	0	0
VGB/VRA	North Anna 1 & 2	7	37	33	4	0
VPA/VIR	Surry 1 and 2	7	17	17	0	0
WAT	Watts Bar 1	4	4	2	2	0
WEP	Point Beach 1	2	12	12	0	0
WIS	Point Beach 2	2	13	13	0	0
WPS	Kewaunee	3	6	5	1	0
BCRY3	Crystal River 3	4	30	30	0	0
BDAV1	Davis Besse	5	24	22	2	0
BOCO1	Oconee 1	4	6	6	0	0
BOCO2	Oconee 2	4	2	2	0	0
BOCO3	Oconee 3	4	3	3	0	0
B3MI1	Three Mile Island 1	4	9	9	0	0
TOTALS	**57**	**217**	**729**	**686**	**43**	**0**

Table 2-4: Summary of Recordable Indications from MUHP-5042 Study

Plant Alpha Designation	Year	Description of Recordable Indications
AEP	1987	Surface examination on RCP flywheel no. 13 showed two 3/8" long recordable indications. Surface chatter removed by minor surface reconditioning.
CAE/CBE	1993	0.45" rounded indication in RCP flywheel 1B keyway area (surface exam) characterized as minor tool mark.
CCE	1991	PT indications on RCP "A" flywheel were acceptable.
	1994	Indications noted on RCP "B" flywheel with PT and VT-1 were resurfaced and found to be acceptable.
CDE	1994	Four 1/16" rounded indications noted in various areas located approximately 0.8" below top surface of RCP "C" flywheel. One linear indication noted (circ. oriented). Indications were acceptable.
CWE	1986	PT recordable indication in loop 1 RCP flywheel, bleed out from gouges and metal folds in keyways.
CPL	1984	PT recordable indication on RCP "C" flywheel bore was filed out and reexamined.
	1992	Gouge on spare flywheel blended out to 3 to 1 taper.
DLW	1980	PT indication, unsatisfactory mechanical damage from removal of RCP "B" flywheel. Grinding repaired condition.
	1987	PT recordable indication dispositioned as satisfactory for RCP "A" flywheel. Damage from handling.
	1993	UT recordable indication in RCP "B" flywheel due to geometry, dispositioned as satisfactory. PT recordable indication due to handling, dispositioned as satisfactory.
	1994	UT recordable indication in RCP "C" flywheel due to geometry, dispositioned as satisfactory.
FPL/FLA	1974	Laminations midwall (UT) in motor 1S-76P499 flywheel accepted as-is.
	1993	Torn metal in keyway (PT) on motor 2S-76P499 flywheel removed by buffing.
NSP	1994	MT of flywheel no. 11 periphery (0.4 inch) to be re-examined in January 1996 outage.
NRP	1995	MT indications in periphery of flywheel no. 21 (which were buffed in 1993) were found to be unchanged.
PGE	1995	Multiple MT linear indications (laminations) on lower periphery of RCP 1-4 flywheel, accept as-is, monitor.
PSE/PNJ	1983-1995	Eleven recorded indications from surface examinations on seven flywheels were identified as minor chatter marks in keyway from original rough machine cuts due to the arbor tool used during manufacture. Accept as is.

Table 2-4: Summary of Recordable Indications from MUHP-5042 Study (Continued)

Plant Alpha Designation	Year	Description of Recordable Indications
SAP	1995	Wear marks on bottom surface of RCP 1 flywheel within seal ring (circular like spacers wear) - removed.
TVA/TEN	1993	Recorded indications (10 year MT) in flywheel 3S-81P352. Laminations in edge, dispositioned as acceptable.
VGB/VRA	1983	Tool marks noted in keyway of flywheel 2S-81P355.
	1986	Four PT indications in the keyway of flywheel 3S-81P355 caused by incorrect installation.
	1988	Six reportable indications from keyway scratches in flywheel 3S-81P777.
	1993	Three acceptable rounded indications in the keyway of flywheel 2S-81P777.
WAT	1986	PT recorded indication in keyway area of RCP 1 flywheel resulted from tool chatter that occurred during manufacture of the flywheel. The indications were formed by the tearing and smearing of the raised metal (introduced by the tool chatter) at disassembly and reassembly of the keys.
	1986	VT recorded indication in keyway area of RCP 4 flywheel.
WPS	1976	Visual recorded indication in RCP "A" flywheel. Machine chips in five small holes in center of shaft.
BDAV1	1975	Volumetric preservice indication in RCP 2 flywheel found to be acceptable. Surface tears in keyway removed by surface conditioning.
	1988	Surface gouges in bore of RCP 4 flywheel from flywheel removal found to be acceptable.
CYW	1971	See Appendix B of Reference 2.

2.3 STRESS AND FRACTURE EVALUATION

The flywheels were subjected to a detailed stress and fracture evaluation, which is summarized in this section. There are two possible failure mechanisms, ductile and brittle, which must be considered in flywheel evaluation. Figure 2-2 shows the results of a typical flywheel overspeed evaluation, where the flywheel failure speed was calculated for a range of postulated crack depths. Note that the brittle failure limit governs for large flaws. The limiting speed increases for small flaws. Using brittle fracture considerations alone, the limiting speed would approach infinity for vanishingly small flaws. For these situations, the ductile failure limit governs, a finding that has been proven by scale model tests as reported in Reference 7.

RG-1.14, Revision 1, Section C, Subsection 2 provides the following regulatory position for flywheel design. These guidelines were followed in the flywheel evaluation reported herein.

a) The flywheel assembly, including any speed-limiting and antirotation devices, the shaft, and the bearings, should be designed to withstand normal conditions, anticipated transients, the design basis loss-of-coolant accident, and the Safe Shutdown Earthquake loads without loss of structural integrity.

b) Design speed should be at least 125% of normal speed but not less than the speed that could be attained during a turbine overspeed transient. Normal speed is defined as synchronous speed of the a.c. drive motor at 60 hertz.

c) An analysis should be conducted to predict the critical speed for ductile failure of the flywheel. The methods and limits of paragraph F-1323.1(b) in Section III of the ASME Code are acceptable. If another method is used, justification should be provided. The analysis should be submitted to the NRC staff for evaluation.

d) An analysis should be conducted to predict the critical speed for nonductile failure of the flywheel. Justification should be given for the stress analysis method, the estimate of flaw size and location, which should take into account initial flaw size and flaw growth in service, and the values of fracture toughness assumed for the material. The analysis should be submitted to the NRC staff for evaluation.

e) An analysis should be conducted to predict the critical speed for excessive deformation of the flywheel. The analysis should be submitted to the NRC staff for evaluation. (Excessive deformation means any deformation such as an enlargement of the bore that could cause separation directly or could cause an unbalance of the flywheel leading to structural failure or separation of the flywheel from the shaft. The calculation of deformation should employ elastic-plastic methods unless it can be shown that stresses remain within the elastic range).

f) The normal speed should be less than one-half of the lowest of the critical speeds calculated in regulatory positions C.2.c, d, and e above.

g) The predicted LOCA overspeed should be less than the lowest of the critical speeds calculated in regulatory positions C.2.c, d, and e above.

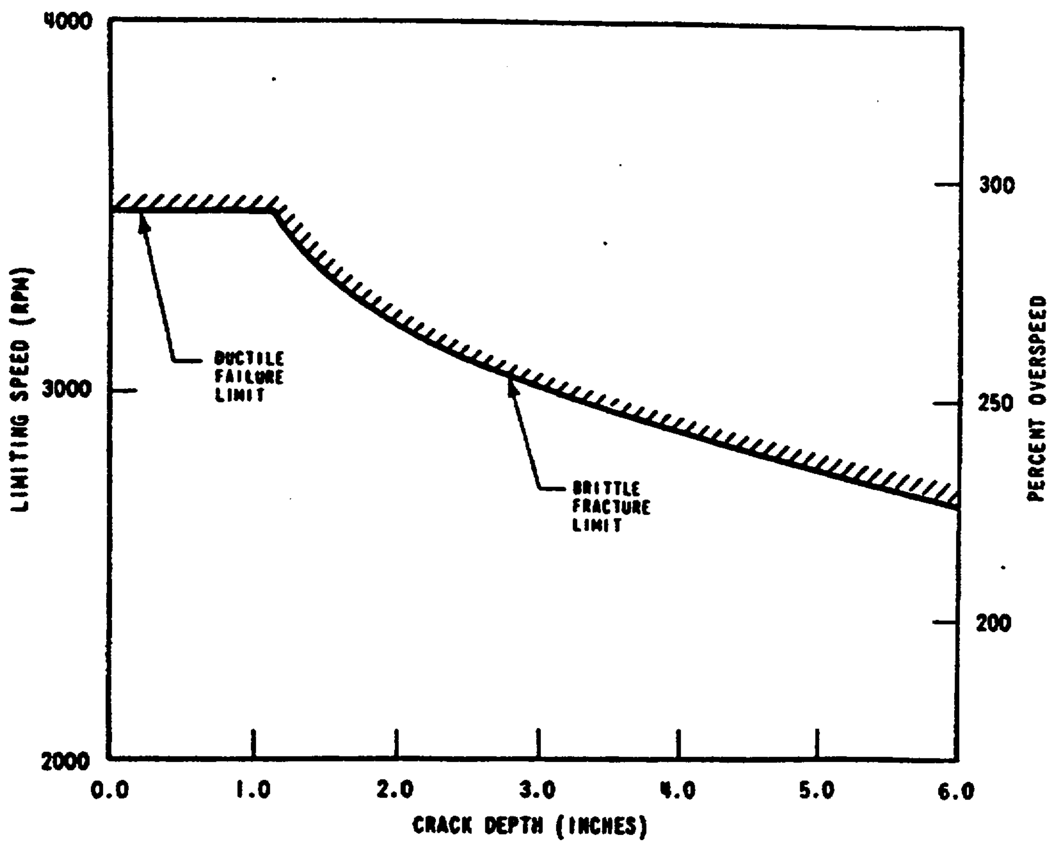

Figure 2-2: Results of a Typical Westinghouse RCP Motor Flywheel Overspeed Evaluation

Selection of Flywheel Groups for Evaluation

As shown in Table 2-2, flywheel outer diameter ranges from 72 to 76.5 inches, bore diameter ranges from 8.375 to 9.375 inches, and keyway radial length ranges from 0.906 to 0.937 inch. The material is the same for all groups. The pump and motor inertia is not a factor in the evaluation. Stresses in the flywheel are a strong function of the outer diameter (approximately proportional to the OD^2). Therefore the two groups with the largest flywheel outer diameter (Groups 1 and 2) bound all other groups in Table 2-2, and were selected for the deterministic and probabilistic evaluations. As shown in Reference 2, these groups yielded the worst case deterministic and probabilistic results.

Table 2-5: Flywheel Groups Evaluated for Program MUHP-5043

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

Ductile Failure Analysis

The capacity for a structure to resist ductile failure with a sufficient margin of safety during faulted conditions can be demonstrated by meeting the faulted condition criteria of Section III of the ASME Boiler and Pressure Vessel Code. The faulted condition stress limits for elastic analysis (P_m and P_m+P_b) are taken as 0.7 S_u and 1.05 S_u, where S_u is the minimum specified ultimate tensile stress of the material. As discussed in Reference 7, 80 ksi was used for S_u, which is the minimum specified value for SA533 Grade B, Class 1 steel. The stresses in the flywheel, neglecting local stress concentrations such as holes and keyways, can be calculated by the following equations (References 2 and 7):

$$\sigma_r = \frac{(3+\nu)}{8}\frac{\rho\omega^2}{386.4}\left(b^2+a^2-\frac{a^2b^2}{r^2}-r^2\right) \qquad \textbf{Equation 1}$$

$$\sigma_\theta = \frac{(3+\nu)}{8}\frac{\rho\omega^2}{386.4}\left[b^2+a^2+\frac{a^2b^2}{r^2}-\left(\frac{1+3\nu}{3+\nu}\right)r^2\right] \qquad \textbf{Equation 2}$$

where:

	σ_r	=	radial stress, psi
	σ_θ	=	circumferential, or hoop stress, psi
	ν	=	Poisson's ratio, 0.3
	ρ	=	flywheel material density, 0.283 $lb_m/inch^3$
	ω	=	flywheel angular speed, radians/second
	b	=	flywheel outer radius, inches
	a	=	flywheel bore radius, inches
	r	=	flywheel radial location of interest, inches

Since the stress in the thickness direction (σ_x) is assumed to be negligible, and the radial stress (σ_r) always falls between σ_x and σ_θ, the maximum stress intensity at any point in the flywheel is equal to the circumferential stress, σ_θ. It should be noted that the circumferential stress peaks at the flywheel bore and keyway locations, and decreases approximately linearly thereafter in the radial direction. To apply the faulted stress limits to a nonlinear stress distribution, the actual stress distribution must be resolved into its membrane and bending components:

$$P_m = \frac{1}{(b-a)} \int_a^b \sigma_\theta \, dr$$

Equation 3

$$P_b = \frac{6}{(b-a)^2} \int_a^b \sigma_\theta (r_m - r) \, dr$$

Equation 4

where r_m is the flywheel mean radius defined as (a+b)/2.

Substituting the circumferential stress term shown above and carrying out the integrations yields:

$$P_m = \left(\frac{3+v}{8}\right) \frac{\rho\omega^2}{386.4(b-a)} (b^3 - a^3) \left[1 - \frac{1}{3}\left(\frac{1+3v}{3+v}\right)\right]$$

Equation 5

$$P_b = \left(\frac{3+v}{8}\right) \frac{6\rho\omega^2}{386.4(b-a)^2} \left[\frac{b^4}{12}\left(\frac{1+3v}{3+v}\right) + \frac{b^3 a}{2}[1 - \frac{1}{3}\left(\frac{1+3v}{3+v}\right)]\right.$$

$$\left. - a^2 b^2 \ln(\frac{b}{a}) - \frac{b a^3}{2}[1 + \frac{1}{3}(\frac{1+3v}{3+v})] - \frac{a^4}{12}(\frac{1+3v}{3+v})\right]$$

Equation 6

As was performed in the Reference 7 evaluation, a ductile failure limiting speed was determined for each flywheel group selected for evaluation, assuming that cracks are not present and neglecting the local stress effects from holes and keyways. Limiting speeds were also calculated considering the reduced cross sectional area resulting from the keyway, and that cracks may be present, emanating radially from the maximum radial location of the keyway, through the full thickness of the flywheel. The results of these calculations are provided in the following table.

Table 2-6: Ductile Failure Limiting Speed (rpm)

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

Per RG-1.14, Revision 1, Section C, item 2f, the normal speed should be less than one-half of the lowest of the critical speeds as calculated for ductile failure, nonductile failure, and excessive deformation. At the minimum calculated limiting speed of 3430 rpm (assuming no cracks), the normal speed must be less than 1715 rpm. Since the normal operating flywheel speed is 1200 rpm, item 2f of RG-1.14 is satisfied for ductile failure with no cracks present. Assuming a rather large crack of 10" in depth, item 2f is still satisfied for ductile failure since one-half of the lowest calculated critical speed (3012 rpm) is 1506 rpm, which is higher than the normal operating flywheel speed of 1200 rpm.

Per item 2g of Section C of RG-1.14, the predicted LOCA overspeed should be less than the lowest of the critical speeds calculated for ductile failure, nonductile failure, and excessive deformation. Since the predicted LOCA overspeed is in all cases less than 1500 rpm (considering LBB), and the minimum calculated limiting velocity for ductile failure is 3430 rpm, item 2g of RG-1.14 is satisfied for ductile failure, assuming no cracks are present. Assuming that a rather large crack of 10" in length is present, item 2g is still satisfied for ductile failure, since the lowest calculated critical speed (3012 rpm) is higher than the LOCA overspeed of 1500 rpm.

Therefore, RG-1.14 acceptance criteria for ductile failure of the flywheels are satisfied.

Nonductile Failure Analysis

As provided in References 2 and 7, an approximate solution for the stress intensity factor for a radial, full-depth (i.e., through the full thickness of the flywheel plate) crack emanating from the bore of a rotating disk may be calculated by the following equation (Reference 16):

$$K_I = \frac{\rho\omega^2}{386.4} b^{5/2} \phi \left[\frac{\pi\left(\frac{c}{b} - \frac{a}{b}\right)}{(1-\nu^2)} \right]^{1/2}$$

Equation 7

where:

$$\phi = \frac{(3+\nu)}{32}\left[3\left(1+\frac{a^2}{b^2}\right)+3\left(\frac{a}{b}\right)\left(\frac{b}{c}\right)+\left(1+\frac{a}{b}+\frac{a^2}{b^2}\right)\frac{\left(1-\frac{a}{b}\right)}{\left(1-\frac{c}{b}\right)}\right]$$

$$-\left(\frac{1+3\nu}{32}\right)\left[\frac{\left(\frac{c}{b}\right)^3-\left(\frac{a}{b}\right)^3}{\left(\frac{c}{b}-\frac{a}{b}\right)}+\frac{1}{3}\frac{\left(1-\frac{a}{b}\right)^3}{\left(1-\frac{c}{b}\right)}\right]$$

Equation 8

where:

ρ	=	flywheel material density (lb_m per $inch^3$)
ω	=	flywheel angular speed (radians per second)
b	=	flywheel outer radius (inches)
a	=	flywheel inner radius (inches)
c	=	radial location of crack tip (inches)
ν	=	Poisson's ratio (0.3)

In the Reference 7 analysis, the keyway radial length was initially assumed to be included as part of the total crack length for conservatism. Using the closed-form solution, a non-zero value of stress intensity was obtained for a zero crack length at the keyway (i.e., c = a + keyway radial length), as would be expected, since the keyway itself was in essence considered to be a crack. To eliminate this undue conservatism for short crack lengths, a finite element analysis was performed. It was shown that cracks emanating from the center of the keyway yielded higher stress intensity factors than cracks emanating from the keyway corner, and that a zero length crack resulted in a zero stress intensity factor. The finite element analysis results were in close agreement with the closed-form solution for crack lengths larger than about 1.0 inch.

It was also shown in the Reference 7 analysis that the ductile failure mode controls for smaller crack lengths (less than 1.15 inches for the particular flywheel evaluated), and that nonductile failure controls for larger crack lengths.

Therefore, the closed-form solution was used for calculation of the stress intensity factors in this report, keeping in mind that it is overly conservative for small cracks. However, small cracks are controlled by the ductile failure mode.

To envelope the range of RT_{NDT} values for the flywheel materials, an upper and lower bound value of 0°F and 60°F were used in this report. The lower bound fracture toughness for ferritic steels was calculated by the following equation from the 1995 Edition of the ASME Boiler and Pressure Vessel Code Section XI (Reference 6):

$$K_{IC} = 33.2 + 20.734 \exp[0.02(T - RT_{NDT})]$$ **Equation 9**

This resulted in fracture toughness values of 117 ksi sqrt inch and 58.5 ksi sqrt inch for RT_{NDT} values of 0°F and 60°F, respectively, at an ambient temperature of 70°F. The ambient temperature used for the fracture evaluation represents a much lower temperature than would be expected in the containment building during normal plant operating conditions (typically 100°F to 120°F), and is therefore conservative with respect to nonductile failure analysis.

At the maximum flywheel overspeed condition of 1500 rpm (considering LBB), the following critical crack lengths were calculated for cracks emanating radially from the keyway. Note that an intermediate RT_{NDT} value of 30°F (K_{IC} = 79.3 ksi sqrt inch) is included in the table. Note also that the crack length is measured radially from the keyway, and the percentage through the flywheel is calculated as the crack length divided by the radial length from the maximum radial keyway location to the flywheel outer radius. As shown in the table, the critical crack lengths are quite large, even when considering higher values of RT_{NDT} and a lower than expected operating temperature.

Table 2-7: 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%)

Fatigue Crack Growth

To estimate the magnitude of fatigue crack growth during plant life, an initial radial crack length of 10% through the flywheel (from the maximum keyway radial location to the flywheel outer radius) was conservatively assumed. The fatigue crack growth rate may be characterized in terms of the range of applied stress intensity factor, and is generally of the form, per Reference 6:

$$\frac{da}{dN} = C_0 (\Delta K_I)^n$$ **Equation 10**

where:
- da/dN = crack growth rate (inches/cycle)
- n = slope of the log (da/dN) versus log (ΔK_I)
- C_0 = scaling constant

The fatigue crack growth behavior is affected by the R ratio (K_{min}/K_{max}, where $0 \leq R < 1.0$) and the environment. Reference fatigue crack growth behavior of carbon and low alloy ferritic steels exposed to an air environment is provided by the above equation with n = 3.07 and $C_0 = 1.99 \times 10^{-10}$ S.

S is a scaling parameter to account for the R ratio and is given by $S = 25.72\,(2.88 - R)^{-3.07}$

Since the maximum stress intensity range occurs between RCP shutdown (zero rpm) and the normal operating speed of approximately 1200 rpm, the R ratio is zero, and S = 1.0. The fatigue crack growth rate for the flywheels may therefore be estimated by:

$$\frac{da}{dN} = 1.99 \times 10^{-10} (\Delta K_I)^{3.07}$$ **Equation 11**

Assuming 6000 cycles of RCP starts and stops for a 60-year plant life (typical for RCP design including the potential for extended plant life, and conservative for actual operation), the estimated radial crack growth is as shown below. As shown, crack growth is negligible over a 60-year life of the flywheel, even when assuming a large initial crack length.

Table 2-8: Fatigue Crack Growth Assuming 6000 RCP Starts and Stops

Flywheel Evaluation Group	Flywheel OD (Inches)	Flywheel Bore (Inches)	Keyway Radial Length (Inches)	Length from Keyway to OD (Inches)	Assumed Initial Crack Length (Inches)	K_I (Ksi sqrt inch)	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

Excessive Deformation Analysis

The change in the bore radius (a) and the outer radius (b) of the flywheel at the overspeed condition may be estimated by the following equations from Reference 15:

$$\Delta a = \frac{1}{4}\frac{\rho\omega^2}{386.4}\frac{a}{E}[(3+\nu)b^2 + (1-\nu)a^2]$$ **Equation 12**

$$\Delta b = \frac{1}{4}\frac{\rho\omega^2}{386.4}\frac{b}{E}[(1-\nu)b^2 + (3+\nu)a^2]$$ **Equation 13**

where:
- a = bore radius (inches)
- b = outer radius (inches)
- ρ = flywheel material density (0.283 $lb_m/inch^3$)
- ω = flywheel angular speed (radians per second)
- E = Young's modulus (30×10^6 psi)
- ν = Poisson's ratio (0.3)

At the flywheel overspeed condition of 1500 rpm (157.08 radians/second), the change in the bore radius and the outer radius is calculated as shown below:

Table 2-9: 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

As shown in the table above, a maximum flywheel deformation of only 0.006 inch is anticipated for the flywheel overspeed condition. As deformation is proportional to ω^2, this represents an increase of 56% over the normal operating deformation. This increase would not result in any adverse conditions, such as excessive vibrational stresses leading to crack propagation, since the flywheel assemblies are typically shrunk fit to the flywheel shaft, and the deformations as calculated are negligible.

Summary of Stress and Fracture Results

The deterministic integrity evaluations presented in this section have shown that the RCP motor flywheels have a very high tolerance for the presence of flaws. The results obtained here are even better than those obtained in earlier evaluations (Reference 7), because the application of Leak-Before-Break (LBB) has demonstrated that flywheel overspeed events are limited to less than the design speed of 1500 rpm. *Note however that the probabilistic assessment discussed later in this report evaluates all credible flywheel speeds.*

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. Fatigue crack growth calculations have shown that for 60 years of operation, crack growth from large postulated flaws is only a few mils. Therefore, based on these deterministic evaluations, the flywheel inspections completed prior to service are sufficient to ensure their integrity during service. In fact, the most likely source of inservice degradation is damage to the keyway region that could occur during disassembly or reassembly for inspection, as discussed previously.

3. RISK ASSESSMENT

The quantitative risk assessment discussed below shows that extending the inspection interval from 10 to a maximum of 20 years has negligible impact on risk (CDF and LERF), i.e., that it is within the bounds of RG-1.174 (Reference 4). A discussion on the requirements of the RG-1.174, and the previous flywheel failure probability assessment of Reference 2 are included.

3.1 RISK-INFORMED REGULATORY GUIDE 1.174 METHODOLOGY

The NRC has developed a risk-informed regulatory framework. The NRC definition of risk-informed regulation is: "insights derived from probabilistic risk assessments are used in combination with deterministic system and engineering analysis to focus licensee and regulatory attention on issues commensurate with their importance to safety."

The NRC issued RG-1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Current Licensing Basis" (NRC, 1998). In addition, the NRC issued application-specific regulatory guides (RGs) and standard review plans (SRPs):

- RG-1.175 and SRP Chapter 3.9.7, related to inservice testing (IST) programs,
- RG-1.176, related to graded quality assurance (GQA) programs,
- RG-1.177 and SRP Chapter 16.1, related to technical specifications, and
- RG-1.178 and SRP-3.9.8, related to inservice inspection of piping programs.

These RG and SRP chapters provide guidance in their respective application-specific subject areas to reactor licensees and the NRC staff regarding the submittal and review of risk-informed proposals that would change the licensing basis for a power reactor facility.

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 basic steps are discussed below.

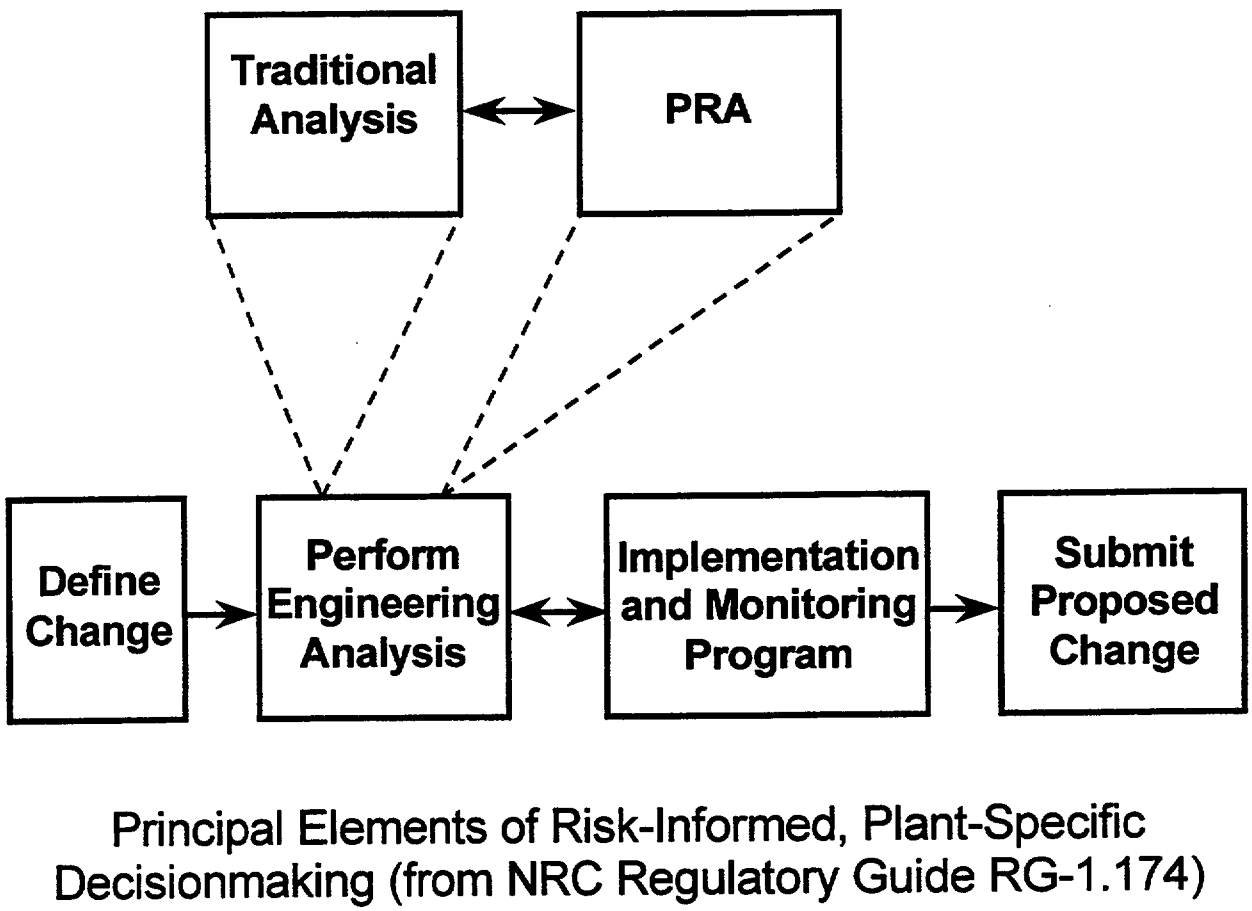

Figure 3-1: NRC Regulatory Guide 1.174 Basic Steps

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 core damage frequency (CDF) and large early release frequency (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 fundamental safety principles are described which each application for a change should meet. These are shown in Figure 3-2, and are discussed below.

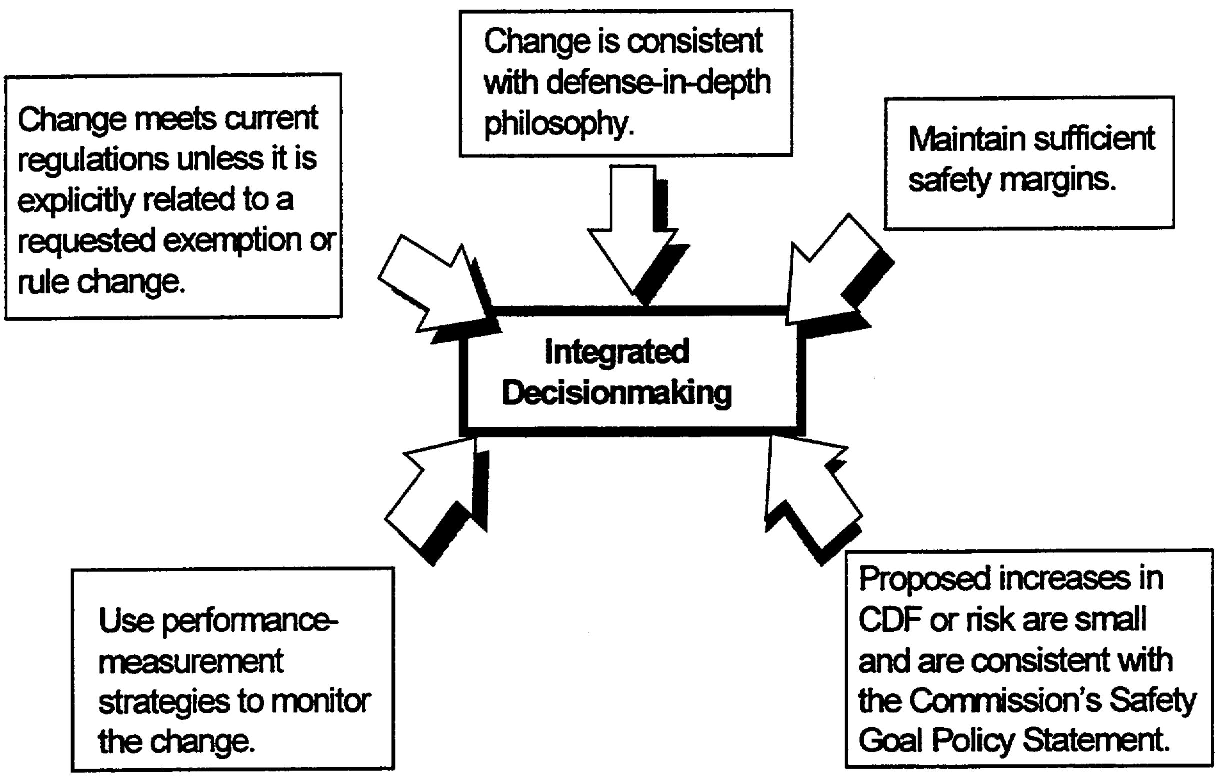

Figure 3-2: Principles of Risk Informed Regulation (from NRC RG-1.174)

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 Commission's 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 being less than 10^{-6} per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF (Region III).
- 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 (Region II).
- Applications which result in increases to CDF above 10^{-5} per reactor year (Region I) 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 (Region III).
- 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 (Region II).
- Applications which result in increases to LERF above 10^{-6} per reactor year (Region I) 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: Use 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 WCAP-14535A (Reference 2), is not considered in the assessment. This is because the purpose of the assessment is to support interval extension, which will eliminate unnecessary occurrences for introducing potential damage.

As discussed in WCAP-8163 (Reference 7), the normal operating speed of the RCP motor flywheel 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 percent of the synchronous speed. The flywheel speed can be altered, however, as a result of plant events, including accidents such as a double-ended guillotine break (DEGB) in the main reactor coolant loop piping.

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 usually 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 PWR plants assures that the electrical power supply to the RCP will be maintained for at least 30 seconds after the turbine trip following a LOCA. This situation is true for the assumption of loss of off-site 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.

Per WCAP-8163, and as shown in Table 3-1, several sensitivity studies have been performed to evaluate the effect of break opening areas on RCP flywheel speed. Break sizes equal to DEGB, 60% of DEGB, and 3 ft^2 have been analyzed. (Note that a 3 ft^2 break size corresponds to a pipe approximately 23 inches in inside diameter; the only RCS pipes greater than this size are those associated with the main coolant loop piping.) The first two breaks have blowdown times equal to or less than the RCP trip time; 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. Hence, smaller breaks are not limiting even though the voltage is maintained for only 30 seconds.

To investigate consequences of even less likely sequences of events, the three break opening cases mentioned above have been analyzed with the assumption that power is removed at the instant of rupture. Peak speeds of 2609 rpm for the 60% DEGB area and 3321 rpm for the DEGB have been calculated. The 3 ft^2 area case showed a decrease in speed such that normal operating speed is not exceeded. Another case was analyzed corresponding to a complete DEGB in an inactive loop during 3-loop operation of a 4-loop plant. The peak speed has been calculated to 2965 rpm for this unlikely sequence of events. However, since Westinghouse plants have not operated with N-1 loop conditions, this case is not considered in the risk evaluation.

Additional sensitivity studies for various cross-sectional area openings assuming longitudinal split geometry have also been performed. Where electrical power is available, the calculated speed does not exceed 1200 rpm. Where the assumption of an instantaneous loss of power is made, the speed still remains below 1200 rpm. Some other cases dealing with variation in the mechanical inertia of the RCP and in fluid density have also been analyzed. However, the results are represented by the above evaluations.

Table 3-1: Summary of LOCA Speed Calculations for Westinghouse Plants

Case No.	Description	Peak Speed (rpm)
1	4 Loop plant, double ended break, RCP trip after 30 seconds	1248
2	Case 1 with instantaneous power loss	3321
3	Case 1 with instantaneous power loss and break area equal to 60% of double-ended break area	2609
4	Case 3 with break area equal to 3.0 ft^2	1189
5	Case 3 with break area equal to 0.5 ft^2	1189
6	Case 3 for a 3 loop plant	2330
7	Case 2 with moment of inertia increased by 10%	3200
8	Case 1 with moment of inertia increased by 10%	1248
9	Case 1 with loop out of service	2965
10	Case 1 with longitudinal split break areas of 0.5 ft^2, 3.0 ft^2 and pipe cross sectional area	1200
11	Case 10 with instantaneous power loss	1200

Therefore, the following scenarios are associated with the primary mode of potential failure in the 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 given 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 given 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 given a DEGB coincident with an instantaneous loss of electrical power, such as loss of offsite power (LOOP) (3321 rpm peak speed). This bounds Cases 3 and 6 in Table 3-1 because there are no equivalent reactor coolant pipe sizes 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 mentioned previously, 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. Failure of these other SSCs could present a threat to 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).

Initial investigations have been performed to determine if any SSCs important to plant safety may pass through the RCP compartments in Westinghouse PWR plants. These investigations indicate that there is not much uniformity with respect to the layout of critical targets that potential flywheel fragments could impact given its failure. In order to address this situation on a generic basis, it is conservatively assumed that failure of the RCP motor flywheel results in core damage and large early release, i.e., the flywheel failure frequency is equal to core damage frequency (CDF) and large early release frequency (LERF).

Section 3.3 now describes 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 from 10 years to 20 years.

3.3 FLYWHEEL FAILURE PROBABILITY

To investigate the effect of flywheel inspections on the risk of failure, a structural reliability and risk assessment is performed. A 40-year plant life including the potential for an extended plant life of 60 years, and 12 month operating cycles are assumed for the evaluation. This section describes the methodology used and summarizes the results from this assessment.

As described in Section 3.2, the RCP has a normal operating speed of 1189 rpm, a synchronous speed of 1200 rpm, and a design speed of 1500 rpm, per WCAP-8163 (Reference 7). 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 makes use of work previously performed and summarized in WCAP-14535A (Reference 2), where the 1500 rpm design speed had been assumed based on arguments that were appropriate for the evaluation that was performed at that time. The evaluation in WCAP-14535A was completed prior to the issuance of RG-1.174 (Reference 4) and the companion Standard Review Plan 19.0 (Reference 5). These documents have additional requirements, including the consideration of all credible flywheel speeds, accounting for the probability of events that result in those speeds. The guidance of these more recent documents is followed for the current risk assessment summarized in this report.

Method of Calculating Failure Probabilities

The probability of failure of the RCP motor flywheel as a function of operating time t, $Pr(t < t_f)$, 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 (Reference 8), is a variance reduction technique to greatly reduce the number of trials required for calculating small failure probabilities. In this very effective technique, random values are selected from the more severe high or low regions of their distributions so as to promote failure. However, when failure is calculated, the count is corrected to account for the lower probability of simultaneously obtaining all of the more severe random values.

To apply this simulation method to RCP motor flywheel failure, the existing Westinghouse PROF (probability of failure) Software System (object library) is combined with the problem-specific structural analysis models described previously in Reference 2. The PROF library provides standard input and output, including plotting, and probabilistic analysis capabilities (e.g. random number generation, importance sampling). The result is the executable program RPFWPROF.EXE for calculation of RCP motor flywheel failure probability with time. The failure mode being simulated by the program is an initial flaw, undetected during pre-service inspection, growing by fatigue crack growth due to RCP startup and shutdown until a critical length is obtained. The critical length is that which causes the stress intensity factor of the flaw due to RCP overspeed during the design-limiting event to exceed the fracture toughness of the flywheel material.

The Westinghouse PROF Software Library, which was used to generate the RPFWPROF program, has been verified and benchmarked in a number of ways. Table 3-2 provides a comparison of probabilities from a hand calculation for simple models where the only random variables are the initial and limiting crack depths. The crack growth due to two independent mechanisms is deterministic (variables are constant). As can be seen, the W-PROF calculated values agree very well (less than 4% error) for a number of different distributions and with the effects of importance sampling.

Table 3-2: Simple Verification of Results for Westinghouse PROF Methods

Type of Distribution on Crack Depths (1)	Importance Sampling Shift (2)	Hand Calculated Probability (3)	W-PROF Calculated Probability	Percent Error
Normal	0.0	0.1003	0.10004	-0.26
Normal	+ 1.0	0.1003	0.09889	-1.41
Log-Normal	0.0	0.1003	0.09880	-1.50
Log-Normal	+ 1.0	0.1003	0.09652	-3.77
Uniform	0.0	0.1003	0.10393	+3.62
Log-Uniform	0.0	0.1003	0.10018	-0.12
Weibull	0.0	0.0950	0.0934	-1.68

(1) Same type of distribution on random values of initial crack depth and limiting crack depth.

(2) Median value of initial depth shifted +1 standard deviation and median value of limiting depth shifted -1 standard deviation when importance sampling (Reference 8) is used with less than half the number of trials.

(3) Calculated using stress-strength overlap techniques on crack depth.

The calculation of failure probability using the W-PROF methods and importance sampling was also compared to that calculated by an alternative method for more complex models. The more complex model also included the uncertainties in growth rate, which were also a function of the crack depth. The alternative method was the @RISK add-in for Lotus 1-2-3 spreadsheets (Reference 9). As seen in Figure 3-3, the comparison of calculated probabilities is excellent at the low probability values, where importance sampling is normally used.

The piping structural reliability and risk assessment (SRRA) programs for risk-informed in-service inspection (Reference 10) also use the same W-PROF methods and have been verified in a number of ways, including comparison with available failure data. Initially, the SRRA calculated small leak probabilities for thermal transient induced fatigue crack growth were compared with results from the pc-PRAISE program (Reference 11). This program, which was developed by Lawrence Livermore National Laboratory for the NRC, is the benchmark standard for calculating the structural reliability of piping. As can be seen in Table 3-3, the comparison of calculated leak probabilities with the number of operating cycles (years), with and without the effects of inspection, was found to be excellent. In addition, the piping SRRA software was also extensively benchmarked by comparison of the SRRA results with independent calculations. Table 3-4 describes the parameters that were used to benchmark some of the piping SRRA model results with pc-PRAISE (Reference 11) for the three failure modes of interest: 1) small leak (through-wall crack), 2) large (system disabling) leak and 3) full break (unstable fracture). Deterministic analyses and comparisons of fatigue crack growth rates with time were also made and found to be similar for several of the cases. Figure 3-4 shows the comparison of the calculated probabilities by the SRRA program LEAKPROF and pc-PRAISE programs after 40 years of operation. As can be seen, the calculated values from the probabilistic fracture mechanics analyses for 40 years of operation agree very well. No changes in the SRRA models were required to obtain such good agreement with pc-PRAISE. More trials (Monte-Carlo simulations) and greater importance sampling were used for better accuracy in calculating the very low values of failure probability.

Table 3-3: Comparison of Small Leak Failure Probabilities

Number of Cycles	No Inservice Inspection		With Inservice Inspection	
	pc-PRAISE	SRRA	pc-PRAISE	SRRA
8	4.55E-4	4.17E-4	4.55E-4	4.18E-4
16	6.28E-4	5.74E-4	5.07E-4	4.58E-4
24	8.09E-4	7.28E-4	5.14E-4	4.85E-4
32	9.54E-4	1.02E-3	5.15E-4	5.05E-4
40	1.05E-3	1.19E-3	5.15E-4	5.14E-4

Table 3-4: Parameters Used for the SRRA Benchmarking Study

Type of Parameter	Low Value	High Value
Pipe Material	Ferritic	Stainless Steel
Pipe Size	6.625" OD, 0.562" Wall	29.0" OD, 2.5" Wall
Failure Modes	Small Leak, Through-Wall Crack	Full Break, Unstable Fracture
Last Pass Weld Inspection	No x-ray	Radiographic
Pressure Loading	1000 psi	2235 psi
Low-Cycle Loading	25 ksi Range, 10 cycles/year	50 ksi Range, 20 cycles/year
High-Cycle*Loading	1 ksi Range, 0.1 cycles/min.	20 ksi Range, 1.0 cycles/sec.
Design Limiting Stress	15 ksi	30 ksi
Disabling Leak Rate	50 gpm	500 gpm
Detectable Leak Rate	None	3 gpm

*Notes: Mechanical Vibration (low stress range and high frequency) for small pipe
Thermal Fatigue (high stress range and low frequency) for large pipe

Therefore, it is concluded that the Westinghouse methods employed in calculating probabilities with the RPFWPROF.EXE program have been sufficiently verified and benchmarked for the assessment of RCP motor flywheel failure risk and the effects of inspection.

The input to the RPFWPROF program, which is described in Table 3-5, includes the key parameters needed for failure probability calculation. Its usage in the program is specified as shown in the last column of Table 3-5 and schematically in the flow chart of Figure 3-5. "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) such as external events (e.g., seismic or failure of other RCP components). Thus, inclusion of this parameter is used to support the proposed RCP motor flywheel ISI interval.

Table 3-5: 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 Cycles 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 inservice inspection (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 (Reference 11). They are somewhat optimistic since there is no correlation between successive inspections of the same material, which may systematically occur in actual practice. 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 in Table 3-5. 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 3-5 are shown in Table 3-6. 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 judgement and previous structural reliability modeling experience. For example, the fracture toughness for initiation as a function of the reference nil-ductility transition temperature and the uncertainties on these parameters are based upon prior probabilistic fracture mechanics analyses of the pressure vessel (Reference 12). Also note that the stress intensity factor calculation for crack growth and failure used the flywheel keyway radial length (variable 17) in addition to the calculated flaw length. This allowed the probabilistic models to be checked using the results of the conservative deterministic evaluations of Tables 2-7 and 2-8.

Table 3-6: 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	Normal	1.200E+02
11	RATE-FCG	9.950E-11	Log-Normal	1.414E+00
12	KEXP-FCG	3.070E+00	Constant	
13	RPM-DLE	1.500E+03	Normal	1.500E+02
14	TEMP-F	9.500E+01	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	

* Note: Uncertainty is either the normal standard deviation, the range (median to maximum) for uniform distributions or the corresponding factor for logarithmic distributions.

Table 3-7 provides sample output from the RPFWPROF Program for the values of the input variables in Table 3-6. The first page of the output describes the input that is used for the calculations. The "SHIFT MV/SD" column indicates how many standard deviations (SD) the median value (MV) is shifted for importance sampling (Reference 8). The second page of the output provides the change in failure probability per fuel (operating) cycle and the cumulative probability. The deviation on the cumulative total that is output is the deviation due to the Monte-Carlo simulation only. Figure 3-6 shows a plot comparing the calculated RCP motor flywheel failure probabilities with and without the effects of inservice inspection. As can be seen, the effect of ISI, even with a 50% probability of detection, is very small. This is because the failure probability is not changing much with time; therefore, the rate of increase cannot be significantly reduced even for a perfect inspection with 100% probability detection.

Table 3-7: Example Output from the RPFWPROF Program

```
                    STRUCTURAL RELIABILITY AND RISK ASSESSMENT (SRRA)
WESTINGHOUSE            PROBABILITY OF FAILURE PROGRAM RPFWPROF               ESBU-NTD
=====================================================================================
     INPUT VARIABLES FOR CASE  1: REACTOR COOLANT PUMP FLYWHEEL FAILURE

     NCYCLE =    60           NFAILS =  1000            NTRIAL =  9999
     NOVARS =    17           NUMSET =     4            NUMISI =     4
     NUMSSC =     0           NUMIRC =     4            NUMFMD =     5

  VARIABLE       DISTRIBUTION      MEDIAN      DEVIATION     SHIFT    USAGE
 NO.   NAME      TYPE      LOG     VALUE       OR FACTOR     MV/SD   NO. SUB

  1  ORADIUS    - CONSTANT -    3.6000D+01                             1  SET
  2  IRADIUS    - CONSTANT -    8.0625D+00                             2  SET
  3  PFE-PSI    - CONSTANT -    1.0000D-01                             3  SET
  4  ILENGTH    NORMAL   YES    1.0000D-01    2.1528D+00      1.00     4  SET
  5  CY1-ISI    - CONSTANT -    3.0000D+00                             1  ISI
  6  DCY-ISI    - CONSTANT -    4.0000D+00                             2  ISI
  7  POD-ISI    - CONSTANT -    5.0000D-01                             3  ISI
  8  DFP-ISI    - CONSTANT -    0.0000D+00                             4  ISI
  9  NOTR/CY    NORMAL   NO     1.0000D+02    1.0000D+01       .00     1  TRC
 10  DRPM-TR    NORMAL   NO     1.2000D+03    1.2000D+02      1.00     2  TRC
 11  RATE-FCG   NORMAL   YES    9.9499D-11    1.4142D+00      1.00     3  TRC
 12  KEXP-FCG   - CONSTANT -    3.0700D+00                             4  TRC
 13  RPM-DLE    NORMAL   NO     1.5000D+03    1.5000D+02      1.00     1  FMD
 14  TEMP-F     NORMAL   NO     9.5000D+01    1.2500D+01     -2.00     2  FMD
 15  RT-NDT     NORMAL   NO     3.0000D+01    1.7000D+01      2.00     3  FMD
 16  F-KIC      NORMAL   NO     1.0000D+00    1.0000D-01     -1.00     4  FMD
 17  DLENGTH    - CONSTANT -    9.0600D-01                             5  FMD
```

Table 3-7: Example Output from the RPFWPROF Program (Cont'd.)

PROBABILITIES OF FAILURE MODE: FATIGUE CRACK GROWTH SIF > TOUGHNESS

NUMBER FAILED = 470 NUMBER OF TRIALS = 9999

END OF CYCLE	FAILURE PROBABILITY WITHOUT FOR PERIOD	AND CUM. TOTAL	WITH IN-SERVICE INSPECTION FOR PERIOD	CUM. TOTAL
1.0	9.00777D-08	9.00777D-08	9.00777D-08	9.00777D-08
2.0	1.00713D-08	1.00149D-07	1.00713D-08	1.00149D-07
3.0	8.70982D-11	1.00236D-07	8.70982D-11	1.00236D-07
11.0	3.56616D-11	1.00272D-07	8.91540D-12	1.00245D-07
12.0	9.40206D-13	1.00273D-07	1.17526D-13	1.00245D-07
13.0	2.17369D-11	1.00294D-07	2.71711D-12	1.00248D-07
14.0	4.71179D-10	1.00766D-07	5.88974D-11	1.00307D-07
18.0	2.91939D-10	1.01058D-07	1.82462D-11	1.00325D-07
19.0	1.59524D-09	1.02653D-07	9.97024D-11	1.00425D-07
24.0	6.00973D-12	1.02659D-07	9.39020D-14	1.00425D-07
26.0	2.07667D-11	1.02680D-07	3.24480D-13	1.00425D-07
31.0	1.30332D-09	1.03983D-07	1.01822D-11	1.00435D-07
32.0	2.87692D-11	1.04012D-07	1.12380D-13	1.00435D-07
34.0	1.81125D-11	1.04030D-07	7.07521D-14	1.00435D-07
35.0	1.30472D-10	1.04160D-07	5.09655D-13	1.00436D-07
38.0	1.12340D-10	1.04273D-07	2.19414D-13	1.00436D-07
40.0	2.93218D-11	1.04302D-07	2.86346D-14	1.00436D-07
46.0	8.71264D-11	1.04389D-07	4.25422D-14	1.00436D-07
47.0	1.12251D-10	1.04501D-07	5.48099D-14	1.00436D-07
50.0	7.94921D-11	1.04581D-07	1.94072D-14	1.00436D-07
51.0	5.07795D-12	1.04586D-07	1.23973D-15	1.00436D-07
52.0	2.88193D-12	1.04589D-07	3.51798D-16	1.00436D-07
54.0	4.48702D-10	1.05037D-07	5.47732D-14	1.00436D-07
55.0	1.17426D-11	1.05049D-07	1.43343D-15	1.00436D-07
58.0	9.35600D-11	1.05143D-07	5.71045D-15	1.00436D-07
59.0	2.43375D-11	1.05167D-07	1.48544D-15	1.00436D-07
60.0	0.00000D+00	1.05167D-07	0.00000D+00	1.00436D-07
	DEVIATION ON CUMULATIVE TOTALS =		4.73585D-09	4.63324D-09

Note: Failure probabilities are provided in double precision format

(e.g., 4.28172D-08 is 4.28172×10^{-8})

Evaluations were performed to determine the effect on the probability of flywheel failure for continuing the current inservice inspections over the life of the plant and for discontinuing the inspections. Since most plants have been in operation for at least ten years, the evaluation also calculated the effects of the inspections being discontinued after ten years. This calculation would bound the effects of any subsequent inservice inspections at 10 to 20 year intervals.

It is important to keep in mind that the probability of failure determined by these evaluations is only a calculated parameter. The reason for this is that the evaluation conservatively assumes that the probability of a flaw existing after preservice inspection is 10%, and that the ISI flaw detection probability is only 50%. In reality, most preservice and ISI flaws would be detected, especially for the larger flaw depths which may lead to 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 to discontinuing the inservice inspections after ten years (cycles) of plant life.

As shown in Figures 3-7 and 3-8, the effect of inservice inspection on failure probability has little effect on minimizing the potential for failure of the flywheel. The results of this assessment are summarized as follows for a plant life of 40 and 60 years:

Table 3-8: Cumulative Probability of Failure over 40 and 60 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 40 and 60 Years	Over 40 Years	Over 60 Years	Over 40 Years	Over 60 Years
1	1500	2.45E-7	2.50E-7	2.57E-7	2	5
2	1500	1.43E-7	1.45E-7	1.47E-7	1	3
1	3321	1.01E-2	1.01E-2	1.02E-2	0	1
2	3321	0.91E-2	0.91E-2	0.91E-2	0	0

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

Note that for the limiting speed of 3321 rpm, the flywheel failure probability is between 1.01E-2 and 1.02E-2 from the first through the 60th year of operation for Flywheel Group 1. It is constant at 0.91E-2 from the first through the 60th year of operation for Flywheel Group 2.

Sensitivity Study

A sensitivity study was performed to determine the effect of some important flywheel risk assessment parameters on the probability of failure. The parameters evaluated included the probability of detection, the initial flaw length, and the initial flaw length uncertainty. The results of this study are summarized in the table below. Note that this study was performed for only 40 years of flywheel operation.

Table 3-9: Effect of Flywheel Risk Parameters on Failure Probability

Description of flywheel risk parameter varied	Probability of flywheel failure after 40 years with ISI prior to and after 10 years	Probability of flywheel failure after 40 years with ISI prior to 10 years and without ISI after 10 years
Base Case (Group 10 of Reference 2)	1.00E-7	1.04E-7
Probability of Detection of 10%	1.03E-7	1.04E-7
Probability of Detection of 80%	1.00E-7	1.04E-7
Initial flaw length of 0.05 inches	4.57E-8	4.74E-8
Initial flaw length of 0.20 inches	2.97E-7	3.01E-7
Ilength 3 Sigma Bound Factor of 3	6.40E-8	6.46E-8
Ilength 3 Sigma Bound Factor of 20	1.94E-7	1.95E-7

The values for the base case, shown in Table 3-9 above are for:

- 10% probability of a flaw existing after preservice inspection
- Initial flaw length of 0.10 inch (1.006 inch with keyway)
- Initial flaw length (Ilength) 3-sigma bound factor of 10
- Initial ISI at 3 years of plant life, and subsequent inspections at 4-year intervals
- Probability of detection of 50% per ISI (see Reference 2, Table 5-5, flywheel Group 10)

The flaw detection probability was varied from 50% to 10% and 80%. The failure probability increased approximately 3% for a decrease in flaw detection probability from 50% to 10%. The failure probability did not change 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 flywheel failure probability.

The initial flaw length was varied from 0.10 inch to 0.05 inch and 0.20 inches. The failure probability decreased by 54% for a decrease in initial flaw length from 0.10 inch to 0.05 inch. The failure probability tripled for an increase in initial flaw length from 0.10 inch to 0.20 inches. Therefore, the initial flaw length does affect flywheel failure probability, but the failure probability is small, even for larger initial flaw lengths. Moreover, the probability of the larger flaw being missed during preservice inspection would be even smaller than the assumed 10 percent.

The initial flaw length 3-sigma bound factor was varied from 10 to 3 and 20. The failure probability decreased about 38% for a decrease in the 3-sigma bound factor from 10 to 3. The failure probability increased about 90% for an increase in the factor from 10 to 20. Therefore, the uncertainty in the deviation factor does affect the flywheel failure probability, but the failure probability is still small, even for a higher 3-sigma bound factor of 20.

Failure Probability Assessment Conclusions

An evaluation of flywheel structural reliability was performed for each of the flywheel groups selected for evaluation, using methods that have been sufficiently verified and benchmarked.

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 for this are that most flaws that could lead to failure would be detected during preservice inspection or at worst early in the plant life, and 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 interval extension, which will eliminate unnecessary occurrences for introducing potential damage.

Sensitivity studies showed that improved flaw detection capability and more inspections result in a small relative change in calculated failure probability. 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 in Table 3-8 show that inspections after 10 years have a very minimal impact on the failure probabilities. These results would 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.

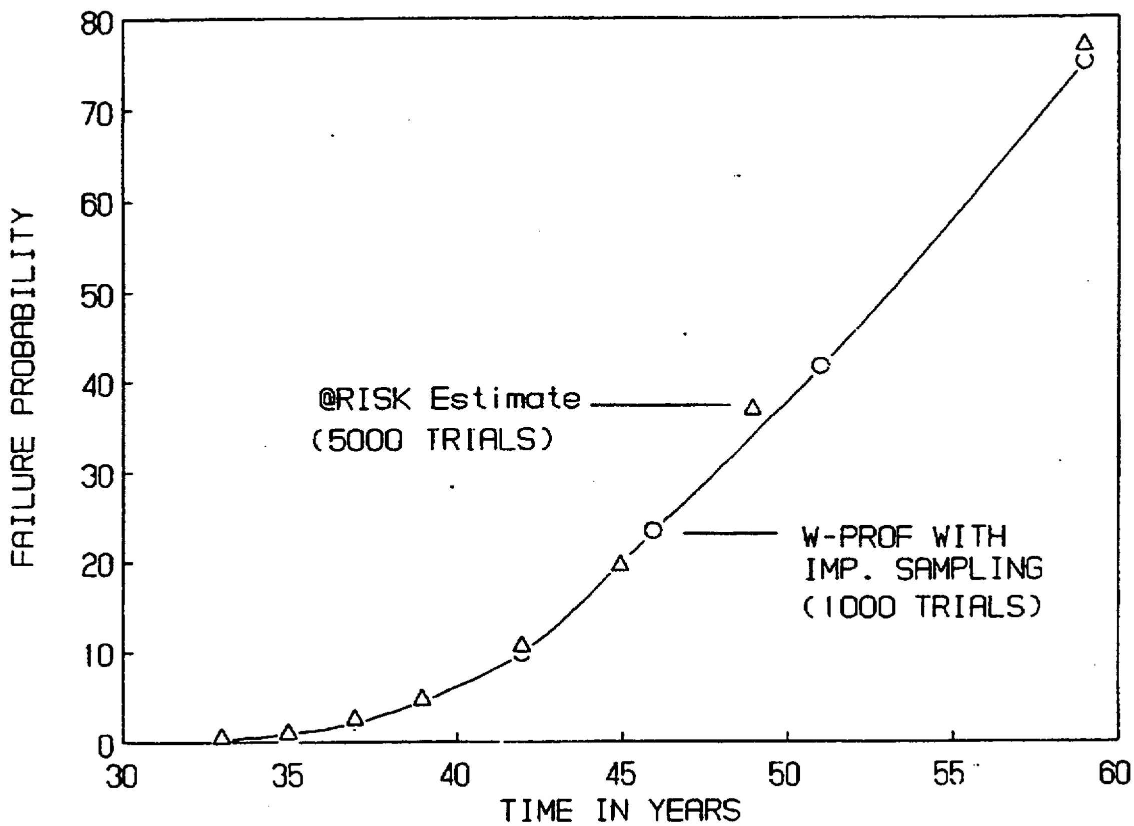

Figure 3-3: Importance Sampling Check of Westinghouse PROF Methods

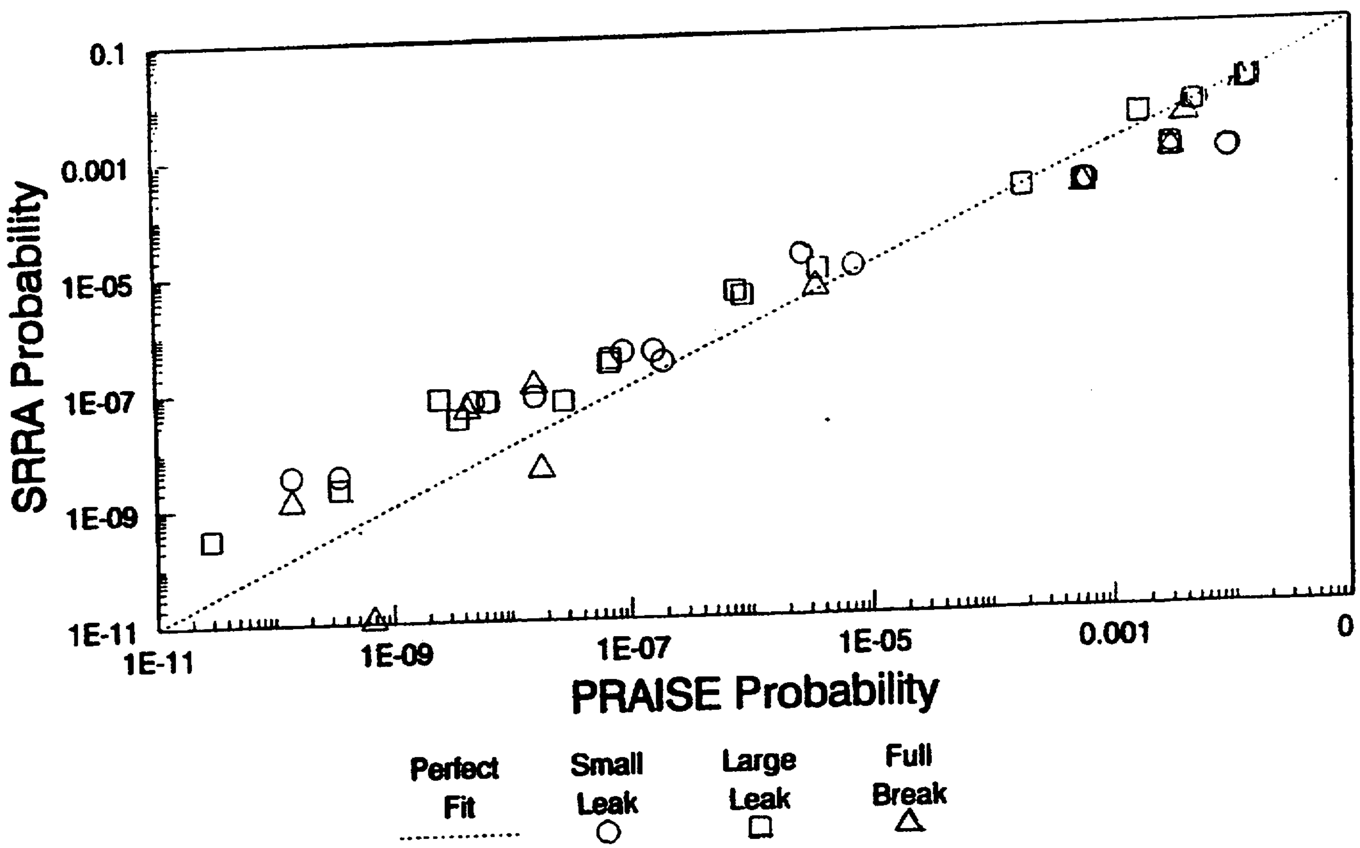

Figure 3-4: Results of the SRRA Benchmarking Study with pc-PRAISE

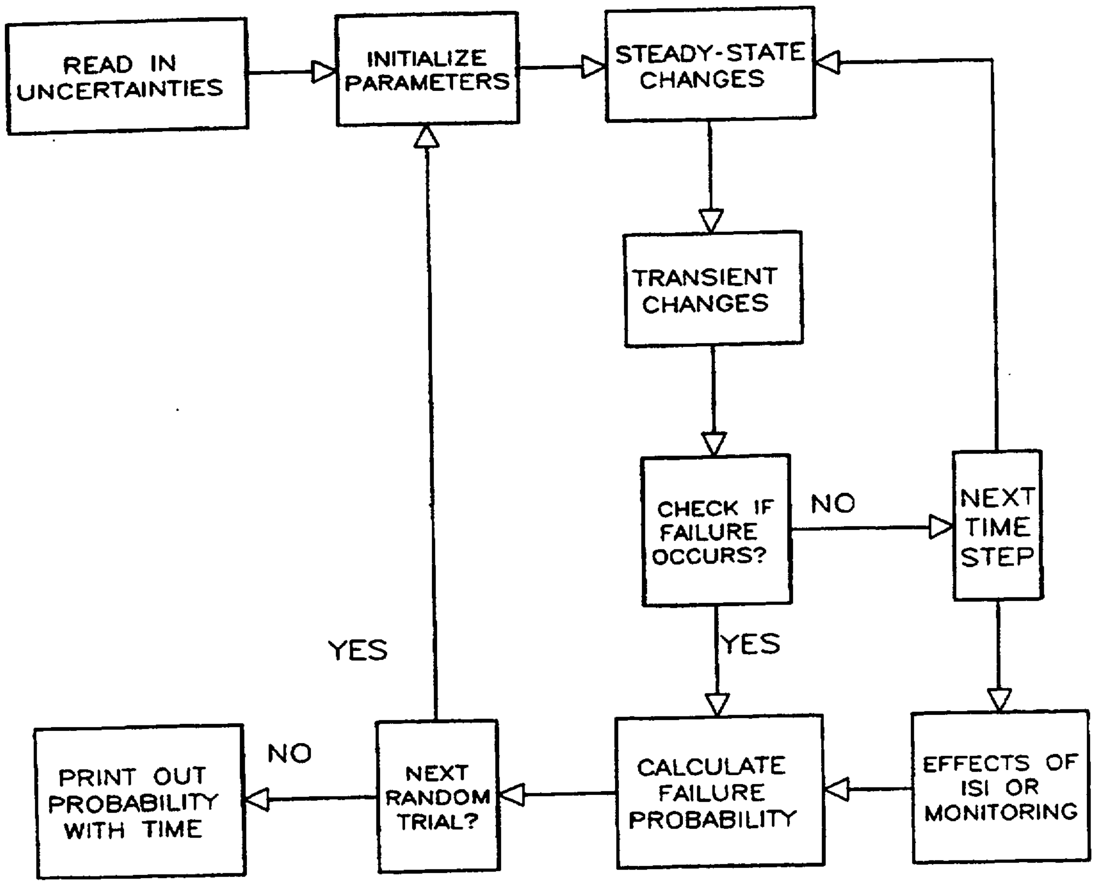

Figure 3-5: Westinghouse PROF Program Flow Chart for Calculating Failure Probability

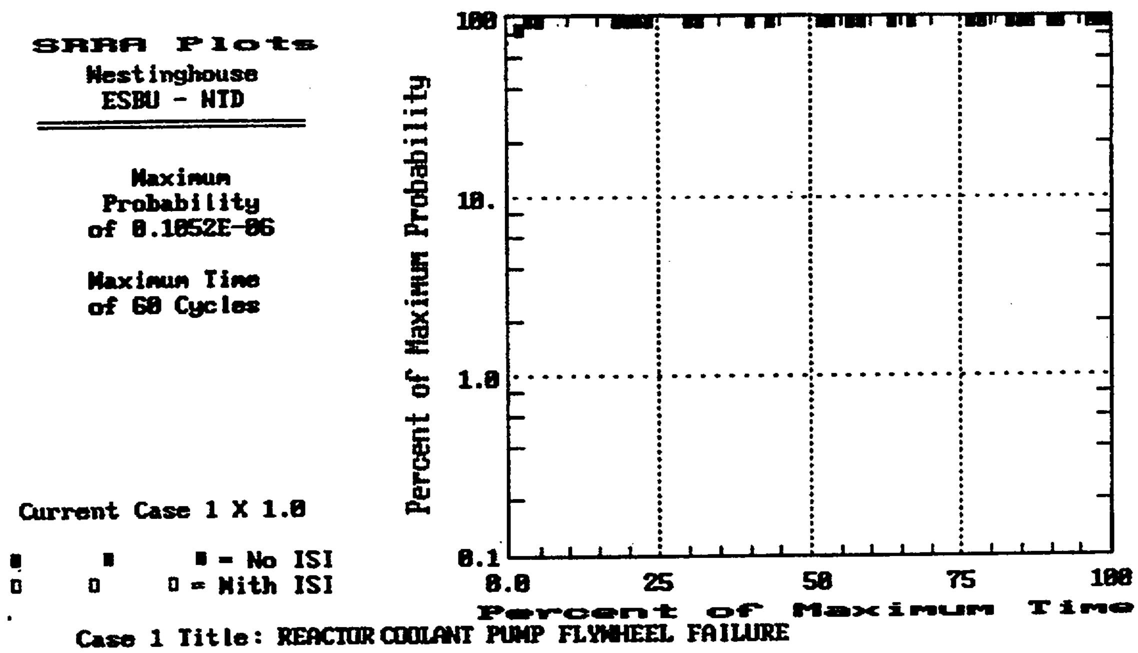

Figure 3-6: Computer SRRA Plot for RCP Motor Flywheel Failure Probability

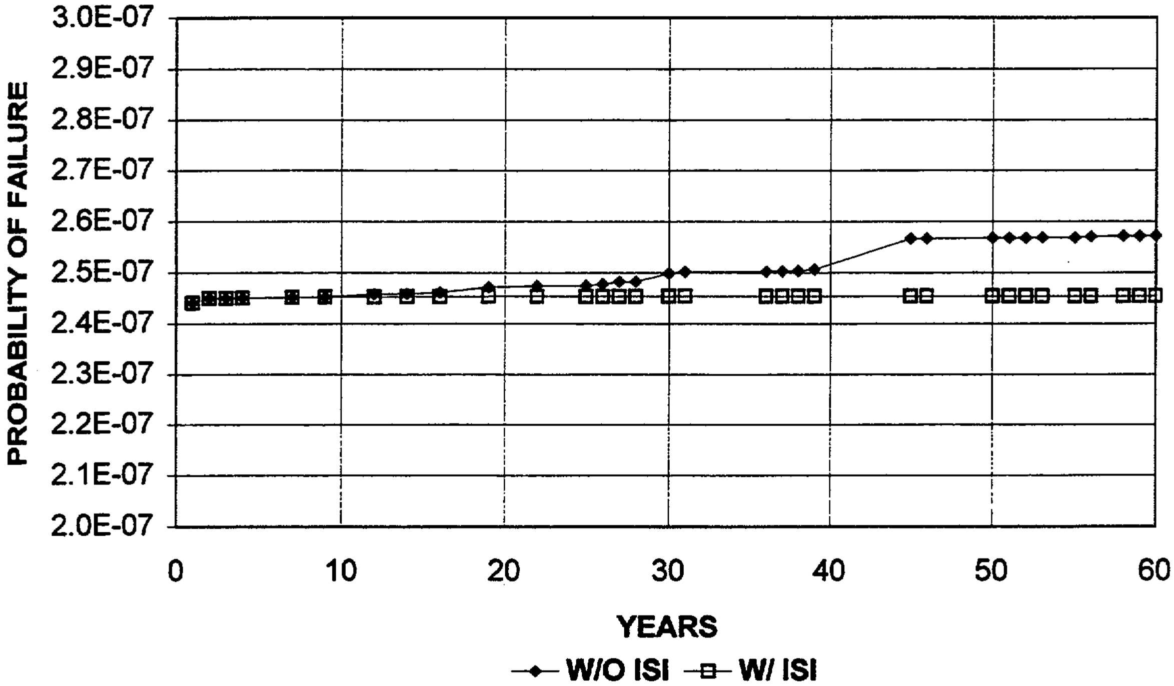

Figure 3-7: Probability of Failure for Flywheel Evaluation Group 1 (Considering LBB)

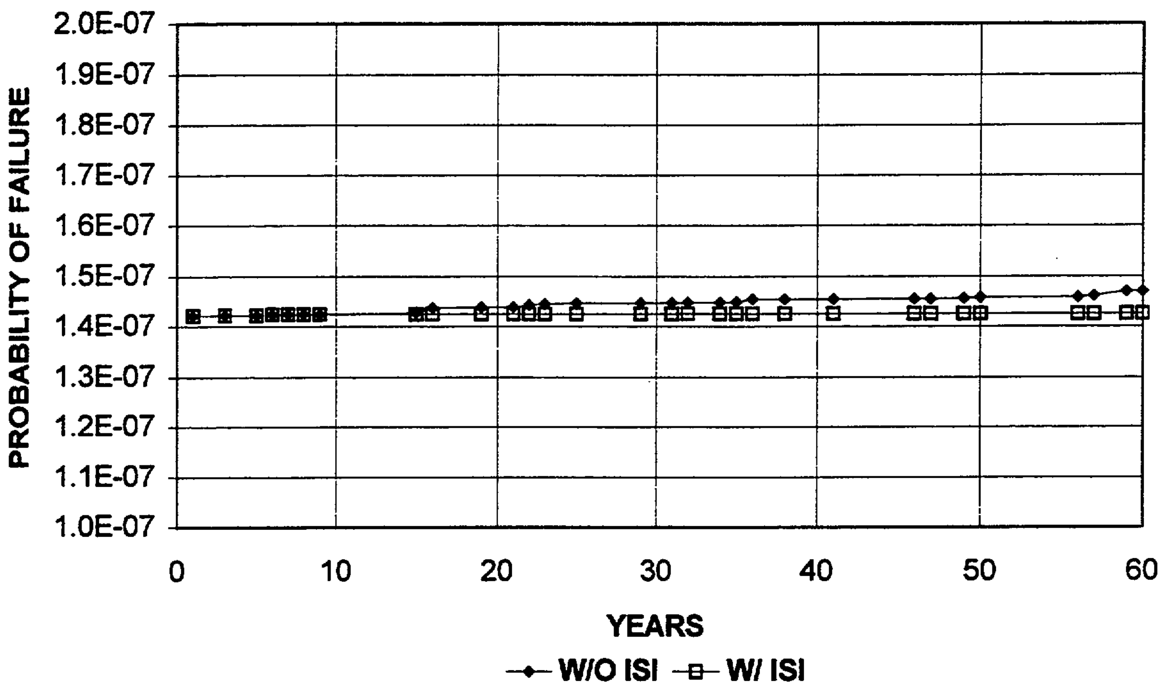

Figure 3-8: Probability of Failure for Flywheel Evaluation Group 2 (Considering LBB)

3.4 CORE DAMAGE RISK 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 relative to other plant risk contributors through a qualitative and quantitative evaluation.

The NRC issued RG-1.174 (Reference 4) in July 1998, which 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 describe 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 failure that are related to its operating speed and potential overspeed under certain conditions:

- Failure during normal plant operation resulting in a plant trip (1200 rpm peak speed)
- Failure of the RCP motor flywheel given 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 given 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 (1200 rpm peak speed)
- Failure of the RCP motor flywheel given a large LOCA (from a greater than 3 ft^2 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 rpm peak speed)

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 3-8 for the two flywheel evaluation groups that bound the other flywheel groups. The estimated failure probabilities for the different conditions are shown in Table 3-10 for Group 1 and Group 2.

Table 3-10: Estimated RCP Motor Flywheel Failure Probabilities

Flywheel Group and Condition*	Cumulative Probability of Flywheel Failure over 60 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	2.45E-07	2.57E-07
Group 1 – LOCA/LOOP	1E-02/year	1E-02/year
Group 2 – Normal/Accident	1.43E-07	1.47E-07
Group 2 – LOCA/LOOP	1E-02/year	1E-02/year

* Mean flywheel speed for normal/accident conditions is 1500 rpm; for LOCA/LOOP it is 3321 rpm.

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 discussed in Section 3.2.

The consequence evaluation identifies both direct effects and indirect effects. 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. With failure of the RCP, a reactor trip would be required.

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

For this evaluation, the conditional core damage probability given 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).

Risk Calculation

This methodology is described in detail in the Westinghouse Owners Group Risk-Informed Inservice Inspection Methodology for Piping, WCAP-14572, Revision 1-NP-A (Reference 17). 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:

$$CDF = IE * CCDP_{IE} \qquad \textbf{Equation 14}$$

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 given 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 license. In other words,

$$IE = FP/EOL \qquad \textbf{Equation 15}$$

where:

FP = Failure probability from failure probability model (dimensionless)

EOL = Number of years used in failure probability model (60 years used to cover an extended plant life). Between 40 and 60 years, the failure probability is relatively constant.

For a RCP motor flywheel failure following another event, the frequency of the event (initiating event with flywheel failure) is defined as:

$$CDF = (IE * CFP) * CCDP \qquad \textbf{Equation 16}$$

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. The initiating event frequency for a plant trip or LOCA 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 or LOCA was estimated from Table 4.2 of NUREG/CR-6538 (Reference 14) as 1.4E-02 for PWR plants.

The frequency of a large break LOCA is estimated from recent WOG work on Redefinition of Large Break LOCA (Reference 13). Failure probabilities for various piping were estimated for several plants using a 5000 gpm leakage rate (not a full DEGB) to estimate the frequency of a large LOCA event by piping size. For piping sizes greater than 23 inches in diameter, the failure frequencies are shown in the Table 3-11.

Table 3-11: Estimated Frequency of Large LOCA (flow greater than 5000 gpm) by Line Size

Line Size (diameter in inches)	Mean Frequency (per year)
27.5	2.62E-07
29	1.86E-07
31	1.93E-07
32	1.29E-06
34	4.19E-07
36	2.31E-07

A given plant has either 27.5, 29 and 31 inch diameter piping or 32, 34, and 36 inch diameter piping. Summing these line sizes equates to 6.41E-07/year for the 27.5-inch cold leg case and 1.94E-06/year for the 32-inch cold leg plant. This evaluation will use the 2E-06/year as the estimated frequency of a large LOCA greater than 23 inches in diameter.

To estimate the probability of flywheel failure given an initiating event, the failure probability is calculated for a continuously operating system as follows:

$$CFP = FR * T_m \qquad \textbf{Equation 17}$$

where:

CFP = Conditional Failure probability [unitless]

FR = Failure probability from the model divided by years at EOL [per hour]

T_m = Total defined mission time [24 hours or 1 day]

Tables 3-12 and 3-13 show the calculations 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 conditional core damage probability (CCDP) is set to 1.0 (no credit taken for safety systems).

The calculations show that the change in CDF for flywheel Evaluation Group 1 is 2E-10/year, while the change in the CDF for flywheel Evaluation Group 2 is 7E-11/year. The RG-1.174 criteria for an acceptable change in risk for CDF are 1E-06/year and for LERF is 1E-07/year. These calculations show the change in risk from extending the inspection interval for the RCP motor flywheel is significantly below the acceptance criteria.

Even considering the uncertainty in the estimated flywheel failure frequency, the change in risk would still be expected to be well below the acceptance criteria.

Table 3-12: RCP Motor Flywheel Evaluation Group 1

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@60 years)	Event with RCP Motor Flywheel Failure (and Core Damage Frequency Given CCDP = 1.0)
Normal Operating Condition	N/A	With ISI after 10 years = 2.45E-07 Without ISI after 10 years = 2.57E-07	With ISI after 10 years: (2.45E-07/60 years) = 4.08E-09/year Without ISI after 10 years: (2.57E-07/60 years) = 4.28E-09/year
Failure of the RCP motor flywheel given a plant transient or LOCA event with NO loss of electrical power to the RCP (1200 rpm peak speed)	1.0/year	With ISI after 10 years = 2.45E-07 Without ISI after 10 years = 2.57E-07	With ISI after 10 years: 1.0/year (2.45E-07/60 years * 1 year/365 days * 1 day) = 1.12E-11/year Without ISI after 10 years: 1.0/year (2.57E-07/60 years * 1 year/365 days * 1 day) = 1.17E-11/year
Failure of the RCP motor flywheel given a plant transient or 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/year * (1.4E-02) = 1.4E-02/year	With ISI after 10 years = 2.45E-07 Without ISI after 10 years = 2.57E-07	With ISI after 10 years: 1.4E-02/year (2.45E-07/60years * 1 year/365 days * 1 day) = 1.57E-13/year Without ISI after 10 years: 1.4E-02/year (2.57E-07/60 years * 1 year/365 days * 1 day) = 1.64E-13/year

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@60 years)	Event with RCP Motor Flywheel Failure (and Core Damage Frequency Given CCDP = 1.0)
Failure of the RCP motor flywheel given a large LOCA (from a greater than 3 ft² 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)	2E-06/year * (1.4E-02) = 2.8E-08/year	With ISI after 10 years = 1E-02/year Without ISI after 10 years = 1E-02/year	With ISI after 10 years: 2.80E-08/year (1.0E-02/year * 1 year/365 days * 1 day) = 7.67E-13/year Without ISI after 10 year: 2.80E-08/year (1.E-02/year * 1 year/365 days * 1 day) = 7.67E-13/year
TOTALS			With ISI after 10 years: 4.08E-09 + 1.12E-11+1.57E-13 + 7.67E-13 = 4.09E-09 / year Without ISI after 10 years: 4.28E-09 + 1.17E-11 + 1.64E-13 + 7.67E-13 = 4.29E-09 / year Change in CDF = 4.29E-09 – 4.09E-09 = 2.0E-10/year

Table 3-13: RCP Motor Flywheel Evaluation Group 2

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@60 years)	Event with RCP Motor Flywheel Failure (and Core Damage Frequency Given CCDP = 1.0)
Normal Operating Condition	N/A	With ISI after 10 years = 1.43E-07 Without ISI after 10 years = 1.47E-07	With ISI after 10 years: (1.43E-07/60 years) = 2.38E-09/year Without ISI after 10 years: (1.47E-07/60 years) =2.45E-09/year
Failure of the RCP motor flywheel given a plant transient or LOCA event with NO loss of electrical power to the RCP (1200 rpm peak speed)	1.0/year	With ISI after 10 years = 1.43E-07 Without ISI after 10 years = 1.47E-07	With ISI after 10 years: 1.0/year (1.43E-07/60years * 1 year/365 days * 1 day) = 6.53E-12/year Without ISI after 10 years: 1.0/year (1.47E-07/60 years * 1 year/365 days * 1 day) = 6.71E-12/year
Failure of the RCP motor flywheel given a plant transient or 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/year * (1.4E-02) = 1.4E-02/year	With ISI after 10 years = 1.43E-07 Without ISI after 10 years = 1.47E-07	With ISI after 10 years: 1.4E-02/year (1.43E-07/60years * 1year/365 days * 1 day) = 9.14E-14/year Without ISI after 10 years: 1.4E-02/year (1.47E-07/60 years * 1 year/365 days * 1 day) = 9.40E-14/year

Condition	Initiating Event Frequency	Likelihood of RCP Motor Flywheel Failure (@60 years)	Event with RCP Motor Flywheel Failure (and Core Damage Frequency Given CCDP = 1.0)
Failure of the RCP motor flywheel given 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)	2E-06/year * (1.4E-02) = 2.80E-08 /year	With ISI after 10 years = 1E-02/year Without ISI after 10 years = 1E-02/year	With ISI after 10 years: 2.80E-08/year (1.0E-02/year * 1 year/365 days * 1 day) = 7.67E-13/year Without ISI after 10 years: 2.80E-08/year (1.0E-02/year * 1 year/365 days * 1 day) = 7.67E-13/year
TOTALS			With ISI after 10 years: 2.38E-09 + 6.53E-12+9.14E-14 + 7.67E-13 = 2.39E-09/year Without ISI after 10 years: 2.45E-09 + 6.71E-12 + 9.40E-14 + 7.67E-13 = 2.46E-09/year Change in CDF = 2.46E-09 - 2.39E-09 = 7.0E-11/year

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 even assuming a CCDP of 1.0 (complete failure of safety systems), the CDF and change in risk would still not exceed the NRC's acceptable guidelines in RG-1.174 (<1.0E-6 per year).

Even considering the uncertainties involved in this evaluation, the risk associated with the postulated failure of an RCP motor flywheel is significantly low. Even if 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 large early release, the calculations were not performed for the large early release frequency (LERF). The CDF and LERF results are below the NRC's LERF acceptance guidelines (taken as 1E-07/reactor year).

As part of this evaluation, the key principles identified in RG-1.174 are reviewed and the responses based on the evaluation are provided in Table 3-14.

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

Table 3-14: 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	• Change to current Regulatory Guide 1.14 requirements is proposed
Change is consistent with defense-in-depth philosophy	• Potential for failure of the RCP motor flywheel is negligible during normal/accident conditions, and does not threaten plant barriers
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	• Proposed increase in risk is estimated to be negligible • Leakage expected before a piping LOCA occurs (no core damage consequences associated with leakage)
Use performance-measurement strategies to monitor the change.	• NDE examinations still conducted, but on less frequent basis not to exceed 20 years • Other indications of potential degradation of RCP motor flywheel available (e.g., pump vibration monitoring, pump maintenance)

4 TECHNICAL SPECIFICATION CHANGES

Proposed changes to Specification 5.5.7, "Reactor Coolant Pump Flywheel Inspection Program," of NUREG-1431, Revision 2, Improved Standard Technical Specifications, are contained on the following pages.

5.5 Programs and Manuals

5.5.4 Radioactive Effluent Controls Program (continued)

i. Limitations on the annual and quarterly doses to a member of the public from iodine-131, iodine-133, tritium, and all radionuclides in particulate form with half lives > 8 days in gaseous effluents released from each unit to areas beyond the site boundary, conforming to 10 CFR 50, Appendix I, and

j. Limitations on the annual dose or dose commitment to any member of the public, beyond the site boundary, due to releases of radioactivity and to radiation from uranium fuel cycle sources, conforming to 40 CFR 190.

The provisions of SR 3.0.2 and SR 3.0.3 are applicable to the Radioactive Effluent Controls Program surveillance frequency.

5.5.5 Component Cyclic or Transient Limit

This program provides controls to track the FSAR, Section [ ], cyclic and transient occurrences to ensure that components are maintained within the design limits.

5.5.6 [Pre-Stressed Concrete Containment Tendon Surveillance Program

This program provides controls for monitoring any tendon degradation in pre-stressed concrete containments, including effectiveness of its corrosion protection medium, to ensure containment structural integrity. The program shall include baseline measurements prior to initial operations. The Tendon Surveillance Program, inspection frequencies, and acceptance criteria shall be in accordance with [Regulatory Guide 1.35, Revision 3, 1989].

The provisions of SR 3.0.2 and SR 3.0.3 are applicable to the Tendon Surveillance Program inspection frequencies.]

5.5.7 Reactor Coolant Pump Flywheel Inspection Program

This program shall provide for the inspection of each reactor coolant pump flywheel per the recommendations of Regulatory Position C.4.b of Regulatory Guide 1.14, Revision 1, August 1975.

In lieu of Position C.4.b(1) and C.4.b(2), a qualified in-place UT examination over the volume from the inner bore of the flywheel to the circle one-half of the outer radius or a surface examination (MT and/or PT) of exposed surfaces of the removed flywheels may be conducted at approximately ~~10~~ year intervals ~~coinciding with the Inservice Inspection schedule as required by~~ ASME ~~Section~~ XI.

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5.5 Programs and Manuals

5.5.7 Reactor Coolant Pump Flywheel Inspection Program (continued)

- REVIEWER'S NOTES -

1. The inspection interval and scope for RCP flywheels stated above can be applied to plants that satisfy the staff requirements in the safety evaluation of Topical Report, WCAP-14535A, "Topical Report on Reactor Coolant Pump Flywheel Inspection Elimination." 15666, "Extension of Reactor Coolant Pump Motor Flywheel Examination."

2. Licensees shall confirm that the flywheels are made of SA 533 B material. Further, licensees having Group-15 flywheels (as determined in WCAP-14535A, "Topical Report on Reactor Coolant Pump Flywheel Inspection Elimination") need to demonstrate that material properties of their A516 material is equivalent to SA 533 B material, and its reference temperature, RT, is less than 30 °F.

3. For flywheels not made of SA 533 B or A516 material, licensees need to either demonstrate that the flywheel material properties are bounded by those of SA 533 B material, or provide the minimum specified ultimate tensile stress, the fracture toughness, and the reference temperature, RT_{NDT}, for that material. For the latter, the licensees should employ these material properties, and use the methodology in the topical report, as extended in the two responses to the staff's RAI, to provide an assessment to justify a change in inspection schedule for their plants.

4. Licensees with Group-10 flywheels need to confirm that their flywheels have an adequate shrink fit to preclude loss of shrink fit of the flywheel at the maximum overspeed, or to provide an evaluation demonstrating that no detrimental effects would occur if the shrink fit was lost as maximum overspeed.

5.5.8 <u>Inservice Testing Program</u>

This program provides controls for inservice testing of ASME Code Class 1, 2, and 3 components. The program shall include the following:

a. Testing frequencies specified in Section XI of the ASME Boiler and Pressure Vessel Code and applicable Addenda as follows:

ASME Boiler and Pressure Vessel Code and applicable Addenda terminology for inservice testing activities	Required Frequencies for performing inservice testing activities
Weekly	At least once per 7 days

5 CONCLUSIONS

Results from previous WOG program MUHP-5042, as summarized in WCAP-14535A (Reference 2), remain valid and are reiterated below:

1. Flywheels are carefully designed and manufactured from excellent quality steel, which has high fracture toughness.
2. Flywheel overspeed is the critical loading, but LBB has limited the maximum speed to 1500 rpm. *(Note however that the LBB exclusion for LBLOCA does not pertain to the risk assessment contained in the current WCAP-15666 report, which does consider the overspeed due to LBLOCA).*
3. Flywheel inspections have been performed for over 20 years, with no service-induced flaws.
4. Flywheel integrity evaluations show a very high flaw tolerance for the flywheels.
5. Crack extension during service is negligible.
6. Structural reliability studies show that eliminating inspections will not change the probability of failure.
7. Inspections result in man-rem exposure and the potential for flywheel damage during assembly and reassembly.

Results from the current WOG program MUHP-5043, summarized in this report, are as follows:

1. The failure probabilities for RCP motor flywheels are small.
2. The change in risk is 3 to 4 orders of magnitude below the Regulatory Guide 1.174 CDF and LERF acceptable guidelines.
3. The extension of the RCP motor flywheel ISI frequency from 10 to 20 years satisfies Regulatory Guide 1.174 criteria as an acceptable change.

Proposed changes to Specification 5.5.7, "Reactor Coolant Pump Flywheel Inspection Program," of NUREG-1431, Revision 2, Improved Standard Technical Specifications, are provided in Section 4 of this report.

6 REFERENCES

1. United States Nuclear Regulatory Commission, Office of Standards Development, Regulatory Guide 1.14, "Reactor Coolant Pump Flywheel Integrity," Revision 1, August 1975.

2. Westinghouse report WCAP-14535A, "Topical Report on Reactor Coolant Pump Flywheel Inspection Elimination," November 1996, Westinghouse Non-Proprietary Class 3.

3. United States Nuclear Regulatory Commission letter from Brian W. Sheron to Sushil C. Jain (Duquesne Light Company), September 12, 1996, "Acceptance for Referencing of Topical Report WCAP-14535, Topical Report on Reactor Coolant Pump Flywheel Inspection Elimination," (included in the Reference 2 report above).

4. United States Nuclear Regulatory Commission, Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," July 1998.

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