CMD 21-H110.1A

File/dossier : 6.01.07
Date : 2021-09-24
e-Docs pdf : 6652476

Written submission from Bruce Power

Mémoire de Bruce Power

In the Matter of

À l'égard de

Request for authorization to return Bruce Nuclear Generating Station (NGS) A Unit 3 to service, following its current planned outage

Demande concernant l'autorisation de la remise en service de la tranche 3 de la centrale nucléaire de Bruce-A à la fin de son arrêt prévu actuel

---

Public Hearing - Hearing in writing based on written submissions

Audience Publique - Audience fondée sur des mémoires

October 2021

Octobre 2021

September 24, 2021

BP-CORR-00531-02077

Mr. M. Leblanc
Commission Secretary
Canadian Nuclear Safety Commission
P.O. Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dr. A. Viktorov
Director General
Canadian Nuclear Safety Commission
P.O. Box 1046
280 Slater Street
Ottawa, Ontario
K1P 5S9

Dear Mr. Leblanc and Dr. Viktorov:

Bruce A Unit 3: Response to CNSC Review of Return to Service Additional Information

The purpose of this letter is to provide the probabilistic evaluation of the existence of dispositionable flaws using the CNSC defined Region of Interest (ROI) for the Unit 3 pressure tubes, requested by CNSC staff in Reference 1.

As noted in previous correspondence and in presentations before the Commission, safety and pressure tube integrity, consistent with the Order (Reference 2), have been demonstrated in Bruce Power's submission to return to Unit 3 to service from its planned outage. This includes factors such as hydrogen concentrations, lack of flaws, fracture protection, operational safety margin and a range of other factors.

Bruce Power recognizes that in August 2021, CNSC staff defined a ROI based on the information available at the time as follows:

- Axially – From the burnish mark to 75 mm inboard of the burnish mark; and
- Circumferentially – Full circumference of 360 degrees.

CNSC have indicated a willingness to consider adjustments to the ROI based on additional information, data and analysis. Bruce Power will continue to engage with CNSC staff on this item as further refinement circumferentially is both appropriate and conservative, while recognizing that time is needed for CNSC staff to review material recently provided in Reference 3. Bruce Power believes the data continues to support the CNSC defined ROI axially of 75 mm.

In the case of Unit 3, a probabilistic evaluation of the existence of dispositionable flaws using CNSC staff's defined extended region of interest is provided for information in Enclosure 1 as defense in depth. Bruce Power believes this meets the requirements of the Order (Reference 2) and demonstrates both safety and pressure tube integrity in combination with other elements previously provided. As discussed with CNSC staff, Bruce Power is continuing to refine the probabilistic evaluation methodology to establish a more robust quantification.

Bruce Power   Maury Burton, Chief Regulatory Officer
P.O. Box 1540 B10 2nd Floor E, Tiverton ON N0G 2T0
Telephone 519-361-5291
maury.burton@brucepower.com

Bruce Power notes that the unitized statistical analysis, previously submitted in Reference 4 using a region of interest limited circumferentially to 60 degrees on either side of 12 o'clock (for a total of 120 degrees), demonstrated very low probability of the existence of a reportable or dispositionable flaw in the region where elevated hydrogen equivalent concentration were measured in Unit 3. This result was based on the inspection data from all units (Bruce 3-8) up to A2131 where there has never been a flaw detected in the region of interest. The inspection results from A2131 also support this observation. The conclusion reached for Unit 3 (and all Bruce Power units) is that the probability for having at least one dispositionable flaw in the region of interest is < 0.5% and as a result, the risk of having a significant flaw in the region of interest defined by Bruce Power, which could challenge pressure tubes fitness for service is also low.

If you require further information or have any questions regarding this submission, please contact Ms. Lisa Clarke, Director, Regulatory Affairs, at (519) 361-2673 extension 16144, or lisa.clarke@brucepower.com.

Yours truly,

Lisa Clarke Digitally signed by Lisa Clarke Date: 2021.09.24 15:47:46 -04'00'

Maury Burton
Chief Regulatory Officer
Bruce Power

cc: Mr. Luc Sigouin, CNSC-Ottawa
CNSC Bruce Site Office

Enclosure:

1. B-REP-31110-00004, Revision 001, Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8.

References:

1. Letter, L. Sigouin to M. Burton, "CNSC Review of Bruce A Unit 3: Return to Service Additional Information", September 23, 2021, e-Doc 6646070, BP-CORR-00531-02071.
2. Letter, R. Jammal to M. Burton, "Designated Officer Order issued to Bruce Power", July 26, 2021, e-Doc 6612485, BP-CORR-00531-01904.
3. Email, A. Glover to A. Robert, "Additional Information in Support of the Region of Interest", September 22, 2021, BP-CORR-00531-02076.
4. Letter, M. Burton to M. Leblanc and A. Viktorov, "Bruce A Unit 3: Return to Service Additional Information", September 17, 2021, BP-CORR-00531-02033.

Enclosure 1

B-REP-31110-00004, Revision 001

Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8

FORM-14287 R000*

Supplier Document Acceptance Form

Bruce Power

KINECTRICS

ESTIMATION OF ENCOUNTERING REPORTABLE & DISPOSITIONABLE PRESSURE TUBE FLAWS IN VARIOUS REGIONS OF INTEREST IN BRUCE POWER UNITS 3-8

B-REP-31110-00004

Rev. 001

- [x] Accepted
- [ ] Accepted As Noted – Revision Required
- [ ] Rejected
- [ ] Accepted As Noted – No Revision Required

FOR USE AT BRUCE POWER

ACCEPTED: **LARRY MICUDA** (Print Name) [signature] (Signature)

TITLE: **SENIOR TECHNICAL SPECIALIST** (Print Title)

DATE: **24SEP2021** (DDMMMYYYY)

ACCEPTANCE OF THIS DOCUMENT DOES NOT RELIEVE THE CONTRACTOR OF RESPONSIBILITY FOR ANY ERRORS OR OMISSIONS.

Kinectrics Confidential

KINECTRICS

Estimation of Encountering Reportable & Dispositionable Pressure Tube Flaws in Various Regions of Interest in Bruce Power Units 3-8

B2266/RP/0010 R01

September 24, 2021

Prepared by:

Dirk Leemans, P.Eng.
Contractor
Component Integrity and Inspection Engineering.

Verified (reviewed) by:

Gregory Allen, P.Eng.
Section Manager (Acting)
Fuel Channel Integrity Support.

Verified (Lead) by:

Suresh Datla
Senior Analyst
Component Integrity and Inspection Engineering.

Approved by:

Jaff Robertson, P.Eng
Service Line Director
Fuel Channel Integrity & Operations

Revision Summary

Rev	Date	Author	Comments
R00	Sept 2021	D. Leemans	Initial issue.
R01	Sept 2021	D. Leemans	Revised to include: 1. Additional definitions of the region of interest (180° & 360°). 2. The estimated number of flaws in the inspected population of each unit for all regions of interest.

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

As part of the evaluation of the fitness for service of Bruce Unit 3, concerns were expressed about the probability of encountering flaws of significance (flaws requiring disposition) in specific regions of interest of the pressure tubes for the population of channels which were not yet inspected full length. The region in question is centered around the top of the pressure tube over a limited axial extent inboard of the Outlet Burnish Mark (OBM), corresponding to measurements of elevated hydrogen isotope concentration. This report provides estimates of the probability of encountering flaws in the reactor in these regions and submits that these probabilities are reassuringly low. Also provided are estimates of the number of dispositionable flaws in these regions.

The following sections describe the methodology and results of the current work to estimate the flaw probability in the regions of interest.

2.0 IDENTIFYING THE REGIONS OF INTEREST

Four regions of interest are defined based on their axial extent inboard of the outlet burnish mark (OBM) and their circumferential extent referenced from the top of the pressure tube:

	Axial Extent	Circumferential Extent
Region 1	OBM + 75 mm	60° (+/- 30°)
Region 2	OBM + 75 mm	120° (+/- 60°)
Region 3	OBM + 75 mm	180° (+/- 90°)
Region 4	OBM + 75 mm	360° (+/- 180°)

While determining the most appropriate definition of the region of interest is beyond the scope of this work, measurements of deuterium concentration obtained in the A2131 outage support Region 2 (highlighted above) per [1].

3.0 OVERALL APPROACH TO ESTIMATING THE PROBABILITY OF ENCOUNTERING A DISPOSITIONABLE FLAW IN THE REGIONS OF INTEREST OF THE UNINSPECTED PRESSURE TUBES IN BRUCE REACTORS

The probability of encountering a dispositionable flaw in a region of interest in a channel is related to four constituent elements[1]:

i. The probability of encountering k reportable flaws in the outlet fuel bundle region of a channel;

ii. The conditional probability given a reportable flaw is present, its axial position (mid flaw position) is within 75 mm inboard of the OBM;

[1] For each of these probabilities the possibility of having more than one flaw in the channel being present is taken into account.

iii. The conditional probability given a reportable flaw is present close to the OBM, its circumferential location is such that it falls within the region of interest.

iv. The product of the three probabilities itemized above provides the probability of a reportable flaw being in the region of interest. Using the conditional probability that given the presence of a reportable flaw that there is actually a dispositionable flaw present allows the evaluation of the presence of a dispositionable flaw in the channel.

4.0 THE MAJOR DATABASE ON REPORTABLE FLAWS IN BRUCE REACTOR UNITS

The primary input to this analysis was a database containing the size and location of all unique flaws obtained during the inspections of the area up to the first fuel bundle with respect to the outlet burnish mark in all Bruce Units 3-8 reactors. It is this database that allows the reliable estimates of many of the conditional probabilities mentioned above. This database and its construction are detailed in [2].

The decision was made to include only flaws up to the axial extent of the first fuel bundle in the outlet end. Increasing the axial extent would increase the number of flaws per tube but would decrease the conditional probability of having the flaw in the axial region of interest. It was judged that the product of these two probabilities would be virtually unaffected by increasing the axial extent of the database. Reducing the axial extent would reduce the sample size and therefore imperil the estimation of the underlying probabilities.

5.0 DETAILED DESCRIPTION OF THE ESTIMATION OF THE PROBABILITY OF ENCOUNTERING DISPOSITIONABLE FLAWS IN THE REGIONS OF INTEREST IN THE UNINSPECTED PRESSURE TUBE POPULATION IN BRUCE POWER REACTORS

5.1 Description of the Probability of Having K Reportable Flaws up to the End of the First Bundle

This probability is assumed to follow a Poisson distribution

$$\Pr(X = k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

where k is the number of flaws occurring within a channel and λ is the mean incidence rate. In the database there are 557 reportable flaws up to the end of the first bundle in the inspection of 448 unique channels and therefore the estimated λ is 1.243304. Figure 1 shows the dependence of probability on the number of flaws in the channel.

The following assumptions underpin these statements:

i. Flaws occur independently.

ii. The incidence rate is independent of reactor.

iii. The incidence rate is independent of the location of the pressure tube in the reactor (e.g., Zone[2]).

iv. The incidence rate is independent of operating time.

v. No distinction is made between different flaw types.

5.2 Description of the Probability of Having I Reportable Flaws Close to the Outlet Burnish Mark

The conditional probability of having the flaw within 75 mm of the OBM given that a flaw is present is estimated to be 0.011606. This is based on the estimation of the cumulative distribution of the axial position at 75 mm[3].

The probability of having I (≤ K) flaws close to the OBM given that there are K flaws in the pressure tube is binomially distributed.

$$\Pr(X = I|K) = \frac{k!}{I!\,(k-I)!}(1-p)^{k-I}p^{I}$$

These binomial probabilities for I are then multiplied with the Poisson probability of k flaws and then summed over all k values (up to 10 were used)[4] which gives the probability of having I flaws close to the OBM.

$$Prob(Y = I) = \sum_{k=I}^{10} \Pr\,(X = I|K)p(K)$$

Figure 2 shows how this probability drops off quickly with increasing values of I.

5.3 Description of the Probability of Having J Reportable Flaws Close to the Outlet Burnish Mark and at the Top of the Pressure Tube

The conditional probability of having a flaw circumferentially at the top of the pressure tube given that a flaw close to the OBM is present assumes that this probability is independent of axial position and therefore the whole database can be used to fit a distribution to the circumferential location. A large number of candidate continuous distribution functions were evaluated including gamma, extreme value, Weibull, Laplace, and lognormal. However, a very good fit was obtained with a simple normal distribution[5].

---

[2] It is known that there is generally a zone dependency on flaw populations, with the outer zone channels generally observed to have a larger number of flaws. This was confirmed to be present in the outlet bundle flaw populations used for this exercise. Grouping flaws from channels from both zones is then in general conservative for the inner zone, to which the region of interest applies.

[3] Given the discontinuous nature of the distribution of the axial position (the majority of flaws are clustered around the residency locations of the fuel bundle bearing pads) no effort was made to fit this distribution to a known probability density distribution. The cumulative probability was estimated by linear interpolation between the two points neighboring 75 mm.

[4] The cutoff of 10 flaws is arbitrary but by this value the probabilities have become vanishingly small.

[5] A three-parameter lognormal distribution does also an adequate job in fitting the circumferential location distribution.

The parameters of this normal distribution are a mean of 176.41 degrees and a standard deviation of 39.03 degrees. Figure 3 and Figure 4 show the adequacy of the fit.

The conditional probabilities of having a flaw in the circumferential extent of the region of interest given that a flaw is present close to the OBM are as follows:

- Region 1 = 0.013%
- Region 2 = 0.22%
- Region 3 = 2.2%
- Region 4 = 100%

As above the probability of having J (≤ I) flaws at the top given that there are I reportable flaws close to the OBM is binomially distributed. Figure 5 shows the probability of having J reportable flaws in the larger area of interest (circumferentially the top 120 degrees of the pressure tube).

$$Prob(Y = J) = \sum_{I=I}^{10} \Pr(X = J|I)p(I)$$

5.4 Description of the Probability of Having H Dispositionable Flaws Close to the OBM and at the Top of the Pressure Tube

The conditional probability of having a dispositionable flaw circumferentially at the top of the pressure tube and close to the OBM given that a reportable flaw is present circumferentially at the top of the pressure tube and close to the OBM is based on the observation that from the 557 reportable flaws in the database 187 were found to be dispositionable (p= 0.335727).

The probability of having H (≤ J) dispositionable flaws at the top of the pressure tube close to the OBM given that there are J reportable flaws at the top of the pressure tube close to the OBM is binomially distributed.

$$Prob(Y = H) = \sum_{J=I}^{10} \Pr(X = H|J)p(J)$$

6.0 RESULTS

6.1 Probability Estimates for Encountering Flaws in the Regions of Interest per Channel

As noted from the outset it is assumed that there is no dependence on reactor and these estimates are applicable to the present situation. The probability of encountering at least one dispositionable flaw in the region of interest per channel is given by

$$Prob(flaw) = \sum_{H=I}^{10} \Pr(Y = H)$$

The results are tabulated in Table 1 for reportable and dispositionable flaws. As expected, these probabilities depend strongly on the circumferential extent of the region of interest. The larger the circumferential extent the larger the probability of encountering a flaw in the region of interest. Also, the probability of encountering a dispositionable flaw is about one third of the probability of encountering a reportable flaw.

6.2 Probability Estimates for Encountering Flaws in the Regions of Interest in the Uninspected Population of Pressure Tubes for Bruce Power Reactors.

The probability of encountering at least one reportable flaw in the regions of interest in the population of uninspected pressure tubes for Bruce Power reactors is tabulated in Table 2 while similar probabilities for dispositionable flaws are given in Table 3. These have been calculated as follows:

$$Prob(at\ least\ 1\ flaw\ in\ uninspected) = 1 - (1 - Prob(flaw))^n$$

where 'n' is the number of uninspected channels.

Estimates of the number of flaws in the regions of interest in the uninspected populations are given in Table 4 for reportable flaws, and Table 5 for dispositionable flaws. These have been calculated as follows:

$$Estimated\ \#\ of\ flaws = Prob(flaw) * n$$

where again 'n' is the number of uninspected channels.

7.0 DISCUSSION

The results of this estimation of the probability of encountering flaws close to the OBM indicate the following:

a. As expected, the probability of encountering flaws increases with increasing size of the region of interest (from Region 1 to Region 4).

b. As expected, the probability of encountering flaws is higher for reportable flaws than dispositionable flaws.

c. The inspections carried out in A2131 (which were not considered when deriving the probabilities) did not reveal the presence of flaws in the regions of interest for the top 180° of the pressure tube. This is consistent with the probability estimates provided in this report.

8.0 CONCLUSIONS

Available inspection data on the incidence of flaws has been used to develop probabilities of a flaw being present in the region of interest in an uninspected pressure tube. Four different definitions of the region of interest were considered with different circumferential extents. The probabilities of at least one flaw in the uninspected populations of pressure tubes in the regions of interest are given Table 2 and Table 3 for reportable and dispositionable flaws, respectively. Estimates of the number of flaws in the regions of interest in the uninspected populations of pressure tubes are given in Table 4 and Table 5 for reportable and dispositionable flaws, respectively. As expected, the predicted incidence of flaws in the region of interest increases with increasing circumferential extent, with reportable flaws being more likely than dispositionable flaws.

9.0 REFERENCES

1. H. Zhou, Letter to L. Micuda, "Hydrogen Equivalent Concentration Measurements Taken Near the Outlet Burnish Mark in the Bruce Unit 3 2021 Outage (A2131)," Kinectrics File: B2038/LET/0013 R00, September 13, 2021.
2. J. Robertson, "B3-B8 Database of Pressure Tube Flaws Just Inboard of the Outlet Burnish Mark," Kinectrics File: B2266/RP/0002 R00, September 15, 2021.

Table 1: Probability per Channel of Encountering at Least One Flaw in the Regions of Interest

	Region 1	Region 2	Region 3	Region 4
Reportable	1.87E-06	3.17E-05	3.12E-04	1.43E-02
Dispositionable	6.28E-07	1.07E-05	1.05E-04	4.83E-03

Table 2: Probability of Encountering at Least One Reportable Flaw in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	7.51E-04	1.27E-02	1.18E-01	9.97E-01
4	398	7.44E-04	1.26E-02	1.17E-01	9.97E-01
5	403	7.53E-04	1.27E-02	1.18E-01	9.97E-01
6	418	7.81E-04	1.32E-02	1.22E-01	9.98E-01
7	410	7.66E-04	1.29E-02	1.20E-01	9.97E-01
8	401	7.49E-04	1.26E-02	1.18E-01	9.97E-01

Table 3: Probability of Encountering at Least One Dispositionable Flaw in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	2.52E-04	4.28E-03	4.13E-02	8.57E-01
4	398	2.50E-04	4.23E-03	4.09E-02	8.55E-01
5	403	2.53E-04	4.29E-03	4.14E-02	8.58E-01
6	418	2.62E-04	4.44E-03	4.29E-02	8.68E-01
7	410	2.57E-04	4.36E-03	4.21E-02	8.63E-01
8	401	2.52E-04	4.26E-03	4.12E-02	8.57E-01

Table 4: Estimate of the Number of Reportable Flaws in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	7.51E-04	1.28E-02	1.26E-01	5.76
4	398	7.44E-04	1.26E-02	1.24E-01	5.70
5	403	7.53E-04	1.28E-02	1.26E-01	5.77
6	418	7.81E-04	1.33E-02	1.31E-01	5.99
7	410	7.66E-04	1.30E-02	1.28E-01	5.87
8	401	7.50E-04	1.27E-02	1.25E-01	5.74

Table 5: Estimate of the Number of Dispositionable Flaws in the Regions of Interest in the Uninspected Population of Pressure Tubes

Unit	# Uninspected Channels	Region 1	Region 2	Region 3	Region 4
3	402	2.52E-04	4.28E-03	4.22E-02	1.94
4	398	2.50E-04	4.24E-03	4.18E-02	1.92
5	403	2.53E-04	4.29E-03	4.23E-02	1.95
6	418	2.62E-04	4.45E-03	4.39E-02	2.02
7	410	2.57E-04	4.37E-03	4.30E-02	1.98
8	401	2.52E-04	4.27E-03	4.21E-02	1.94

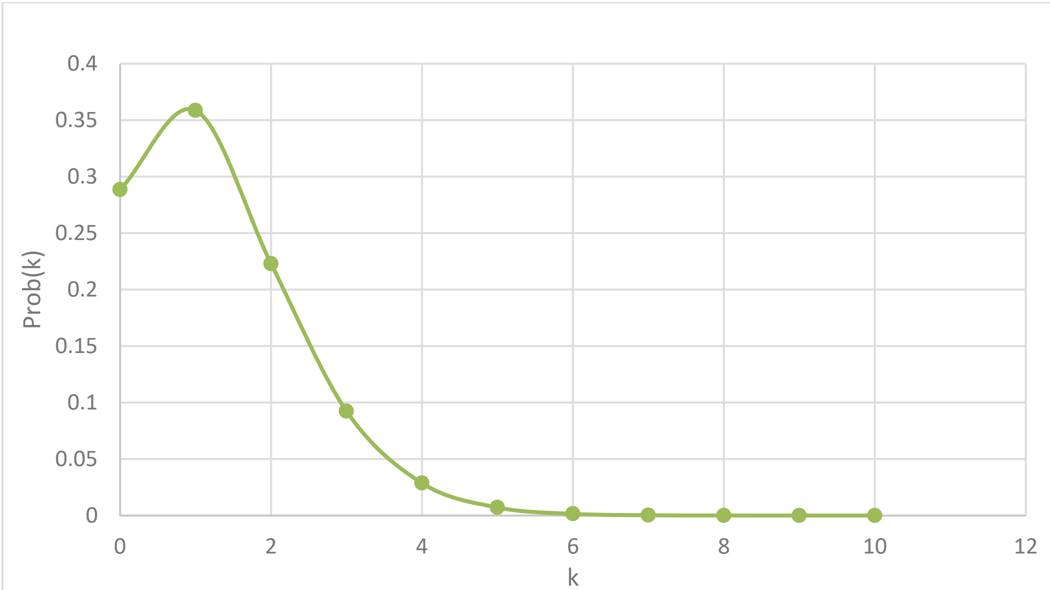

Figure 1: Probability of Encountering k Reportable Flaws in a Single Channel

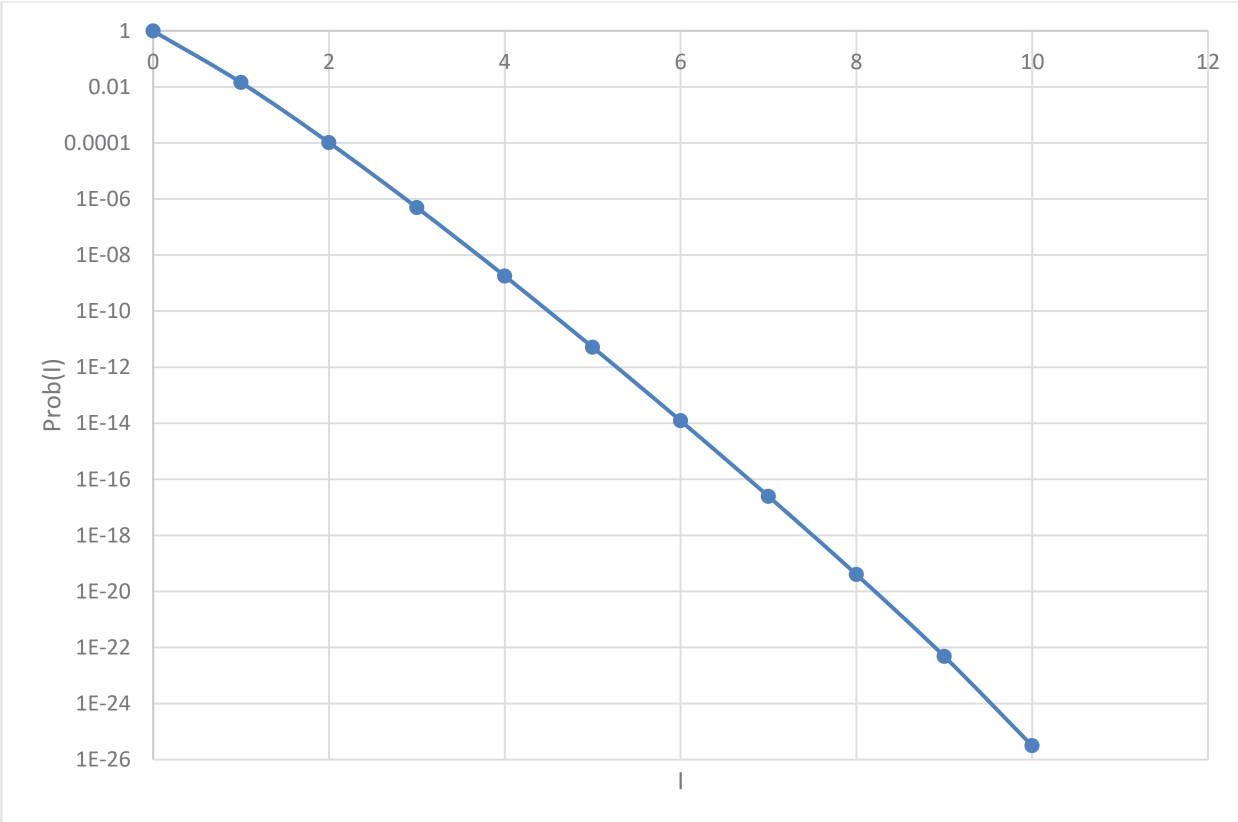

Figure 2: Probability of I Reportable Flaws Close to the OBM in a Single Channel

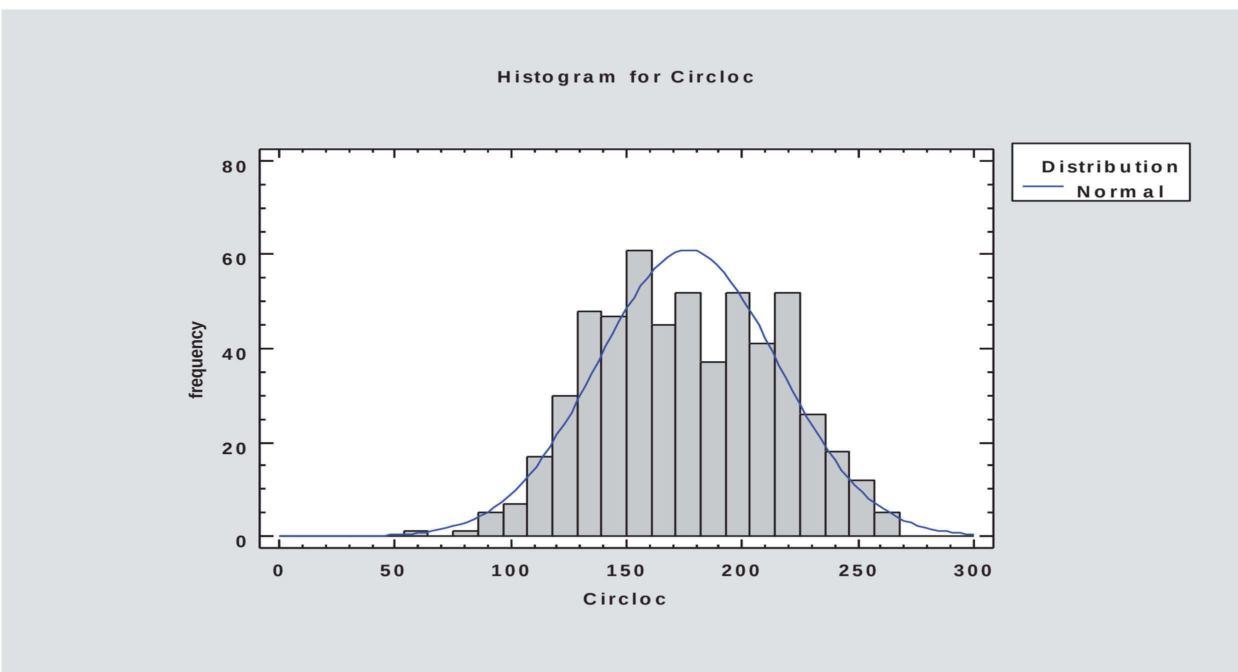

Figure 3: Histogram for the Distribution of the Circumferential Location

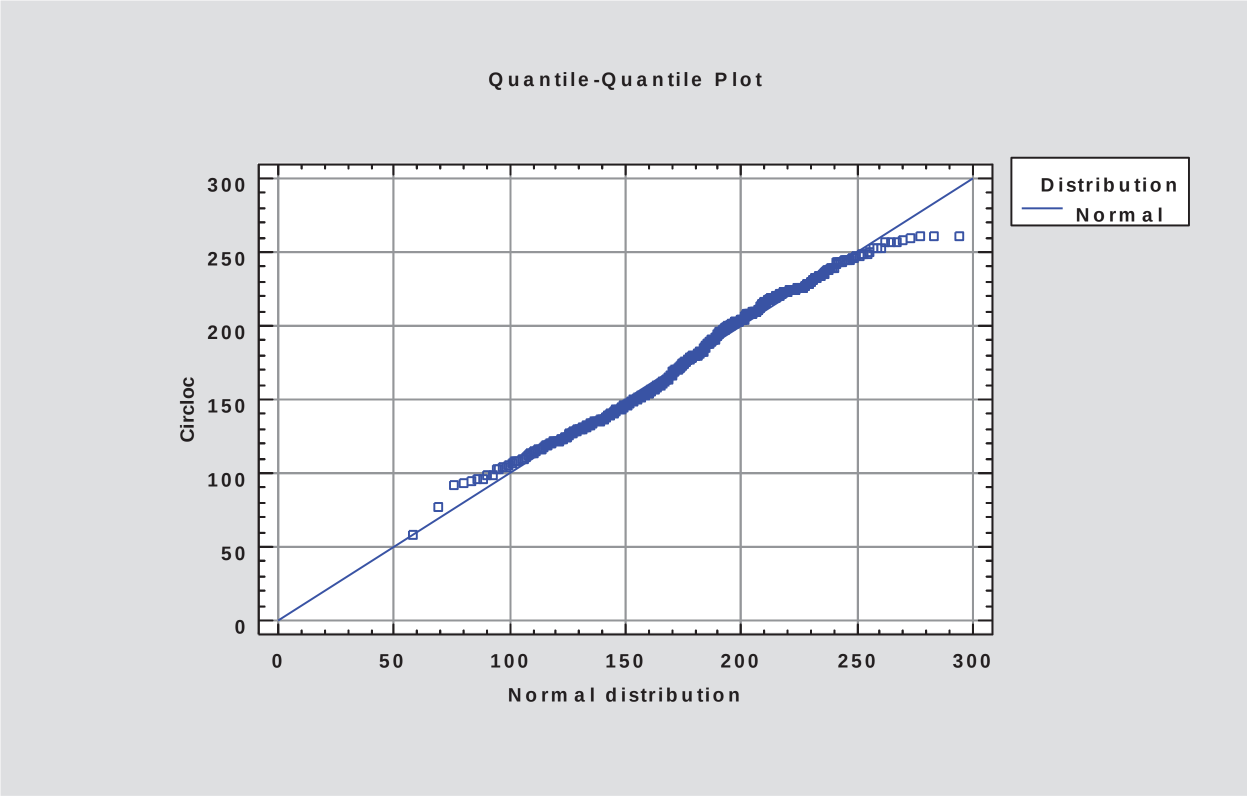

Figure 4: Quantile-Quantile Plot of Observed Distribution and Proposed Distribution

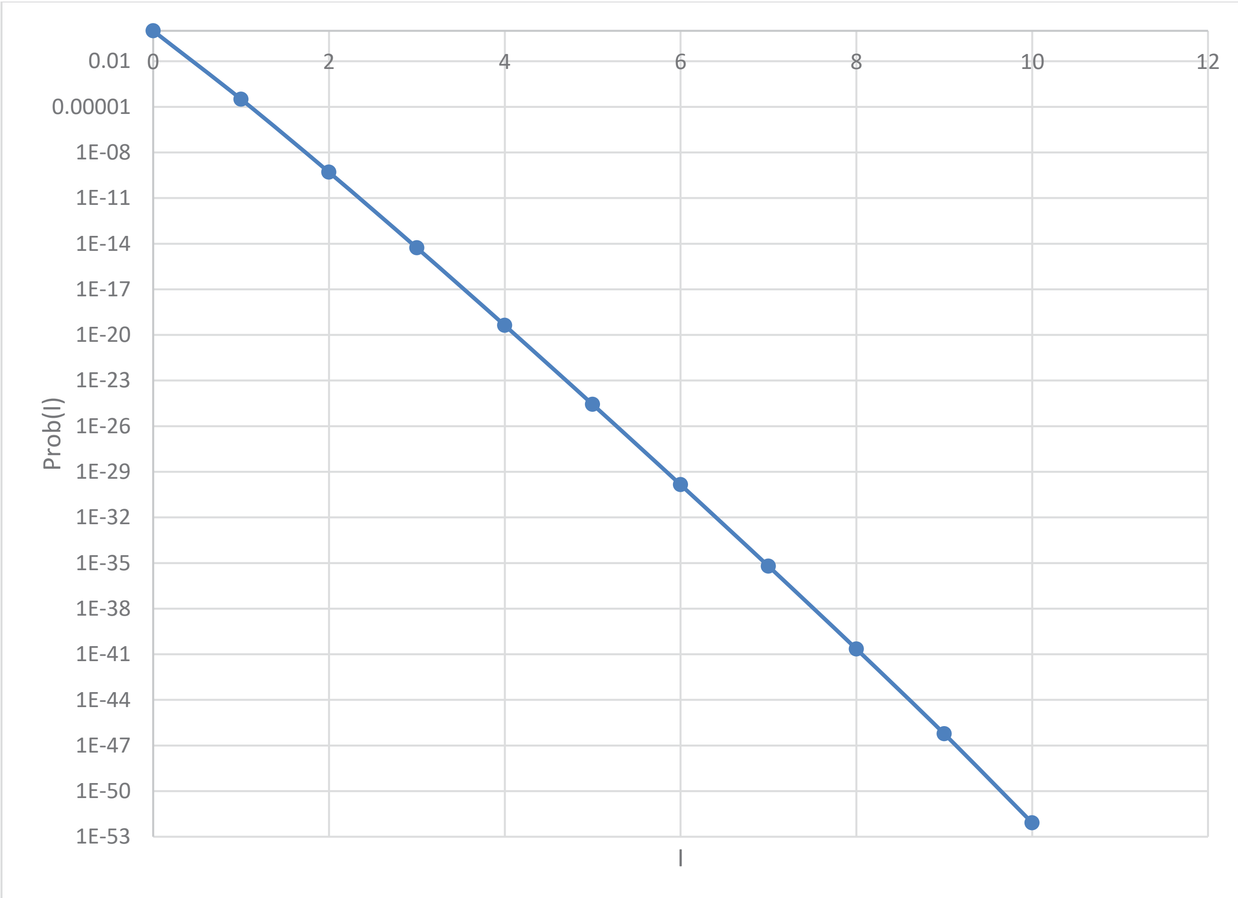

Figure 5: Probability of J Reportable Flaws in the Top 120 Degrees for the Region of Interest.