

## Problem Set 2

UN0701 – Engineering Risk and Reliability

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- ( 8 ) 1. The load ( $S$ ) and resistance ( $R$ ) are modelled as Normally distributed random variables with the following parameters: the mean and COV of the load are 100 kN and 0.25, respectively, while the COV of resistance is given as 0.15.
- Calculate the nominal load ( $S_N$ ), which is the 95<sup>th</sup> percentile of the distribution.
  - If the design criterion says that  $R_N = S_N$ , then what should be the mean resistance? Assume the nominal resistance ( $R_N$ ) is the 5<sup>th</sup> percentile of the distribution.
  - What is the reliability index for the design?
  - What is the probability of failure if we follow the design criterion  $R_N = S_N$ ?

- ( 15 ) 2. A limit state function is given as

$$g(X, Y) = X^2 - 2Y$$

where  $X$  follows the Weibull distribution with  $\alpha = 2$  and  $\beta = 25$ , and  $Y$  is Normally distributed with mean 100 and COV equal to 0.2.

- Estimate the mean and standard deviation of the limit state function using the Taylor series (first-order) expansion. Use this information to calculate the reliability index and the probability of failure.
- Use Monte Carlo simulation to estimate the probability of failure.

- ( 15 ) 3. Deuterium ingress is a major concern for the integrity of pressure tubes in CANDU reactors. It can result in hydride blister formation in the presence of PT/CT contact and lead to delayed hydride cracking (DHC) initiation and growth and possibly PT rupture. Consider the following scrape sample data taken from the rolled joint region of 20 pressure tubes at different times from various reactors: (*the data will be available on the course website*)

Time (EFPH $\times 10^4$ )	7.5	9.8	10.6	11.2	11.4	11.5	11.8	12.0	12.1	12.9
Deuterium (mg/kg)	20	28	26	33	32	36	35	28	33	31

Time (EFPH $\times 10^4$ )	13.1	13.4	13.6	14.1	15.2	16.1	16.2	17.1	17.2	17.4
Deuterium (mg/kg)	41	40	34	32	40	49	46	42	45	52

One of the main concerns for the stations is to ensure that the deuterium ingress does not exceed the critical limit of 70 mg/kg prior to the pressure tube design life of 210,000 EFPH. Using linear regression

- Estimate the parameters, standard error, and the coefficient of determination of the best fit linear regression line.
- Plot the observed deuterium ingress against the predicted values, and also the standardized residuals as a function of time (i.e., EFPH).
- Estimate the deuterium ingress at the design life of 210,000 EFPH and compute the 95 % prediction interval for the estimate. Comment on the results.

- ( 10 ) 4. A nuclear station relies on one of three back-up diesel generators to provide emergency power in the event of loss of class IV power (i.e., only one of the generators is required to operate in the event of the accident). Because of the importance of back-up power, the generators are tested monthly to ensure they start-up on demand and are able to run for the required mission time of 72 hours. Based on data analysis of the test data, it was determined that the generators fail to start approximately 10 % of the time and fail during the mission in approximately 1 in 10 tests.
- Assuming the time to failure during the test (i.e., runtime failure) is described by the Exponential distribution, estimate the probability of failure of the back-up emergency power supply in the event of an accident using Monte Carlo simulation. Assume no repair is possible after start-up or during the mission.
- Bonus:* Estimate the probability of failure analytically (2 marks).
- ( 6 ) 5. The mean time to failure (MTTF) of 36 fuelling machine encoders was estimated as 8 years with a standard deviation of 6 years. With what confidence can one assert that the mean lifetime of the encoders does not exceed 10 years?
- ( 8 ) 6. Variable spring hangers are used to support the dead weight and thermal expansion movements of upper horizontal sections of CANDU feeder pipes. During the last inspection outage, a total of 6 spring hangers were found to be out of design specification. Given that only 10 % of the entire population of 600 spring hangers were inspected in the last outage
- How many spring hangers would be expected to be out of tolerance in the rest of the (i.e., uninspected) population?
  - Compute the 95 % confidence interval for the estimate in part (a).
- ( 8 ) 7. During the last year of operation, a total of 3 defective fuel bundles were detected by the delayed neutron (DN) monitoring system and removed from service at a CANDU station. Based on detailed examinations, the defects were found to be fabrication flaws. The fuel manufacturer's quality control procedures and documentation indicate that the error rate should be approximately 1 defect per 10,000 bundles. Given that there were approximately 5,000 bundles in service at the station during the last year, does the data seem to indicate that the fabrication defect rate is in fact higher than claimed by the fuel manufacturer?
- ( 10 ) 8. Flow accelerated corrosion (FAC) is a serious form of degradation affecting the outlet feeders in CANDU reactors. Based on inspection, the FAC wear rate was estimated on average to be 0.1 mm/year with a standard deviation of 0.03 mm/year. However, because of measurement errors the variability in the estimate is likely to be larger. Assuming the FAC wear rate follows the Normal distribution
- Estimate the upper bound (i.e., 95<sup>th</sup> percentile) wear rate.
  - Assuming the error in the standard deviation is equal to 10 % on average and can be described by the Exponential distribution (i.e., the error is always positive), use the 95/95 rule and estimate the upper 95<sup>th</sup> percentile FAC wear rate with 95 % confidence using Monte Carlo simulation.