NPRE 457
Safety Analysis of Nuclear Reactor Systems
Fall 2022

Online Temporary Alternative Coverage and access during Covid-19 Pandemic and possible resurgence through mutations and variants

1. Please read the assigned-reading lecture-notes chapters.
2. Then answer the corresponding written assignment,
3. For questions about the assignments, please access the teaching assistants by email:
https://www.mragheb.com/NPRE%20402%20ME%20405%20Nuclear%20Power%20Engineering/talist.htm
4. Submit the corresponding written assignment through email to https://canvas.illinois.edu
5. Please use either the Word or pdf formats
6. In case of internet "rationing" (e. g. to health and government authorities), instability, or collapse through overload, please read the lecture notes and submit the corresponding assignments. Already-taken tests and submitted assignments would be used in assessing the final grade.

Threat of nuclear war:
https://www.youtube.com/watch?v=M7hOpT0lPGI

Regrettably, some 3,278 colleges and universities across the USA have been impacted by the Covid-19 pandemic, with many temporarily closing their campuses and switching to online classes, affecting more than 22 million students.

To all and everyone we wish good health and well-being.

<table>
<tr><th>Number</th><th>Date Assigned</th><th>Due Date</th><th>Description</th></tr>
<tr><td>1</td><td>8/22</td><td>8/29</td><td>Reading assignment
Preface
1. Overview
Written Assignment
For a rare failure event in chemical reaction vessels with a design failure likelihood of 10^{-4} failures / (vessel.year), calculate the frequency of occurrence for:
a. 100 vessels in service,
b. 1,000 vessels in service.

For a Loss Of Coolant Accident (LOCA) likelihood of 10^{-5} [occurrences / (reactor.year)], calculate the frequency of occurrence for:
a. 97 reactors in service in the USA,
b. 448 reactors globally.</td></tr>
<tr><td>2</td><td>8/24</td><td>8/31</td><td>Reading assignment
Preface
1. Overview
Written Assignment
Estimate the "Risk" to individuals in the USA population of 319 million persons from the different types of traffic accidents shown in the table in units of fatalities / (person . year)
<table><tr><th>Consequences</th><th>fatalities / year</th><th>Risk</th></tr><tr><td>Fatalities in traffic crashes</td><td>41,059</td><td></td></tr></table></td></tr>
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Injuries in traffic crashes	2,491,000	
Alcohol related deaths	12,998	
Speeding related deaths	13,040	

Generate the corresponding fraction of land area required to provide for the energy needs in the USA using different energy options.
Hint: The USA existing power flux is 0.4 Watts / m^2

Energy option	Power flux [Watts / m^2]	Fraction of Land area needed
Energy crops, biomass, plants	0.5	
Wind power	2.5	
Solar Photo Voltaic panels, (PV)	5.0-20.0	
Concentrated thermal solar power, deserts	15.0-20.0	
Nuclear electricity	1,000.0	

3	8/26	9/2	**Reading assignment** **2. Natural Disasters and Man Made Accidents** **Written Assignment** Briefly describe any differences between the natural events: 1. Hurricanes, 2. Typhoons, 3. Cyclones. Identify the 10 most devastating known natural disasters in terms of human casualties and order them in a descending order.
4	8/**29**	9/**5**	**Reading assignment** **2. Natural Disasters and Man Made Accidents** **Written Assignment** The difference between two Richter Scale magnitudes is given by: $\Delta M = \log_{10} \frac{M_2}{M_1}$ Estimate the ratio of the actual magnitude (9.0M) to the design-basis magnitude (8.6M) for the Fukushima March 11, 2011 earthquake. 2. The relationship between the intensity (E) and magnitude (M) scales can be expressed as: $\frac{E_2}{E_1} = 10^{1.5(M_2 - M_1)}$ Estimate the ratio of the actual intensity to the design-basis intensity for the Fukushima March 11, 2011 earthquake.
5	8/31	9/7	**Reading assignment** **2. Natural Disasters and Man Made Accidents** **Written Assignment**

			List the names of the scales used to describe the expected damage from the following natural hazards: 1. Astral impacts, 2. Earthquakes, 3. Hurricanes, 4. Tornadoes. For each scale, list the description of the expected maximum damage level. Identify any: 1. Design flaws, 2. Equipment failures, 3. Human errors, 4. Natural Events. In the following accidents: 1. Challenger space shuttle accident, 2. Columbia space shuttle accident.
6	9/2	9/9	**Reading assignment** **3. Safety Definitions and Terminology** **Written Assignment** If the fuzzy variable Y = "tolerable" is represented by the discrete membership function: $\mu_Y = \begin{bmatrix} 1.0 & 1.0 & 1.0 & 0.0 & 0.0 \\ 0 & 5 & 10 & 15 & 20 \end{bmatrix}$ Calculate the performance levels of the information granule: g = X *is* Y = "Failure rate" *is* "tolerable", for the following discrete probability density functions representing X = "failure rate" : a) $p_{X1} = \begin{bmatrix} 0.1 & 0.8 & 0.1 & 0.0 & 0.0 \\ 0 & 5 & 10 & 15 & 20 \end{bmatrix}$ b) $p_{X2} = \begin{bmatrix} 0.0 & 0.2 & 0.6 & 0.2 & 0.0 \\ 0 & 5 & 10 & 15 & 20 \end{bmatrix}$ c) $p_{X3} = \begin{bmatrix} 0.0 & 0.0 & 0.3 & 0.4 & 0.3 \\ 0 & 5 & 10 & 15 & 20 \end{bmatrix}$ Plot the discrete functions and discuss the obtained results for the security performance levels.
7	9/7	9/14	**Reading Assignment** **4. Accidents Occurrence** **Written Assignment** Identify on a diagram the different modes of stability. Carry out the shoe box experiment suggested by Per Bak, Chao Tang and Kurt Wiesenfeld, to test the concepts of self-organized critical equilibrium. Describe your observations. Prove that the power law for the energy release in an earthquake: $P(E)dE = \frac{E_0}{E^2}dE, \; E \geq E_0,$ is a probability density function (pdf). Hint: Apply the normalization condition for a pdf.

			Briefly explain: 1. Black Swan event, 2. Critical states, 3. Fingers of instability, 4. Minsky moment.
8	9/9	9/16	**Reading Assignment** **5. Risk Quantification** **Written Assignment** An insurance company requires an overhead on the premiums it collects from its customers. If the payment to a beneficiary is $100,000 and it collects $1,000 per year in premiums, what is the probability of death in the year that the insurance company used to calculate the collected premium if the overhead charge is: 1. 10 percent 2. 20 percent. 3. 30 percent? Compare the result to the case of breakeven for the actuarial risk.
9	9/12	9/19	**Reading Assignment** 6. Incidence and Likelihood Risk and Safety Indices **Written Assignment** Describe the difference between: 1. Incidence risk indices, 2. Likelihood risk indices. 1. Calculate the likelihood risk indices for: a) Obtaining a value of "heads" in the flip of a coin. b) Obtaining a value of "six" in the throw of a single die.
10	9/14	9/21	**Reading Assignment** 7. The Risk Assessment Methodology **Written Assignment** List the conditions for the existence of "Risk". For the *discrete* random variable of the outcomes from throwing a single die, plot: 1. The probability distribution as a function of the outcomes x_i. 2. The cumulative distribution function (cdf) as a function of the outcomes x_i. 3. The complementary cumulative density functions as a function of the outcomes x_i. Use the same scale for comparison, and briefly explain the meaning conveyed by each one of these plots. Hint: For a discrete probability distribution, Cumulative distribution function: $$cdf(x) = \sum_{x_i \leq x} p_i(x)$$ Complementary cumulative distribution function $ccdf(x) = 1 - cdf(x)$ Consider a component that fails at a constant rate λ and a probability density function (pdf): $\lambda e^{-\lambda t}$. 1. Prove that the pdf satisfies the normalization condition. 2. Derive the expression for the mean time to failure or the first moment of the pdf. $$\overline{t} = \frac{\int_0^\infty t.\lambda e^{-\lambda t} dt}{\int_0^\infty \lambda e^{-\lambda t} dt}$$
11	9/16	9/23	**Reading Assignment** **7. The Risk Assessment Methodology** **12. Cost Effectiveness Analysis** **Written Assignment** In Probabilistic Risk Assessment (PRA), risk profiles are generated for likelihoods as a function of outcomes. Consider the probability (likelihood) density function (pdf):

			$\lambda \exp(-\lambda t)$ for the time t to failure of a component with a constant failure rate λ. Derive an expressions for, then use a plotting routine to plot the following: 1. The probability density functions as a function of t. 2. The cumulative distribution functions (cdf) as a function of t. 3. The complementary cumulative density function (ccdf) as a function of t. This is designated as the Farmer's Curve or the Risk Profile. Use the same scale for comparison, and briefly explain the meaning conveyed by each one of these plots. Hint: For a *continuous* pdf: f(x)dx, Cumulative distribution function: $$cdf(x) = \int_0^x f(x)dx$$ Complementary cumulative distribution function $$ccdf(x) = 1 - \int_0^x f(x)dx = \int_x^\infty f(x)dx = 1 - cdf(x)$$ Generate the level of Risk against the cost of risk reduction or Cost-Effectiveness graph for the case of an automobile safety design where extra safety measures are being introduced seeking reduced risk levels. Use tentative values for the entries in the table.

Risk Reduction Measure	Risk Reduction ratio	Cost of Risk Reduction [$]
Seat belts	1/2	$200
Anti-lock brakes	---	---
Front air bags	---	---
Side air bags	---	---
Backup camera	---	---
Front collision avoidance radar	---	---
Lane change sensor	---	---

12	9/19	9/26	**Reading Assignment** **12. Cost Effectiveness Analysis** **Written Assignment** In Risk Assessment using Cost/ Benefit Analysis or Marginal Cost Analysis, calculate the Cost to Benefit Ratio (CBR) using the following information: The annualized cost of an Engineered Safety Feature (ESF) is $C = 15 \times 10^6$ [$/year], the risk before addition of the safety feature is $R_{before}=1.4 \times 10^5$ [person.rem/year], and the risk after the addition of the safety feature is $R_{after} = 2.5 \times 10^4$ [person.rem/year]. The current Nuclear Regulatory Commission (NRC) guideline is to spend $1,000 per [person.rem] reduction in the risk from a radiological accident. What is your recommendation as a Safety Engineer regarding the addition of this ESF? For the following radiological quantities, fill out the table showing the corresponding units and their abbreviations.

Radiological quantity	Conventional System Unit	SI System Unit
Effective dose, dose equivalent		
Absorbed dose		
Activity		
Exposure		

13	9/21	9/28	**Reading Assignment** **13. Boolean Algebra** **Written Assignment** Use Venn diagrams to prove the L10 de Morgan law or axiom of a Boolean Algebra. 1. Use Venn diagrams to prove the L10 de Morgan law or axiom of a Boolean Algebra.

			Consider the “two-element” Boolean Algebra: $B[\{0,1\}, \wedge, \vee, \bar{\ }, 0, 1]$ where: $\wedge$ means the lesser of, $\vee$ means the greater of, $\bar{\ }$ means the opposite of. Fill up the following operation or truth tables: $\begin{array}{c\|c} - & \\ \hline 0 & \\ 1 & \end{array} \quad \begin{array}{c\|cc} \wedge & 0 & 1 \\ \hline 0 & & \\ 1 & & \end{array} \quad \begin{array}{c\|cc} \vee & 0 & 1 \\ \hline 0 & & \\ 1 & & \end{array}$
14	9/23	9/30	**Reading Assignment** **14. Fuzzy de Morgan Algebra** **Written Assignment** Use Zadeh diagrams to prove the L10 de Morgan law or axiom of a Fuzzy De Morgan Algebra. Use Kosko's interpretation of fuzzy sets as points on the unit interval, unit square, unit cube and unit hypercube to analytically calculate, and graphically show: 1. On the unit interval, the point A:{1/3}, A^c, (A OR A^c), (A AND A^c). 2. In the unit square, the fuzzy set A:{2/3,1/4}, A^c, (A OR A^c), (A AND A^c). 3. In the unit cube, the fuzzy set, A:{1/4,1/2,2/3}, A^c, (A OR A^c), (A AND A^c). 4. For the case of the four dimensional hypercube set, A:{1/3, 1/4, 1/2, 3/4} calculate A^c, (A OR A^c), (A AND A^c).
15	9/26	9/30	**Reading Assignment** 15. Probabilistic and Possibilistic Fault Tree Analysis **Written Assignment** Consider the Boolean expression for a Fault Tree: T=A+(B.C.D)+(E.F.G) 1. Graphically construct the corresponding Fault Tree. 2. Analytically deduce the expression for the “operational” tree as the complement of the Fault Tree, and show it graphically. 3. Calculate the *probability* of failure for the top event for probabilities of failures of the basic events equal to 10^{-2}. 4. Show how you can reduce the top event failure probability by modifying the design. Show your suggestion graphically and write its Boolean expression. 5. Compare the failure probability of the modified design to that of the original one.
16	9/28	9/30	**Reading Assignment** 15. Probabilistic and Possibilistic Fault Tree Analysis **Written Assignment** For the Fault tree with the Boolean expression: T=A+(B.C)+(E.F), 1. Graphically construct the corresponding Fault Tree. 2. Analytically deduce the expression for the “operational” tree as the complement of the Fault Tree, and show it graphically. 3. Calculate the *possibility* of failure for the top event for the following possibilities of failures of the basic events: $\Pi(A)=10^{-2}$, $\Pi(B)=\Pi(C)=\Pi(D)=\Pi(E)=\Pi(F)=\Pi(G)=10^{-3}$ Construct a simple Fault Tree describing the top event: “Car would not start in winter-time.”
		9/30	**First Midterm Exam. During class period**
17	10/3	10/10	

Assignments Policy

Assignments will be turned in at the beginning of the class period, one week from the day they are assigned.
They need to be submitted earlier when tests are scheduled.
The first five minutes of the class period will be devoted for turning in, and returning graded assignments.
Late assignments will be assigned only a partial grade. Please try to submit them on time since once the assignments are graded and returned to the class, late assignments cannot be accepted any more.
If you are having difficulties with an assignment, you are encouraged to seek help from the teaching assistants (TAs) during their office hours. Questions may be e-mailed to the TA's, but face-to-face interaction is more beneficial.
Although you are encouraged to consult with each other if you are having difficulties, you are kindly expected to submit work that shows your individual effort. Please do not submit a copy of another person's work as your own. Copies of other people's assignments are not conducive to learning, and are unacceptable.
For further information, please read the detailed assignments guidelines.