NPRE 457
Safety Analysis of Nuclear Reactor Systems
Fall 2020

<table>
<tr><th>Number</th><th>Date Assigned</th><th>Due Date</th><th>Description</th></tr>
<tr><td>1</td><td>8/24</td><td>9/9</td><td>Reading Assignment
NEW Preface
NEW 1. Overview
Written Assignment
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>8/26</td><td>9/9</td><td>Reading Assignment
NEW 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>
<tr><td>Injuries in traffic crashes</td><td>2,491,000</td><td></td></tr>
<tr><td>Alcohol related deaths</td><td>12,998</td><td></td></tr>
<tr><td>Speeding related deaths</td><td>13,040</td><td></td></tr>
</table></td></tr>
<tr><td>3</td><td>8/28</td><td>9/9</td><td>Reading Assignment
NEW 2. Natural Disasters and Man Made Accidents
Written Assignment
Identify the 10 most devastating known natural disasters in terms of human casualties and order them in a descending order.

Briefly describe the differences between the natural events:
1. Hurricanes,
2. Typhoons,
3. Cyclones.</td></tr>
<tr><td>4</td><td>8/31</td><td>9/9</td><td>Reading Assignment
NEW 2. Natural Disasters and Man Made Accidents
Written Assignment
1. 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:</td></tr>
</table>

			$$\frac{E_2}{E_1} = 10^{1.5(M_2 - M_1)}$$ Estimate the ratio of the actual intensity to the design-basis intensity for the Fukushima March 11, 2011 earthquake.
5	9/2	9/9	**Reading Assignment** NEW **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. List the general "initiating events" that general experience reveals are associated with accidents.
6	9/4	9/11	**Reading Assignment** NEW **3. Safety Definitions and Terminology** **Written Assignment** Read then write a short summary of the paper: L. Tsoukalas, G. W. Lee, M. Ragheb, "Anticipatory Monitoring and Control in a Process Environment," IEA/AIE '89 Proceedings of the 2nd International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems, Volume 1, pp.278-287, 1989, Digital Library, Association of Computing Machinery, ACM. If the fuzzy variable Y = "tolerable" is represented by the discrete membership function: $$\mu_Y = \begin{pmatrix} 1.0 & 1.0 & 1.0 \\ 0 & 5 & 10 \end{pmatrix},$$ Calculate the performance level of the security: g = X *is* Y = Failure rate *is* tolerable, for the following discrete probability density functions representing X = "failure rate" : a) $$p_{X1} = \begin{pmatrix} 0.1 & 0.8 & 0.1 \\ 0 & 5 & 10 \end{pmatrix}$$ b) $$p_{X2} = \begin{pmatrix} 0.2 & 0.6 & 0.2 \\ 5 & 10 & 15 \end{pmatrix}$$ c) $$p_{X3} = \begin{pmatrix} 0.3 & 0.4 & 0.3 \\ 10 & 15 & 20 \end{pmatrix}$$ Plot the discrete functions and discuss the obtained results for the security performance levels.
-	9/7	-	**Labor day, no class**
7	9/9	9/16	**Reading Assignment** NEW **4. Accidents Occurrence** **Written Assignment** 1. Identify on a diagram the different modes of stability. 2. Carry out the shoe box experiment suggested by Per Bak, Chao Tang and Kurt Wiesenfeld, to test the concepts of self-organized critical equilibrium.

<table>
<tr><td></td><td></td><td></td><td>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 with E_0 as the lower limit of the normalization integral.

Briefly explain:
1. Black Swan event,
2. Critical states,
3. Fingers of instability,
4. Minsky Moment.</td></tr>
<tr><td>8</td><td>9/11</td><td>9/18</td><td>Reading Assignment
NEW 5. Risk Quantification
Written Assignment
A person in a certain age group with a 1 percent probability of dying in a year: p = 0.01. He purchases a life insurance policy with a payoff value of $ 1,000,000. To break even, or for the net income to the insurance company to be equal to the net award that it must pay, calculate the monthly premium the insurance company must have him pay.</td></tr>
<tr><td>9</td><td>9/14</td><td>9/21</td><td>Reading Assignment
NEW 5. Risk Quantification
Written Assignment
List the stages of the cycle of the eventual acceptance of risk consequences.

Fill out the USA Department of Defense, DOD’s table comparing the risk of the 1018 Spanish Flu pandemic compared with wars:

<table>
<tr><th></th><th>American deaths in wars</th><th>American deaths from 1918 flu</th></tr>
<tr><td>World War I</td><td>-</td><td></td></tr>
<tr><td>World War II</td><td>-</td><td></td></tr>
<tr><td>Korea</td><td>-</td><td></td></tr>
<tr><td>Vietnam</td><td>-</td><td></td></tr>
<tr><td>Iraq</td><td>-</td><td></td></tr>
<tr><td>Afghanistan</td><td>-</td><td></td></tr>
<tr><td>Total</td><td>-</td><td>-</td></tr>
</table>

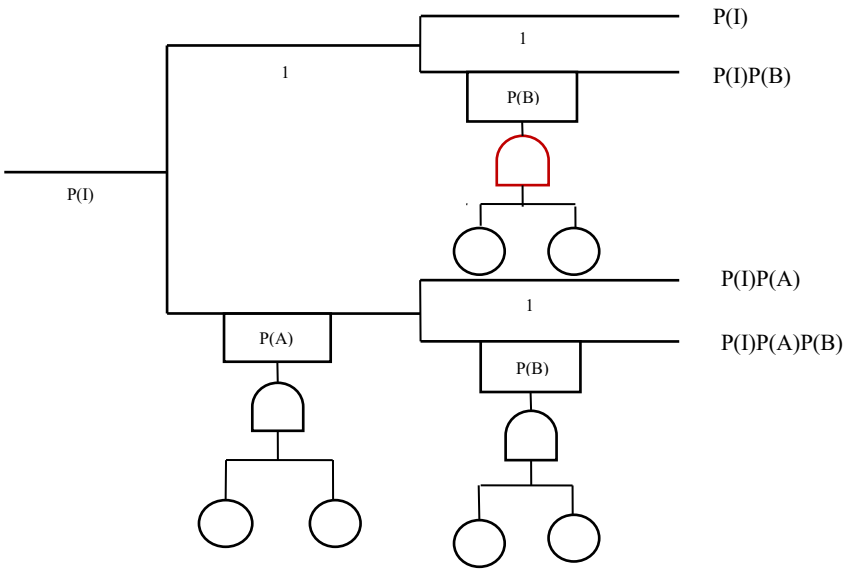
Fill out the table listing the leading causes of death in the USA according to the Center for Disease Control and Prevention, CDC.

<table>
<tr><th>Cause</th><th>Number of deaths/year</th></tr>
<tr><td>Heart disease</td><td>-</td></tr>
<tr><td>Cancer</td><td>-</td></tr>
<tr><td>Health services error and malpractice</td><td>-</td></tr>
<tr><td>Chronic lower respiratory diseases</td><td>-</td></tr>
<tr><td>Stroke, cerebro-vascular diseases</td><td>-</td></tr>
<tr><td>Accidents, unintentional injuries</td><td>-</td></tr>
<tr><td>Alzheimer’s diseases</td><td>-</td></tr>
<tr><td>Diabetes</td><td>-</td></tr>
<tr><td>Influenza and pneumonia</td><td>-</td></tr>
<tr><td>Nephritis, nephrotic syndrome, and nephrosis</td><td>-</td></tr>
<tr><td>Intentional self-harm, suicide</td><td>-</td></tr>
</table>
</td></tr>
<tr><td>10</td><td>9/16</td><td>9/23</td><td>Reading Assignment</td></tr>
</table>

			NEW **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: $$cdf(x) = \sum_{x_i \le x} p_i(x)$$ Complementary cumulative distribution function $ccdf(x) = 1 - cdf(x)$ In Probabilistic Risk Assessment (PRA), risk profiles are generated for likelihoods as a function of outcomes. Consider the probability density function (pdf): $$f(t) = \lambda e^{-\lambda t}$$ for the time t to failure of a component with a constant failure rate λ. Derive an expression 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 $ccdf(x) = 1 - \int_0^x f(x)dx = \int_x^\infty f(x)dx = 1 - cdf(x)$
11	9/18	9/25	**Reading Assignment** NEW **9. The Source Term** **Written Assignment** Identify the health physics concerns from the following fission products that could potentially be released in a nuclear reactor accident: Isotope / Half life / Health Concern Sr^{90} / 28 a / Cs^{137} / 33 a / I^{131} / 8 d / Kr^{87} / 78 m / Calculate the effective half-lives in terms of the physical and biological half-lives of the following fission products of safety concern: a. Sr^{90} b. Cs^{137} c. I^{131} d. T^3
12	9/21	9/28	**Reading Assignment** NEW **10. Environmental Remediation of Radioactive Contamination** **Written Assignment** List the decontamination approaches for CS^{137}. The soil to plant transfer ratio for Cs^{137} for tropical fruit grown on the Bikini Island ranges between 2 to 40. For crops grown on continental soils this factor ranges between the much smaller values of 0.005 to 0.5. 1. Calculate the specific activity of Cs^{137} in a contaminated soil in [Bq/gm] if the percentage weight of the isotope in the soil is 0.01 percent. 2. Calculate the corresponding ranges of the specific activities of Cs^{137} of plants grown in contaminated tropical and continental soils in Bq/gm.

<table>
<tr><td>13</td><td>9/23</td><td>9/30</td><td>Reading Assignment
NEW 11. Decay Heat Generation in Fission Reactors
Written Assignment
A nuclear power reactor is operated according to the following power history:
1. Operation at a power level of 3,000 MWth for 1 year, followed by,
2. Operation at a power level of 1,500 MWth, for 6 months, followed by a scram (shut-down).
Using the analytical formulae derived in the class, determine the decay-heat power in MWth:
1. Six minutes after shutdown,
2. One day after shutdown,
3. One month after shutdown.
Hint: The decay-heat contributions from the two operational periods add up linearly.</td></tr>
<tr><td>14</td><td>9/25</td><td>10/2</td><td>Reading Assignment
NEW 11. Decay Heat Generation in Fission Reactors
Written Assignment
A nuclear power reactor is operated according to the following power history:
1. Operation at a power level of 3,000 MWth for 1 year, followed by,
2. Operation at a power level of 1,500 MWth, for 6 months, followed by a scram (shut-down).
Using the Systems Analysis Handbook graphs, determine the decay heat power at one day after shutdown.</td></tr>
<tr><td>15</td><td>9/28</td><td>10/2</td><td>Reading Assignment
NEW 12. Cost Effectiveness Analysis
Written Assignment
For the Emergency Core Cooling System (ECCS) for a Pressurized Water Reactor (PWR) system the annualized cost of the Engineered Safety Feature (ESF) is:
$C=1.5\times10^{6}$ [$/year]
The existing risk from n identified accident sequences is:
$\sum_{i=1}^{n} f_i R_i = 1.0\times10^{5}$[person.rem/year]
The risk from m accident sequences after implementation of the ESF is:
$\sum_{i=1}^{m} f_i' R_i' = 3.0\times10^{4}$[person-rem/year]]
Estimate the cost-benefit ratio, clearly showing its units.</td></tr>
<tr><td>16</td><td>9/30</td><td>10/2</td><td>Reading Assignmeny
NEW 12. Cost Effectiveness Analysis
Written Assignment
Fill out the table of the common radiological units
<table><tr><th>Radiological quantity</th><th>Conventional System Unit</th><th>SI System Unit</th><th></th></tr><tr><td>Effective dose, dose equivalent</td><td></td><td></td><td></td></tr><tr><td>Absorbed dose</td><td></td><td></td><td></td></tr><tr><td>Activity</td><td></td><td></td><td></td></tr><tr><td>Exposure</td><td></td><td></td><td></td></tr></table></td></tr>
<tr><td>17</td><td>10/2</td><td>10/2
First
Midterm</td><td>NPRE 457 Fall 2020 First Midterm Exam
Please submit exam answers as an email attachment to: *****</td></tr>
<tr><td>18</td><td>10/5</td><td>10/12</td><td>Reading Assignment
NEW 6. Incidence and Likelihood Risk and Safety Indices
NEW 13. Boolean Algebra
Written Assignment
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.</td></tr>
</table>

			c) Playing the game of Russian Roulette 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: $-$ | 0 | 1 | $\wedge$ | 0 1 0 | 1 | $\vee$ | 0 1 0 | 1 |
19	10/7	10/14	**Reading Assignment** NEW **13. Boolean Algebra** **Written Assignment** Graph then construct a table of combinations for the gating network given by the Boolean expression: (X1+X2).X3
20	10/9	10/16	**Reading Assignment** NEW **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). Write a one page summary of the article on the construction of "Expert Systems" in the field of Applied Artificial Intelligence: Dan Rehfeldt and Magdi Ragheb, "Building Expert Systems in Prolog on the Explorer Machine," TI Professional Computing, Vol. 3, No. 6, pp. 12-27. June 1986. What kind of logic does it use?
21	10/12	10/19	**Reading Assignment** NEW **15. Probabilistic and Possibilistic Fault Tree Analysis** **Written Assignment** Construct a simple Fault Tree describing the top event: "Car would not start in winter-time." For the cases of n=2 and n=3 prove that the summation and the product formulae for the probability of the union of n events are equivalent. Use Venn diagrams to prove the formulae for n = 2 and n =3.
22	10/14	10/21	**Reading Assignment** NEW **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 Boolean expression for the "operational" tree as the complement of the Fault Tree, and show it graphically. 2. Calculate the probability of failure for the top event for probabilities of failures of the basic events equal to 10^{-3}.

			3. Show how you can reduce the top event failure probability by modifying the design. Show your suggestion graphically and write its Boolean expression. 4. Compare the failure probability of the modified design to that of the original one. 5. Calculate the possibility of failure for the top event for the following possibilities of failures of the basic events: $\Pi(A)=10^{-2}$, $\Pi(B)=\Pi(C)=\Pi(D)=\Pi(E)=\Pi(F)=\Pi(G)=10^{-3}$.
23	10/16	10/23	**Reading Assignment** NEW **16. Event Tree Analysis** **Writing Assignment** An initiating event for an accident occurs with a probability $P(I)=10^{-3}$. To mitigate that type of accident the system was designed with three Engineered Safety Features (ESFs). The probabilities of failure of these ESFs are: $P(A) = 10^{-2}$, $P(B) = 10^{-3}$, and $P(C) = 10^{-4}$. a. Construct the event tree that describes this system. b. Using the small probabilities approximation, calculate the probabilities of failure for each of the different accident sequences in the Event Tree. c. If we consider that we have a possibilistic rather than a probabilistic Event Tree, calculate the possibilities for the different accident sequences for: $\pi(I)=10^{-3},\pi(A)=10^{-2},\pi(B)=10^{-3},\pi(C)=10^{-4}$.  1. In the shown coupled event and fault tree, if the probabilities of failure of the basic events are all equal to 10^{-3}, and the probability of the initiating event is 10^{-4}, calculate the probabilities of the different accident sequences. 2. If one uses the same values as possibilities of failure, estimate the possibilities of the different accident sequences.
24	10/19	10/26	**Reading Assignment** NEW **8. Risk and Safety Ethics** **Written Assignment** For a maximum load of 500 kgs on a structural element, pick appropriate choices for the factor of safety and the ignorance factor. What is the design load according to these choices?
25	10/21	10/28	**Reading Assignment** NEW **8. Risk and Safety Ethics** **Written Assignment** The concept of acceptable risk defines the professional and ethical dimension of the engineering profession.

			Because of the element of uncertainty involved in risk, a bias or predisposition in favor of one set of values or another is inevitable. Explain the difference between the observed two sets of values, biases or orientations: 1. The Good Science (GS) approach 2. The Respect for Persons (RP) approach Describe by an example how the "Precautionary Principle" is differently applied in Europe and in the USA.
26	10/23	10/30	**Reading Assignment** NEW **21. Fluid Mechanics Equations** **Written Assignment** From Euler's equation: $dp = -\rho V dV$ Derive the expression for Bernoulli's law suggesting that the sum of the static and kinetic pressures is a constant between two points at steady-state in an inviscid flow without body forces. A wind turbine rotor airfoil is placed in the air flow at sea level conditions with a free stream speed of 10 m/s. The density at standard sea level conditions is 1.23 kg/m^3 and the pressure is 1.01 x 10^5 Newtons / m^2. At a point along the rotor airfoil the pressure is a lower 0.90 x 10^5 Newtons / m^2, generating lift. By applying Bernoulli's equation estimate the accelerated wind speed at this point.
27	10/26	11/2	**Reading Assignment** NEW **22. Safety Computational Fluid Dynamics** **Written Assignment** 1. List the four basic relationships that define Computational Fluid Dynamics (CFD) for single phase flow. 2. List the variables used in a numerical CFD one phase flow computational scheme together with their units in the conventional cgs (centimeter, gram, sec) system of units 3 In CFD, the discretization of the energy conservation equation proceeds as follows. The specific internal energy can be calculated based on the work done on the slab assuring conservation of energy through the thermodynamic relation: $dE = -pdV$ $\Delta E \simeq -p\Delta V$ $E^n_{j-\frac{1}{2}} - E^{n-1}_{j-\frac{1}{2}} = ?$ $E^n_{j-\frac{1}{2}} = ?$ 4. The discretization of the momentum conservation equation proceeds as follows. An updated velocity can now be calculated using the acceleration equation or the equation of motion: $\frac{du}{dt} = -V\nabla p = -V\frac{\partial p}{\partial x} = -V\frac{\Delta p}{\Delta x}$ $\frac{u_j^{n+\frac{1}{2}} - u_j^{n-\frac{1}{2}}}{(\Delta t)^n} = ?$ $u_j^{n+\frac{1}{2}} = ?$
28	10/28		

Assignments Policy

Assignments will be turned in at the beginning of the class period, one week from the day they are assigned.
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 emailed to 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.