NPRE 457
Safety Analysis of Nuclear Reactor Systems

Fall 2018

<table>
<tr><th>Number</th><th>Date Assigned</th><th>Due Date</th><th>Description</th></tr>
<tr><td>1</td><td>8/27</td><td>9/5</td><td>Estimate the risk to individuals in the USA population of 319 million persons from the different types of traffic accidents shown in the table. Use the appropriate units.
<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>
For a Loss Of Coolant Accident (LOCA) likelihood of 10^{-5} occurrences / (reactor . year), calculate the frequency of occurrence for:
a. 104 reactors in service in the USA,
b. 446 reactors globally.</td></tr>
<tr><td>2</td><td>8/29</td><td>9/5</td><td>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>3</td><td>8/31</td><td>9/7</td><td>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:

$$\frac{E_2}{E_1} = 10^{1.5(M_2 - M_1)}$$

Estimate the ratio of the actual intensity to the design-basis intensity for the Fukushima March 11, 2011 earthquake.</td></tr>
<tr><td>4</td><td>9/5</td><td>9/12</td><td>Identify any:
1. Design flaws,
2. Equipment failures,
3. Human errors,
4. Natural Events.
In the following accidents:
1. Challenger space shuttle accident,</td></tr>
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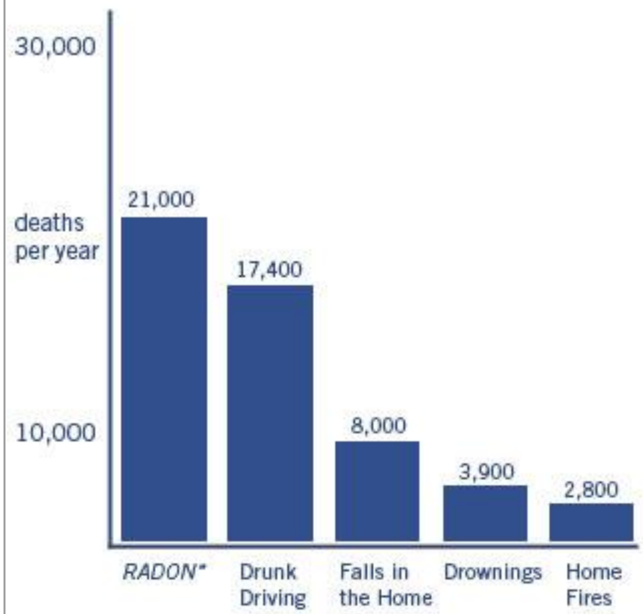
			2. Columbia space shuttle accident.
5	9/7	9/14	If the fuzzy variable Y = “tolerable” is represented by the discrete membership function: $\mu_Y = \begin{bmatrix} 1.0 & 1.0 & 1.0 & 0.0 & 0.0 \\ 0 & 5 & 10 & 15 & 20 \end{bmatrix}$ Calculate the performance levels of the information granule: g = X *is* 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.
6	9/10	9/17	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. Describe your observations.
7	9/12	9/19	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. 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. $\bar{t} = \frac{\int_0^\infty t.\lambda e^{-\lambda t} dt}{\int_0^\infty \lambda e^{-\lambda t} dt}$
8	9/14	9/21	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	9/17	9/24	List the objectives of the typical risk assessment methodology. Use the following diagram to estimate the individual risk of death per year from different sources for a USA population of 325 million persons. Write a paragraph about the source and the properties of Radon gas. 
10	9/19	9/26	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 $ccdf(x) = 1 - \int_0^x f(x)dx = \int_x^\infty f(x)dx = 1 - cdf(x)$
11	9/21	9/27	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.

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Hint: For a discrete probability distribution,
Cumulative distribution function:
$$cdf(x) = \sum_{x_i \le x} p_i(x)$$
Complementary cumulative distribution function $ccdf(x) = 1 - cdf(x)$

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.
<table>
<tr><th>Risk Reduction Measure</th><th>Risk Reduction ratio</th><th>Cost of Risk Reduction [$]</th></tr>
<tr><td>Seat belts</td><td>1/2</td><td>$200</td></tr>
<tr><td>Anti-lock brakes</td><td>---</td><td>---</td></tr>
<tr><td>Front air bags</td><td>---</td><td>---</td></tr>
<tr><td>Side air bags</td><td>---</td><td>---</td></tr>
<tr><td>Backup camera</td><td>---</td><td>---</td></tr>
<tr><td>Front collision avoidance radar</td><td>---</td><td>---</td></tr>
<tr><td>Lane change sensor</td><td>---</td><td>---</td></tr>
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<tr>
<td>12</td>
<td>9/24</td>
<td>10/1</td>
<td>
For the following radiological quantities, fill out the table showing the corresponding units and their abbreviations.
<table>
<tr><th>Radiological quantity</th><th>Conventional System Unit</th><th>SI System Unit</th></tr>
<tr><td>Effective dose, dose equivalent</td><td></td><td></td></tr>
<tr><td>Absorbed dose</td><td></td><td></td></tr>
<tr><td>Activity</td><td></td><td></td></tr>
<tr><td>Exposure</td><td></td><td></td></tr>
</table>

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?
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<td>13</td>
<td>9/26</td>
<td>10/3</td>
<td>
Identify the health physics concerns from the following fission products that could potentially be released in a nuclear reactor accident:
<table>
<tr><th>Isotope</th><th>Half life</th><th>Health Concern</th></tr>
<tr><td>Sr^{90}</td><td>28 a</td><td></td></tr>
<tr><td>Cs^{137}</td><td>33 a</td><td></td></tr>
<tr><td>I^{131}</td><td>8 d</td><td></td></tr>
<tr><td>Kr^{87}</td><td>78 m</td><td></td></tr>
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<tr>
<td>14</td>
<td>9/28</td>
<td>10/3</td>
<td>
Calculate the effective half-lives in terms of the radioactive and biological half-lives of the following fission products of safety concern:
a. Sr^{90}
b. Cs^{137}
c. I^{131}
d. T^3
</td>
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<tr>
<td>15</td>
<td>10/1</td>
<td>10/3</td>
<td>
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.
</td>
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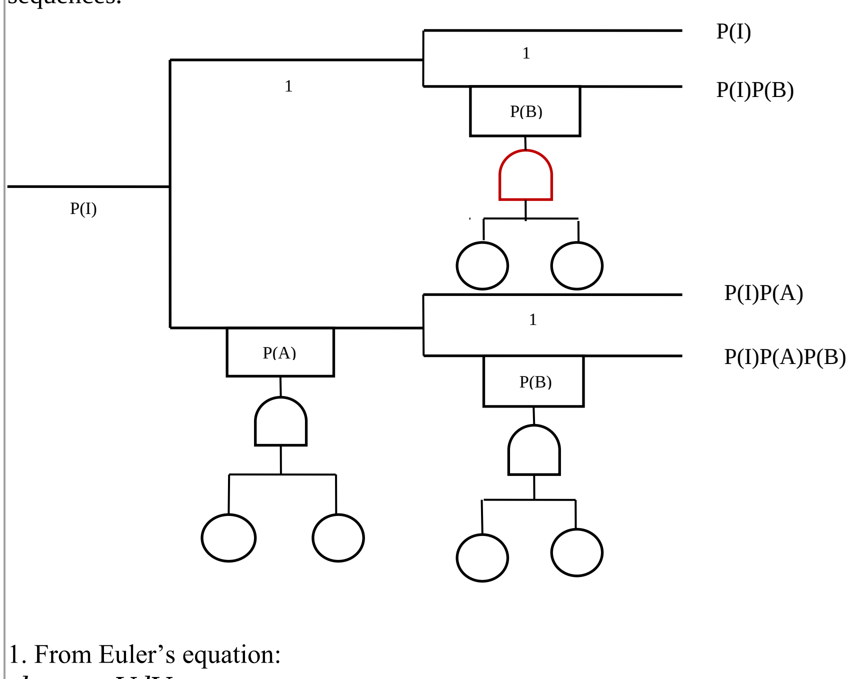
</table>

			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.
16	10/5	10/12	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.
17	10/8	10/15	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.
18	10/10	10/17	1. Use Venn diagrams to prove the L10 de Morgan law or axiom of a Boolean Algebra. 2. 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: $\begin{array}{c\|c} - & \\ \hline 0 & \\ 1 & \end{array}$ $\begin{array}{c\|cc} \wedge & 0 & 1 \\ \hline 0 & & \\ 1 & & \end{array}$ $\begin{array}{c\|cc} \vee & 0 & 1 \\ \hline 0 & & \\ 1 & & \end{array}$
19	10/12	10/19	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).
20	10/15	10/22	Graph then construct a table of combinations for the gating network given by the Boolean expression: (X1+X2).X3
21	10/17	10/24	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?
22	10/19	10/26	Construct a simple Fault Tree describing the top event: "Car would not start in winter-time."
23	10/22	10/19	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. 2. Calculate the *probability* of failure for the top event for probabilities of failures of the basic events equal to 10^{-2}. 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.
24	10/24	10/31	For the Fault tree with the Boolean expression: 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 *possibility* of failure for the top event for the following possibilities of failures of the basic events: $\Pi(A)=10^{-2}$, $\Pi(B)= \Pi(C)= \Pi(D)= \Pi(E)= \Pi(F)= \Pi(G)=10^{-3}$
25	10/26	11/2	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: $\pi(I)=10^{-3}, \pi(A)=10^{-2}, \pi(B)=10^{-3}, \pi(C)=10^{-4}$.
26	10/29	11/2	In the shown coupled event and fault tree, if the probabilities of failure of the basic events are all equal to 10^{-4}, and the probability of the initiating event is 10^{-5}, calculate the probabilities of the different accident sequences. If one uses the same values as possibilities of failure, estimate the possibilities of the different accident sequences.  1. 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 in an inviscid flow without body forces.

			2. A wind rotor airfoil is placed in the air flow at sea level conditions with a free stream velocity 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 0.90 x 10^5 Newtons/m^2. By applying Bernoulli's equation estimate the velocity at this point.
27	10/31	11/2	a) List the four basic relationships that define Computational Fluid Dynamics (CFD) for single phase flow. b) 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 c) 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: $dE = -pdV, \Delta E \simeq -p\Delta V$ $E^n_{j-\frac{1}{2}} - E^{n-1}_{j-\frac{1}{2}} = ?$ $E^n_{j-\frac{1}{2}} = ?$
28	11/5	11/12	Consider a model of a "Steam explosion" with an energy release of 2 GJ. a) If the mass of a generated vertically moving water piston is 9 metric tonnes, and it acquires the energy release as kinetic energy, calculate its vertical speed in m/sec. a) Assuming that the top concrete shielding plate with a weight of 700 metric tonnes exchanges momentum with the water piston upon their collision, by applying the law of conservation of momentum, calculate its vertical speed in m/sec. b) Estimate the height in meters to which that top plate would have risen vertically as a result of the collision with the water piston by applying conservation of the kinetic and potential energies and use the gravity acceleration constant as g = 9.81 m/sec^2. Briefly describe what caused the criticality-steam-explosion accident at the SL1 reactor.
29	11/7	11/14	Identify any possible: 1. Human error, 2. Equipment failure, 3. Design flaw, in the Chernobyl accident.
30	11/9	11/16	Identify the similarities and differences between: 1. The Windscale accident, 2. The Chernobyl accident. Apply conservation of charge and of nucleons to balance the following two "fissile breeding" reactions, ignoring the antineutrinos:

			${}_{0}n^{1} + {}_{92}U^{238} \rightarrow {}_{92}U^{?}$ ${}_{92}U^{?} \rightarrow {}_{-1}e^{0} + {}_{?}?^{?}$ ${}_{?}?^{?} \rightarrow {}_{-1}e^{0} + {}_{?}?^{?}$ $-------------$ ${}_{0}n^{1} + {}_{92}U^{238} \rightarrow 2\,{}_{-1}e^{0} + {}_{?}?^{?}$ ${}_{0}n^{1} + {}_{90}Th^{232} \rightarrow {}_{90}Th^{?}$ ${}_{90}Th^{?} \rightarrow {}_{-1}e^{0} + {}_{?}?^{?}$ ${}_{?}?^{?} \rightarrow {}_{-1}e^{0} + {}_{?}?^{?}$ $-------------$ ${}_{0}n^{1} + {}_{90}Th^{232} \rightarrow 2\,{}_{-1}e^{0} + {}_{?}?^{?}$
31	11/12	11/26	
32	11/14	11/26	
33	11/16	11/26	
34	11/26	12/3	

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.