NATIONAL EXAMS

December 2019

11-CS-3, Sustainability, Engineering and the Environment

3 hours duration

NOTES:

1. If a doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. Any Casio or Sharp approved calculator is permitted. This is a **closed-book** exam. Write the name and model designation of the calculator, on the first inside left hand sheet of the exam book.

3. Any four (4) questions constitute an exam paper. Indicate on the front of the exam booklet(s) which four questions were attempted, otherwise only the first four questions, as they appear in your answer book, will be marked.

4. All questions are of equal value.

Marking Scheme

1.	25 marks total	(a) 7 marks
		(b) 3 marks
		(c) 6 marks
		(d) 5 marks
		(e) 4 marks
2.	25 marks total	(a) 3 marks
		(b) 3 marks
		(c) 3 marks
		(d) 4 marks
		(e) 7 marks
		(f) 5 marks
3.	25 marks total	one question
4.	25 marks total	(a) 8 marks
		(b) 2 marks
		(c) 4 marks
		(d) 6 marks
		(e) 5 marks
5.	25 marks total	(a) 2 marks
		(b) 5 marks
		(c) 10 marks
		(d) 8 marks

Question (1) – 25 marks

a. The Unites States Environmental Protection Agency has an expression about ozone: "bad nearby, good up high". What are the two kinds of ozone to which they are referring? Explain the difference between the two types, in terms of (i) formation, (ii) harmful/beneficial effects, and (iii) the influence of human activities. **(7 marks)**

b. What size of airborne particulate matter is most harmful to human health, and why? **(3 marks)**

c. What are the two main types of acid that make up acid rain? What is the main source of each? List <u>two</u> effects of acid rain. **(6 marks)**

d. Calculate the carbon dioxide equivalents of the following four emissions of gases: 9.3 tonnes of CO_2, 0.93 Mg CH_4, 93 kg of N_2O, and 0.93 kg of SF_6. Rank them in terms of their global warming potential. **(5 marks)**

Table / 2.3

100-Year Global Warming Potentials (GWP) Used to Convert Mass Greenhouse Gas Emissions to Carbon Dioxide Equivalents (CO_2e)

Type of Emission	Multiplier for CO_2 Equivalents (CO_2e)
Carbon dioxide	1
Methane	25
Nitrous oxide	298
Hydrofluorocarbons (HFCs)	124–14,800 (depends on specific HFC)
Perfluorocarbons (PFCs)	7,390–12,200 (depends on specific PFC)
Sulfur hexafluoride (SF_6)	22,800

SOURCE: Values from Intergovernmental Panel on Climate Change.

e. Describe the main mechanism of the global warming theory and how CO_2 is involved. **(4 marks)**

Question (2) – 25 marks

a. One of the 12 Principles of Green Engineering* is *Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.* Give a specific example of how this principle can be used to prevent pollution. **(3 marks)**

b. One of the 12 Principles of Green Engineering* is *Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.* Give a specific example of how this principle can be used to prevent pollution. **(3 marks)**

c. One of the 12 Principles of Green Engineering* is *Products, processes, and systems should be designed for performance in a commercial "afterlife".* Give a specific example of how this principle can be used to prevent pollution. **(3 marks)**

d. Aluminum is one of the raw materials used by a factory to make bodies for computers. The factory purchases 100 tonnes of raw materials per year and 91 tonnes end up in the finished products that leave the factory every year. The difference ends up leaving the factory as pollution: particulate matter exhausted through the stack, turnings collected from the shop floor and thrown out, or in the wastewater. Draw and label a diagram to show the mass balance of aluminum for the factory. Draw and label another diagram to show the mass balance if pollution prevention measures were implemented to reduce the pollution by half, while maintaining the same production. **(4 marks)**

e. Assume that you have been hired by a restaurant chain to conduct a life-cycle assessment (LCA) on the use of single-use plastic straws versus reusable metal straws. **(7 marks)**

   i. What would be a good functional unit for the LCA?
   ii. List the four main *stages/phases* of the product life-cycle to be considered in a LCA. (*Hint: consider what each company does in the life of the product*)
   iii. In *what stage/phase* of the LCA would you expect to find the greatest environmental impact for *each* of the two alternatives?

f. A toxic material is used in a manufacturing process, but ideally, it does not comprise part of the product. Rank the following measures (listed here in alphabetic order of the bolded words) in order of *desirability* for pollution prevention: **(5 marks)**

- collecting and **destroying** the used material through incineration or chemical reaction
- capturing, containing, and **disposing** the used material
- **eliminating** the need for the toxic material in the process
- capturing the used material and sending it to an **off-site recycling** facility
- capturing the used material and **recycling it within the factory**
- **substituting** the material for one which is less toxic

*Anastas, P. and Zimmerman, J. (2003) Design Through the 12 Principles of Green Engineering. *Env. Sci. Tech.* March 1, p. 94-101.

Question (3) – 25 marks

Compare the environmental, social, and economic impacts of installing and operating a plant to produce **300 MW** of electricity, utilizing the following generating technologies:

- a "farm" of wind turbines
- a nuclear power plant
- a power plant with natural gas turbines
- a power plant fuelled by wood pellets
- a coal-fired power plant

Create a table to summarize your analysis. Use the following five headings in your table: capital cost, fuel cost, land requirement, greenhouse gas emissions, and health risks to neighbors. Consider the plant itself **and any *upstream processes*** used to make or feed the plant. Use H, M, L (high, medium, low) ratings for each cell of the table ***and provide a brief explanation for each***.

Question (4) – 25 marks

a. Draw a flow diagram to show the sequence of processes in a typical *drinking water* treatment plant. Include the following processes (listed here in alphabetic order): coagulation/flocculation, disinfection, filtration, grit chamber, screens, and sedimentation. Label each process and describe which contaminant(s) it removes. **(8 marks)**

b. Turbidity is a parameter used to control processes in drinking water treatment plants. What is turbidity? How is turbidity related to microbial water quality? **(2 marks)**

c. Fecal bacteria in the guts of warm-blooded animals decrease when outside their hosts. When raw sewage is discharged into a lake or river, the fecal bacteria numbers decrease by exponential decay $\left[\frac{dX}{dt} = -k_d X\right]$. What is the decay coefficient (k_d), if the viable bacteria concentration of 10^8 cell/mL is reduced to 100 cell/mL in 6.0 days? Show your calculations. **(4 marks)**

d. Conserva, an island country of 72,000 inhabitants, wants to ensure that its total water consumption does not increase. Due to immigration, the island's population is expected to grow exponentially at a growth rate of 1.2%/year. The country will implement conservation measures to *reduce* its per capita water consumption linearly from its current value of 114 L/person·day. What rate of decrease of per capita water consumption must it achieve so that the total water consumption at the end of 20 years is the same as it is now? **(6 marks)**

e. BOD is a parameter monitored at wastewater treatment plants. What does BOD mean? What material in the wastewater does it measure? Describe two ways that BOD is reduced as the wastewater flows through the treatment plant. **(5 marks)**

Question (5) – 25 marks

Equations for this question:

$ppb = \frac{C \cdot R \cdot T}{MW \cdot P}$ where C = concentration (μg/m^3)

$Average\ Daily\ Dose\ (ADD) = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot AT}$

where C = concentration (mg/L)
IR = intake rate (L/day)
BW = body weight (kg)
AT = averaging time (days) = lifetime (70 years) for carcinogens
= actual exposure (days) for non-carcinogens

Risk = ADD*(slope factor) [acceptable risk is 10^{-4}]

Hazard Quotient = ADD/(reference dose) [acceptable HQ<1]

Table 6.14

Land Uses and Examples of Exposure Assessment Associated with Each Use The EPA publishes an *Exposure Factors Handbook* (EPA, 2011b) that provides more detail on specific values used in exposure assessment (EPA/600/R-09/052F, 2011).

Land Use	Examples of This Land Use	Example IR for Drinking Water; Air Inhalation, and Soil Ingestion	Example Exposure Frequency (EF) (days per year) and Exposure Duration (ED) (years)
Residential (primary activity is residential)	Single-family dwellings, condominiums, apartment buildings	Children drink 1 L/day Adults drink 2 L/day Adults inhale 20 m^3/day Children age 1–6 consume 200 mg soil/day Adults consume 100 mg soil/day	For drinking water EF: 350 days/year ED: 30 years For air inhalation EF: 350 days/year ED: 30 years For soil ingestion ED: 6 years for children 1–6 ED: 24 years for adults EF: 350 days for children and adults
Industrial (primary activity is industrial, or zoning is industrial)	Manufacturing, utilities, industrial research, and development, petroleum bulk storage	Adults drink 1 L/day Adults inhale 10 m^3/day	For drinking water EF: 245 days/year ED: 21 year For air inhalation EF: 245 days/year ED: 21 years For soil ingestion ED: 21 years for adults EF: 245 days for children and adults
Commercial (use is a business or is intended to house, educate, or provide care for children, the elderly, the infirm, or other sensitive subpopulations)	Day-care centers, educational facilities, hospitals, elder-care facilities and nursing homes, retail stores, professional offices, warehouses, gas stations, auto services, financial institutions, government buildings	Adults drink 1 L/day Adults inhale 10 m^3/day	For drinking water EF: 245 days/year ED: 21 years For air inhalation EF: 245 days/years ED: 21 years For soil ingestion ED: 21 years for adults EF: 245 days for children and adults

*Recall that the average weight for a male, female, and child are 70 kg, 50 kg, and 10 kg, respectively.

a. Explain the statement "Exposure to a single molecule of a carcinogen will result in a risk of cancer." **(2 marks)**

b. A average-weight woman breathes 20 m^3 of air each day containing 70 ppb of the carcinogen trichloroethylene (MW = 131.4 g/mol). The inhalation *unit risk factor* is 4.1×10^{-6} $(\mu g/m^3)^{-1}$. Is this a safe exposure? **(5 marks)**

c. Arsenic is a chemical that causes cancer, and also other toxic effects. It has a reference dose of 3×10^{-4} mg/kg-d and an oral slope factor of 1.5 $(mg/kg\text{-}d)^{-1}$. Calculate the lifetime cancer risk and the hazard quotient for an average man consuming water containing 7 µg/L of arsenic in a *residential* exposure. Are either of these exposures considered unsafe? **(10 marks)**

d. The job of a gas station attendant is to pump gas into each car that stops at the gas pump. As such, the gas station attendant is exposed to gasoline vapours, which contain benzene, a carcinogen. Describe at least three ways to reduce the gas station attendant's risk of cancer in his job, considering control at the source, control along the path, and control at the worker. State which of the three is preferred, and why. **(8 marks)**