

NATIONAL EXAMS

December 2018

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 *non-communicating* calculator is permitted. This is an open book exam. Write the name and model designation of the calculator, on the cover 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

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

Question (1) – 25 points

- a. Explain how $\text{NO}_{(g)}$ is involved in the formation of ground-level ozone, using chemical equations in your answer. Why is ground-level ozone a pollutant, whereas stratospheric ozone beneficial? What are CFCs, and how does releasing them into the atmosphere affect ozone? (6 points)
- b. Describe two natural sources of particulate matter and two anthropogenic sources of particulate matter in the atmosphere. What is meant by $\text{PM}_{2.5}$? (5 points)
- c. Acid rain is a secondary pollutant formed from the emission of “acid” gases. List the two most common primary pollutants that form acid rain. (2 points)
- d. Calculate the carbon dioxide equivalents of the following three emissions of gases: 47 kg of N_2O , 540 kg of CH_4 , and 605 g of SF_6 . Rank these emissions in terms of their global warming potential. (4 points)

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 two examples of actions or technologies to *mitigate* climate change and two examples of actions or technologies to *adapt* to climate change. (8 points)

Question (2) – 25 points

- 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 points)
- b. One of the 12 Principles of Green Engineering* is *Design for unnecessary capacity or capability should be considered a design flaw. This includes engineering “one size fits all” solutions*. Give a specific example of how this principle can be used to prevent pollution. (3 points)

- c. One of the 12 Principles of Green Engineering* is *Multi-component products should strive for material unification to promote disassembly and value retention (minimize material diversity)*. Give a specific example of how this principle can be used to prevent pollution. **(3 points)**
- d. Define pollution prevention and explain *two* ways in which pollution prevention can reduce operating costs in a manufacturing operation. **(3 points)**
- e. A school board wants to be more sustainable in its operations. It can either give disposable *wooden* pencils to each child during the school year, or give one refillable *mechanical* pencil to each child and supply refills. You are hired as a consultant to perform a life cycle assessment (LCA) of the environmental impact of these two options. **(10 points)**
- i. What would be a good functional unit for the LCA?
 - ii. List the *stages/phases* of the pencil life-cycle to be considered in a LCA.
 - iii. For *each* stage/phase listed in (ii), decide which of the two alternatives (wood or mechanical) would have the greatest environmental impact, and describe why.
 - iv. In *what stage/phase* of the LCA would you expect to find the greatest environmental impact for the wood pencil? In what stage/phase of the LCA would you expect to find the greatest environmental impact for the mechanical pencil?
- f. True sustainability means that a system, product, or process must be sustainable in three ways. What is meant by the *triple bottom-line* of sustainability? **(3 points)**

*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 points

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

- wind turbines
- (one) nuclear power plant
- solar photovoltaic array
- (one) power plant fuelled by wood pellets
- (one) natural gas-fired power plant

Creating a table to summarize your analysis. Use the following five headings in your table: land requirement, purchased fuel cost, greenhouse gas emissions, health risks to local populations, and capital cost. 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 points

- a. Draw a flow diagram to show the sequence of processes in a typical potable water treatment plant. Include the following processes (listed here in alphabetic order): disinfection, coagulation/flocculation, filtration, grit chamber, screens, and sedimentation. Describe which pollutant(s) each process removes. **(8 points)**
- b. 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. What is the decay coefficient if the viable bacteria concentration decreases from 10^5 cell/mL to 10 cell/mL in 2.0 days? Show your calculations. **(3 points)**
- c. Dandriff Creek carries $5.0 \text{ m}^3/\text{s}$ of water with a selenium concentration of 0.0014 mg/L . A farmer withdraws $1.0 \text{ m}^3/\text{s}$ of the creek water to irrigate her land. During irrigation, the water picks up selenium from the salts in the soil. One-half of the irrigation water goes to the ground and plants, and the other half is returned to Dandriff Creek. The irrigation run-off to the creek contains 1.0 mg/L selenium. Selenium is a conservative pollutant (does not degrade) and the farmer's field is the only source of selenium. If the farmer irrigates continuously, what will be the steady-state **concentration of selenium** in the stream (in ppm) after the run-off has mixed with the stream? Draw a diagram and show the mass balance equation(s) in your solution. **(7 points)**
- d. Calculate the future water demand, in ML/day, for a town of 5,500 inhabitants at the end of a 20-year design span. The town population is expected to grow exponentially, at a growth rate of 1.4 \%/year , whereas the water demand is expected to grow linearly at 0.4 \%/year from the current level of 400 L/person/day . **(5 points)**
- e. The average Ontarian uses 204 litres of water per day and 25% of this is used for toilet flushing. How many cubic meters of water does a household of four persons use for toilet flushing in a year? **(2 points)**

Question (5) – 25 points

- a. Risk may be described in terms of hazard and exposure. Using these terms, comment on the risk due to contaminants in indoor air (as compared to outdoor air). **(3 points)**
- b. A 70 kg man breathes 20 m^3 of air each day containing 210 ppb of the carcinogen trichloroethylene (MW = 131.4 g/mol). The inhalation *unit risk factor* is $4.1 \times 10^{-6} (\mu\text{g}/\text{m}^3)^{-1}$. Is this a safe exposure? **(4 points)**
- c. Arsenic is a chemical that causes cancer, and other toxic effects. It has a reference dose of $3 \times 10^{-4} \text{ mg/kg-d}$ and an oral slope factor of $1.5 (\text{mg/kg-d})^{-1}$. Calculate the lifetime cancer risk *and* the hazard quotient for a 50 kg woman consuming 2 L/d of

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water containing 6 ppb of arsenic in a residential exposure (350 days/year for 30 years). Are either of these exposures considered unsafe? (8 points)

d. Define any two of the following terms. (2 points)

- LC₅₀
- environmental justice
- dose-response curve
- NOAEL
- mutagen

e. Read the following report from the Ontario Ministry of Labour. Describe at least three ways that this tragedy could have been prevented, considering control at the source, control along the path, and control at the worker. State which of the three is preferred, and why. (8 points)

Two Companies Fined a Total of \$285,000 After Worker Fatally Electrocuted by Overhead Lines

Convicted: PGC Services Inc., a company that provides hydro vacuum excavation to the construction and utilities industries; K-Line Maintenance & Construction Limited, a company that provides design, procurement, construction and maintenance services for overhead distribution lines.

Description of Offence: A worker was killed when a boom became activated and came into contact with live overhead electrical lines.

Background:

- K-Line was retained by the utility owner to replace the existing overhead lines. PGC was sub-contracted to excavate holes for the installation of new electrical utility poles.
- Hydrovac excavation was being used on the site. Crews use specialized hydrovac trucks equipped with long articulating booms along with a high-pressure water hose and a water tank. On November 24, 2015, PGC sent two of its hydrovac crews to the site.
- The two crews then began setting up their equipment by extending the boom arms of the hydrovac trucks and by installing dig tube extensions to allow the vacuum to reach the excavation areas.
- The excavation area along the road was serviced by existing overhead power lines with a phase-to-phase voltage of 27,600 volts and the work was taking place in proximity to the lines.
- All members of both crews were busy performing work tasks preparing the equipment for excavation. There was no one present monitoring the movement of the hydrovac boom arms in order to warn the operator to ensure the

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equipment did not encroach upon the legal safety standard, which states: "No object shall be brought closer than three meters from an energized overhead electrical conductor with a nominal phase-to-phase voltage of between 750 and 150,000 volts."

- The boom arms of the hydrovac trucks are operated by a remote control. For the truck operated by the first crew, movements were controlled by a series of elevated toggles on the unit. One of the workers was removing the final dig tube from its storage rack on the driver's side undercarriage of the first truck. This worker, while attempting to pull the dig tube out of the rack, had the boom's remote control unit hanging underneath one arm.
- The other worker, on the passenger side of that truck, had pulled a length of the high pressure water hose from its spool in the equipment cabinet on the undercarriage of the truck, and was in the process of attaching it to the digging gun/water wand used for the excavation. The water hose was connected to the truck, and has a metal-mesh lining that is a conductor of electricity.
- As the driver's-side worker was pulling the final dig tube out of the storage rack, one or more of the toggles on the remote control was triggered by coming into contact with or being caught on a body part or a piece of clothing. The movement of the toggle(s) caused the boom arm to move and to come into contact with the overhead electrical lines parallel to the road.
- The boom arm's contact with the 27,600-volt energized overhead electrical conductor caused the electrical current to pass through the first truck. The worker on the passenger side of the truck was fatally electrocuted.
- The boom arm was on fire in the overhead electrical lines. The remote control was used to separate the boom arm from the lines. Emergency services were called. The worker was pronounced deceased at hospital.