National Examination December 2017

98-Phys-B1, Radiation Physics

Three (3) Hours Duration

Notes

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer a clear statement of any assumptions made.
2. This is an **Open Book** exam.
3. Any non-communicating calculator is permitted. You must indicate the type of calculator being used, i.e. write the name and model designation of the calculator, on the first left hand sheet, of the exam work book.
4. This exam has 7 questions, for a total of 74 points.
5. **You are required to answer only sixty (60) points worth of questions.** Any combination of parts of any questions can be answered to make up 60 points.
6. Total worth of each question is given with the question or its parts.
7. Duration: Three (3) Hours

Marking Scheme

Subdivision of marks are shown in question's parts.

Q.1 12 points.

Q.2 10 points.

Q.3 5 points.

Q.4 6 points.

Q.5 5 points.

Q.6 20 points.

Q.7 16 points.

Sixty (60) points constitute a full mark.

QUESTION 1. Radioactivity

On May 9, 2017, the Washington Post[1] reported on the collapse of a 6 m-long portion of a tunnel used to store contaminated radioactive materials at the U.S. Department of Energy (DOE) Hanford nuclear site in Washington State. The newspaper stated that the tunnel runs into of a facility once used to extract plutonium from spent nuclear fuel, up to 1980. The tunnel is 6.6 high and 5.7 m wide, and its walls 315 mm thick and held up by pressure-treated Douglas fir timbers, resting on reinforced concrete footings. The tunnel was covered with about 2.4 m of soil. A 1997 DOE report indicated that inspection of the tunnels was "not feasible because of radiation levels in excess of five roentgens per hour." An official was quoted in the article as saying that there was no indication of a release of contamination at this point.

(a) (1 point) Based on the above quoted DOE report, what would have been the exposure in gray (Gy)?

(b) (1 point) Based on the above quoted DOE report, what would have been the dose in sievert (Sv)?

(c) (1 point) Speculate on the nature of radioactive material in a spent nuclear fuel after the extraction of uranium.

(d) (2 points) Assuming an effective half-life of 90 years, estimate the dose at the tunnel at the time of its collapse in May 2017.

(e) (3 points) Given your above estimate of the current dose, devise a plan to inspect the collapsed tunnel by nuclear energy workers, assuming that two (2) hours are needed to complete the inspection. Hint: Determine the number of workers needed and the length of time each should spend near the tunnel.

(f) (2 points) The newspaper's report quotes Edwin Lyman of the Union of Concerned Scientists saying "[c]ollapse of the earth covering the tunnels could lead to a considerable radiological release." Comment on this assessment and based on your answer discuss the impact on the inspection plan you proposed above.

(g) (2 points) Suggest a couple of instruments to monitor the radiation level in the proximity of the collapsed tunnel.

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[1] `https://www.washingtonpost.com/news/post-nation/wp/2017/05/09/tunnel-collapses-at-hanford-nuclear-waste-site-in-washington-state-reports-say/?tid=a_inl&utm_term=.65647ec9b72b`

QUESTION 2. Nuclear Interactions, Radiation Detection

Consider the following[2]:

Rhodium (^{103}Rh) has a (n-β) interaction with a 145 b cross-section for thermal neutrons and a resonance at 1.25 eV.

Vanadium (^{51}V) has a (n-β) interaction with a thermal neutron cross-section of 4.9 b, featuring a $1/v$ characteristic without resonances in the energy range of thermal/epithermal neutrons.

Cobalt (^{59}Co) has a (n-γ) interaction with a 37 b thermal neutron cross-section, as well as a (γ-photon) reaction.

Hafnia (HfO_2) has a (n-γ) interaction with a 115 b thermal neutron cross-section and a (γ-photon) reaction.

Silver (Ag) has a (n-β) interaction with a 64.8 b cross-section for thermal neutrons and a few resonances in the range 5-134 eV range.

Platinum (^{195}Pt) has a (n-γ) interaction with a 24 b thermal neutron cross-section and γ-photon reaction.

(a) (1 point) Speculate on what is meant by "(γ-photon reaction)" in the above statement. Why is it called a reaction, not an interaction? Hint: The term "reaction" is used to describe chemical changes.

(b) (5 points) The above mentioned interactions and reactions are candidates for use in self-powered neutron detectors for use in nuclear power reactors. Explain:

i. What is meant by self-powered?

ii. Why is the (n-β) interaction indicative of reactor power?

iii. Why is the (n-γ) interaction indicative of reactor power, given the delayed γ decay of fission products in a power reactor?

iv. How would the (γ-photon) reaction produce an electronic signal reflective of reactor power?

v. At low power, which interaction, (n-β) or (n-γ), would you rely on for measuring reactor power?

(c) (2 points) Given the above information, recommended best arrangement (material, reaction, or interaction) most suited in your view for use as a **fixed** in-core self-powered neutron detector to measure the nuclear power in a thermal reactor over the lifetime of the reactor. Explain your answer. Hint: Read the next part of the question before answering this part.

(d) (2 points) Answer the above part of this question for a **movable** in-core self-powered neutron detector. Explain your answer.

[2] https://www.oecd-nea.org/science/rsd/ic96/4-2.pdf

QUESTION 3. (5 points) **Non-ionizing Radiation**

Assume that you live in a town midway between two cities 100 km apart. The first city has a radio station that transmits at a power of 70 kW, while the second city has a 50 kW radio station. Both stations use a non-directional antenna, but transmit at slightly different frequencies. How long will you travel from your town and in which direction (towards or away from either city) so that the two radio station have the same mean power density.

QUESTION 4. (6 points) **Radiation Interactions**

The threshold energy of pair-production due to the interaction of photons with the electromagnetic field of a nucleus is 1.022 MeV, while that caused in the field of an electron is 2.044 MeV. Elaborate on this statement, explaining the reason for the difference in the threshold energy of the two processes.

QUESTION 5. (5 points) **Radiation Interactions**

Can visible light cause the ejection of an electron from a sodium atom? The minimum energy required to remove an electron from a sodium atom is 5.12 eV. Support your answer with calculations.

QUESTION 6. Radioactive Decay

The activity recorded as count rate from a freshly produced radioactive substance was as follows:

Time, t (hr)	Counts, C (per minute)	$\sigma(C)$	$g(t) = -\ln\left[1-\frac{C}{C_\infty}\right]$	$\sigma(\lambda t)$
0	1000	...	...	...
4	1150	...	...	...
8	1300	...	...	...
16	1500	...	...	...
32	1900	...	...	...
48	2200	...	...	...
80	2500	...	...	...
120	2800	...	...	...
∞	3000	...		

where $\sigma(x)$ refers to the statistical variability (standard error) in x.

(a) (6 points) Recreate the table in your answer booklets, filling in the dots in the table. Hint: Remember the variance combination rule, for $h = f(x)$: $\sigma^2(h) = \left(\frac{\partial h}{\partial x}\right)^2 \sigma^2(x)$.

(b) (3 points) What does the count rate at infinite time, $C_\infty = 3000$, physically signify?

(c) (6 points) Show, within statistical variability, that $g(t) = \ln\left[1 - \frac{C_2}{C_{2\infty}}\right]$ is a linear function of time.

(d) (2 points) What is the physical significance of the slope: $\frac{\mathrm{dg}}{\mathrm{dt}}$?

(e) (3 points) Estimate the half-life of the daughter substance that is building up.

QUESTION 7. Radiation Safety

On June 30, 2017, Matt Flowers of the Waterkeepr blog reported the following[3]:

> On June 23, heavy rains triggered an overflow of untreated water from the collection pond at Port Hope Long-Term Waste Management Facility.
>
> There was also an overflow from the catch basin at the Port Granby Waste Management Facility.
>
> According to the Port Hope Area Initiative (PHAI)-the group responsible for the management of nuclear waste for both communitiesboth overflows have since been contained, but untreated water did make its way into Lake Ontario.
>
> Both sites store low-level radioactive waste. Both sites are part of the large-scale radioactive waste cleanup project beginning in the Port Hope Area.
>
> PHAI released a statement on June 28 saying: "The results of independent analysis of water samples collected offsite were measured against the provincial and federal criteria for the protection of aquatic life and confirm that the effect on the environment was negligible." This is in reference to samples taken at the Port Hope facility.
>
> No further details were disclosed.
>
> On June 30, Lake Ontario Waterkeeper submitted a request to both PHAI and the Canadian Nuclear Safety Commission to release the complete sample results, along with information about the sampling methodologies.
>
> We will share the information if/when it is made available.
>
> July 17 Update: The CNSC conducted a field inspection and has identified deficiencies in CNL's emergency preparedness for offsite releases and contingency planning for storing untreated water at the Port Hope Long-Term Waste Management Facility.
>
> As a result, the CNSC has issued an order to the Canadian Nuclear Laboratories (CNL) requiring:
> 1. The licensee to ensure its emergency preparedness measures are available to mitigate accidental releases of untreated water from the licensed site.
> 2. The licensee must also review its water management plans and program, to ensure adequate storage capacity is available to prevent the release of radiological and nuclear and/or hazardous substances from the licensed site.
>
> CNL oversees the Port Hope Area Initiative, and is the licensee in this case.

Question #7 continues on next page.

[3] `http://www.waterkeeper.ca/blog/2017/6/30/heavy-rains-cause-overflow-of-untreated-water-at-port-hope`

Port Hope, Ontario, was the site of Eldorado Ltd., which refined radium and uranium. The Toronto Star on April 1, 2011[4] stated:

> The federal government took over Eldorado in the early 1940s and controlled it till 1988, when the company was re-privatized and merged with the Saskatchewan Mining Development Co. to become Cameco.
>
> The oldest nuclear refinery in the world, it is the only supplier of fuel-grade unenriched uranium dioxide (UO2), which is used in heavy-water CANDU reactors. The refinery also produces uranium hexafluoride (UF6), used in light-water reactors across the globe.
>
> Cameco owns Ziratec, also located in Port Hope, which produces fuel bundles for CANDU reactors.

The newspaper also noted that '[t]he Canadian Nuclear Safety Commission says there is no danger to health in Port Hope; that more than 40 studies indicate residents have low levels of exposure to all types of contaminants".

(a) (10 points) From your perspective as someone familiar with nuclear radiation, write a 500-word response to the Waterkeepr blog, identifying the type of radioactive material present in the waste and their effect on the health of the citizen of Port Hope.

(b) (2 points) Why CANDU reactors use unenriched uranium?

(c) (2 points) Why CANDU reactors use uranium dioxide, not metallic uranium?

(d) (2 points) Light-water reactors use enriched uranium, but the Toronto Star's story indicates uranium hexafluoride (UF_6) is used in light-water reactors. Given that UF_6 is made of natural (unenriched) uranium, rewrite the relevant portion in the Toronto Star's story in a more precise scientific manner.

End of Examination

[4] https://www.thestar.com/news/gta/2011/04/01/port_hopes_nuclear_past_pits_economic_interests_against_health.html