# NE585 – Nuclear fuel cycle analysis
# Project 5 – Monte Carlo methods and MCNP

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2024.12.03

Total – 420

# Preface

For problems 1 – 3 use Monte Carlo techniques to obtain the solutions.

# 1 Evaluating an integral I

**(30)**

Solve for G using Monte Carlo techniques. Solve the integral analytically and graph g(x). Also plot G v N for $N = 10,\ 10^2.\ 10^3,\ 10^4,\ 10^5,\ 10^6$.

$$G = \int_0^1 g(x)dx \tag{1}$$

$$g(x) = 1 - e^{-x} \tag{2}$$

## 2 Evaluating an integral II

**(30)**

Do the same for the following function. This g(x) does not have an analytical solution. However, use a numerical solver or other technique to compare the Monte Carlo result. Graph g(x) and plot G v N.

$$\int_0^{\frac{\pi}{2}} sin(x^2)dx \tag{3}$$

# 3 Approximation

**(30)**

Approximate $\sqrt{2}$ in a similar manner to the way we approximated $\pi$. Plot the convergence.

# 4 Hot cell modeling

**(50)**

Conduct a short modeling study of the metal fuel alloy for the hot cell facility using -

- 4_ff.alloy.inp (flux)
- 4d_ff.alloy.inp (dose)

See also the related paper on hot cell shielding for more information.

Apply the following procedure –

(a) Look at the original geometry in the plotter/VisEd.

(b) Modify the facility to only include the SE and SW cells.

(c) Use MCNP to compute the volume averaged (F4) flux tallies for the SE cell and SW cell.

(d) Use a neutron emission rate of of $1.1 \times 10^7$ $n/s/g$ for 24 grams of material.

(e) Increase NPS from the original files to reduce standard error.

(f) Start with a wall thickness of 15 cm using the material already included in the deck. It is a form of borated concrete that is common to these kinds of facilities. Increase the wall thickness until the dose rate falls below 1 $\mu Sv/h$ and the relative flux falls below 0.01. *There seems to be some issues with dose card IC = 10. Appendix F should have a fix. Try to see if it will work.*

(g) Plot dose rate v wall thickness and the relative flux v wall thickness.

(h) Justify that the results are scientifically sound.

*Is this wall thickness reasonable? As in, could a facility be practically built like this using current engineering design techniques?*

*Include the MCNP file at the end in an appendix.*

## Criticality modeling

For the criticality models, to get full credit –

(i) Include a screenshot of the model from the VisEd/plotter.

(ii) Use finite geometries.

(iii) Design geometries that will minimize leakage. Show (as part of making the mcnp file and results; not calculating by hand) that leakage has been minimized.

(iv) For criticality, get to 3 9s or 0s (.999x, 1.000x) for the mean for full credit. Bonus for 4 9s/0s.

(v) Report output in a table – k, standard deviation, 95% confidence.

(vi) Justify the results are scientifically sound.

(vii) Include the input deck in the appendix.

**PROTIP –** k can vary weird when your trying to get the critical radius to 4 or 5 decimal places. Study the KCODE parameters. You could also add more particles on KSRC, but be careful where you place them.

# 5 Critical mass I

**(20)**

What is the critical mass of a bare sphere of plutonium containing (1) $95.5\%$ $^{239}Pu$ and (2) $80\%$ $^{239}Pu$, where the rest is $^{238}Pu$? *Comment on the results.*

# 6 Critical mass with reflector

**(20)**

What is the critical mass for the above, but with a thin nickel shell of 0.10 cm?

# 7 Critical mass II

**(20)**

What is the critical mass of pure $^{239}Pu$ of a bare cylinder?

## Reflector modeling

For the next three problems, select 3 – 5 typical reflector materials for each fissionable source. Make a table for each source with results from the reflectors.

# 8 Critical mass I

**(30)**

Taking the bare sphere $^{239}Pu$ model, what is the 'optimal' reflector that minimizes the *critical mass*? Pick at least one reflector material that is 'exotic'; e.g., maybe for a reactor powering a Mars Rover style robot mining on an asteroid or a moon.

# 9 Critical mass II

**(30)**

Do the same for $^{235}U$.

# 10 Critical mass III

**(30)**

Do the same for $^{233}U$.

# 11 Reflector analysis

**(30)**

Put all the results from the reflector problems together in a table. Which reflector material is minimal and why, neutronically speaking? Check the output files for different types of neutron losses as part of the analysis. Comment on cost in the analysis of optimal material, generally estimate; no need to research specific costs.

## 12 Geometry challenge

**(50)**

Three unreflected aluminum cylinders contain $U(93.2)O_2F_2$ water solutions. The inside cylinder diameter and critical height measured 20.3 cm and 41.4 cm. The aluminum container had a density of $2.71\ g/cm^3$ and was 0.15 cm thick. The three cylinders were set in an equilateral configuration with a surface separation of 0.38 cm. The solution concentration parameters were $0.90\ g(^{235}U)/cm^3$ with $H:^{235}U = 309$.

(a) It was estimated that the solution density was approximately $1.131\ g/cm^3$ and consisted of $0.0021345\ ^{235}U,\ 0.00015382\ ^{238}U,\ 0.33383\ O,\ 0.65930\ H,\ 0.0045756\ F\ atoms/b-cm.$

(b) MCNP gives $k = 0.9991 \pm 0.0011$. *Get within 15% for full credit.*

Reproduce the model to get the result. See the MCNP benchmark document for guidance.

# 13 Critical mass IV

**(30)**

Find the critical mass for a bare cylinder of 10.9% enriched U with a density of 18.63 g/cc. Optimize the radius and height for neutronics, again based on neutron losses.

# 14 Critical mass V

**(20)**

Find the minimum critical mass for an infinite graphite reflected 93.5% enriched U sphere. Use 18.8 g/cc for the U density and just use carbon for the graphite.

# 15 Critical mass VI

**(20)**

Find the critical mass of 97.67% enriched U cube in an infinite water reflector. Use a density of 18.794 g/cc.

# Tables

# Figures

# Appendix I: Hot cell MCNP input decks

# Appendix II: Criticality MCNP input decks