NPRE412 Spring 2025
HW 13 Due 2025.05.29

- Show your work.
- This work must be submitted online as a `.pdf` through Canvas.
- Work completed with LaTeX or Jupyter earns 1 extra point. Submit source file (e.g. `.tex` or `.ipynb`) along with the `.pdf` file.
- If this work is completed with the aid of a numerical program (such as Python, Wolfram Alpha, or MATLAB) all scripts and data must be submitted in addition to the `.pdf`.
- If you work with anyone else, document what you worked on together.

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1. In class, we discussed Megatons to Megawatts. The program claims that 500 tons of HEU (90% enriched) was converted to 7 billion MWh.
   (a) (10 points) Under the following assumptions, how many MWh would have been generated? (**you must show your work.**)
   - depleted uranium for downblending was 0.2% enriched
   - enrichment of LEU sent to U.S. 5%
   - avg. U.S. capacity factor 90%
   - avg. U.S. thermal efficiency 33%
   - avg. U.S. burnup 50,000 MWd/MTIHM

   Solution: Mahmoud and I got 3.70e9 MWh.
   Use feed factor equation.
   $$ff = \frac{x_p - x_w}{x_f - x_w} \tag{1}$$
   Divide mass (m) by feed factor to get the mass of fuel.
   $$M = \frac{m}{ff} \tag{2}$$
   Find power.
   $$P = M \cdot \eta \cdot BU \cdot 24\frac{hours}{day} = 3.7e9\ MWh \tag{3}$$

   (b) (20 points) Make some different **but still reasonable** assumptions that will result in the claim made by the program (500 tons of 90% enriched HEU ultimately produced 7billion MWh). **List all assumptions** and **show** that the resulting calculation now gives approximately 7billion MWh generated.

   Solution: To get the values the government got, assume:
   - the product enrichment is 3.5%, the lower bound of LWR enrichment,

- η is 35.75% as Rankine turbines have gotten better at extracting heat, and
- BU is 60 because we got better at loading the cores.

Next, find the new feed factor

$$ff = \frac{x_p - x_w}{x_f - x_w} = 0.0367 \tag{4}$$

Find the new mass of the fuel.

$$M = \frac{m}{ff} = 1.36e7\ kg \tag{5}$$

Find new power

$$P = M \cdot \eta_2 \cdot BU_2 \cdot 24\frac{hours}{day} = 7e9MWh \tag{6}$$

2. (10 points) How many significant quantities are in 500 tons of 90% enriched HEU?

Solution: Mahmoud and I got 18,000 significant quantities.

We know the significant quantity of direct use U-235 is 25 kg. Use this to find the number of significant quantities.

$$SQs = \frac{m \cdot x_f}{m_{sq}} = \frac{500e3\ kg \cdot 0.9}{25\ kg} \tag{7}$$

3. (10 points) How many significant quantities are in 500 tons of natural thorium?

Solution: Mahmoud and I got 25 significant quantities.

We know the significant quantity of direct use U-235 is 25 kg. Use this to find the number of significant quantities.

$$SQs = \frac{m}{m_sq} = \frac{500e3\ kg}{20e3\ kg} \tag{8}$$

4. You are an inspector at Natanz.

   On February 1:

   - You concluded that there were 4 canisters on site containing 5% enriched uranium.
   - They collectively hold 8.2kg of ^{235}U.
   - You tag the canisters with tamper-resistant seals.

   On March 1:

   - You count 4 canisters.

- Three of the original 4 canisters are present and remain tagged.
- The missing one contained 1kg of ^{235}U (according to your records).
- You are told that in February, enriched uranium was created, resulting in 2kg ^{235}U, placed in the new, untagged canister.
- And, you are shown that the missing 1kg ^{235}U canister had been shipped to a reactor facility.

(a) (10 points) What is the book inventory?

Solution: The book inventory is 9.2 kg.

$$BI = PB + X - Y = 8.2 + 2 - 1 = 9.2\ kg \tag{9}$$

(b) (10 points) You take 10 readings of the mass of ^{235}U in the new canister. They give: 2.102, 2.015, 2.022, 1.998, 1.989, 2.101, 2.077, 1.970, 1.92, 2.01. What is the mean of the MUF?

Solution: The mean MUF is 0.0204 kg.
Find the means using numpy.

$$means = np.means(masses) \tag{10}$$

Find the MUF.

$$MUF = means - 2 = 0.0204 = kg. \tag{11}$$

(c) (10 points) What is σ_{MUF}?

Solution: The standard deviation is 0.055 kg. I just used numpy to find the standard deviation.

(d) (10 points) Has this inspection broken the three-sigma rule?

Solution: No. MUF is less than 3 σ.

$$0.0204\ kg < 0.166\ kg \tag{12}$$

(e) (10 points) If all following months have a MUF exactly like this, how many months until $MUF_c \geq 1SQ$?

Solution: It would take 73,529.4 months to get a significant quantity.
For indirect use, enrichment below 20%, the significant quantity is 75 kg. Use this to find the months required.

$$M = \frac{SQ_{U235}}{5e - 2 \cdot MUF} \tag{13}$$