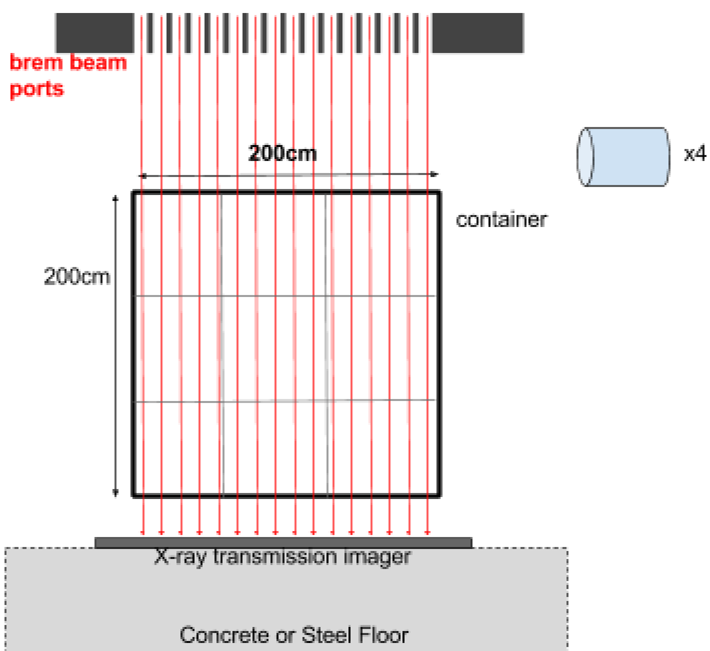
Qualifying Exam, 2017

ADNS

You are working with a scanning system designed to detect Weapons Grade Plutonium (WGP). The system diagram is shown below. The scanning beam is bremsstrahlung with an 8-MeV endpoint. The beam is continuous wave (CW). The container moves into the page. There are 4 neutron detectors -- liquid scintillators, e.g. EJ-309 -- which you can place anywhere you want. **Notation**: for normal distributions don't write out the full formula, simply use $\aleph(mean, variance)$.

1) Describe at least two processes which results in emission of neutrons from WGP exposed to this photon beam.

2) Let's assume that the smuggler is competent. What (single) material(s) would they use for shielding, and why. Given the weight limits on containers, assume that the density cannot be > 0.5 g/cc.



3) Where would the smuggler locate the WGP? Where would you (i.e. the inspector) put your four neutron detectors, to maximize the neutron signal (while keeping in mind that the smugglers know the system configuration)? Re-draw this on the board and mark it up. Would you rather have the floor made of concrete or steel, and why?

4) Let's say you fill your container *uniformly* with shielding you described above. Let's say the WGP object is about flat at the center. The (energy independent) mean free path for photons and neutrons in this material is λ_γ and λ_n. Assume that any interaction will result in the "loss" of the neutron (from the detector's energy acceptance, anyway) or the photon. The measurement time is t. Write down the expression for the total signal for one of the detectors, assuming $\sigma(E)$ for the cross section of "neutron producing" processes, and dN/dE the energy distribution of the 8 MeV bremsstrahlung photons. You can list and include the necessary variables for this calculation.

5) Above you calculated N, the neutron counts in a single measurement. To determine the detection ability of your system you also need to determine what your background is. Let's call it b. What are the main sources of background of neutrons? What else will contribute to your background count?

6) Let's say you know both N, the counts from Pu alone for a particular smuggling scenario, and b, the background. Assuming Poisson statistics, provide an alarm threshold n_{th}, such that the system will false alarm no more than 1% of the measurements. Write down the formula for the detection probability of the system which operates with this threshold.

7) You are scanning a container. You get C counts, and let's say $b < C < n_{th}$. Assume that $C \gg 1$.
   a) Give the probability (write the formula) P that a smuggling attempt is underway.

   b) $b = 25, C = 30, P = ?$

8) Let's consider scenario 8.b. Right after the measurement you have received an intelligence briefing, which claims that the probability that that particular container is carrying WGP is 90%. Using what you've learned in classes of statistics/probability,

propose a probabilistic method to combine this info with the information from your system and determine the total probability that a smuggling attempt is taking place. Determine that probability (the committee will help with the arithmetics).

9) You have done your calculations for the necessary measurement times and dose for the most densely packed container (i.e. max shielding), and the dose is 1000 Rad. Why is this a problem? Can you come up with a more intelligent operation of this system which will reduce this problem? Hint: the beam intensity is variable.

10) Your adviser is very entrepreneurial. He first tells you that a 8 MeV CW system is too expensive, and proposes to go for a 5 MeV CW system because it is 10x cheaper. Is this a good idea? After hearing your answer he concludes that a 20 MeV CW system could be the better alternative. What do you think of *that*?

11) Is there a reason as to why the answer in (4) is limited in accuracy? And if so, is it an overestimate or underestimate? How would you go about getting a more complete estimate of the total signal?

12) How can we make the detection times shorter? Suggest a few technical solution, using:
    a) same configuration, but additional detector *types*. List a few.

    b) reconfiguring (think shielding)