Robotic Neutron Detector for Non-Proliferation Testing

Harry Fetsch[1], advised by Rob Goldston[2]

1: Harvey Mudd College

2: Princeton Plasma Physics Lab

Goals

Build an autonomous system for locating sources of neutron radiation.

Motivation

Enrichment facilities for nuclear fuel can be modified for rapid production of Highly Enriched Uranium (HEU).

Material in arms reduction treaties is vulnerable to theft or modification.

In both scenarios, it is desirable to locate radioactive sources.

"Neutron Bloodhound" Design

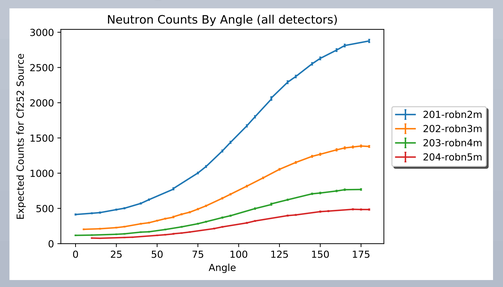
The three-detector configuration gives directional sensitivity.

Higher-energy neutrons penetrate further into the moderator: front-to-back count ratio gives information on spectrum.

The robot can be controlled manually by remote control or positioned autonomously using onboard cameras.

Neutron Transport Simulation

The Monte Carlo code OpenMC was used to predict readings near a ^{252}Cf test source.



The onboard Raspberry Pi reads detector counts from GPIO pins using hardware interrupts.

Using the Robot Operating System (ROS) architecture, the Raspberry Pi wirelessly transmits counting statistics and receives instructions

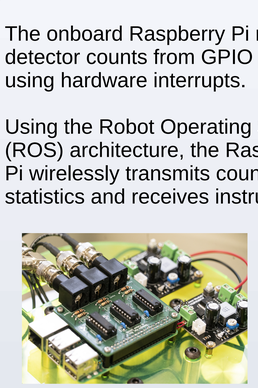


Fig. 10: Close-up image of robot electronics

Three boron carbide neutron detectors are contained in high-density polyethylene (HDPE) moderator, with thin cadmium shielding and a structural aluminum shell.

HDPE thermalizes fast neutrons, increasing the likelihood of detectors capturing them.

Fig. 7: Model of three detectors in HDPE moderator, and structural aluminum rods & shell.

Higher-energy neutrons travel further before being absorbed: by comparing counts in front and back detectors, the robot can determine through spectrum changes whether a source is hidden behind shielding.

Fig. 8: Schematic diagram of the counting circuit.

Fig. 9: Layout of the printed circuit board (PCB) used for reading counts.

Asynchronous digital counting chips receive detector pulses of varying lengths, and each counter outputs its current count in parallel on four digital pins.

Mechanum wheels allow omnidirectional movement.

The robot can be rotated about its center, allowing multiple angle measurements to be taken without moving relative to the source.

Onboard cameras at the front and bottom of the robot allow it to be controlled remotely in cases where the operator cannot be present.

Using its bottom camera, the robot can position itself autonomously to take high-accuracy directional measurements.

Diagnostic Results

Cosmic Neutron Background

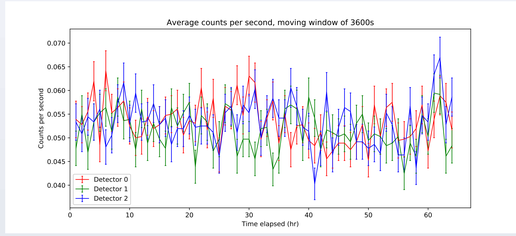


Fig. 2: Counts per second, aggregated into 1-hour windows, collected 4pm 8/9/19 to 8am 8/12/19.

PuBe Source

Fig. 3: Counts per second, collected with robot 2m from the PPPL PuBe source as source is exposed for 30s.

Future Work

Measure neutron counts near the ^{252}Cf source at PPPL to validate simulations.

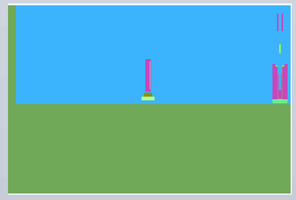


Fig. 4: Model of test cell with robot and source.

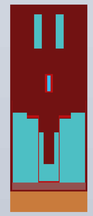


Fig. 5: Model of cask containing ^{252}Cf source.

Simulate robot measurements in a realistic centrifuge hall environment.

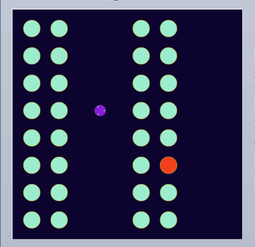


Fig. 6: Model of a nuclear centrifuge hall with the robot patrolling a corridor. Most centrifuges contained low-enriched uranium (LEU). One has been modified to contain highly-enriched uranium (HEU).

Contact

- Harry Fetsch, hfetsch@hmc.edu
- Rob Goldston, goldston@pppl.gov