SLOWPOKE-2 GAMMA DOSE EXPERIMENT

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Summary

The gamma dose rate within the SLOWPOKE-2 (Safe Low-Power Kritical Experiment) reactor at Royal Military College (RMC) was measured using two methods. PMMA (polymethylmethacrylate) dosimeters were used to determine the dose rate at the bottom of the inner irradiation tubes, and a silica fibre-optic bundle was used to find a profile of the dose rate in the inner and outer irradiation tubes. The results of the two methods were compared to make conclusions about the dose rate.

1. Introduction

The SLOWPOKE-2 is a low energy research reactor. The reactor is considered inherently safe due to its passive cooling system. The SLOWPOKE-2 at RMC serves as a learning and research tool for the college. However, not much is known about the gamma radiation within the reactor.

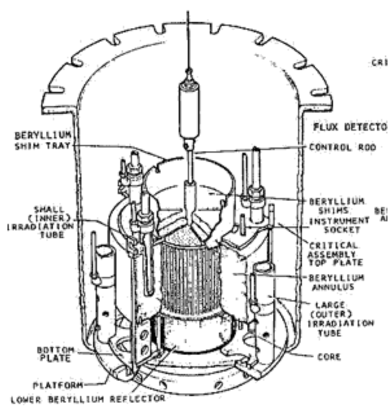

Figure 1. SLOWPOKE Reactor

To find the dose rate from gamma radiation, two methods were used. PMMA dosimeters are developed by Harwell and are commercially available. The second method used a bundle made of polyimide-coated silica fibres to detect Cherenkov radiation.

Figure 2. Harwell Perspex Red 4034 Dosimeter

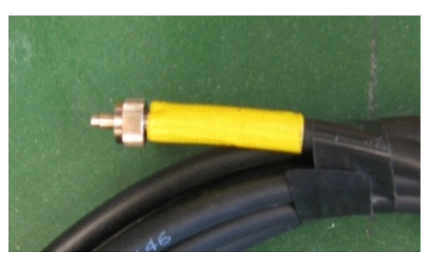

Figure 3. Fibre bundle end

The dosimeters and the fibre bundle were placed in the irradiation tubes of the reactor. The inner sites are located in the reflector, and the outer sites are outside the reflector. Measurements were made when the reactor was off and on.

2. PMMA Dosimeters

Harwell's dyed-PMMA dosimeters were used to measure the gamma field in the inner irradiation tubes of the SLOWPOKE-2. The two types of dosimeters used were Red 4034 (dose range of 5 to 50 kGy) and Amber 3042 (dose range of 1 to 30 kGy). The dosimeters are 30 x 11 mm rectangular units that visibly darken upon irradiating. They are sealed individually in water impermeable pouches. A lithium-loaded plastic was wrapped around some of the dosimeters for neutron shielding. The radiation dose absorbed is determined with a spectrophotmeter and a calibration curve is used to determine the dose rate. Red 4034 and Amber 3042 are read at 640 and 603 nm respectively.

Normally the dosimeters are irradiated in their packaging to protect them from atmospheric humidity until they are read, but unfortunately the size of the capsule could only accommodate the bare dosimeter. However, the effects of irradiating without packaging have been found to be negligible, and can in fact lead to a more accurate measurement [1].

Lithium-loaded plastic was also initially seen as a necessity, but studies show that irradiating PMMA in a mixed gamma-neutron field has accuracy better than 15% [1]. Therefore, the dosimeters were not shielded when the reactor was at full power, but a comparison of shielded vs. unshielded detectors was performed when the reactor was off to observe the effect of neutron shielding on the dose rate. The shielding comparison was not meant to determine absolutely whether lithium-loaded plastic is needed or not, but merely to eliminate as many variables as possible and note the outcome.

The dosimeters were preliminarily irradiated in a gamma cell to become better acquainted with the measurement process and to test its accuracy. Four Amber 3042 dosimeters were irradiated for one hour and four Red 4034 dosimeters were irradiated for 5 hours. The results were compared to a Fricke dosimeter.

2.1 Results

Dosimeter	Exposure Time (h)	Abs @ 603 nm	Abs @ 640 nm	Thickness (mm)	Specific Abs	Dose (kGy)	Dose Rate (kGy/h)
Amber 3042 w/ Li #1	18.5	0.0555		3.02	0.0184	0.468	0.0253
Amber 3042 #1	18.5	0.0384		2.98	0.0129	0.382	0.0206
Amber 3042 w/ Li #2	2.00	0.0131		3.17	0.00412		
Amber 3042 #2	2.00	0.00255		3.12	0.000817		
						Avg.	**0.0230**

Table 1. Reactor off results

Dosimeter	Exposure Time (h)	Abs @ 603 nm	Abs @ 640 nm	Thickness (mm)	Specific Abs	Dose (kGy)	Dose Rate (kGy/h)
Red 4034 #1	0.75		0.267	3.12	0.0854	6.47	8.63
Red 4034 #2	1.25		0.277	3.13	0.0886	6.82	5.46
Amber 3042 #3	0.50	0.297		2.89	0.103	2.45	4.90
Amber 3042 #4	1.00	0.303		2.76	0.110	2.74	2.74
						Avg.	**5.43**

Table 2. Reactor on results

2.2 Analysis

The dosimeters irradiated when the reactor was off received doses below the lower dose range limit. The fibre bundle's measurement of the dose rate was approximately 50 Gy/h, meaning the dosimeters would need to be irradiated for over 20 hours to reach the lower limit dose if this result is correct. Therefore, an accurate dose rate could not be determined with PMMA when the reactor was off.

The dosimeters irradiated when the reactor was on gave varied results. This can be attributed to a couple factors. Firstly, the dosimeters barely reached the dose range lower limit. Ideally, the dosimeters should be irradiated to reach as many different doses as possible within the dose range for accuracy. Secondly, the dosimeters were irradiated at 3 different sites, with Amber 3042 #3 and Red 4034 #2 being irradiated at the same site. The gamma dose at each site can vary due to the size of the reactor and different equipment surrounding it e.g. neutron beam, cadmium control rod (used to control power level). Thus, the dose rate may not be the same at each site, which is reflected in the results. Notably, the dosimeters irradiated at the same site have similar results for dose rate. So, the results obtained are reasonable, but not perfect.

In conclusion, these results provide a good baseline to conduct more measurements in the SLOWPOKE-2 reactor, taking into account the dosimeters' dose ranges and the variation of gamma fields in the irradiation tubes.

3. Fibre Bundles

Two polyimide-coated silica fibre bundles were used to measure the gamma field in the SLOWPOKE-2 reactor. Cherenkov radiation created as gamma photons dislodge electrons from the silica was carried up the bundle to a photomultiplier tube (PMT) at 900 volts, which created a measurable current. Each bundle was 5.9 m long with one containing 100 polyimide-coated silica fibres (only 90 could be inserted into the connector), and the other containing 3. The fibres each had a diameter of 0.2 mm. The bundles were sheathed in Poly-Flo polyethylene tubing, giving a total diameter of 6.35 mm. The fibre was held in place at the bottom of the tube with epoxy, and the bottom was covered in 2 layers of electrical tape to prevent visible light from entering the fibres. The bundle was calibrated in a gamma cell, and measurements were taken by raising the bundle in the irradiation tube by increments of 1 cm and recording the change in the reading.

3.1 Results

3.1.1 Reactor off

From 0 to 16 cm from the bottom, the average gamma dose rate measured was 0.05323 kGy/h for the inner site, and 0.013646 kGy/h for the outer site.

3.1.2 Reactor on

Using the gamma cell calibration and the first test, the dose rate from 0 to 16cm in the inner tube was measured to be 36.9 kGy/h. However, the bundle was noticeably and unexplainably losing signal, so timed tests were conducted in the inner and outer site to determine how much of the signal was lost.
The timed test showed that the reading was stable around 80% of its initial value after 5 minutes. Using this ratio to adjust the calibration, a second inner site test averaged 44.340 kGy/h for 0 to 16 cm, and for the outer site 15.437 kGy/h.

3.2 Analysis

3.2.1 Radiation damage/degradation

Whereas the signal from the inner bundle degraded fairly quickly to a stable reading around 80% of its maximum, the outer bundle decayed slower and more linearly. This could be explained either by the slight shielding effect of the outside fibres, causing the neutrons to burn through the fibre at a more constant rate, or the lower flux at the outer site, causing the fibre to simply degrade with a slower exponential.
Assuming the difference was due solely to the lower flux at the outer site, the outer bundle was degrading at 25.6% of the rate of the outer bundle based on curve fitting.

3.2.2 Inner and outer site ratio

While the reactor was off, the ratio of the signal in the first 16 cm of the outer site to those of the inner site was 0.29395. After the reactor was turned on, this ratio increased to 0.400345 for the first test and 0.348117 for the second.
The difference in ratio of the measured outer site dose rate to the measured inner site dose rate reading can be explained by spectrum hardening; when the reactor was on, it presumably generated higher energy gammas, which pass through the beryllium reflector to the outer tube more easily than the gamma photons could when the reactor was off. This explains why the ratio of the outer site to the inner site increased when the reactor was turned on.

3.2.3 Dose rates

The dose rates found by the bundle while the reactor was off were about 2.212 times the dose rate found by the PMMA dosimeters, which, as mentioned earlier, were below their recommended dose range for accurate measurements. While the reactor was on, the measurements from the bundle were about 8.166 times greater than those of the PMMA dosimeters.

The dose rate predicted by the fibre bundle was likely higher because of the higher energy of the gamma photons in the reactor than those in the gamma cell. These photons caused a higher energy Compton edge, which resulted in a larger fraction of emitted electrons exceeding the minimum energy of 0.195 MeV necessary to generate Cherenkov radiation in silica. The increased energy could have exaggerated dose rates by a factor of up to 1.806. This is not enough to explain the results.

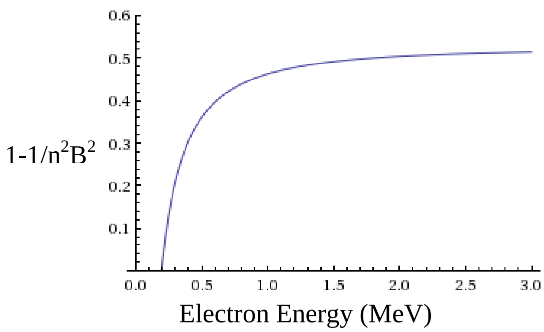

Figure 4. Photon emission's dependence on energy

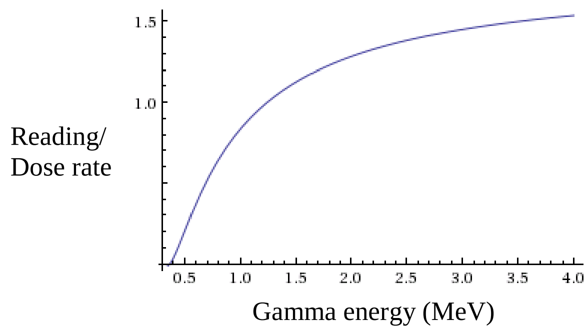

Figure 5. Ratio of reading to dose rate

4. Conclusion

The average gamma dose rate as determined by the PMMA dosimeters in the inner tubes of the SLOWPOKE-2 reactor at RMC was measured to be 5.43 kGy/h when the reactor is at full power and 0.023 kGy/h when the reactor is off. Further measurements should be conducted to achieve more consistent results. Longer irradiation times and several irradiations in each inner tube will presumably give more consistent data.

In the bottom 16 cm of the irradiation sites, the average dose rate as measured by the fibre bundle with the reactor off was 0.0507 kGy/h for the inner site, and 0.0136 kGy/h for the outer site. With the reactor on, the dose rate increased to 38.6 kGy/h and 44.3 kGy/h for the inner site and 15.4 kGy/h for the outer site. The real dose rate is likely less than this, due to higher energy gammas in the reactor.

An estimation of the gamma spectrum in a SLOWPOKE-2 reactor could be used along with the results from the fibre bundle to form a more accurate perception of the gamma dose rate in the reactor. A simulation of the path lengths and patterns of Compton electrons of various energies could also help to find a more accurate dose rate.

5. References

[1] B. Brichard, A.F. Fernandez, H. Ooms, F. Berghmans, "Gamma dosimetry using Red 4034 Harwell dosimeters in mixed gamma-neutron environments," *Radiation and Its Effects on Components and Systems, 2003. RADECS 2003. Proceedings of the 7th European Conference on* , vol., no., pp. 517- 521, 15-19 Sept. 2003.

[2] B Brichard, A F Fernadez, H Oomes, F Berghmans. "Fibre-optic gamma flux monitoring in a fission reactor by means of Cerenkov radiation", *IOP Publishing Ltd*, September 12, 2007.