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# Neutron flux monitoring

*GSTR flux*

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By

SAMUEL KERBER AND GUILLAUME L'HER



Department of Nuclear Engineering  
COLORADO SCHOOL OF MINES

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## ABSTRACT

The absolute values of the neutron flux over the vertical axis of the core can be computed by irradiating a sample and determining the neutron flux received from spectrometry results. Knowing the absolute neutron flux values at different positions in or out the core can be used to obtain local peak factor in the fuel elements, more precise fuel burnup, the production rate of fission products, and other useful information. Well chosen target materials are used. They are irradiated for a given period of time, after which the samples decay until they can be used in the spectrometry chamber. Their activation are used to compute the neutron flux they experienced within the reactor.

Sodium is used in this experiment to calculate the flux in the central thimble. Due to some amount of measurement errors, we had to disregard two of our data points, which tremendously skewed our final results. We expect that accurate measurements at these two positions would have given us more insight into the flux profile across the central thimble. As these two positions were near to the center of the thimble, we would expect them to have high values of flux, and as such, we would expect a more symmetric flux profile across the central line. Thus, we must recommend that this lab be repeated in order to obtain more valid measurements.

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A very valuable measurement obtained from a reactor core is the neutron flux. Its computation allow the iperator to know what the core and fuel elements are subjected to, in terms of local power peak, temperature and irradiation. In a reactor such as the GSTR, used mainly for sample irradiation, knowing the flux seen by the samples in the different testing tubes is very important. This allows for the irradiation to be done for an adequate period of time. Neutron detectors can give a good idea of the overall flux in the core, but are oblivious to local effects. The theory is based off of the course material [2].

## 1.1 Target selection

The sample to be irradiated needs to be chosen carefully. The choice depends on the threshold energy, the corresponding cross section of the element and its half-life. Table 1.1 presents potential elments that could be used for thermal flux monitoring.

Gold is an obvious candidate, its high cross-section allowing for lower concentrations and its half-life being long enough to give the operator some time, and potentially do several measurements over the course of a week to confirm the results. The half-life is also short enough that after a month, the sample would be back to its normal activation state. Aluminium use in a neutron flux monitoring case is limited by its short half-life. The samples activation would have to be measured in an unrealistically constrained time. Dysprosium presents a very high cross-section and a reasonable half-life. All things considered, for our experiment, Sodium is an obvious choice, due to its abundance in high purity form and its 15 hours half-life.

NaCl compound, used in this project, can be obtained at high purity at low cost. The other activated isotopes created by irradiation of Sodium present either a very short ( $T_{20}$ , few sec-

Table 1.1: Foil element characteristics after irradiation

Foil Element	Reaction	Threshold energy (keV)	Cross-section (b)	Half-life
Gold	(n, $\gamma$ )	thermal	98.8	2.69d
Aluminium	(n, $\gamma$ )	thermal	0.23	2.3m
Dysprosium	(n, $\gamma$ )	thermal	920	139m
Sodium	(n, $\gamma$ )	thermal	0.53	15h

onds) or fairly high ( $Na_{22}$ , several years) half-life, thus not compromising the results from the spectrometry.

## 1.2 Target activation

In order to compute the irradiation time needed as well as the decay time to apply to the sample, one can use equation 1.1. This equation gives the sample activation given a theorized flux after the irradiation of the sample in the core during  $t$ . It can then be plugged into equation 1.2 in order to compute the expected sample activation after a decay time  $T$ .

$$(1.1) \quad A_0 = \sigma \phi \frac{m}{A} \frac{N_A}{c} (1 - e^{-\lambda t})$$

Where:

$A_0$  = Activity at the end of the irradiation ( $Ci$ )

$\sigma$  = Microscopic neutron cross-section ( $cm^2$ )

$\phi$  = Neutron flux ( $n.cm^{-2}.s^{-1}$ )

$m$  = Mass of the target isotope ( $g$ )

$A$  = Atomic weight of the target isotope

$\lambda$  = Decay constant of the radionuclide ( $s^{-1}$ )

$t$  = Irradiation time ( $s$ )

$N_A$  = Avogadro constant

$c$  = Conversion factor from number of disintegrations per second to Curies :  $3.7 * 10^{10}$

$$(1.2) \quad A_1 = A_0 e^{-\lambda T}$$

Where:

$A_1$  = Activity at the end of the decay period ( $Ci$ )

$T$  = Decay time after irradiation ( $s$ )

In the case of the NaCl compound considered, Table 1.2 gives the intermediate calculation steps. It considers that Chlorine-38 represents 25% of the total Chlorine activated, the other 75%



Table 1.2: Specific data for NaCl compound

NaCl	$Na_{24}$	$Cl_{38}$
$\sigma (cm^{-2})$	$5.3 * 10^{-25}$	$3.55 * 10^{-23}$
$m (g)$	$1.57 * 10^{-4}$	$6.07 * 10^{-5}$
$A$	22.9898	35.453
$\lambda (s^{-1})$	$1.28 * 10^{-5}$	$3.10 * 10^{-4}$

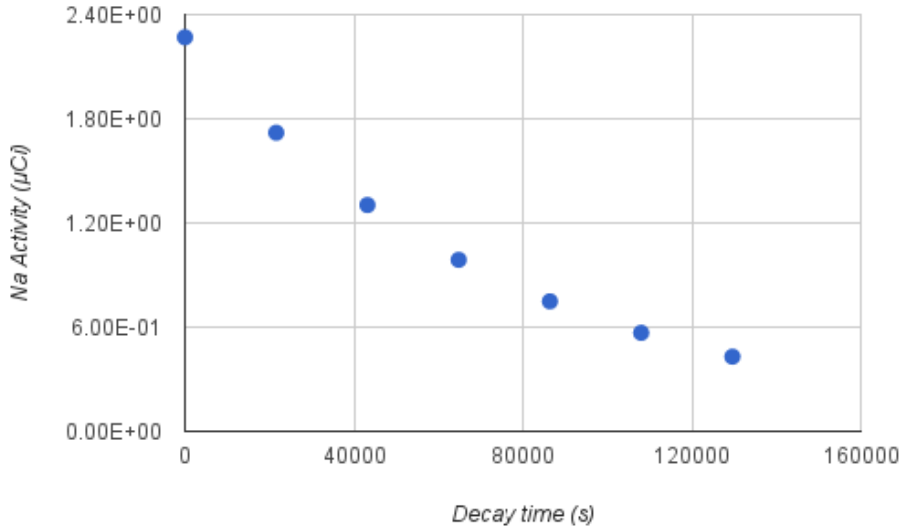


FIGURE 1.1. Activity of the sample after irradiation.

being considered stable (half-life around 300000 years). A mass of 0.4 mg of NaCl compound is considered. Considering a neutron flux estimated at  $10^{13} n.cm^{-2}.s^{-1}$  within the central thimble, and an irradiation time of five minutes, the activity estimated right after the five minutes irradiation is 2.27  $\mu Ci$  for the Sodium, and 879  $\mu Ci$  for the Chlorine. Figure 1.1 presents the activity change with time during the decay period. A decay time of around 24 hours was chosen. It can be noted that the activity provided by the Chlorine-38 disappears almost completely after 10 half-life, around 6 hours.

The experiment will consequently measure the activation from samples of 0.4 mg of NaCl placed over a 20 cm distance in the core. It is expected, if the flux estimates of  $10^{13} n.cm^{-2}.s^{-1}$  is correct, to obtain an activity of around 0.7  $\mu Ci$  during the spectrometry data experiments, a day after the irradiation.

It is interesting to note that starting after around five half-lives of irradiation time, the sample can be considered irradiated at saturation. This means that the equilibrium between the buildup of radioisotopes through irradiation and the decay of those isotopes in the sample has been

reached. At this point, the sample activity will reach a plateau. In the case of our experiment, the sample will not be anywhere near saturation levels, since this would imply an irradiation time greater than three days.

### 1.3 Spectrometry

The samples activities are measured using a spectrometer. A more detailed explanation of the spectrometer use can be found in a previous report [1].

### 1.4 Flux calculation

From the samples activities  $A_1$  measured at various axial positions in the reactor, the mass  $m$  associated with the sample and its irradiation time  $t$  and decay time  $T$  known, it is possible, using equation 1.3 computed trivially from equations 1.1 and 1.2, to obtain the neutron flux profile in the reactor.

$$(1.3) \quad \phi = \frac{A_1}{\sigma \frac{m}{A} \frac{N_A}{c} (1 - e^{-\lambda t}) e^{-\lambda T}}$$

### 1.5 Procedure

The flux can be measured at different radial positions in the core, using existing sample testing tubes in the GSTR: lazy susan, central thimble and R1 dry tube. The location analyzed in this particular experiment is the central thimble.

A vertical span of 20 centimeters in the core is considered. Every two centimeters, approximately, a sample will be placed. The samples need to be weighed carefully and irradiated for the right amount of time. This ensures that the activity levels of the samples are not so high that the samples cannot be easily manipulated or so low that the activity cannot be accurately measured. The irradiation time and the decay time must be practical from a GSTR operator standpoint. These constraints, coupled with Equations 1.1 and 1.2, allowed us to compute the given sample weight (0.4 mg), irradiation time (10 minutes) and decay time (24 hours).

The target sample are placed in an irradiation container, hold in position by a piece of foam. The position and weight of each target is carefully measured. Gloves need to be worn in order to not contaminate the samples.

The reactor is brought to full power and the sample positionned around the estimated location of the flux peak by the operators. Once the sample has been irradiated and decayed for the given times, the target are taken out of the foam and their activity is measured using the spectrometer.

## RESULTS

In this section, the results are given. And they're shit. This presents what results are shown, etc. Not much to say actually, besides showing the plot. This is a simple lab. We discuss about the uncertainties too.

## 2.1 Results

Figure 2.1 illustrates the position of each sample versus the calculated flux in that area. From the figure, we may surmise that the samples were not fully centered, as we would expect a symmetrical curve centered around the zero position. Instead, we see a skewing to the left (corresponding to down in the reactor), meaning that flux was greatest in the lower areas, and peaked around the  $-58$  mm position.

We see in the above graph two obviously erroneous points, which we have circled in red. These points have been disregarded and will be further examined in the errors and uncertainty portion of the report delineated below. It is possible that with more accurate measurements and sample points, we would see a peak nearer the zero position, meaning that flux is maximized at this point.

From our usable data, a maximum value of  $0.296 \mu\text{Ci}$  was achieved at the  $-27$  mm position. From our measured mass of  $0.42$  mg, this activity corresponded to a neutron flux of  $4.11 * 10^{12} \text{ n.cm}^{-2}.\text{s}^{-1}$ . A maximum flux of  $4.40 * 10^{12} \text{ n.cm}^{-2}.\text{s}^{-1}$  was found at position  $-58$  mm. This flux is a decade off from the expected maximum flux of  $1$  to  $3 * 10^{13} \text{ n.cm}^{-2}.\text{s}^{-1}$ .

A full presentation of sample positions, masses, activity, and flux values are presented in the appendix.

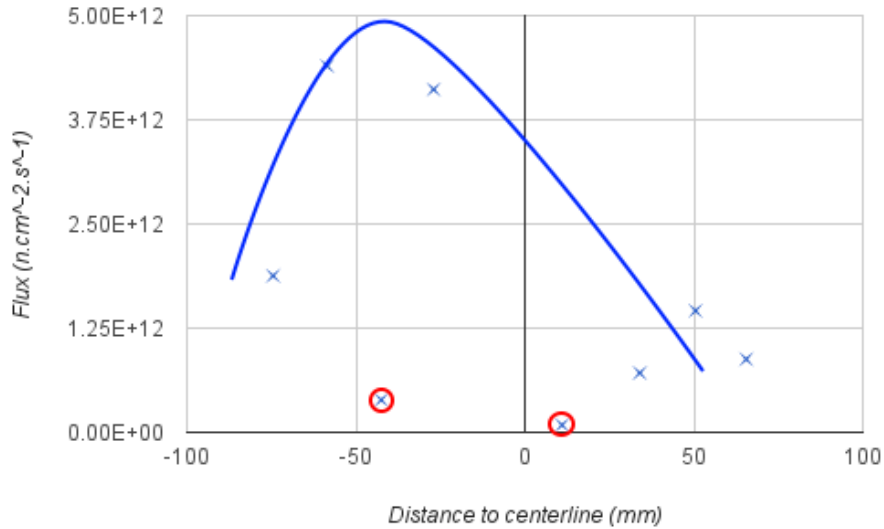


FIGURE 2.1. Thermal neutron flux seen in the samples.

## 2.2 Uncertainties

Several errors persist through this lab that caused a variance in our expected results.

First, we used a very small amount of mass in our samples. This lends itself to several errors. With this small amount of salt in the container, even small variance in the scale's reading can lead to huge deviations from our expected values. Small currents of air could have affected our measurements on the scale, even though the scale area has a small box in order to prevent such an event. When we use 0.4 mg of salt, every single grain is important. Most containers needed only 2 or 3 grains of salt to meet our weight requirement. This means that salt sticking to the outside of our container could have skewed our weight measurements. When this salt was brushed or washed off the outside of the container, our assumed weight would no longer be valid, and our calculations would be tremendously off.

Irradiation times also play a small role in our uncertainty calculations. Our sample was irradiated for a five minute fetch of time, however our calculations had assumed a ten minute irradiation period. This, initially, lead to a large deviation of observed values of activity from our expected values.

A human error may have been introduced during irradiation. It is possible that some of the sample containers were not entirely shut. This would lead to water penetrating the container, and washing away the salt.

During extraction and activity measurement of the samples, several human errors may have

been introduced to cause a large deviation from our expected results. During the extraction of the sample containers from the tube, tweezers were used to pull containers from a Styrofoam housing. Due to the orientation of the plastic containers in the Styrofoam, it was very difficult to extract the container with the tweezers without popping the pressure-sensitive lid open. Lid-opening occurred on several occasions, though we were careful to try to not spill any salt, it is possible that a grain or two fell out of the containers, which may explain the variance in our results. It is recommended that if the experiment is repeated, that the containers be oriented differently in the styrofoam housing.

When the activity of the salt was measured, it was placed on the gamma spectrometer in the plastic container. It is possible that some of the salt stuck to the top side of the plastic container instead of sitting at the bottom, immediately on top of the detector. This could cause small deviations and incongruities in the activity measurements of the samples.



## CONCLUSION

We utilized Gamma Spectrometry to irradiate high purity NaCl in order to ascertain flux values across the profile of the reactor in the Central Thimble. We irradiated 8 samples of salt for five minutes, then a day later measured the activity of the  $Na_{24}$  to determine flux values. By waiting a day, the radioactive Cl, due to its short half life, decayed away into a stable state, thus allowing us to focus solely on the sodium. The low mass of salt we loaded into the core allowed us to use such a short irradiation time.

Our calculations determined that flux was maximized 58 mm below the center of the Central Thimble. A maximum flux value of  $4.40 \times 10^{12}$  was calculated. This varies by a decade from our expected maximum of approximately  $10^{13}$ . A maximum activity of 0.296  $\mu\text{Ci}$  was measured using the Gamma Spectrometer.

Due to some amount of measurement errors, we had to disregard two of our data points, which tremendously skewed our final results. We expect that accurate measurements at these two positions would have given us more insight into the flux profile across the central thimble. As these two positions were near to the center of the thimble, we would expect them to have high values of flux, and as such, we would expect a more symmetric flux profile across the central line. Thus, we must recommend that this lab be repeated in order to obtain more valid measurements.







## DETAILED DATA TABLES

This appendix presents the raw data from the experiment in table A.1. The discrepancy in the decay time is due to the time of spectrometry measurement, ten minutes, and the time to set up the next sample in the spectrometer. One can note that the masses given for sample 3 and 5 (respectively -42.5 mm and 11 mm) and the associated activity and flux are, as discussed in the uncertainty section, likely erroneous.

Table A.1: Detailed data

Height (mm)	mass (mg)	Activity (Ci)	Time of decay (s)	Flux ( $n.cm^{-2}.s^{-1}$ )
-74.5	0.48	1.50E-07	95590	1.88E+12
-58.5	0.34	2.51E-07	94796	4.40E+12
-42.5	0.47	3.09E-08	94131	3.88E+11
-27	0.42	2.96E-07	93397	4.11E+12
11	0.44	6.63E-09	92698	8.73E+10
34	0.4	4.96E-08	91931	7.12E+11
50.5	0.4	1.03E-07	91146	1.46E+12
65.5	0.42	6.55E-08	90355	8.77E+11



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