Neutron-Flux Mapping of AFRRI Exposure Rooms

Craig R. Heimbach

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Neutron flux
Fission chambers
Threshold foils

The neutron flux in the Armed Forces Radiobiology Research Institute (AFRRI) reactor exposure rooms has been mapped by means of a National Bureau of Standards fission chamber. The chamber contained loadings of both $^{239}$Pu and $^{237}$Np, so that the reported fluxes are for neutrons <10 and >600 keV in energy. Most of the measurements were taken along the centerline height of the reactor core and perpendicular to the wall facing the reactor pool. A few
measurements were also made at other heights and angles in order to establish the flux distribution in a wide volume in each exposure room.

This mapping will aid neutron damage experiments at APRRI by allowing a more precise determination of the neutron environment.
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1. INTRODUCTION

A series of measurements was taken in the exposure rooms of the Armed Forces Radiobiology Research Institute (AFRRI) to better characterize the fast-neutron environment. These measurements were taken in anticipation of Harry Diamond Laboratories (HDL) personnel using these exposure rooms for radiation-damage experiments.

The AFRRI reactor is a TRIGA Mark F reactor, and can be operated either at a steady-state power level or in a pulsed mode. All measurements for this report were taken in the steady-state mode. The AFRRI reactor has two exposure rooms which differ in size (see fig. 1). The larger exposure room (ER1) has a movable lead shield which may be positioned in front of the reactor.

![Figure 1. Design of AFRRI exposure rooms.](image)

Fast neutrons were detected by means of a boron-covered National Bureau of Standards (NBS) fission chamber, as pictured in figure 2. The chamber consists of two back-to-back ionization chambers; one chamber had a deposit of 0.000472 g of plutonium-239 and the other had a deposit of 0.000604 g of neptunium-237. When neutrons enter the chamber, they cause the neptunium and plutonium to fission. The fission fragments are detected, and give rise to an electronic pulse. The number of pulses per second is equal, after some corrections are applied,1 to the number of fissions per second. This is related to the neutron flux by

$$\phi = \frac{A}{N_a M \langle\sigma\rangle} f,$$  (1)

where \(\phi\) is the total neutron flux, \(A\) is the atomic weight of the fissionable isotope, \(N_a\) is Avogadro's number, \(M\) is the mass of the fissionable isotope, \(\langle\sigma\rangle\) is the spectrum-averaged cross section, and \(f\) is the number of fissions per second. Since there are actually two chambers, both the flux as determined by plutonium and that determined by neptunium may be found simultaneously. The chambers were covered with 2.21 g/cm² of boron-10 to eliminate any response to neutrons below 10 keV.

2. POWER LEVEL MONITOR

Operating the reactor in a pulsed mode would saturate the chamber, so all data were taken with the reactor operating in the steady-state mode. In the taking of data, the reactor was run at various power levels. Close to the reactor, the chambers were run at lower levels to minimize dead-time corrections. Farther back into the room, the reactor was run at higher power levels to obtain sufficient statistics in a reasonably short time. At many positions, the reactor was run at several power levels.

In theory, with the fission chamber in a given position, changing the power level of the reactor should change the number of fissions per second by a proportionate amount; for example, doubling the power should double the number of fissions per second. This was not, however, observed to be the case. Table I is a summary of results obtained when the power levels were varied while the chamber was left in a given position. This table shows averages found from several different positions of the chamber in both exposure rooms. All the data in this table are normalized under the assumption that the 1000 W indicated by reactor instrumentation was correct.

### Table I. Power Indicated by Fission Chambers as a Function of Reactor Power

<table>
<thead>
<tr>
<th>Reactor power (W)</th>
<th>Indicated power (W)</th>
<th>Percent deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>15.1 ± 0.05</td>
<td>+0.6</td>
</tr>
<tr>
<td>50.</td>
<td>50.9 ± 0.08</td>
<td>+1.8</td>
</tr>
<tr>
<td>100.</td>
<td>104.7 ± 0.6</td>
<td>+4.7</td>
</tr>
<tr>
<td>500.</td>
<td>488.0 ± 3.</td>
<td>-2.4</td>
</tr>
<tr>
<td>1000.</td>
<td>1000.</td>
<td>0.0</td>
</tr>
<tr>
<td>2000.</td>
<td>1980. ± 13</td>
<td>-1.0</td>
</tr>
<tr>
<td>5000.</td>
<td>4750. ± 40</td>
<td>-5.0</td>
</tr>
</tbody>
</table>

Table I shows that the fission-chamber and the reactor power-level monitors differ by as much as 5 percent in the range from 15 to 5000 W. One should be especially cautious in trying to extrapolate these results beyond 5000 W.

### 3. Flux Results

The results of the experiment are listed in tables II and III. Measurements were taken from various places in the exposure rooms, specified in the “Location” columns. The dotted lines in figure 1, labelled “0 deg,” are parallel to the left and right walls of the exposure rooms, and originate at the height of the center of the reactor core (120 cm from the floor in exposure room 2—ER2—and 92 cm in ER1). Distances are measured from the tank wall surface; off-angle positions are diagrammed in figure 3. The only positions not at the height of the reactor core are labelled “up.” Measurements were also taken in ER2 with the reactor moved back into the water an extra 6 in. (15.24 cm) and an extra 12 in. (30.48 cm). Distance measurements in the exposure rooms are accurate to ±0.5 cm.

![Figure 3](image-url)

Figure 3. Off-angle positions in exposure rooms 1 and 2; A is in exposure room 1; B, C, and D are in exposure room 2.

The results are given both in terms of fissions per second and flux (n/cm²-s) in order to separate out the effect of the uncertainty in the boron-covered spectrum-averaged cross section, which is the largest source of error. This will affect only the normalization of the flux. The values used to convert from fissions per second to flux are $K = 4.43 \times 10^3 \pm 5$ percent for neptunium-237 (giving $> 600$ keV flux) and $5.64 \times 10^3 \pm 7$ percent for plutonium-239 (giving $> 10$ keV flux), using the equation

$$\phi = K \psi.$$  

(2)
### TABLE II. FISSION RATES AND FLUX IN EXPOSURE ROOM 1

<table>
<thead>
<tr>
<th>Location</th>
<th>Neptunium-237 fissions/s at 1000 W</th>
<th>Plutonium-239 fissions/s at 1000 W</th>
<th>10-keV flux at 1000 W (n/cm²-s)</th>
<th>600-keV flux at 1000 W (n/cm²-s)</th>
<th>Ratio &gt;10 keV &gt;600 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle from centerline (deg)</td>
<td>Distance from core (cm)</td>
<td>Height from floor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>6</td>
<td>HC</td>
<td>983 ± 15</td>
<td>1323.9 ± 20</td>
<td>7.47 × 10⁸</td>
</tr>
<tr>
<td>0</td>
<td>11.5</td>
<td>HC</td>
<td>710.8 ± 40</td>
<td>963 ± 20</td>
<td>5.43 × 10⁸</td>
</tr>
<tr>
<td>0</td>
<td>28</td>
<td>HC</td>
<td>335.2 ± 6</td>
<td>498 ± 65</td>
<td>2.81 × 10⁷</td>
</tr>
<tr>
<td>0</td>
<td>72</td>
<td>HC</td>
<td>99.2 ± 3</td>
<td>150 ± 6</td>
<td>8.46 × 10⁶</td>
</tr>
<tr>
<td>0</td>
<td>160</td>
<td>HC</td>
<td>28.3 ± 0.7</td>
<td>73.5 ± 1.6</td>
<td>4.14 × 10⁶</td>
</tr>
<tr>
<td>0</td>
<td>247</td>
<td>HC</td>
<td>14.1 ± 0.5</td>
<td>45.7 ± 2</td>
<td>2.58 × 10⁶</td>
</tr>
<tr>
<td>42 (A)b</td>
<td>70</td>
<td>HC</td>
<td>110.4 ± 2</td>
<td>173.4 ± 4</td>
<td>9.78 × 10⁵</td>
</tr>
<tr>
<td>0</td>
<td>78</td>
<td>41 cm up</td>
<td>29.4 ± 1.0</td>
<td>68.0 ± 1.0</td>
<td>3.83 × 10⁵</td>
</tr>
<tr>
<td>0</td>
<td>79</td>
<td>70 cm up</td>
<td>54.2 ± 1.5</td>
<td>97.1 ± 3</td>
<td>5.48 × 10⁵</td>
</tr>
<tr>
<td>(with lead shield)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>72</td>
<td>HC</td>
<td>74.3 ± 1.5</td>
<td>123.2 ± 4</td>
<td>6.95 × 10⁵</td>
</tr>
<tr>
<td>0</td>
<td>160</td>
<td>HC</td>
<td>19.9 ± 0.5</td>
<td>53.7 ± 1.2</td>
<td>3.03 × 10⁵</td>
</tr>
</tbody>
</table>

a) HC = height at core (92 cm in ER1)
b) See figure 3 for diagrams of angle positions.

### TABLE III. FISSION RATES AND FLUX IN EXPOSURE ROOM 2

<table>
<thead>
<tr>
<th>Location</th>
<th>Neptunium-237 fissions/s at 1000 W</th>
<th>Plutonium-239 fissions/s at 1000 W</th>
<th>10-keV flux at 1000 W (n/cm²-s)</th>
<th>600-keV flux at 1000 W (n/cm²-s)</th>
<th>Ratio &gt;10 keV &gt;600 keV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle from centerline (deg)</td>
<td>Distance from core (cm)</td>
<td>Height from floor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8</td>
<td>HC</td>
<td>851.8 ± 30</td>
<td>1432.2 ± 30</td>
<td>8.08 × 10⁸</td>
</tr>
<tr>
<td>0</td>
<td>11.5</td>
<td>HC</td>
<td>642.3 ± 9</td>
<td>1116 ± 18</td>
<td>6.29 × 10⁸</td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>HC</td>
<td>301.0 ± 5</td>
<td>519.5 ± 8</td>
<td>2.93 × 10⁷</td>
</tr>
<tr>
<td>0</td>
<td>71.5</td>
<td>HC</td>
<td>98.7 ± 2.5</td>
<td>217.6 ± 5</td>
<td>1.23 × 10⁶</td>
</tr>
<tr>
<td>0</td>
<td>158</td>
<td>HC</td>
<td>29.0 ± 1.8</td>
<td>104.9 ± 4</td>
<td>5.92 × 10⁵</td>
</tr>
<tr>
<td>26 (B)b</td>
<td>52</td>
<td>HC</td>
<td>282.0 ± 6</td>
<td>1.59 × 10⁶</td>
<td>—</td>
</tr>
<tr>
<td>26 (C)b</td>
<td>163</td>
<td>HC</td>
<td>—</td>
<td>93.0 ± 2.5</td>
<td>5.24 × 10⁵</td>
</tr>
<tr>
<td>26 (D)b</td>
<td>52</td>
<td>61 cm up</td>
<td>282.0 ± 6</td>
<td>1.59 × 10⁵</td>
<td>—</td>
</tr>
<tr>
<td>0</td>
<td>49</td>
<td>61 cm up</td>
<td>239.4 ± 6</td>
<td>1.35 × 10⁵</td>
<td>—</td>
</tr>
<tr>
<td>(with H₂O)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>HC</td>
<td>24.23 ± 2.2</td>
<td>44.9 ± 1.5</td>
<td>2.53 × 10⁴</td>
</tr>
<tr>
<td>0</td>
<td>30</td>
<td>HC</td>
<td>3.48 ± 0.15</td>
<td>9.1 ± 0.3</td>
<td>5.13 × 10³</td>
</tr>
</tbody>
</table>

a) HC = height at core (120 cm in ER2)
b) See figure 3 for diagrams of angle positions.
Some of the results of the neptunium flux for ER2 are missing because one of the preamplifiers necessary for taking data failed during the course of the experiment.

The 0-deg data for the two exposure rooms are plotted in figures 4 and 5.

The two exposure rooms have about the same flux out to a distance of 40 cm from the tank wall. Beyond that distance, ER2 has more \( >10 \)-keV neutrons and about the same number of \( >600 \)-keV neutrons, indicating a softening of the spectrum as one approaches the back wall of the exposure room.

The effect of the lead shield in ER1 is to cause about a 25-percent decrease in total fast flux and a slight softening of the spectrum. Moving the reactor back into the water significantly reduces neutron flux and greatly softens the neutron spectrum.

4. CONCLUSIONS

The \( >10 \) and \( >600 \) keV neutron fluxes have been measured in the two AFRRRI exposure rooms with emphasis in the direction along the 0-deg line at the height of the center of the reactor core. The results are reported in terms of 1000 W of reactor power. The positioning errors are \( \pm 0.5 \) cm, the relative point-to-point fission rate errors are about 3 percent, and the absolute normalization uncertainty is 7 and 5 percent for \( >10 \) and \( >600 \) keV flux, respectively.
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