SHORT-LIVED NUCLIDES AND QUALITY CONTROL

The NIST rapid irradiation and counting system

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Apparatus is being developed for shot~ irradiation and rapid counting at the NIST Reactor, optimized for accurate neutron activation analysis via activation products ranging in half-life from about 500 ms to 500 s. This facility is designed to irradiate a sample either in a well-thermalized neutron flux at 3 \cdot 10^{13} \text{ n cm}^{-2} \text{ s}^{-1}, or in a higher flux with a larger fast and epithermal component. The design transfer time for a 1-mL rabbit is 500 ms, measured to 10 ms precision. Timing information for both irradiation and counting will be transferred automatically to the activation analysis workstation computer. The γ-ray spectrometer system is selected and tuned for accurate measurement at high and varying counting rates, using loss-free counting (LFC) technology. A detailed calibration and characterization of this system has been performed. Accurate measurement requires that attention be paid to the systematic and random errors to which LFC is subject, but this requirement is minor compared to the advantages of undistorted spectral shape, the ability to solve the decay equations exactly, and the wider useful range of counting rates in the spectrometer system.

Introduction

The NIST Reactor (NBSR) is a heavy-water 20-MW research reactor, designed for neutron beam experiments and materials characterization, including neutron activation analysis. Five pneumatic tubes (rabbits) are incorporated in its design for neutron activation and other irradiation experiments. The original rabbit systems installed in the middle 1960s are large (40 ml sample capacity) but slow (3 to 15 seconds transit time). Transferring samples from the reactor to the γ-ray detector is entirely manual, so the speed of this operation is limited by the skill of the operator. Because time intervals are recorded by stopwatch or equivalent, accurate activation analysis with these systems is practical only for activation products with half-lives longer than about one minute, where human reaction time is sufficiently reproducible. An extended shutdown of the NBSR has permitted an unused rabbit tube (designated RT2) to be converted into a new irradiation system, designed for neutron activation analysis with short-lived nuclides. When this system enters routine use, a number of activation products (e.g., 190, 20F, 36Cl, 46mSc, 75m,77mGe, 77mSc, 86mRb, 107mPd, 116mIn, 167mEr, 177mYb, 179mHf, 183mW, 199mPt and 208mPb) will be analytically useful for the first time in this laboratory. The rapid irradiation system comprises three major subsystems: the irradiation terminal inside the reactor, the rabbit transport and control equipment, and the γ-ray spectrometer. Intertech Worldwide, MF Physics, and Canberra Industries, respectively, were the primary vendors of these subsystems.

Design specifications

1. The transfer time from the reactor to the detector is designed to be < 500 ms, so that products with half-lives as short as a few hundred milliseconds will be measurable before they decay. For the necessary acceleration to be achievable with reasonable pressure of the driving gas, small rabbits (net volume 1.4 ml) will be used.

2. Timing is designed to be accurate to better than 10 ml. An experienced analyst with a stopwatch can measure the interval between the end of irradiation and the start of the count to a standard deviation of about 0.2 second. Moreover, manual timing is subject to momentary blunders and fatigue, and there may be no record of when problems occur. The new system will sense and record the decay time more than a factor of 20 better. For example, in the analysis of fluorine through 11-second 20F, the relative uncertainty (95% confidence) in the decay correction of a sample or a standard is 2.4% with manual timing, and better than 0.12% with the new system.

3. For maximum flexibility, two irradiation positions were planned for the existing RT2 thimble. One position was located near a fuel element in order to obtain a high flux of both thermal and fast neutrons, and one was further away in the reflector with a lower but well-thermalized flux. Fabrication difficulties encountered in the construction of the dual terminal have forced the high-flux position to be abandoned in the present installation, although the rest of the system will permit it to be added later.

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Table I. Characteristics of pneumatic tubes in the NBSR at 20 MW

<table>
<thead>
<tr>
<th>Rabbit name</th>
<th>$\Phi_{\text{th}}$ $\text{cm}^{-2} \cdot \text{s}^{-1}$</th>
<th>$\Phi_{\text{g}}$ $\text{cm}^{-2} \cdot \text{s}^{-1}$</th>
<th>$\Phi_{\text{gheating}}$ $\text{cm}^{-2} \cdot \text{s}^{-1}$</th>
<th>Gamma-transfer heating, W/g</th>
<th>Transfer time, s</th>
<th>Volume, ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT1</td>
<td>$7.7 \times 10^{13}$</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>Old RT2*</td>
<td>$12 \times 10^{13}$</td>
<td></td>
<td></td>
<td>5*</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>New RT2 (thermal)**</td>
<td>$3 \times 10^{13}$</td>
<td>$5 \times 10^{12}$</td>
<td>$1 \times 10^{13}$</td>
<td>0.3</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>RT3</td>
<td>$10.3 \times 10^{13}$</td>
<td>$1.2 \times 10^{12}$</td>
<td>$1 \times 10^{12}$</td>
<td>0.8*</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>RT4</td>
<td>$2.7 \times 10^{13}$</td>
<td>$4 \times 10^{10}$</td>
<td>$6 \times 10^{10}$</td>
<td>0.1*</td>
<td>3</td>
<td>40</td>
</tr>
<tr>
<td>RT5</td>
<td>$3.5 \times 10^{11}$</td>
<td>$9 \times 10^{8}$</td>
<td>$&lt; 8 \times 10^{8}$</td>
<td>15</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

* Extrapolated from measurements at 10 MW.
** Calculated.

Table 1 shows the characteristics of the new irradiation system in comparison with other rabbits in this reactor. A survey of six months of irradiations at the NBSR showed that the well-thermalized RT4 facility accounted for not only most of the irradiation hours but also most of the fluence, so the addition of the new thermal rabbit will relieve pressure on the most popular facility.

In-reactor terminal

An earlier communication has described the irradiation terminal subsystem. The terminal installed in the NBSR is 1.80 m in overall length and 5.1 cm in outside diameter.

The thermal irradiation position is located 95 cm horizontally from the core centerline, 22 cm below the midplane, 38 cm from the nearest fuel element and 11 cm from the edge of the D$_2$O reflector. Because the axis of the rabbit is nearly perpendicular to the flux contours, the axial gradient can be accurately canceled by reirradiating the sample after a 180° end-for-end inversion. Circulating D$_2$O occupies the end of the thimble between the thermal rabbit position and the reactor core to moderate neutrons and to remove γ-ray heat from the terminal.

The entire assembly inside the biological shield is made of 6061-T6 aluminium alloy, welded by a certified welder with 4043 aluminium filler rod. X-radiography and dye penetrant testing were used for inspection, after which

Fig. 1. Flow diagram of the rabbit flight path. Irradiated samples can be returned to the reactor from the counting station at the detector, or by manual transfer from the shielded dump station to the loader.