The disintegration of $^{103}\text{Rh}$

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**ABSTRACT**

A technique for determination of the disintegration rate of $^{103}\text{Rh}^m$ in thick foils is described.

In addition values for the following parameters were determined:

- total internal conversion coefficient
  \[a = 1531 \pm 30,\]

- K shell internal conversion coefficient \[a_K = 127 \pm 6\]

- conversion ratio \[R = \frac{K}{L + M + \ldots} = 0.0914 \pm 0.0043\]
INTRODUCTION

The utilization of the $^{103}\text{Rh}(n,\gamma)^{103}\text{Rh}^m$ reaction for fast neutron flux and dose determinations depends on the knowledge of the excitation function and reaction rate determination. Many papers have been published on this subject (1-12). Because all the reported cross section data have been obtained by the activation technique, a special care has to be taken in the activity determination (13). There is no simple way to obtain the absolute activity in a rhodium foil from the measured counting rate. Since the previously reported nuclear data ($\alpha_k$, $\alpha$) are not in agreement with observations here, a re-determination seemed worthwhile.

$^{103}\text{Rh}^m$ decays to the ground state with a half-life of 56,116 min (14) and a transition energy of 39,75 keV. This isomeric level is strongly converted. The activity can, therefore, be obtained by measuring either the electrons or the X-rays produced in the conversion. The 20 keV X-rays are the most convenient for this measurement.

Determination of rhodium activity

The detector for counting rhodium activity is an integral assembly of a NaI(Tl) crystal (38 mm diameter x 2 mm thickness) and a beryllium window ($\sim 0.125$ mm thick). The counter is shielded with 10 cm of lead for background reduction. The pulse height spectrum is displayed on a multichannel analyzer. The efficiency of the detector for the 20 keV K X-rays was determined with calibrated sources of $^{103}\text{Rh}^m$ electro-deposited on VYNS films. The disintegration rate of these sources was determined by $4\pi e-X$ coincidence technique. The efficiency of the $4\pi$ counter for the 17 keV K-conversion electrons was 99.5%.
A detailed description of the 4πe-X calibration and source preparation from a Pd-Rh generator is given elsewhere (15,16).

In this way the X-ray detector calibration for 4 detector-to-source distances (see Table I) was obtained independently of the conversion factors \((a, a_k)\) and fluorescence yield \(\omega_k\) values.

\[
N_i = \varepsilon_i \cdot N_0 \cdot \frac{\alpha_k}{1 + \alpha} \cdot \omega_k \cdot b_{xki} \cdot f_{at} \cdot N_0
\]

\(f_{at}\) = correction for the Be window attenuation and the transparency of the detector to 20 keV photons \((0.997)\) (9)

\(\varepsilon_i\) = detector efficiency for the \(i\) position

\(N_i\) = count rate of a calibrated source \(N_0\) in the \(i\) position

\(b_{xki}\) = geometric efficiency of the detector for the 20 keV K X-rays

This equation is valid for infinitely thin sources.

Radius correction is not necessary because VYNS sources and rhodium discs have the same size. The detector resolution (FWHM) for 20 keV photons was about 25%.

For a rhodium foil of finite thickness, there will be a decrease in the counting rate due to absorption and scattering within the foil.

\[
N_i = F_{\text{self}} \cdot \varepsilon_i \cdot N_0
\]

\(F_{\text{self}}\) is the self-absorption factor.

The exact calculation of the dependence of self-absorption on foil thickness \(d\) and counting geometry is rather difficult due to multiple interactions, but a rough approximation can be made assuming an exponential absorption coefficient, \(\mu\), independent of the depth from which the radiation emanates. An experimental method for self-absorption determination is to obtain an
absorption curve for the active material by adding more material of
the same specific activity, A, to make a thicker foil. The activity A', of
a foil of thickness, d, is:

\[ A' = \frac{A}{\mu \cdot d} \left( 1 - e^{-\mu d} \right) \]

where: \( \mu \) = mass absorption coefficient for foil (cm\(^{-1}\))

It is possible to lump self-scattering, self-absorption, and back-scattering
into a single correction, \( \mu \), for a specific foil thickness, mounting and
geometrical arrangement in a particular counting system.

Here we determined the self-absorption factor by a simulatenous irradiation
of a rhodium disc (10 mm diameter and 0.1 mm thickness, m \( \sim \) 95 mg) and
a disc (same size) of Al-Rh alloy (4% Rh by weight) in the reactor to ensure
that each disc experienced the same specific activity. The self-absorption
factor, \( F_{\text{self}} \), is the ratio between the activity of the rhodium disc and
the alloy disc:

\[ F_{\text{self}} = \frac{N_{\text{Rh}}}{N_{\text{Alloy}} \cdot K_i} \]

\( K_i \) = correction due to absorption in the alloy

The rhodium self-absorption correction in the alloy was found by calculation
to be less than 1% (assuming an \( \mu_{\text{Rh}} = 13.5 \text{ cm}^2 / \text{g} \)).

This was verified experimentally by relative activity determinations with
and without rhodium absorbers of different thicknesses between source
and detector for the 4 detector-to-source distances. The same procedure
was performed for absorption of the 20 keV photons in aluminium absorbers
of different thicknesses.

The results of \( F_{\text{self}} \) are summarized in Table I.
Determination of $a$, $a_K$ and the conversion ratio $R$.

The internal conversion coefficients $a$ and $a_K$ of the 39.75 keV transition in $^{103}\text{Rh}^{m}$ were determined from data shown in Fig. 1, the X-ray and $\gamma$-ray pulse height distributions were obtained from a $^{103}\text{Rh}^{m}$ source prepared from an elution of the Pd-Rh generator and detected by the NaI(Tl) crystal. The area of the pertinent peaks in the spectra at 20 and 40 keV were determined and corrected for any background present. From the following formula the absolute number of 40 keV photons was determined:

$$N_{40} = \frac{4}{A + \alpha} \cdot b_{\gamma} \cdot F_{\text{escape}} \cdot f_{\text{at}} \cdot N_0$$

$F_{\text{escape}}$ = the iodine X-ray escape correction factor

$b_{\gamma}$ = solid angle geometric efficiency of the NaI(Tl) crystal

$N_0$ = disintegration rate of the source

$f_{\text{at}}$ = correction for Be-window attenuation and the transparency of the detector to 40 keV photons (0.997)

To determine $F_{\text{escape}}$ an absorber of stainless steel (0.5 mm) and aluminium (0.2 mm) was placed between the detector and source so that the 20 keV photons and the produced 6.4 keV X-rays were almost all absorbed. Fig. 2 shows such a spectrum. From the peak area ratio, one obtains directly the escape correction factor:

$$F_{\text{escape}} = \frac{F_{40}}{F_{44} + F_{40}} = 0.797 \pm 0.016$$

This value is in very good agreement with reported data (17). The solid angle geometric efficiency $b_{\gamma} = 0.0684 \pm 0.0004$ for a collimator of 2 cm diameter was calculated. The calculation was verified to within 0.5% by measurement with several collimators of different diameters using $^{103}\text{Pd}$ sources.
For five $^{103}\text{Rh}^m$ sources from different generator elutions a mean value

$$\alpha = 1531 \pm 30$$

was obtained at the 95\% confidence level.

From the ratio of the two peak areas (20 keV and 40 keV) in Fig. 1, the K-internal conversion coefficient $a_K = \frac{e_K}{\gamma}$ can be obtained.

$$a_K = \frac{N_{20} \cdot \Gamma_{\text{escape}}}{N_{40} \cdot \omega_K}$$

$N_{20}, N_{40}$ = peak area for the 20 (40) keV peak corrected (background and attenuation)

$$\omega_K = 0.807 \pm 0.031 \quad (18)$$

From different generator elutions five $^{103}\text{Rh}^m$ sources were prepared and measured, from which a mean value

$$a_K = 127 \pm 6$$

was obtained. This is in good agreement with the predicted theoretical value of 140 (19). The uncertainty of the $a_K$ value is mostly due to $\Delta \omega_K$ (18).

In Table II data reported in the literature are presented with our results. From our results, a conversion ratio

$$R = \frac{a_K}{a_L + a_M + \ldots} = 0.0914 \pm 0.0043$$

was calculated.

For long-term control of the equipment, several $^{103}\text{Pd}$ sources were calibrated in the rhodium counter and measured before each day's experiment. The $^{103}\text{Pd}$ half-life used was 16.96 $\pm$ 0.06 days (16).

In each experiment several rhodium activity determinations were performed. The counting rate at time zero was obtained using $T_{1/2} = 56,116$ min and the
least square method. This was an additional check that the equipment was working properly.

ACKNOWLEDGEMENT

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<table>
<thead>
<tr>
<th>Position</th>
<th>Detector-to-source distance [mm]</th>
<th>$\epsilon_i$ [%]</th>
<th>$F_{\text{self}}$</th>
<th>$\epsilon_i F_{\text{self}}$</th>
<th>$K_i$</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>2.7</td>
<td>3.065 ± 0.015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12.6</td>
<td>1.600 ± 0.006</td>
<td>0.436 ± 0.002</td>
<td>6.93 $\cdot 10^{-3}$</td>
<td>0.923 ± 0.003</td>
</tr>
<tr>
<td>3</td>
<td>22.8</td>
<td>0.835 ± 0.004</td>
<td>0.466 ± 0.002</td>
<td>3.89 $\cdot 10^{-3}$</td>
<td>0.935 ± 0.003</td>
</tr>
<tr>
<td>4</td>
<td>52.9</td>
<td>0.220 ± 0.002</td>
<td>0.482 ± 0.002</td>
<td>1.06 $\cdot 10^{-3}$</td>
<td>0.937 ± 0.003</td>
</tr>
</tbody>
</table>

**TABLE II**  
$^{103}\text{Rh}^{m}$ internal conversion coefficients values

<table>
<thead>
<tr>
<th>Source</th>
<th>Conversion ratio, $R$</th>
<th>$a_K/a$</th>
<th>$a_K$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kondiah(20)</td>
<td>0.20 ± 0.04</td>
<td>0.17 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>Cork et al. (21)</td>
<td>0.10 ± 0.04</td>
<td>0.076 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>Avignon et al. (22)</td>
<td>0.09 ± 0.01</td>
<td>0.069 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Drabkin et al. (23)</td>
<td>0.18 ± 0.03</td>
<td>0.129 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>Bresesti et al. (24)</td>
<td>0.0986 ± 0.0050</td>
<td>0.0865 ± 0.005</td>
<td></td>
</tr>
<tr>
<td>De Raad et al. (25)</td>
<td>0.098 ± 0.005</td>
<td>0.089 ± 0.005</td>
<td></td>
</tr>
<tr>
<td>Vuorinen (3)</td>
<td>0.105 ± 0.01</td>
<td>0.0955 ± 0.010</td>
<td></td>
</tr>
<tr>
<td>Ing et al. (9)</td>
<td>0.095 ± 0.005</td>
<td>0.0865 ± 0.0055</td>
<td></td>
</tr>
<tr>
<td>Lepri(26)</td>
<td></td>
<td></td>
<td>180 ± 20</td>
</tr>
<tr>
<td>Pazsit et al. (27)</td>
<td></td>
<td></td>
<td>235 ± 15</td>
</tr>
<tr>
<td>Hegedus(28)</td>
<td>0.116 ± 0.030</td>
<td>0.131 ± 0.030</td>
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<tr>
<td>Nischmidt et al. (29)</td>
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<td></td>
<td>138 ± 5</td>
</tr>
<tr>
<td>Theoretical value (19)</td>
<td></td>
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<td>140 ± 20</td>
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<tr>
<td>Present work</td>
<td>0.0914 ± 0.0043</td>
<td>0.0826 ± 0.0050</td>
<td>127 ± 6</td>
</tr>
</tbody>
</table>


Fig. 1  Pulse height distribution obtained from a $^{103}\text{Rh}^{m}$ source.
Fig. 2 Pulse height distribution obtained when an absorber was placed between source and detector.