Report on
Quality Assessment of IAEA Medical Isotope Data

Prepared by
Natalie Gaughan

June 2021
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Introduction

In the field of medical isotope production, there is ongoing interest in identifying new useful isotopes and new production routes for isotopes already in use. In order to analyse isotope production routes, it is necessary to know cross section and yield data for the relevant reactions.

To this end, the Nuclear Data Section at the IAEA has is interested in consolidating and organizing nuclear reaction data. Many data sets from different experiments are found in the EXFOR database. EXFOR contains cross section and yield data for all types of reactions. TALYS, a code that models nuclear reactions theoretically, is widely used as another way to obtain cross section or yield values. TALYS is particularly important for reactions that have not been studied experimentally very much.

Generally, the best way to get an accurate understanding of a reaction is to use a combination of theoretical and experimental data, considering both TALYS and EXFOR. For this purpose, it is necessary to know how accurate TALYS is, and which experimental data is reliable. The overall purpose of this internship was to assist in evaluating current capabilities of predicting medical isotope production data.

Database

For some reactions that are relevant to medical applications, the experimental data available is not always very reliable. There are several reasons for this, such as unclear cross section definitions, using incorrect (outdated) decay data to calculate beam current, etc.

IAEA-TECDOC-1211 [1] evaluates the available experimental cross section data for several important reactions. Each data set is either "selected" or "deselected" by the TECDOC for use in calculating recommended cross-section and yield values.

The first task of this internship was to build a “database” from IAEA-TECDOC-1211. In this database, each entry has the EXFOR accession number of the data, and a quality score of either 0 or 1. A quality score of 1 indicates that the TECDOC found the data to be acceptable, and a quality score of 0 indicates that the TECDOC says this data should be excluded. This database
includes every reaction in section 5.1 of IAEA-TECDOC-1211, which are reactions that produce diagnostic gamma emitters.

Some special cases arose while compiling this database. For a few publications, the TECDOC does not give an accession number. In these cases, the correct EXFOR entry could usually be found by searching the authors names. In 2 cases, the publications still were not found in EXFOR. In 9 other cases, the accession number given in the TECDOC turned up no results when searched for in EXFOR. It appears that some accession numbers may have changed since the TECDOC was written. In these cases, all but 1 publication were found by searching the authors names in EXFOR.

For 12 publications, EXFOR only has yield values, not cross section values. Other special cases are that a few data sets were deemed acceptable by the TECDOC for a certain energy range only, or after being altered in some way (renormalized or shifted). Additionally, there is now some new data that has been added to EXFOR since the TECDOC was published. These data sets are included in the database but their quality scores have been left blank. The database is included in this report in Appendix 1.

**Evaluation of TALYS cross sections**

The second main goal of this internship was to evaluate the cross sections calculated by TALYS. For each reaction in section 5.1 of the TECDOC, cross sections were obtained from TALYS and plotted with experimental data. The plots can be found in Appendix 2.

Certain reactions show discrepancies between TALYS and the experimental data. These discrepancies should be examined in the future. It is interesting to note that a few reactions have similar discrepancies. Common trends are that TALYS’s excitation function is shifted to low energy, or only the right side (downward slope) is too low, in relation to the experimental data.

Next, some input parameters were adjusted to see how they affect the cross section calculations. The parameters tested were rvadjust n, rvadjust p, gnadjust, gpadjust, aadjust, and ldmodel. In general, aadjust, gnadjust, and gpadjust did not change the cross section very much. rvadjust n generally made little difference or shifted the excitation function to the left. rvadjust p could change the height of the peak. ldmodel 2 and ldmodel 5 generally gave the best results in terms of matching TALYS to the experimental data, because they tend to increase the right side of the curve (shifting the portion of the curve with a downward slope to higher energy). Figures 1-4 show examples of these effects.
Figure 1. rvadjust n sometimes shifts the excitation function to the left (for both >1 and <1).

Figure 2. rvadjust p changes the height of the peak.
Figure 3. ldmodel often increases the right side of the curve.

Figure 4. ldmodel 5 often increases the right side of the curve, or shifts the entire curve to the right.
Evaluation of yield calculations from TALYS

The third main task in this internship was to evaluate the yield calculation capabilities in TALYS. As an example, yield calculations for the $^{111}$Cd(p,n)$^{111}$In reaction are shown in Figure 5. These were calculated using the TALYS’s default setting for irradiation time (1 day) and beam current (1 mA). This reaction was chosen because the cross sections from TALYS match pretty well to experimental data and the TECDOC.

Figure 5. Yield calculated with TALYS for $^{111}$Cd(p,n)$^{111}$In.

The TECDOC gives recommended yield values for each reaction at a range of incident energies. Yield results from TALYS were compared to these values. Two reactions from TECDOC section 5.1 were not included in this analysis, $^{nat}$Kr(p,x)$^{81}$Rb, and $^{124}$Xe(p,pn)$^{123}$Xe. TALYS does not give yield calculations for natural targets (the yield output files show all zeros). For the (p,pn) reaction, there are discrepancies in the experimental data, so the TECDOC does not give recommended yield values.

The result of this evaluation is that TALYS calculates yields correctly, subject to the accuracy of the cross section. When the cross sections calculated by TALYS are correct, then the yield values it gives are also correct.

For example, the TALYS cross sections match the experimental data pretty well for the reaction $^{111}$Cd(p,n)$^{111}$In. For this reaction, the yield results from TALYS are within 20% of the suggested values in the TECDOC.

Figure 6 shows how TALYS compares to the recommended yields in the TECDOC. The TECDOC gives yield values for a range of incident energies. Yields were calculated in TALYS for each of these energies, and the ratios of the TALYS value to the TECDOC value were calculated at each energy point. Then the ratios were averaged for the energy points in the main part of the excitation function curve. The extremities of the excitation function were not included in the averaging because they often gave a disproportionately worse ratio. From a practical standpoint this is not a big problem because the cross section is so low at those points that even if the ratio is large, the actual values are still small.
Even for cases where the TALYS cross sections are not as accurate, the yield results still make some sense. If the TALYS cross sections are too high, then the yield values will be similarly high. From this evaluation it can be said that the yield calculation function in TALYS works correctly (provided that the cross sections used to calculate the yield are accurate).

A similar comparison was performed with a 2016 article by Qaim [2], which examines nuclear data needs for radionuclides used in medical applications. This article gives a specific energy range for each reaction, so those values were used as Ebeam and Eback in TALYS. Again, the ratios between the TALYS yield and the yield from this article were calculated. The results are shown in Figure 7.

![Yield comparison with TECDOC](image)

Figure 6. Comparison of TALYS yield results with TECDOC recommended values.

<table>
<thead>
<tr>
<th>Reaction Number</th>
<th>Reaction</th>
<th>Yield comparison with TECDOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$^{67}$Zn (p,n) $^{67}$Ga</td>
<td>$^{124}$Te (p,n) $^{124}$I</td>
</tr>
<tr>
<td>2</td>
<td>$^{68}$Zn (p,2n) $^{67}$Ga</td>
<td>$^{125}$I (p,5n) $^{125}$Xe→$^{125}$I</td>
</tr>
<tr>
<td>3</td>
<td>$^{82}$Kr (p,2n) $^{81}$Rb</td>
<td>$^{125}$I (p,3n) $^{125}$Xe→$^{125}$I</td>
</tr>
<tr>
<td>4</td>
<td>$^{111}$Cd (p,n) $^{111}$In</td>
<td>$^{124}$Xe (p,2n) $^{123}$Cs→$^{123}$Xe→$^{123}$I</td>
</tr>
<tr>
<td>5</td>
<td>$^{112}$Cd (p,2n) $^{111}$In</td>
<td>$^{203}$Tl (p,3n) $^{203}$Pb→$^{203}$Tl</td>
</tr>
<tr>
<td>6</td>
<td>$^{125}$Te (p,n) $^{125}$I</td>
<td>$^{203}$Tl (p,2n) $^{203}$Pb→$^{203}$Tl</td>
</tr>
<tr>
<td>7</td>
<td>$^{125}$Te (p,2n) $^{125}$I</td>
<td>$^{203}$Tl (p,4n) $^{203}$Pb→$^{203}$Tl</td>
</tr>
</tbody>
</table>
## Summary

Regarding the reliability of experimental data, the TECDOC is a very useful resource, but it does not include every medical isotope. The document is already 18 years old. A similar evaluation may be needed in the future to evaluate other isotopes that have gained interest in the last 18 years. In some cases, the TECDOC excluded data because the publication was not clear in exactly what quantities were measured/calculated. Perhaps this can be avoided in the future.

As for TALYS, in general the code is fairly accurate. It produces excitation functions with the approximate correct shape and peak height for most reactions. On a more precise level however, there is room for improvement in understanding how to better match the theory to the experimental data. Since TALYS has similar discrepancies for several reactions, such as the right side of the curve being too low, it is possible that the same solution will fix the problem.

<table>
<thead>
<tr>
<th>Reaction Number</th>
<th>Reaction</th>
<th>TALYS yield/Qaim yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$^{38}$Ar(p,n)$^{38}$Kr</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$^{44}$Ca(p,n)$^{44}$Sc</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$^{45}$Sc(p,n)$^{45}$Ti</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$^{64}$Ni(p,n)$^{64}$Cu</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$^{66}$Ni(p,n)$^{66}$Cu</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$^{64}$Ni(p,n)$^{64}$Cu</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>$^{66}$Zn(p,n)$^{66}$Ga</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>$^{76}$Se(p,n)$^{76}$Br</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>$^{82}$Kr(p,n)$^{82}$mRb</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>$^{86}$Sr(p,n)$^{86}$Y</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Comparison of TALYS yield results with Qaim 2016.
for all or many reactions. The yield calculation capability in TALYS works properly. As long as the cross section data is accurate, the yields will be accurate as well.
References


Appendix 1
Database based on IAEA-TECDOC-1211, Section 5.1 on diagnostic gamma-emitters

Questions and potential problems are color-coded by type.

Key:
- **Yellow**: not found in EXFOR. TECDOC did not give an EXFOR accession number, and it was not found by searching for the authors or the reaction.
- **Neon green**: The TECDOC gave an EXFOR number, but the publication/reaction was not found with that number.
- **Blue**: Same as the neon green case, but the publication/reaction was found in EXFOR with a different accession number by searching the authors.
- **Pink**: EXFOR shows multiple accession numbers for the same publication and reaction, and it was not clear which one is relevant.
- **Purple**: The only EXFOR number found for that reaction and publication was for yields, not cross sections.
- **Teal**: uncertain about target A.
- **Dark green**: The data were adjusted in some way for the TECDOC.

Notes:
- Some data sets are only selected within a certain energy range. In these cases the quality score has format “Quality_1: 1 0. 12.” where, in this example, the data is selected between 0 and 12 MeV.
- Some data sets used natural targets.
- Some additional data sets were found in EXFOR that were not mentioned in the TECDOC, and are included in this database with the quality score left blank.
  - Some are (p,x)

Special cases/questions:
- For Zn-68, many sources used a natural target. The TECDOC says this is fine between 17 and 30 MeV because the Zn-67 contribution is negligible in this range (see TECDOC page 160). Does this mean that those data sets are only good in that range?
- TECDOC notes on Kr82(p,2n)Rb81: “The three "production cross-section" measurements for the natKr(p,xn)81Rb process by Acerbi et al. (1981), Steyn et al. (1991) and Kovács et al. (1991), can, however, also be used for evaluation up to 22 MeV after normalisation.” (TECDOC page 170)
  - 3 data sets from natKr(p,xn)81Rb are also used for Kr82(p,2n)Rb81, so these 3 appear twice in this database.

Zn67(p,n)Ga67

# Projectile: p
# Target El : Zn
# Target A  : 0
# Final El  : Ga
# Final A  : 67
# X4 ID  : 00086017
# Quality  1 : 0
Comment 1: IAEA-TECDOC-1211: “Data excluded: although very good agreement exists with the results of other groups up to 10 MeV, it is noted that the rapid decrease of the excitation function in the tail is unusual for a (p,n) reaction in this energy region.”

# Projectile: p
# Target El : Zn
# Target A : 67
# Final El : Ga
# Final A : 67
# X4 ID : B0048005
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

Comment 1: Cross section data from this publication was selected by IAEA-TECDOC-1211. However, O1062003 is yield data, and no cross section data for this publication and reaction was found in EXFOR.


Comment 1: IAEA-TECDOC-1211: “Data selected. Remark: Since the values are "estimated" values above 12 MeV based on a ‘tail-fitting’ procedure, the results are used only up to this energy.”

Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A : 67
# Final El : Ga
# Final A : 67
# X4 ID : T0126012 (TECDOC says B0068)
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.
# Target A  : 0
# Final El : Ga
# Final A  : 67
# X4 ID  : D0089003
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 67
# Final El : Ga
# Final A  : 67
# X4 ID  : A0510090
# Quality 1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: although the energy position of the cross-section maximum is in good agreement with the majority of the other works, the cross-section values were unexpectedly high over the whole energy range.”

# Projectile: p
# Target El : Zn
# Target A  : 67
# Final El : Ga
# Final A  : 67
# X4 ID  : A03210051
# Quality 1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: energy shift towards higher energy.”

# Projectile: p
# Target El : Zn
# Target A  : 67
# Final El : Ga
# Final A  : 67
# X4 ID  : A04980023
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 67
# Final El : Ga
# Final A  : 67
# X4 ID  : C05060041 or C05060051 These are identical and one will be deleted from EXFOR
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 67
# Final El : Ga
Zn68(p,2n)Ga67

Zn68(p,2n)Ga67

Zn68(p,2n)Ga67

Zn68(p,2n)Ga67

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El   : Ga
# Final A    : 67
# X4 ID     : A04940052
# Quality  1 : 1
# Comment 1: : IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El   : Ga
# Final A    : 67
# X4 ID     : D40880052
# Quality  1 : 1
# Comment 1: : IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El   : Ga
# Final A    : 67
# X4 ID     : D0089003
# Quality  1 : 0
# Comment 1: : IAEA-TECDOC-1211: “Data excluded: cross-section values too low.”

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El   : Ga
# Final A    : 67
# X4 ID     : A0510094
# Quality  1 : 1
# Comment 1: : IAEA-TECDOC-1211 – Data selected.
# X4 ID  : A03210061
# Quality 1 : 0
# Comment 1 : IAEA-TECDOC-1211: “Data excluded: energy shift towards higher energy.”

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A   : 67
# X4 ID : B0053003
# Quality 1 : 0
# Comment 1 : IAEA-TECDOC-1211: “Data excluded: cross-section values too low (even after normalisation by the compiler).”

# Projectile: p
# Target El : Zn
# Target A  : 0
# Final El  : Ga
# Final A   : 67
# X4 ID : A04980023
# Quality 1 : 1
# Comment 1 : IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A   : 67
# X4 ID : D40040042
# Quality 1 : 1
# Comment 1 : IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A   : 67
# X4 ID : D4276006
# Quality 1 :
# Comment 1 :
# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A  : 67
# X4 ID   : O1002003
# Quality 1 :
# Comment 1:

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A  : 67
# X4 ID   : C05060061
# Quality 1 :
# Comment 1:

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A  : 67
# X4 ID   : D40930091
# Quality 1 :
# Comment 1:

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A  : 67
# X4 ID   : D40250041
# Quality 1 :
# Comment 1:

# Projectile: p
# Target El : Zn
# Target A  : 68
# Final El  : Ga
# Final A  : 67
# X4 ID   : B0024005
# Quality 1 :
# Comment 1:
# X4 ID  : B0050013
# Quality  1 :
# Comment  1:

# Projectile: p
# Target El  : Zn
# Target A  : 68
# Final El     : Ga
# Final A     : 67
# X4 ID  : D41470031
# Quality  1 :
# Comment  1:

# Projectile: p
# Target El  : Zn
# Target A  : 68
# Final El     : Ga
# Final A     : 67
# X4 ID  : C05060101
# Quality  1 :
# Comment  1:

# Projectile: p
# Target El  : Kr
# Target A  : 0
# Final El     : Rb
# Final A     : 81
# X4 ID  : D0847003
# Quality  1 : 0
# Comment  1: Cross section data from this publication was selected by IAEA-TECDOC-1211. However, O0847003 is yield data, and no cross-section data for this publication and reaction was found in EXFOR.

Acerbi, E., Birattari, C., Bonardi, M., De Martinis, C., Salomone, A.: 
Kr(p,xn) excitation functions and $^{81}$Rb-$^{81m}$Kr generator studies. 

# Projectile: p
# Target El  : Kr
# Target A  : 0
# Final El     : Rb
# Final A     : 81
# X4 ID  : A04890021
# Quality  1 : 0
# Comment  1: IAEA-TECDOC-1211: “Data from natural target excluded, cross-section values too low. Remark: Data on natural Kr (Kovács b) excluded; too low cross-sections values.”
# Projectile: p
# Target El : Kr
# Target A  : 82 or 83
# Final El     : Rb
# Final A     : 81
# X4 ID  : A04890031 (Kr82) or A04890041 (Kr83)
# Quality  1 : 1 0. 20.
# Comment 1: IAEA-TECDOC-1211: “Data on enriched target selected, after being normalized. Remark: The data measured on enriched target (Kovács a) were normalised and included in the evaluation up to 20 MeV as Kovács, B.”

# Projectile: p
# Target El : Kr
# Target A  : 0
# Final El     : Rb
# Final A     : 81
# X4 ID  : none
# Quality  1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: cross-section values extremely high.”


# Projectile: p
# Target El : Kr
# Target A  : 0
# Final El     : Rb
# Final A     : 81
# X4 ID  : D0115004
# Quality  1 : 0
# Comment 1: Quality = 0 because this is yield data, not cross-section. No cross-section data was found in EXFOR for this publication and reaction. Data was also excluded by IAEA-TECDOC-1211: “too low cross-section values.”


# Projectile: p
# Target El : Kr
# Target A  : 0
# Final El     : Rb
# Final A     : 81
# X4 ID  : A04990022 or A04990032
# Quality  1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.
Kr$^{82}$(p,2n)Rb$^{81}$

# Projectile: p
# Target El : Kr
# Target A  : 0
# Final El  : Rb
# Final A   : 81
# X4 ID : D0847003 (36-KR-0(P,X)37-RB-81-G,IND/M+,TTY,,DT)
# Quality 1 : 1 0. 22.
# Comment 1: IAEA-TECDOC-1211: “Data selected after normalization” (see first paragraph on TECDOC p170)

# Projectile: p
# Target El : Kr
# Target A  : 82
# Final El  : Rb
# Final A   : 81
# X4 ID : A04890031
# Quality 1 : 1 0. 22.
# Comment 1: IAEA-TECDOC-1211: “Data selected after normalization” (see first paragraph on TECDOC p170)

# Projectile: p
# Target El : Kr
# Target A  : 0
# Final El  : Rb
# Final A   : 81
# X4 ID : A04990021 or A04990032
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

Cd$^{111}$(p,n)In$^{111}$

# Projectile: p
# Target El : Cd
# Target A  : 111
# Final El  : In
# Final A : 111
# X4 ID : B0048010
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : B0052016
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : A0335005
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : A05000023
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : A01590026
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : A01350022
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected
# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : A0001004
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : D4027002
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : C0345002
# Quality 1 : 
# Comment 1: 

Cd112(p,2n)In111-----------------------------------------------------------------------------------------

# Projectile: p
# Target El : Cd
# Target A : 112
# Final El : In
# Final A : 111
# X4 ID : T0124008 (TECDOC says B0065)
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Cd
# Target A : 111
# Final El : In
# Final A : 111
# X4 ID : C0345002
# Quality 1 : 
# Comment 1: 

Cd112(p,2n)In111-----------------------------------------------------------------------------------------

# Projectile: p
# Target El : Cd
# Target A : 112
# Final El : In
# Final A : 111
# X4 ID : C0345003
# Quality 1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: values reported only above the investigated energy range.”

# Projectile: p
IAEA-TECDOC-1211: “Data excluded: shifted to higher energies. Remark: the compiler calculated the cross-sections for the above reaction up to the threshold energy of the $^{124}\text{Te}(p,2n)$ reaction using the results measured on natural tellurium targets.”

IAEA-TECDOC-1211: “Data excluded: only one low energy point reported, too low cross-section value.”

The TECDOC says that two data sets were taken from this source but does not explain the difference between the two. Is it from the natural target, A0473004?

\# Projectile: p
\# Target El : Te
\# Target A : 0
\# Final El : I
\# Final A : 123
\# X4 ID : B01670021 or B01670031 (unsure which)
\# Quality 1 : 0
\# Comment 1: Quality = 0 because this is yield data, not cross-section. No cross-section data was found in EXFOR for this publication and reaction. Data was also excluded by IAEA-TECDOC-1211: “shifted to higher energies, too high cross-section values.”


\# Projectile: p
\# Target El : Te
\# Target A : 0
\# Final El : I
\# Final A : 123
\# X4 ID : O1260002
\# Quality 1 : 0
\# Comment 1: IAEA-TECDOC-1211: “Data excluded: systematically too low cross-section values. Remark: The compiler calculated the cross-sections for the above reaction up to the threshold energy of the $^{124}\text{Te}(p,2n)$ reaction using the results measured on natural tellurium targets.”

$^{124}\text{Te}(p,2n)^{123}\text{I}$

\# Projectile: p
\# Target El : Te
\# Target A : 124
\# Final El : I
\# Final A : 123
\# X4 ID : A0266008
\# Quality 1 : 0
\# Comment 1: IAEA-TECDOC-1211: “Data excluded: significantly higher than those of the other authors.”

\# Projectile: p
\# Target El : Te
\# Target A : 124
\# Final El : I
\# Final A : 123
\# X4 ID : B00900032
Kondo a and Kondo b have different enrichments according to the TECDOC, but it is not clear what the enrichments are (See p188 of TECDOC)

Int. J. Applied Radiation Isotopes 28 (1977) 395

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# Target El : Te  
# Target A : 124  
# Final El : I  
# Final A : 123  
# X4 ID : C0346004  
# Quality 1 :  
# Comment 1 :  

# Projectile: p  
# Target El : Te  
# Target A : 124  
# Final El : I  
# Final A : 123  
# X4 ID : B0071009  
# Quality 1 :  
# Comment 1 :  

Te124(p,n)I124 –– IAEA-TECDOC-1211 – Data selected.  

# Projectile: p  
# Target El : Te  
# Target A : 124  
# Final El : I  
# Final A : 124  
# X4 ID : A0266009  
# Quality 1 : 1  
# Comment 1: IAEA-TECDOC-1211 – Data selected.  

# Projectile: p  
# Target El : Te  
# Target A : 124  
# Final El : I  
# Final A : 124  
# X4 ID : B00900022  
# Quality 1 : 0  
# Comment 1: IAEA-TECDOC-1211: “Data excluded: energy shift towards higher energies.  
Remark: 2 sets of data are available on targets of different enrichments and are included  
(Kondo a and Kondo b, see Fig. 5.1.9a [on page 193 of TECDOC]).”  
Kondo a and Kondo b have different enrichments according to the TECDOC, but it’s unclear  
what the enrichments are;  
Kondo, K., Lambrecht, R.M., Wolf, A.P.:  
123I production for radiopharmaceuticals-XX. Excitation functions of the 124Te(p,2n)123I and  
124Te(p,n)124I reactions and effect of target enrichment on radionuclidic purity.  
Int. J. Applied Radiation Isotopes 28 (1977) 395
Kondo, K., Lambrecht, R.M., Wolf, A.P.:

\(^{123}\text{I}\) production for radiopharmaceuticals-XX. Excitation functions of the \(^{124}\text{Te}(p,2n)^{123}\text{I}\) and \(^{124}\text{Te}(p,n)^{124}\text{I}\) reactions and effect of target enrichment on radionuclidic purity.
Int. J. Applied Radiation Isotopes 28 (1977) 395


A new approach to target chemistry for the iodine-123 production via the \(^{124}\text{Te}(p,2n)\) reaction.
Int. J. Applied Radiation Isotopes 28 (1977) 255
127I(p,5n)123Xe→123I

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 123
# X4 ID : B0081004
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.
# Final El  : Xe
# Final A   : 123
# X4 ID     : D0116006
# Quality   : 1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: cross-section values too low.”

# Projectile: p
# Target El  : I
# Target A   : 127
# Final El   : Xe
# Final A    : 123
# X4 ID      : A0161002
# Quality    : 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El  : I
# Target A   : 127
# Final El   : Xe
# Final A    : 123
# X4 ID      : E1867015
# Quality    : 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El  : I
# Target A   : 127
# Final El   : Xe
# Final A    : 123
# X4 ID      : E1868002
# Quality    : 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El  : I
# Target A   : 127
# Final El   : Xe
# Final A    : 123
# X4 ID      : A0265002 (TECDOC says R0024)
# Quality    : 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.
# Projectile: p
# Target El : I
# Target A : 127
# Final El  : Xe
# Final A  : 123
# X4 ID  : A0062002A
# Quality  1 :
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El  : Xe
# Final A  : 123
# X4 ID  : B0148002
# Quality  1 :
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El  : Xe
# Final A  : 123
# X4 ID  : R00050022
# Quality  1 :
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El  : Xe
# Final A  : 123
# X4 ID  : A0918013
# Quality  1 :
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El  : Xe
# Final A  : 123
# X4 ID  : C0967004
# Quality  1 :
# Comment 1: (p,x)

127I(p,3n)125Xe→125I  

# Projectile: p
# Target El : I  
# Target A : 127  
# Final El : Xe  
# Final A : 125  
# X4 ID : O0306004  
# Quality 1 : 1  
# Comment 1: IAEA-TECDOC-1211 – Data selected.  

# Projectile: p  
# Target El : I  
# Target A : 127  
# Final El : Xe  
# Final A : 125  
# X4 ID : B0081003  
# Quality 1 : 1  
# Comment 1: IAEA-TECDOC-1211: “Data selected. Remark: Data were corrected upwards by 30% because the authors used a very old $\gamma$-abundance value.”  

# Projectile: p  
# Target El : I  
# Target A : 127  
# Final El : Xe  
# Final A : 125  
# X4 ID : A03630031  
# Quality 1 : 1  
# Comment 1: IAEA-TECDOC-1211 – Data selected.  

# Projectile: p  
# Target El : I  
# Target A : 127  
# Final El : Xe  
# Final A : 125  
# X4 ID : D0116005  
# Quality 1 : 1  
# Comment 1: IAEA-TECDOC-1211 – Data selected.  

# Projectile: p  
# Target El : I  
# Target A : 127  
# Final El : Xe  
# Final A : 125  
# X4 ID : A0161003  
# Quality 1 : 1  
# Comment 1: IAEA-TECDOC-1211 – Data selected.  

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# X4 ID : E1867014
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : R00070022
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : E1868003
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : A0265003 (TECDOC says R0024)
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : O0768338
# Quality 1 : 1
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : A0062002B
# Quality 1 : 1
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : R00050023
# Quality 1 : 
# Comment 1:

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : O2052013
# Quality 1 :
# Comment 1: (p,x)

# Projectile: p
# Target El : I
# Target A : 127
# Final El : Xe
# Final A : 125
# X4 ID : C0967005
# Quality 1 :
# Comment 1: (p,x)

\[ ^{124}\text{Xe}(p,2n)^{123}\text{Cs} \rightarrow ^{123}\text{Xe} \rightarrow ^{123}\text{I} \]

# Projectile: p
# Target El : Xe
# Target A : 124
# Final El : Cs
# Final A : 123
# X4 ID : A04360021
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Xe
# Target A : 124
# Final El : Cs
# Final A : 123
# X4 ID : D4029002
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.
$^{124}$Xe(p,pn)$^{123}$Xe$\rightarrow^{123}$I

# Projectile: p
# Target El : Xe
# Target A  : 124
# Final El  : Xe
# Final A  : 123
# X4 ID : A04360022
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

$^{124}$Xe(p,pn)$^{123}$Xe$\rightarrow^{123}$I

# Projectile: p
# Target El : Xe
# Target A  : 124
# Final El  : Xe
# Final A  : 123
# X4 ID : D4029003
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

$^{124}$Xe(p,pn)$^{123}$Xe$\rightarrow^{123}$I

# Projectile: p
# Target El : Xe
# Target A  : 124
# Final El  : Xe
# Final A  : 123
# X4 ID : D4238004
# Quality 1 :
# Comment 1:

$^{124}$Xe(p,pn)$^{123}$Xe$\rightarrow^{123}$I

# Projectile: p
# Target El : Xe
# Target A  : 124
# Final El  : Xe
# Final A  : 123
# X4 ID : D4238003
# Quality 1 :
# Comment 1: (p,x)

$^{203}$Tl(p,3n)$^{201}$Pb$\rightarrow^{201}$Tl

# Projectile: p
# Target El : Tl
Bonardi, M., Birattari, C., Salomone, A.:

203TI production for medical use by (p,xn) nuclear reactions on Tl and Hg natural and enriched targets.
Additional information in: F. Girardi, L. Goetz, E. Sabbioni, E. Marafante, M. Merlini, E. Acerbi, C. Birattari, M. Castiglioni, F. Resmini
Preparation of 203Pb compounds for studies on pathways and effects of lead pollution

# Projectile: p
# Target El : Tl
# Target A : 203
# Final El : Pb
# Final A : 201
# X4 ID : D0114007
# Quality 1 : 0
# Comment 1: Cross section data from this publication was selected by IAEA-TECDOC-1211. However, D0114007 is yield data, and no cross-section data for this publication and reaction was found in EXFOR.

Bonardi, M., Birattari, C., Salomone, A.:

203TI production for medical use by (p,xn) nuclear reactions on Tl and Hg natural and enriched targets.
Additional information in: F. Girardi, L. Goetz, E. Sabbioni, E. Marafante, M. Merlini, E. Acerbi, C. Birattari, M. Castiglioni, F. Resmini
Preparation of 203Pb compounds for studies on pathways and effects of lead pollution

# Projectile: p
# Target El : Tl
# Target A : 0
# Final El : Pb
# Final A : 201
# X4 ID : D0114003
# Quality 1 : 0
# Comment 1: Quality = 0 because this is yield data, not cross-section. No cross-section data was found in EXFOR for this publication and reaction. Data was also excluded by IAEA-TECDOC-1211: “Data on natural targets excluded: cross-section values too low.”

Bonardi, M., Birattari, C., Salomone, A.:

203TI production for medical use by (p,xn) nuclear reactions on Tl and Hg natural and enriched targets.
Additional information in: F. Girardi, L. Goetz, E. Sabbioni, E. Marafante, M. Merlini, E. Acerbi, C. Birattari, M. Castiglioni, F. Resmini
Preparation of 203Pb compounds for studies on pathways and effects of lead pollution
# X4 ID  : A04940022
# Quality  1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Tl
# Target A  : 203
# Final El  : Pb
# Final A  : 201
# X4 ID  : T0148005 (TECDOC says B0168)
# Quality  1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Tl
# Target A  : 203
# Final El  : Pb
# Final A  : 201
# X4 ID  : C1028002
# Quality  1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: cross-section values too low.”

# Projectile: p
# Target El : Tl
# Target A  : 00
# Final El  : Pb
# Final A  : 201
# X4 ID  : P0013003 (TECDOC says P013 – This seems to be a typo in the TECDOC)
# Quality  1 : 0
# Comment 1: IAEA-TECDOC-1211: “Data excluded: discrepant.”

# Projectile: p
# Target El : Tl
# Target A  : 00
# Final El  : Pb
# Final A  : 201
# X4 ID  : A0185005
# Quality  1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

Tl203(p,2n)Pb202m -> Tl202------------------------------------------------------------------------------------------------------------------------
Bonardi, M., Birattari, C., Salomone, A.:
203TI production for medical use by (p,xn) nuclear reactions on TI and Hg natural and enriched targets.
Additional information in: F. Girardi, L. Goetz, E. Sabbioni, E. Marafante, M. Merlini, E Acerbi, C. Birattari, M. Castiglioni, F. Resmini
Preparation of 203Pb compounds for studies on pathways and effects of lead pollution
Int. J. Applied Radiation Isotopes 26 (1975) 267

Tl203(p,4n)Pb200 -> Tl200-------------------------------
Comment 1: IAEA-TECDOC-1211: “Data excluded: only data sets that were selected for the $^{203}$Tl(p,3n)$^{200}$Pb reaction were considered.”

Projectile: p
Target El : Tl
Target A : 203
Final El : Pb
Final A : 200
X4 ID : D0114006
Quality 1 : 0

Comment 1: Cross section data from this publication was selected by IAEA-TECDOC-1211. However, D0114006 is yield data, and no cross-section data for this publication and reaction was found in EXFOR.

Bonardi, M., Birattari, C., Salomone, A.:
$^{201}$Tl production for medical use by (p,xn) nuclear reactions on Tl and Hg natural and enriched targets.
Additional information in: F. Girardi, L. Goetz, E. Sabbioni, E. Marafante, M. Merlini, E Acerbi, C. Birattari, M. Castiglioni and F. Resmini
Preparation of $^{203}$Pb compounds for studies on pathways and effects of lead pollution
Int. J. Applied Radiation Isotopes 26 (1975) 267

Projectile: p
Target El : Tl
Target A : 00
Final El : Pb
Final A : 200
X4 ID : D0114002
Quality 1 : 0

Comment 1: Quality = 0 because this is yield data, not cross-section. No cross-section data was found in EXFOR for this publication and reaction. Data was also excluded by IAEA-TECDOC-1211: “Data on natural targets excluded.”

Bonardi, M., Birattari, C., Salomone, A.:
$^{201}$Tl production for medical use by (p,xn) nuclear reactions on Tl and Hg natural and enriched targets.
Additional information in: F. Girardi, L. Goetz, E. Sabbioni, E. Marafante, M. Merlini, E Acerbi, C. Birattari, M. Castiglioni and F. Resmini
Preparation of $^{203}$Pb compounds for studies on pathways and effects of lead pollution
Int. J. Applied Radiation Isotopes 26 (1975) 267

Projectile: p
Target El : Tl
Target A : 203
Final El : Pb
Final A : 200
X4 ID : A04940023
Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected

# Projectile: p
# Target El : Tl
# Target A  : 203
# Final El   : Pb
# Final A    : 200
# X4 ID : T0148003 (TECDOC says B0168)
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.

# Projectile: p
# Target El : Tl
# Target A  : 00
# Final El   : Pb
# Final A    : 200
# X4 ID : A0185006
# Quality 1 : 1
# Comment 1: IAEA-TECDOC-1211 – Data selected.
Appendix 2

$^{67}$Zn(p,n)$^{67}$Ga

Cross section [mb]

Energy [MeV]

$^{68}$Zn(p,2n)$^{67}$Ga

Cross section [mb]

Energy [MeV]
$^{123}\text{Te}(p,n)^{123}\text{I}$

Cross section [mb]

Energy [MeV]

124$^{}\text{Te}(p,2n)^{123}\text{I}$

Cross section [mb]

Energy [MeV]
$^{124}\text{Te}(p,n)^{124}\text{I}$

![Cross section vs Energy graph for $^{124}\text{Te}(p,n)^{124}\text{I}$](image)

$^{127}\text{I}(p,5n)^{123}\text{Xe}$

![Cross section vs Energy graph for $^{127}\text{I}(p,5n)^{123}\text{Xe}$](image)