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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

IAEA CONSULTANTS' MEETING ON NUCLEAR DATA FOR MEDICAL RADIOISOTOPE PRODUCTION

Vienna, 13 - 15 April 1981

SUMMARY REPORT

Edited by

K. Okamoto

Nuclear Data Section
International Atomic Energy Agency

June 1981

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ABSTRACT

The IAEA Consultants' Meeting on "Nuclear Data for Medical Radioisotope Production" was convened by the IAEA Nuclear Data Section on 13 to 15 April 1981 at the IAEA Headquarters in Vienna.

The meeting participants reviewed the current requirements for nuclear data for medical radioisotope production, identified the required data with priority and recommended to have the IAEA promote the compilation and evaluation of excitation function, thick target yields and decay data for specified radioisotopes.

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OUTLINE OF THE MEETING

In view of the rapidly increasing needs for radiopharmaceuticals and special medical radioisotopes, the International Nuclear Data Committee at its last meeting in June 1980 recommended that a small meeting on "Nuclear Data for Medical Radioisotope Production" be convened. In response to this recommendation, the IAEA Nuclear Data Section asked an organizing committee, comprised of:

Dr. W.G. Cross
Health Physics Branch
AECL Chalk River
Canada

Dr. A.T.G. Ferguson
Nuclear Physics Division
AERE Harwell
United Kingdom

Dr. S.M. Qaim
Institut für Chemie 1, Nuklearchemie
Kernforschungsnalage Jülich Gmbh
Federal Republic of Germany

to assist in the selection of topics and participants.

The Meeting was held from 13 to 15 April 1981 at the IAEA Headquarters in Vienna and was attended by 12 scientists from 8 Member States and several observers from the Agency. The list of participants is given in Appendix A, the Agenda is given in Appendix B and the papers distributed at the meeting are listed in Appendix C.

While a full text of conclusions and recommendations is attached to this Summary Report, the main parts are summarized as follows:

The Meeting

- reviewed the current requirements for nuclear data for medical radioisotope production such as half-lives, gamma-spectra, excitation functions and other nuclear data;

- identified the present status, surveyed the uncertainties and gaps in nuclear data in this field, and identified the required data and priorities;

- recommended to have the Agency promote the compilation and evaluation of excitation functions, thick target yields and decay data for specified radioisotopes, and

- recommended not to convene a larger specialist meeting on this topic at the present time because the subject matter is treated to the extent necessary at the international symposia on radiopharmaceutical chemistry held every two years.

SUMMARY OF THE MEETING AND COMMENTS

Soon after the discovery of artificial transmutation of elements, efforts were started to make use of radioisotopes in medicine. With the advent of nuclear reactors, and the associated large scale production of radioisotopes, the applications in nuclear medicine became more extensive. This number has been constantly increasing and today use of radiopharmaceuticals has become rather commonplace.

Though radioisotopes are produced rather easily in a nuclear reactor, there are two drawbacks in the use of nuclear reactors for medical radionuclide production. Firstly, radioisotopes of organic elements (C, N, O etc.) more suitable for in-vivo metabolic studies cannot be produced. Secondly, radioisotopes of other elements produced are mostly β^- emitters and cause considerable radiation dose to the patient, $^{99}Tc^m$ being an exception. Though $^{99}Tc^m$ has almost ideal nuclear properties for applications in nuclear medicine, its chemical properties are not suitable for many metabolic studies.

Radioisotopes suitable for in-vivo applications in medicine are better produced using a cyclotron. Those radioisotopes are generally neutron deficient and decay either by EC or β^+ emission. The latter are useful for positron emission coincidence tomography. Since a wide variety of nuclear reactions can be induced (using various types of accelerated charged particles and varying incident energies) the possibilities of producing short-lived radioisotopes are large. However, this calls upon utilization of diverse expertise since the problems to be overcome are then also large. As far as nuclear data are concerned, studies of nuclear reactions, measurement, systematics and evaluation of cross section data, as well as investigations of decay schemes are of great importance. Realizing the increasing importance of nuclear data for medical radioisotope production the International Nuclear Data Committee (INDC) recommended convening a Consultants' Meeting to look at the matter rather critically and to bring the importance of nuclear data in the right perspective.

The Meeting was held in Vienna from 13 to 15 April 1981. The participants represented a fairly good cross section of the community dealing with nuclear chemistry and nuclear physics related to medical radioisotope production, some coming from hospital attached nuclear chemistry laboratories while the others from university institutes and multipurpose nuclear research centres. The energy region of the cyclotrons used in home institutions of the participants extended from a few MeV to about 800 MeV.

Introductory discussions showed that the cyclotrons used for medical radioisotope production can be roughly divided into three groups:

(i) Low-energy machines ($E \leq 15$ MeV) associated with hospitals. These are used mainly for the on-site production and application of short-lived β^+ emitting nuclides like ^{11}C ($T_{1/2}$ = 20 min), ^{13}N ($T_{1/2}$ = 10 min) and ^{15}O ($T_{1/2}$ = 2 min).

(ii) Multipurpose multiparticle medium-energy machines ($E \leq 200$ MeV). A large variety of radioisotopes are produced using such machines.

(iii) High-energy machines ($E \geq 300$ MeV), accelerating mostly protons, are used basically for high-energy physics studies but some radioisotope production work is also carried out.

A discussion of the general problems related to medical radioisotope production and short reports from various laboratories on the technical details of some production methods showed explicitly that a knowledge of nuclear data is very important but other factors like target design and construction, heat transfer, remote handling, chemical processing and quality control, etc. are of equal (if not greater) importance. It is therefore imperative that efforts in the field of nuclear data should go hand in hand with the other development work.

A general survey of the status of nuclear data for the production of various types of radioisotopes suggested that in the low-energy region the available data are satisfactory. Since in the high-energy region ($E \geq 300$ MeV) the cross section is relatively independent of the energy of the incident particle, one needs mostly information on the production yields. The existing experimental data, systematic trends and calculational methods can reproduce yields of main products within a factor of 2. Only for products very near or very far from the target nucleus further experimental and theoretical studies are needed.

Since a greater part of the research and development work in the field of medical radioisotope production is performed in the medium-energy region, most of the nuclear data needs also arise in that energy region. Those needs may differ from one laboratory to another and depend upon such factors as the types of particles accelerated, the energy ranges considered, the particular route chosen for the production of an isotope etc. The data needs are therefore difficult to define. However, since most of the larger establishments doing radiopharmaceutical development work (e.g. BNL, Hammersmith, Jülich) are also engaged in nuclear data activities, the data needs, as and when they arise, are met through experimental programmes in those laboratories.

A discussion of the uncertainties in experimental nuclear data suggested that many of the discrepancies arise possibly due to the

lack of use of uniform sets of standards for beam current measurements. Errors in the energy scale, originating from uncertainties in foil thicknesses and range-energy calculations, are often not quoted and may cause discrepancies. It is therefore essential that enough experimental details be given in papers dealing with nuclear data measurements.

Some of the nuclear model calculations and semi-empirical methods for predicting unknown cross sections were discussed. In the medium-energy region theoretical methods can in general reproduce cross sections of proton induced nuclear reactions within a factor of 2. From the viewpoint of yields, as a first approximation, these predictions may be acceptable. However, for a check on the impurities this accuracy is often not sufficient and precise experimental measurements are needed. In the case of d, ^{3}He, and α-particle induced reactions improved computational methods are needed.

In the Workshop part of the Meeting the nuclear data activities related to the production of medical radioisotopes were considered in more detail. The conclusions and recommendations arising from those deliberations are outlined separately.

The general consensus among the participants of the Consultants' Meeting was that nuclear data are important for the production of medical radioisotopes. Though a larger IAEA Specialists' meeting on this topic was not to be recommended at the present stage, the IAEA is encouraged to review the subject from time to time and to undertake the 'user oriented' compilation work, possibly in collaboration with other Nuclear Data Centres, as stipulated in the recommendations. The participants were, however, also of the opinion that attempts on the parts of some data producers and evaluators to sell every experimental or theoretical activity in the field of charged particle data under the name of medical radioisotope production should be discouraged. Since the data needs are rather specialized, it is urged that any experimental or theoretical programmes be started after thoughtful consultations with the users.

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CONCLUSIONS, RECOMMENDATIONS

The aim of the Consultants' Meeting was to review the current requirements of nuclear data for medical radioisotope production; to identify the present status, survey the uncertainties and gaps in nuclear data in this field, and to identify the required data; and to make any recommendations to the IAEA, if necessary.

General discussions showed that nuclear data play a very important role but that in addition other factors such as target design, chemical recovery procedures etc. are of equal importance (sometimes even greater) in the production of medically useful radioisotopes.

The choice of a particular radioisotope for in-vivo medical applications depends on several factors, such as nuclear properties suitable for detection by the available γ-cameras, radiation dose caused to the patient, chemical and biological properties of the element. Decay data are thus of great importance.

Production of radioisotopes requires information on excitation functions, thick target yields, range energy data for charged particles in target elements. Wherever possible it is desirable that excitation function data should be available in order that

(i) one may select the particle energy that will maximize the yield of the desired product and minimize that of the radioactive impurities,

(ii) the theoretical maximum yield from a given target may be calculated, and compared to the practical yield achieved, and

(iii) the radionuclidic impurities may similarly be calculated for a given thickness and enrichment of the target material.

The Meeting considered the following specific topics:

NUCLEAR DATA FOR REACTOR-PRODUCED RADIOISOTOPES

Most of the radioisotopes produced in reactors use one of the four methods, viz. (n,γ), (n,p), (n,α) and (n,fission). The cross sections for all pertinent reactions concerned are in general well known. Therefore the Working Group could not identify any specific needs for extension or revision of data in this area.

PHOTONUCLEAR REACTIONS

The use of (γ,xp) and (γ,xn) reactions in the light and heavy mass regions, respectively, are of interest for production of some special radioisotopes. The participants were conscious of the lack of cross section data in this field, but they also believe that such reactions are of very limited application because of low production cross sections, and that there are very few laboratories in a position to generate the relevant nuclear data.

SPALLATION REACTIONS

Spallation is characterized by the formation of many elements in the target and a wide variety of radioisotopes. The number of facilities capable of producing radionuclides by this technique is limited at the present time. Due to the complex nuclear reactions and the radioproducts therefrom, there is an increased need for nuclear data at these facilities. However, scientists staffing these programs are capable of easily identifying the necessary data needs and of one assuring them, if necessary. Therefore the participants do not recommend any specific IAEA action in this area other than the incorporation of cross sections and yield data into appropriate compilations.

LOW AND MEDIUM ENERGY CHARGED-PARTICLE INDUCED REACTIONS

In the energy region below 15 MeV, cross section data are in general well documented. It would however be useful if for the commonly used β^+-emitters (^{11}C, ^{13}N, ^{15}O, ^{18}F) the data could be evaluated, under the auspices of the IAEA, and a recommended set of such data could be made available.

Furthermore, three nuclear reactions leading to potentially useful medical radioisotopes were identified for which as yet no cross-section data are available. These were the following:

$$^{19}F(p,n)^{19}Ne$$
$$^{16}O(\alpha,n)^{19}Ne$$
$$^{16}O(d,n)^{17}F$$

With increasing energy the data needs also increase. Many existing data are adequate, but in some cases more experimental data are needed. The participants found it difficult to specify those particular nuclear data requirements due to the fact that each institution is in a different situation as regards the maximum particle energy available at a given cyclotron, the types of particles accelerated, the chemical form and enrichment of the target, etc.

The Meeting concluded that it would be useful if the IAEA in collaboration with other nuclear data centres could compile the experimental information available on cross-sections and thick target yields for the production of the more commonly used radioisotopes and their contaminants. These are the following:

^{11}C, ^{13}N, ^{15}O, ^{18}F, ^{28}Mg, $^{52}Fe(^{52}Mn^{m})$, ^{67}Ga, ^{68}Ge, ^{75}Br, ^{77}Br, ^{77}Kr, $^{81}Rb(^{81}Kr^{m})$, $^{82}Rb^{m}$, ^{111}In, ^{123}Xe, ^{127}Xe, ^{123}I, ^{201}Tl

It was recognized that there is no general agreement on the use of standard reactions for monitoring beam currents, and that this may be responsible for some of the discrepancies in reported cross-section data. It would therefore be useful if IAEA could arrange to generate and disseminate evaluated excitation curves for the formation of the following radioisotopes in various nuclear reactions, and over as wide a range of energies as possible:

^{7}Be, ^{11}C, ^{22}Na, ^{24}Na, ^{48}V, ^{65}Zn (*)

DECAY DATA

The decay data for radioisotope are in most cases well-known and well-documented. However, the meeting did identify some radioisotopes for which revision or extension of the available decay data would be desirable. These were as follows:

^{55}Co, ^{68}Ge, $^{81}Kr^{m}$ (half-lives uncertain)
^{48}V, $^{52}Mn^{m}$, ^{62}Zn, ^{68}Ga, ^{75}Br, ^{76}Br, ^{75}Kr, $^{82}Rb^{m}$ (branching ratios uncertain)

The IAEA is asked to bring these deficiencies to the attention of the relevant bodies.

In connection with problems of microdosimetry, the Meeting recognized the importance of reliable information on the energies and abundances of Auger electrons and very low energy Xrays. In particular for the following radioisotopes;

^{97}Ru, $^{99}Tc^{m}$, ^{111}In, $^{113}In^{m}$ $^{117}Sn^{m}$ and ^{125}I

(*) ^{64}Cu, in some special circumstances, may also serve as useful beam monitoring nuclide.

The participants felt that the medical community would welcome more reliable information and asked the IAEA to review the reliability of those data.

GENERAL

The Meeting discussed the necessity of setting up a WRENDA (World Request List on Nuclear Data)-type list for nuclear data for medical radioisotope production, but concluded that this was not necessary at the present time.

If computer codes and calculations were to be developed for the prediction of unknown data, the Meeting advised that it should be kept in mind that users are unlikely to be experts in the field of nuclear theory. The information to be derived should therefore be "user-oriented".

The Meeting noted with interest that the IAEA has issued a questionnaire to all accelerator laboratories, seeking information on radioisotope production programmes and the need for specific nuclear data. Participants would like to be informed of the analysis of the information derived from this questionnaire.

The Meeting felt that it had given adequate consideration to the present nuclear data requirements for medical radioisotope production, and concluded that a larger specialist meeting solely on this topic was not to be recommended at the present stage, especially because the subject matter is expected to be treated to some extent at the future international symposia on radiopharmaceutical chemistry held every two years.

Appendix A

List of Participants

IAEA Consultants' Meeting on Nuclear Data for Medical Radioisotope Production

Vienna, 13-15 April 1981

Crouzel, C.	CEA Service Hospitalier Frederic Joliot 4, place du General Leclerc F-91406 Orsay
Lorenz, A.	IAEA Nuclear Data Section
Motta, M.	Comitato Nazionale per l'Energie Nucleare Via Mazzini 2 I-40138 Bologna
Nowotny, R.	Institut für Radiumforschung Oesterreichische Akademie der Wissenschaften Boltzmanngasse 3 A-1090 Vienna
Nozaki, T.	The Institute of Physical and Chemical Research Wako-shi, Saitama 351
O'Brien Jr., H.A.	Leader of Medical Radioisotope Research M-514 Los Alamos National Laboratory Los Alamos, New Mexico 87545
Okamoto, K. (Scientific Secretary)	IAEA Nuclear Data Section
Qaim, S.M. (Chairman)	Institut für Chemie 1, Nuklearchemie Kernforschungsanlage Jülich GmbH Postfach 1913 D-5170 Jülich 1
Reist, H.W.	Schweizerisches Institut für Nuklearforschung (SIN) CH-5234 Villigen
Schmidt, J.J.	IAEA Nuclear Data Section
Silvester, D.J. (Co-Chairman)	Head, Chemistry Section MRC Cyclotron Unit Hammersmith Hospital Ducane Road London W12 OHS
Vera Ruiz, H.	IAEA Industrial Appl. & Chemistry Section

Appendix B

IAEA Consultants' Meeting on
Nuclear Data for Medical Radioisotope Production

Vienna, 13 - 15 April 1981

ADOPTED MEETING AGENDA

Monday, 13 April, 9:30 hrs

Opening, Election of Chairman, Adoption of Agenda

SESSION I Introduction

1. Role of IAEA in the compilation and dissemination of nuclear data
2. Recommendations of the INDC regarding the radioisotope production data

SESSION II General overview of nuclear data needs and uses

1. Special problems in the production of short-lived medical radioisotopes
2. Techniques and facilities used in medical radioisotope production
3. Special problems in the production of radioactive gases by medical cyclotrons
4. Short Laboratory Reports
5. Nuclear data needs and uses in medical radioisotope production
6. Nuclear data for production of radioisotopes using low and medium energy machines
7. Nuclear data for high-energy spallation reactions

Tuesday, 14 April

SESSION III Status of required nuclear data

1. Report on Coordinated Research Programme on the Production of Radiopharmaceuticals from Accelerator-produced radioisotopes (especially questionnaires related to nuclear data requests)
2. Experimental Nuclear Data and their Error
3. Nuclear Models and Systematics
4. Data Files and Handbooks

SESSION IV Working Group Sessions

Wednesday, 15 April

SESSION V Summary, conclusions and recommendations

Appendix C

LIST OF DISTRIBUTED PAPERS

It was not planned to publish any presented papers to the Meeting except the Summary, Conclusions and Recommendations. For the convenience of readers, the titles of distributed papers, notes, tables and others are given as follows. Full information can be requested directly from the contributors, whose names are given in brackets.

1. Papers submitted by H.A. O'Brien Jr.

   a) Seven Tables of Spallation Cross Sections

      Vanadium Thin Target Cross Sections for 590 and 800 MeV Protons

      Measured Spallation Cross Sections of V, Ni, As, Rb, Br, Mo, La, Ta, Pb and Bi

      Spallation of Arsenic with 590 MeV Protons (from J. Inorg. Nucl. Chem. 23 (1961) 161)

      Cumulative Yield of Selective Isotopes from Irradiation of La-Cu, Mo and Zr with 100 to 600 MeV Protons

      Cross Sections for the Formation of Radioactive Products from the Reaction of 800 MeV Protons with Molybdenum

      Comparison of Measured and Calculated Thin Target Cross Sections from 590 MeV Protons on Niobium

      Comparison of Experimental Cross Sections with Values Calculated by Bertini: Assumed Target for Calc'n = ^{207}Pb
      Experimental Target = natural Pb

   b) National Nuclear Data Center Publications (Oct 1976-Feb 1980) Reference List from Introduction to Reference Nuclear Data and the National Nuclear Data Center

   c) Major Sources of Nuclear Data

   d) Interlaboratory Comparison of Spallation-Reaction Cross Sections for Iron and Copper with 590 MeV Protons
      C.J. Arth et al., J. Inorg. Nucl. Chem. 38 (1976) 13-17

   e) Extract from "Minutes of 4th Annual Meeting of the Panel on Reference Nuclear Data" (Outline of the Handbook of Radio Nuclides), BNL-NCS-51250, June 1980

f) Spallation Cross Sections and the LAMPF Medical Radioisotope Program
B.R. Erdal et al, Nuclear Cross Sections and Technology NBS Special Publication 425,(1975) 492-495

g) Accelerator-Produced Radioisotope Program: Quarterly Report July 1-Sept 30, 1972, LA-5120-PR (1972)

h) Target Insertion and Handling System for the Isotope Production Facility
C.E. Cummings et al, Proc. 26th Conf. on Remote System Tech. (1978) 201-206

i) Half-lives of ^{82}Sr and ^{82}Rb
P.M. Grant et al, Phys. Rev. C18 (1978) 2799-2800

j) Spallation Yields of Fe-52, Cu-67, Ga-67 and Ti-201 from Reaction of 800 MeV Protons with Ni, As, Pb and Bi Targets
P.M. Grant et al, Abstract from Society of Nuclear Medicine, 25th Annual Meeting (1978)

2. Nuclear Data for the Production of Medically Useful Radioisotopes
S.M. Qaim and R. Weinrich, Invited Paper to the 2nd Symposium on Radiopharmaceutical Chemistry, Oxford, July 1978
(submitted by S.M. Qaim)

3. Recent Trends in Nuclear Reaction Data Needs for Nuclear Medicine
G, Stöcklin and S.M. Qaim; Invited Paper to the 1978 Harwell Conference on Nuclear Data (submitted by S.M. Qaim)

4. Radionuclides produced at Jülich (as of Nov 1980)
(submitted by S.M. Qaim)

5. Lists prepared for discussions by the Nuclear Data Section

a) List: The Radioisotope for Bio-Medical Applications, Part I Half-life

b) List: The Radioisotope for Bio-Medical Applications, Part II Gamma Spectra, extracted from the "Table of Isotopes" 7th Edition (1978)

c) List of Medical Radioisotopes: Pure β^-Emitter, Positron Emitter, α Emitter, Generator Isotopes (produced by Accelerator and Reactor)

d) Bibliographic Information on $^{52}Fe(^{52}Mn^{m})$ and $^{81}Rb(^{81}Kr^{m})$ extracted from "The Bibliography of Integral Charged Particle Nuclear Data", BNL-NCS-50640 (4th ed.) and from Private Comm. from T.W. Burrows (Feb 1981)

e) Retrieval of Numerical Data on the Production of ^{52}Fe from EXFOR Charged Particle Nuclear Reaction Series

f) List of Data File and Handbooks

6. Statement on "Standard Reference Material for Activity Measurement and for Activity Analysis" (submitted by T. Nozaki)

7. Medical Cyclotron, 1980 Progress Report
Service Hospitalier Frederic Joliot, Dept. de Biologie
(submitted by C. Crouzel)

8. The Use of Statistical-Model Codes for an A-Priori Calculation of Isotope Production Yields (contributed paper to the Meeting)
R. Nowotny, IRK 80/34 (1981) (submitted by R. Nowotny)

9. Statistical-Model Based Evaluation of Reactions Producing ^{123}I and ^{127}Xe
G. Grabmayr and R. Nowotny, Int. J. Appl. Radiat. Isot. 29 (1978) 261-267 (submitted by R. Nowotny)

10. Calculation of Proton-Induced Radioisotope Production Yields with Statistical-Model Based Code
R. Nowotny, Int. J. Appl. Radiat. Isot. 32 (1981) 73-78
(submitted by R. Nowotny)

11. Radioisotope Production at the M.R.C. Cyclotron Unit with Special Reference to the Use of Nuclear Data Sources
D.J. Silvester (Note prepared for the Meeting)
(submitted by D.J. Silvester)

12. Extract from Annual Report 1980: M.R.C. Cyclotron Unit, Chemistry Section, Head of Section D.J. Silvester (submitted by D.J. Silvester)

13. A Short Note on the Production and Use of Radioisotope for Medical Applications in Italy (submitted by M. Motta)

The following documents were also introduced during the Meeting:

1) The Stopping and Ranges of Ions in Matter
Organized by J.F. Ziegler, published by Pergamon Press

Vol. 3 Hydrogen: Stopping Powers and Ranges in All Elements
H.H. Andersen, J.F. Ziegler (1977)

Vol. 4 Helium: Stopping Powers and Ranges in All Elements
J.F. Ziegler (1977)

Vol. 5 Handbook of Stopping Cross-Sections for Energetic Ions in All Elements
J.F. Ziegler (1980)

Vol. 6 Handbook of Range Distributions for Energetic Ions in All Elements
U. Littmark, J.F. Ziegler (1980)

2) WRENDA 79/80 World Request List for Nuclear Data, INDC(SEC)-73 (1979)
(The new 81/82 issue will be published)