International Atomic Energy Agency

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INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

NUCLEAR DATA NEEDED FOR NEUTRON THERAPY

SUMMARY REPORT

The First Research Co-ordination Meeting

organized by the
International Atomic Energy Agency
Vienna, 17-20 November 1987

Prepared by
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March 1988

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Abstract

This is the summary report of the First Research Co-ordination Meeting of the IAEA Co-ordinated Research Programme (CRP) on Nuclear data Needed for Neutron Therapy, convened by the IAEA Nuclear Data Section in Vienna, from 17 to 20 November 1987. The main objectives of the CRP are to improve the present state of nuclear data for neutron therapy.

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Foreword

The First Research Co-ordination Meeting (RCM-1) of the participants of the IAEA Co-ordinated Research Programme (CRP) on Nuclear Data Needed for Neutron Therapy was convened by the IAEA Nuclear Data Section at the IAEA Headquarters in Vienna during the week 17-20 November 1987. The RCM was organized by K. Okamoto as scientific secretary and chaired by Roger M. White, Lawrence Livermore National Laboratory.

During the meeting the original title of "Nuclear Data Needed for Nuclear Particle Therapy" was modified to "Nuclear Data Needed for Neutron Therapy" unanimously by all participants.

The main objectives of the CRP are to improve the present deficient status of nuclear data for neutron therapy. The scientific scope of the CRP includes the following aspects:

a) Measurement and analysis of neutron data for transport calculations in phantoms including the effect of inhomogeneities.

b) Measurement and analysis of primary and secondary charged particle spectra required to determine variations of absorbed dose at interfaces.

As a result of this programme, it is expected that improved nuclear data will be produced and used in the dosimetry protocols for radiotherapy applications of neutron beams as formulated by ECNEU (European Clinical Neutron Dosimetry Group) and AAPM (American Association of Physicists in Medicine).

The principal objectives of this first RCM were to present reports and exchange the views of participants related to the above-mentioned objectives and to specify in detail the work to be carried out under this CRP programme.

The next RCM Meeting (RCM-2) is planned to be held during January 1989 in Vienna.

1. Introduction

The Nuclear Data Section is currently engaged in two medical application programmes, namely Nuclear and Atomic Data for Radiotherapy and Nuclear Data for Medical Radioisotope Production. These two programmes obtained many favourable comments and received encouragement for the further development of medical applications.

A number of high energy neutron radiotherapy installations are near completion and especially for these high energy neutron beams, more reliable basic physical data are required. During the Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Related Radiobiology held at TNO Rijswijk, the Netherlands, from 16-20 September 1985, future needs for nuclear data and their accuracies were identified. It has been concluded that for medical applications information is required on the following aspects:

1) Kerma values for the neutron energy range between 15 and 100 MeV; reaction and total cross sections especially for oxygen and carbon.

2) Neutron transport calculations for in-phantom conditions including the effect of inhomogeneities.

3) Primary and secondary charged particle spectra which are of specific relevance for the variations of absorbed dose at interfaces.

This CRP and the planned CRP on Atomic and Molecular Data for Radiotherapy work supplementarily to achieve the objectives of data requirements for radiotherapy.

2. Organization of the meeting

Eight participants attended the meeting. The CRP consists of nine Research Agreements and no Research Contract. One of the chief scientific investigators, R.C. Haight, Los Alamos National Laboratory, could not participate because of the late settlement of the Research Agreement.

3. Reports by participants to the First RCM

Seven participants presented reports on their recent work and, after the discussions, the proposed programme for the CRP was summarized.

4. Summary of observations and recommendations

The draft of the meeting's observations and recommendations proposed by several meeting participants was adopted at the final plenary session. After the meeting all participants sent further modifications to the draft which were incorporated by the Chairman in the final summary report.

SUMMARY OF OBSERVATIONS AND RECOMMENDATIONS

First RCM "Nuclear Data Needed for Neutron Therapy"
IAEA Headquarters, Vienna
17-20 November 1987

Introduction

Fast neutron therapy is being developed in several countries and the amount of clinical information is increasing steadily. At present more than 10.000 patients have been treated with fast neutrons, either as a single modality or combined with other types of treatment; for some centres the follow-up period of patients now exceeds 15 years.

The superiority of fast neutron therapy, compared to conventional photon therapy, is now established for some types and/or sites of tumours, such as locally extended salivary gland tumours, locally extended prostatic adenocarcinomas, and slowly growing sarcomas. For other tumour types, the available clinical results are still equivocal and further studies, conducted under strict statistical and dosimetric conditions, are needed to definitely identify all the indications (or contra-indications) of fast neutrons.

The introduction of high-energy, therapy-dedicated, hospital-based cyclotrons now allows the therapist to perform irradiations with physical selectivity (beam penetration, etc.) similar to that achieved with modern linear accelerators. In these conditions, the role of fast neutrons in cancer therapy can be fully assessed. The previous handicap related to the poor dose distributions produced by lower-energy neutron sources is being progressively eliminated.

From radiobiological and clinical evidence, and in particular due to the steepness of the dose-effect relations for local tumour control and normal tissue complications, it has been recommended that an accuracy better than ± 5% and a precision of ± 2% should be aimed at in clinical radiation dosimetry for photons. A high level of physical selectivity and an accurate dosimetry are at least as important, and probably more important, for high local-energy-transfer (LET) radiations like neutrons when compared to low-LET radiations. This is due to a reduction of the differential effect between the different cell populations when increasing LET.

The progressive replacement of low-energy neutron generators by high-energy cyclotrons (four therapy centres are using p(65)+Be neutrons, i.e., neutrons produced by 65 MeV protons on beryllium) has raised new dosimetric problems:

- nuclear data and kerma factors for neutrons in the high-energy range are not available;

- treatment planning: a greater accuracy in dose assessment is required due to the higher doses which can now be delivered at depth because of the increased penetration;

- corrections for heterogeneities in the body composition and/or density and evaluation of the dose at the interfaces of tissues with different atomic composition related to the increased ranges of secondary charged-particles produced;

- specification of radiation quality at a reference point, and its variation throughout the patient's body (since radiation quality determines the RBE and influences the dose prescription). In order to facilitate the selection of the best "institutional RBE" (or "clinical RBE") at a given centre, and to facilitate exchange of information between different centres, the value of microdosimetry and other methods for specification of the radiation quality should be investigated. This implies systematic measurements and RBE determinations.

These aspects are not only dependent on the nuclear interactions of the primary neutrons, but also on the interactions and transport of the secondary charged particles. Adequate treatment of these problems therefore requires the availability of both nuclear and atomic data.

Dosimetry aspects of neutron therapy

The aim of dosimetry is to specify the spatial and temporal distribution of energy deposition by ionizing radiation at a macroscopic and microscopic level with a sufficient degree of accuracy and precision. Compared to conventional photon therapy, the interactions of neutrons with matter are more complex with respect to energy of the primary particles, influence of the composition of the materials involved and types and spectra of secondary charged particles produced. In addition, neutron beams are always accompanied by photons originating both from the neutron source as well as from neutron interactions with irradiated objects.

The first generation of neutron therapy machines produced neutrons with energies of up to about 15 MeV. At present, higher energy neutrons are used (e.g., neutrons produced by the p(65)+Be reaction) and they will progressively replace the use of lower energy neutrons. At these higher neutron energies non-elastic nuclear processes become more important. They are strongly dependent on neutron energy and type of nuclides involved. The macroscopic and microscopic distribution of energy deposition (absorbed dose distribution and variation of radiation quality) will show a stronger dependence on neutron energy and composition of materials involved in the case of higher energy neutrons than for neutrons of lower energy (e.g. below 15 MeV).

Most neutron therapy facilities now use cyclotrons to accelerate protons or deuterons to energies greater than 50 MeV which, in turn, are used to generate neutrons via the p(E)+Be and d(E)+Be reactions. The typical maximum neutron energy produced at this time is approximately 65 MeV with machines being planned to produce neutrons up to 100 MeV in the near future. The p(E)+Be reaction produces a relatively flat spectrum of neutrons from maximum energy down to low energies where the evaporation portion of the spectrum becomes significant. Typically, polyethelyene filters are used to remove neutrons from the lower-energy portion of the spectrum. Those machines employing a d(E)+Be neutron source provide a more forward-peaked neutron spectrum with a smaller low-energy component.

The macroscopic and microscopic distributions of energy deposition, which determine absorbed dose and radiation quality, show a strong dependence on neutron energy and elemental composition of irradiated materials. Local energy depositions in tissue-like materials by energetic neutrons produce a complex spectrum of energetic particles. For all neutron energies elastic scattering by hydrogen dominates, but substantial alpha-particle and heavier ion production occurs. The yield of these particles varies significantly with neutron energy and elemental composition of the irradiated material.

The spectra of charged particles released and the energy dependence of these interactions are of relevance for fast neutron therapy and related clinical dosimetry for two reasons:

(1) The evaluation of absorbed dose in tissue from a measured quantity, e.g., ionization in a gas filled cavity surrounded by conductive plastic, requires basic dosimetric data such as W-values, stopping power ratios and kerma ratios.

(2) Radiation quality, i.e., the biological effect per unit absorbed dose (often specified as RBE), depends on the microscopic pattern of energy deposits on the molecular and subcellular level. This pattern (sometimes described in terms of the track structures of charged particles, or in terms of energy deposition distribution in microscopic volumes) depends on the spectra of the charged particles at the point of interest.

Physical dosimetry must employ materials of compositions different from human tissues. Moreover human tissues vary considerably in elemental composition. Thus it is important to understand the microscopic particle yield that is due to elastic, inelastic and reaction channels. Of particular interest is the production of alpha-particles, which dominates the high-LET component of the secondary particle spectrum in the LET region of greatest biological impact. Fortunately, carbon, oxygen and, to a lesser extent, calcium are the only elements of significance other than hydrogen in tissue and tissue-like materials.

For practical clinical neutron dosimetry to be applied in radiotherapy with neutron energies up to about 15 MeV several dosimetry protocols (AAPM 1980, ECNEU 1981, and ICRU-43) are available. In these protocols, recommendations are made for the relevant basic physical parameters (including kerma factors, W-values, gas-to-wall conversion factors, and displacement correction factors). Before values for basic physical parameters (nuclear as well as atomic and molecular data) can be recommended, sufficient confidence has to be attained on the values of the parameters and particularly on the dependence of the parameters on neutron energy and atomic composition of relevant materials. The dosimetry methods and procedures used at higher neutron energies are the same as for neutron dosimetry below 15 MeV. The detectors used include A-150 plastic and non-hydrogenous ionization chambers, proportional counters, and Geiger-Muller counters. In addition, A-150 plastic calorimeters are available at several institutes. The lack of tissue equivalence of A-150 or any other plastic with respect to the amount of oxygen and carbon is an increasingly serious problem at higher neutron energies because of non-elastic nuclear processes.

At an integral level, the use of proportional counters (or ionization chambers) with walls of various materials combined with fluence measurements or/and the use of water, carbon, or A-150 calorimeters may provide a practical solution with respect to kerma factors and ratios. Adequate information on secondary charged particle spectra, however, cannot be derived from "integral" measurements. This latter information is also of importance with respect to interface problems (which are more important at higher energies in view of the increased ranges of the charged secondaries), choice of W-values, and gas-to-wall absorbed dose conversion factors. In addition, information on changes in neutron energy distribution within irradiated objects will be required.

Recommendations

For a given neutron therapy generator, collimator system, and irradiation geometry, it is essential to be able to accurately determine the spatial and energy distributions of incident neutrons at the patient site. The microscopic double-differential (energy and angle-correlated) cross sections must therefore be measured at sufficient incident proton and deuteron energies up to 100 MeV to establish evaluated data files for Be.

For the determination of tissue absorbed dose, A-150 plastic-to-tissue kerma ratios are needed. These ratios can be calculated if kerma factors for hydrogen, carbon, oxygen and with lesser importance, calcium and nitrogen, are well known. As the hydrogen cross section is well known, the determination of neutron-induced cross sections on carbon and oxygen are of highest priority.

The reactions which should contribute most to the kerma for carbon and oxygen are: $(n,x\alpha)$, (n,xp), (n,n), (n,n'), and (n,d). Most of these cross sections are not well known above 15 MeV. In the energy range from 15 to 25 MeV, there exist some measurements of (n,n), (n,n') and $(n,n'3\alpha)$ cross sections for carbon. However, more complete measurements of (n,α) and $(n,n'\alpha)$ cross sections are recommended. For oxygen the situation is even worse as higher energy cross section measurements are nonexistant.

It seems impossible to experimentally determine all the needed cross sections on carbon and oxygen up to 100 MeV within the next five years with the limited resources available. Currently perhaps only two facilites exist where neutron cross section measurements for neutron energies above 25 MeV are likely to be performed. A collaborative effort will therefore be necessary to achieve even a limited number of measurements.

In order to obtain all the necessary data, there has to be an increasing reliance on theoretical models. For testing and fitting the model calculations, measurements of elastic and inelastic neutron scattering cross sections and secondary neutron, photon, and charged-particle spectra must be made for neutron-induced reactions on carbon and oxygen at least at neutron energies of 30, 50, and 80 MeV.

Absolute integral measurements, which can be done to high accuracy with instruments such as calorimeters and proportional counters are required to test the accuracy of the evaluated data files. The value of such measurements is well documented for neutron energies below 20 MeV for doses in A-150 plastic and carbon. Extension of these measurements to higher energy and inclusion of water-calorimeters and counters constructed of other materials is essential. Calorimetric and ionization measurements are mutually complementary as the former avoids a detailed understanding of atomic processes while the latter gives information about the equilibrium secondary particle energy distribution.

For the broad spectrum, high-energy neutron beams currently employed or planned for therapy, an accurate evaluated data file is required for neutron transport calculations. These calculations are necessary to fully describe the distribution of absorbed dose and radiation quality in the irradiated patients. This method can help to solve specific problems which cannot be solved adequately by the current dosimetric methods. In addition, the availability of such an evaluated file would allow the optimization of shielding and collimation design at neutron therapy facilities.

Coordinated Research Programme on
NUCLEAR DATA NEEDED FOR NEUTRON THERAPY

Institute Chief Sci. Investigator Research Agreement No.	Proposed Programme	Report at First RCM
Lawrence Livermore National Laboratory (USA) Robert J. Howerton (Roger M. White) 4753/CF	1) Extension of calculated Kerma factors to other composite materials. 2) Updating of Kerma factors on new evaluated data in the ENDL File. 3) Neutron and gamma-ray transport calculation with Monte Carlo cord TART. 4) Comparison with other Kermas (calculations and measurements).	- Neutron Kerma factors for 15 composite materials and for isotopes or elements from Z=1 to 29 (H through Cu). $1.9\times10^{-5}<E_n<20$MeV for composite material $1.3\times10^{-9}<E_n<20$MeV for the isotope elements. - Photon Kerma factors for the elements from Z=1 to 30 and for 15 composite materials $100\text{eV}<E_\gamma<$ 100MeV for 191 energy groups.
University of Wisconsin (USA) H.H. Barschall (P.M. DeLuca Jr.) 4752/CF	1) Measurements of Kerma factors on O,Mg,Al,Si and Fe at $14<E_n<20$MeV.	- Measurement of Kerma factors of oxygen by cylindrical proportional counter with walls of Zr and ZrO. - Previous measurement of the Kerma factor of Carbon $14<E_n<20$MeV.
Physikalisch-Technische Bundesanstalt (FRG) G. Dietze 4750/CF	1) Measurement of neutron spectra of p + ^{9}Be for $15<E_p<23$MeV. 2) Measurement of cross-sections and angular distr. of α particles of $^{12}C(n,\alpha)^{9}B$ for $8<E_n<20$MeV.	- Thick target yields at zero degree for d(9.4-13.6)+Be p(17-22)+Be - Angular dependence of spectral neutron yield between 0 and 150 degrees for E_d=13.5MeV and E_p=19.1MeV

Institute Chief Sci. Investigator Research Agreement No.	Proposed Programme	Report at First RCM
Universität des Saarlandes (FRG) H.G. Menzel 4751/CF	1) Measurements of Kerma factors (ratios) on A-150 and C at monoenergetic neutron energies between 25 and 60 MeV. 2) Similar measurements of Kerma factors for broad neutron spectra (i.e. p-Be and d-Be).	- Results of gas-to-wall absorbed dose conversion factors ($\gamma m,g$) for high energy neutrons for graphite chambers filled with C_3H_8-TE gas. - (n,p) reaction in C becomes increasingly important above En=20MeV. - Kerma ratios of $Kc/_{KA-150}$ (up to E_n= 20MeV) follow the shape of theoretical curves.
National Institute of Radiological Sciences (NIRS) (Japan) K. Kawashima 4706/CF	1) Measurement of neutron response, Ku, of various neutron insensitive ionization chambers. 2) Relative measurements of stopping powers of dosimetric compounds and W-values of various gases for protons. 3) Measurement of neutron depth dose curves in a lung phantom. 4) Measurement of lineal energy distribution for neutron and proton beams.	- The values of Ku of various non-hydrogenous chambers for d(30)+Be.
Uppsala Universitet (Sweden) H. Condé (N. Olsson) 4837/CF	1) Neutron scattering measurements at 16.5 to 22MeV for C, and at 21.6MeV for N and O. (Short term). 2) Measurements analysis of neutron cross-section data mainly for tissue materials for neutron energies between 20 and 100MeV (Long term).	- Differential neutron scattering cross-sections for carbon at E_n=16.5, 17.6, 18.7, 19.8, 20.9, 21.6 and 22.0 MeV.

Institute Chief Sci. Investigator Research Agreement No.	Proposed Programme	Report at First RCM
Université Catholique de Louvain (Belgium) A. Wambersie 4806/CF	1) Systematic RBE determination. 2) Absorbed dose determination at the interface: e.g. A-150, plastic materials, air, etc.	- Neutron therapy beam from Louvain-la-Neuve Orleans Clatterbridge Heidelberg. - Role of microdosimetry in neutron therapy. (Distribution of a note on σ_T for $H(n,d)\gamma$ with 1.5% accuracy at 39, 61 and 76MeV of neutron energies by Dupont et al)
TNO Radiobiological Inst. (Netherlands) J.J. Broerse (J. Zoetelief) 4779/CF	1) Characteristics of Mg-Ar ionization chambers (in cooperation with PTB). 2) Determination of radiation quality with a TE ionization chamber. 3) Investigation of the biological consequence of lack of secondary charged particle equilibrium at interfaces (in cooperation with UCL, Louvain).	- Characteristics of Mg-Ar ionization chambers used as gamma-ray dosimeters in mixed neutron-photon fields. - Determination of radiation quality with high-pressure ionization chambers filled with various gases.
Los Alamos National Laboratory (USA) R.C. Haight 4910/CF	1) Evaluation of the new Target-4 fast "white" neutron source 2) Cross-section measurement of $^{12}C(n,p)$ $20<E_n<100MeV$ 3) Plans to make direct measurements of Kerma factors $20<E_n<100MeV$	- Settlement of research agreement came late and CSI could not attend the meeting.

First Research Co-ordination Meeting
of the
IAEA Co-ordinated Research Programme (CRP)
NUCLEAR DATA NEEDED FOR NUCLEAR PARTICLE THERAPY

IAEA Headquarters, Vienna
17 - 20 November 1987

Meeting Room: Tower A, Floor 11, Room 71

Opening: Tuesday, 17 November 1987, 9:30 hrs

AGENDA

A. Opening, Election of Chairman, Adoption of Agenda

B. Brief reports by participants:

- activities completed and being done
- special problems encountered
- plans for the future

C. Discussion on intercomparison

D. Working Group discussions

E. Conclusions and Recommendations

F. Date of next meeting

G. Others

First Research Coordination Meeting
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